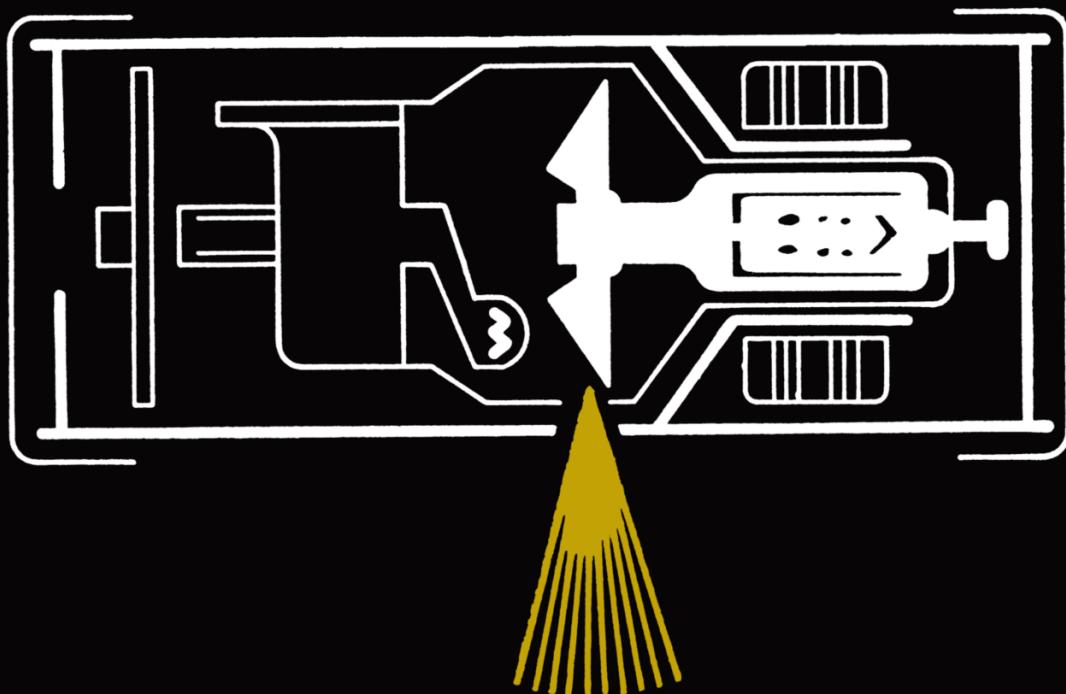


# **Medical X-ray Techniques in Diagnostic Radiology**

**Fourth edition**



**G.J. van der Plaats**

# **MEDICAL X-RAY TECHNIQUES IN DIAGNOSTIC RADIOLOGY**

# **MEDICAL X-RAY TECHNIQUES IN DIAGNOSTIC RADIOLOGY**

A Textbook for Radiographers and Radiological Technicians

**G.J. VAN DER PLAATS**

*Former Chief Radiologist, St Annadal Hospital, Maastricht*

with the assistance of

**P. VIJLBRIEF**

*Radiologist, Research Laboratory,  
Radiological Clinic, University of Leiden*

**M**

© G. J. van der Plaats 1959, 1961, 1969, 1980

Softcover reprint of the hardcover 1st edition 1980 978-0-333-26415-7

All rights reserved, no part of this publication may be reproduced or transmitted, in any form or by any means, without permission

First edition published by Centrex Publishing Company,  
Eindhoven, The Netherlands, 1959

Second edition 1961

Third edition 1969

Fourth edition first published 1980  
in Europe (excluding the United Kingdom, Eire,  
and Comecon countries), the United States and Canada,  
by Martinus Nijhoff Publishers,  
The Hague, The Netherlands

Published in the rest of the World by  
THE MACMILLAN PRESS LTD

*London and Basingstoke*

*Associated companies in Delhi Dublin*

*Hong Kong Johannesburg Lagos Melbourne*

*New York Singapore and Tokyo*

ISBN 978-1-349-04632-4      ISBN 978-1-349-04630-0 (eBook)  
DOI 10.1007/978-1-349-04630-0

This book is sold subject to the standard conditions of the  
Net Book Agreement

# Contents

<i>Foreword</i>	vii
1 Discovery and production of X-rays; construction and function of the X-ray tube	1
2 Formation and properties of X-rays	35
3 Dosimetry, radiation hazards and protective measures	58
4 Methods of image formation and laws of projection	85
5 Sharpness and unsharpness	104
6 Contrast	114
7 Perceptibility of detail in the radiographic image; Image quality	131
8 Properties of fluoroscopic screens, radiographic films, intensifying screens and cassettes	143
9 Image intensification and X-ray television	171
10 Processing technique	192
11 Fluoroscopy and radiographic technique in general	237
12 Special radiographic techniques	260
13 Radiographic examinations using contrast media	329
14 Exposure, exposure tables, automatic density control	337
15 Diagnostic X-ray apparatus	378
16 Diagnostic stands and accessories	412
<i>Index</i>	445

# Foreword

*by Professor J. H. Middlemiss,  
Department of Radiodiagnosis,  
The Medical School,  
University of Bristol*

This book, for so long and so deservedly, has been a favourite and reliable guide for any person undergoing training in diagnostic radiology whether that person be doctor or technician. This new, largely re-written edition is even more comprehensive. And yet throughout the book simplicity of presentation is maintained.

Professor G. J. van der Plaats has been well known to radiologists in the English-speaking world for more than three decades. He has been, and still is, respected by them for his vision, his thoroughness, determination and meticulous attention to detail and for his unremitting enthusiasm. The standard of radiography in the Netherlands throughout this period has been recognised as being of the highest quality, and this has, in no small measure, been due to the pattern set by Professor van der Plaats and his colleagues.

As radiology has developed and grown, as new techniques have been devised, as apparatus has become more complex and sophisticated, as automation has been introduced, so has there been a tendency for both radiologist and radiographer, especially those in training, to become divorced from the fundamental essentials of their work. The exotic attracts and often there does not seem to be any glamour in the basic concepts and the basic practices through which radiology has passed and out of which modern radiology has grown. Yet it is only by having a complete understanding of the basic practices that modern radiology can exist or can expect to develop even further. In this book Professor van der Plaats guides the beginner with great expertise and with consummate interest through all the fundamental problems step by step, dealing in turn with every aspect of the technical factors involved in the production of X-ray images. As automation has invaded our dark-rooms there are radiographers qualifying in some industrialised countries who have never performed and in some cases have never even seen hand processing. The author has forgotten nothing. He takes the learner through all the fundamental aspects of processing with a wealth of practical wisdom and experience.

As radiology continues to grow and as its uses are spreading further and further into the remote areas of non-industrialised countries, so is simple X-ray apparatus being designed and manufactured for use in those places. This type of X-ray service is likely to be termed a primary radiological service. In such a service there will be no place for image intensifiers, or television chains, probably no place for fluoroscopy; there certainly will not be automatic processing. It is unlikely that there will be enough trained radiologists to give constant radiological cover in such a service. Yet there must be trained radiographers and there must be facilities for the training of technicians to operate these machines and to provide a service to the clinician. Professor van der Plaats' book will provide all the knowledge required by persons undergoing such training, and provide it in such a way that it is understood. For this reason alone this book deserves the widest circulation possible in those parts of the world where a primary radiological service is being developed and where the training of X-ray operators is being undertaken.

Yet, let it not be thought that this book is only for use where rudimentary use of radiology is contemplated or where only a primary radiological service is provided. As mentioned earlier the book is comprehensive. It includes adequate presentation and discussion on such subjects as contrast media, routine radiographic techniques, special techniques, tomography, macro-radiography, stereoscopic fluoroscopy, cine-radiography and even C.T. scanning; it gives details of exposures and exposure tables, and density control; it gives details of apparatus construction. It truly is a compendium.

I recommend it to all training schools where radiographers and radiologists are trained. And many experienced radiologists will benefit from browsing through its pages and will wish to keep it on the bookshelf in their departments where they can refer to it when some technical problem occurs, as inevitably they do occur in everyday life. This book is about everyday life in a Department of Diagnostic Radiology.

# 1

## Discovery and Production of X-Rays; Construction and Function of the X-Ray Tube

On 8 November, 1895 Professor Wilhelm Conrad Röntgen (1845–1923) discovered an unknown kind of ray, which he called X-ray. While he was busy with experiments on the behaviour of cathode rays (these tests were very much in vogue at that time) in Hittorf-Geissler-Crookes tubes (glass envelopes in which the air has been evacuated to a very high degree) he happened to notice that some crystals lying near the tube had become strongly fluorescent. Röntgen studied this phenomenon and decided that it was caused by a hitherto unknown radiation.

On 28 December, 1895 in Würzburg, he made the first announcement of this radiation in a paper entitled: 'Über eine neue Art von Strahlen' (about a new kind of rays). His presentation of the facts was so convincing as to leave no doubt that a new kind of radiation had indeed been discovered. Moreover, Röntgen had already thoroughly investigated—as appeared later—the most important properties of this new radiation. The discovery of X-rays ranks as one of the greatest discoveries of the last century.

In some languages one no longer calls these rays X-rays (in German: Röntgenstrahlen; Dutch: röntgenstralen; English: X-rays; French: rayons X; Spanish: rayos X). Röntgen was born in Remscheid-Lennep (near Wuppertal), a town which is worth visiting for its own intrinsic charm. A Röntgen museum has been founded near the house of his birth and here it is possible to see many instruments and documents of his time. The museum is constantly kept up to date and demonstrates the development of X-ray technique throughout the years. A visit to the place is warmly recommended.

There are several biographies of W. C. Röntgen, which give particulars of his great discovery, interspersed with much information about that period and his

private life. Interesting facts about the pioneers and forerunners of radiology are also found in other publications. Only a few are mentioned below:

- O. Glasser, *Dr W. C. Röntgen*, Charles C. Thomas, Springfield, Illinois  
W. A. H. van Wylick, W. C. Roentgen and the early days of X-rays, *Medicamundi*,  
16 (1), 1-8  
D. R. Hill, *Principles of Diagnostic X-ray Apparatus*, Philips Medical Systems Ltd,  
London

### **1.1 BREMSSTRAHLUNG, CHARACTERISTIC RADIATION, GAMMA RADIATION**

X-rays arise whenever electrons collide at very high speed with matter and are thus suddenly retarded. The X-rays emitted in this way are known as *Bremsstrahlung* (from the German 'bremsen' to brake). The greatest part by far (99 per cent) of the kinetic energy of the electrons is converted, by means of collisions, into kinetic energy (heat) of the matter bombarded by these electrons. X-radiation is produced due to the braking (slowing down) of some electrons in the electric fields within the material.

When an electron loses all or part of its energy due to the electric fields within the atom then a photon is created. Its energy ( $h\nu$ , where  $h$  is Planck's constant and  $\nu$  frequency) depends on the manner of energy transfer; if this is virtually complete then a photon with a great deal of energy is created and this represents short wavelength radiation. Even if all the electrons were to collide with the anode material with exactly the same speed (for example by means of a constant equal voltage between the cathode and anode) then the energy transfer of the individual electrons would still be different and, thus, the photons created would also have different energies. This is the explanation of the fact that Bremsstrahlung always consists of X-radiation of many different wavelengths, which together form a *continuous spectrum*. In general, the (few) electrons, which give up all their energy, produce the most 'energetic' photons that can be created at that particular collision velocity; this is also how the shortest wavelength is determined in this radiation mixture. Still 'greater' photons (with still shorter wavelengths) can only be produced by means of high electron speeds (thus higher tube voltage). Apart from the Bremsstrahlung if the energy of the bombarding electron is great enough yet another kind of radiation, with certain particular wavelengths that are characteristic of the material with which the electrons collide, will also be produced. This is connected with the characteristic energy of the electrons of the innermost orbits of the atom of every element. The *characteristic radiation* is superimposed upon the continuous Bremsstrahlung with one or several spectral lines. The intensity of the characteristic radiation of an X-ray tube is usually low in comparison with the intensity of Bremsstrahlung. However, in specially constructed tubes such as those for X-ray spectrography and mammography use is made of characteristic radiation in particular.

The maximum energy (or minimum wavelength) of an emitted spectrum is determined by the maximum speed of the bombarding electrons, in the case of both Bremsstrahlung and characteristic radiation.

The emission of electromagnetic radiation in the X-radiation range of wavelengths also occurs in certain radioactive processes. Radiation emitted by the nucleus of an atom is called *gamma radiation*; radiation which originates outside the nucleus is known as *X-radiation*. In principle there is really no difference between this gamma radiation and X-radiation if one disregards their origins. Formerly, it was impossible to produce X-rays with as great an energy as hard gamma rays. Today, apparatus such as betatrons, synchrotrons and linear accelerators can generate X-rays of energy equal to that of even very hard gamma rays.

## 1.2 ION TUBES

Before discussing X-ray tubes as used in modern diagnostic techniques, it will be informative to consider briefly the tubes originally used to generate X-radiation.

These tubes were known as *gas (or ion) tubes*.

Ion tubes are glass envelopes in which two electrodes are sealed into the glass at opposite ends. The air is pumped out of these tubes, so that the atmosphere inside becomes more and more rarefied (approaching a vacuum). At the same time a great potential difference is applied between the two electrodes making one positive (*anode*) and the other negative (*cathode*). When the air pressure is low enough, current passes through the tube—which until this point was non-conductive—producing a luminous effect (due to ionisation). With further reduction in air pressure the electrons and ions are given greater speeds and in their turn cause further ionisation due to collisions. The electrons travel to the anode, where a certain amount of X-radiation is then generated; what is more important, however, is that the heavy atomic residues, or gas ions as they are called, are attracted to the cathode, where the impact of their relatively larger mass releases many more electrons. When the cathode is shaped like a concave reflector the heavy concentration of electrons thus released is united into a beam and focused on to a particular spot on the anode (*the focal spot*) and there produces intense X-radiation. Often such ion tubes were provided with a third electrode, the *anticathode*, (connected with the anode), mounted opposite the cathode as a target for the focused electrons. Figure 1.1 shows such a tube diagrammatically.

In the very beginning of their history these tubes were continuously evacuated by connecting them to an air pump; later, when it became possible to achieve the required vacuum, the tubes were ‘sealed off’. Almost all later tubes were of the

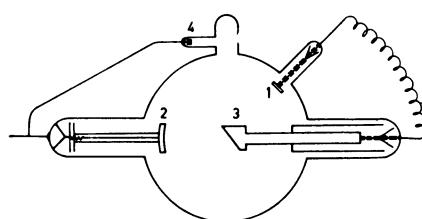


Figure 1.1 Ion tube. 1. Anode; 2. cathode; 3. anticathode at anode potential; 4. regenerating device at cathode potential.

sealed-off vacuum-tight type; tubes operated 'on the pump' were only found in certain experimental installations.

As long as there is sufficient gas in the ion tube for a strong current and with that the voltage between the anode and cathode does not need to be particularly high, then the speed with which the electrons bombard the anticathode is also not very great. X-rays are then produced with relatively low energy which have little penetrating power: *soft X-radiation*. When the air-pressure is reduced still further then the voltage between the anode and the cathode must be increased considerably to enable current to pass through the tube and consequently the electrons bombard the anticathode with greater speed. In this way X-radiation with more energy and consequently greater penetrating power, *hard X-radiation*, is produced. Thus, the quality of the X-radiation generated in gas tubes (hard or soft) depends not only upon the applied voltage but also on the pressure of the residual air in the tube. As the tube aged due to use, the amount of gas gradually diminished since the ions (that is the split gas molecules) chemically combined with the anode material resulting in a progressively higher vacuum. Therefore, higher and higher voltages were then required to maintain sufficient flow of current. It was then said that the tube became 'harder'. Eventually, the time came when there were no longer any gas molecules available for ionisation so that the current could not be sustained even by applying the maximum voltage; hence the tube became useless. Thus, a great disadvantage of these ion tubes was that they lacked stability; they became harder the longer they were used. With the aid of ingenious regeneration, fresh gas could be introduced into the tube and so prevent too high a vacuum and consequent 'hardening' of the tube. The most important disadvantage of ion tubes was that the tube current and tube voltage could not be varied independently. The seriousness of this drawback became more and more apparent with the development of more advanced techniques in medical X-ray practice. It was noticed that on selecting the tube voltage required for a particular subject, gas tubes gave no scope for the variation of tube current. Consequently, the exposure time required to ensure the desired density could become unduly long.

Ion tubes may still be found as museum specimens, but they are no longer used for practical purposes.

### 1.3 ELECTRON TUBES

Electron tubes were first introduced by Coolidge in 1912 (died in 1975, aged over 100) after he had succeeded in drawing into wire the previously unmalable metal, tungsten. He made the cathode of the X-ray tube into a tungsten spiral filament, which glows when an electric current (filament current) is passed through it. When this tungsten spiral is heated to a high temperature, it emits electrons (thermionic emission of electrons). The number of electrons emitted by an incandescent element increases very sharply when the temperature of this element increases. In this way the number of electrons emitted can be regulated by varying the filament current. By means of a low-voltage transformer (the filament transformer) a current of 3-8 A is passed through the filament at a voltage of 7-20 V.

As long as no voltage is applied between the anode and the cathode, the emitted electrons will drift around the cathode in the form of an electron cloud.

When the anode is given a positive potential with respect to the cathode, the electrons emitted by the cathode are attracted by the anode. The greater the potential difference between the cathode and the anode, the faster (thus, with greater energy) the rate at which the electrons will reach the anode (provided the electrons are not retarded by collision with gas molecules). Thus, in order to give the electrons sufficient velocity to cause the production of X-rays, one needs a very high voltage and a very high degree of vacuum. The number of electrons which flow from the cathode to the anode when the voltage is applied across the tube, that is the electron current (opposite to the direction of the tube current), is mainly determined by the filament current, as has been described above, and is practically independent of the high voltage between the anode and cathode.

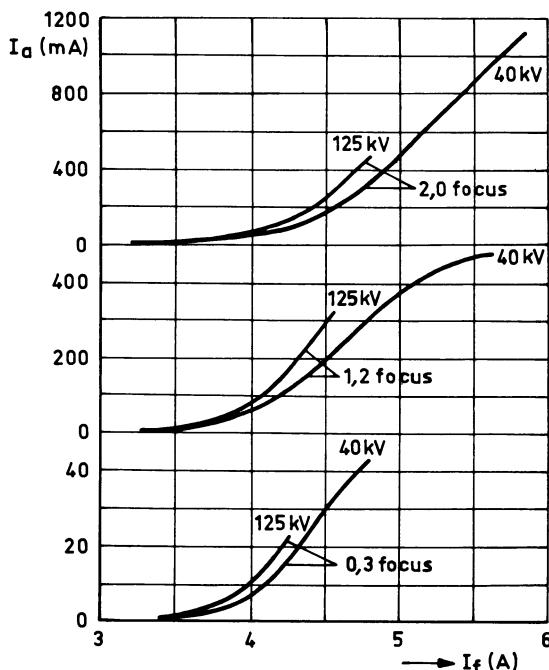


Figure 1.2 Relation between tube current ( $I_a$  in mA) and filament current ( $I_f$  in A) for various foci of tubes with rotating anode.

The relationship between the filament current (in A) and the tube current (in mA) is shown in the emission curve of the X-ray tube. An example of such emission characteristics is shown in figure 1.2. In figure 1.3 the cathode of a tube with two foci, 1.2 mm and 2 mm can be seen. The smaller filament is used for the 1.2 mm focus and the larger filament for the 2 mm focus.

The high voltage is obtained by means of high-tension transformers, which are also capable of supplying high current values. The high voltage between the anode (+) and cathode (-) determines the velocity of the electrons. The

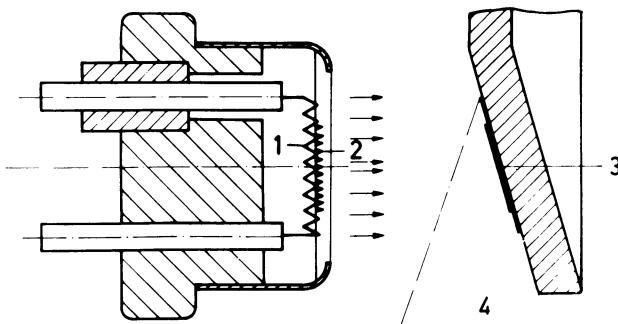


Figure 1.3 Cathode and anode of a dual-focus rotating anode tube. Left: section of the cathode. 1 and 2. Filaments. The smaller is intended for a 1.2 mm focus and the larger for a 2.0 mm focus. The arrows represent the electron beam. Right: section through the edge of the (tungsten) target (3) of the anode disc. 4. Effective X-ray beam.

number and velocity of the electrons colliding on the anode determines the quantity and quality of the radiation, respectively. The more electrons (that is the stronger the filament current) the greater the tube current and, hence, the more X-rays will be produced. The greater the velocity of the electrons, the greater the energy converted into X-ray energy for each electron impinging on the anode, and, hence, the greater the energy of the X-rays produced. After all, the X-rays consist of a very great number of X-ray quanta (= X-ray photons), each with an amount of energy equal to  $h\nu$  and this energy is directly proportional to  $\nu$  (that is the energy is greater when  $\nu$  is greater and vice versa).

A *high voltage* is associated with: fast electrons; high X-ray energy; short wavelength; great penetrating power; *hard X-rays*; high energy quanta ('large quanta'). A *lower voltage* is associated with: slower electrons; less X-ray energy; longer wavelength; less penetrating power; *soft X-radiation*; lower energy quanta. ('smaller quanta'). Note that the *filament current* flowing through the cathode has a tension of about 15 V and a current value of about 4 A. The *tube current* flowing through the X-ray tube from anode to cathode has a tube tension of about 40 kV or higher and a current value of a few tenths of a mA or more. A higher filament current is associated with a higher tube current and hence with more X-rays.

The electron current in the tube flows from the cathode to the anode, but since, according to the *accepted definition* an electric current flows from positive to negative, it is also assumed, in this case, that the *tube current in an X-ray tube flows from the anode to the cathode* (the conventional direction). However, in order to understand electric circuits and phenomena, it is often more instructive to follow the route of the electrons (the actual travellers.) Thus, this is opposite to the conventional direction of an electric current.

In fluoroscopy use is made of voltages from 40 to 100 kV (seldom more) at a current of a few tenths to 4 mA. For producing radiographs the values of voltages used are 25–150 kV and higher, the current values depending on the amount the tubes can withstand and on the size of the apparatus; with a small apparatus the current varies between 10 and 40 mA, whereas with larger

apparatus the current can amount to hundreds and even to 1000 mA. In X-ray therapy (treatment with X-rays) voltages of 5–250 kV and higher are used with currents from 1 to about 30 mA.

When the tubes are manufactured, extremely careful degassing is necessary during the pumping (evacuating) process. Moreover, X-ray tubes should be slowly 'run-in' in practice, to accustom them gradually to operating conditions. This is also recommended after long periods of rest (weekends), especially in the case of therapy tubes. The reason for this is that residual gas which has been liberated can then with low voltage and current be ionised and combined. If this is not done there is the risk that due to high voltages in the presence of gas or metal vapour the tube will be 'blown', that is ruined.

#### 1.4 ANODE, FOCUS, GOETZE PRINCIPLE, HEEL EFFECT

In the very first tubes (Crookes' tubes) the glass that formed the wall of the tube was the first anode material which was bombarded by the liberated electrons. However, since at the point of impact 99 per cent of the liberated energy is converted into heat, it proved not to be a very efficient anode material. Hence, anodes of metals such as aluminium, platinum and tungsten were soon introduced instead. The choice of anode material is determined by several factors, the most important being *efficiency* (expressed as that percentage of the electron energy which is converted into X-rays) and the *maximum permissible specific load* per mm<sup>2</sup> of focal surface.

The efficiency of the anode is proportional to the atomic number of the anode material; therefore, a metal of high atomic number is chosen (for example tungsten ( $Z = 74$ ), platinum ( $Z = 78$ ) or gold ( $Z = 79$ )). For the same reason aluminium ( $Z = 13$ ), for example, is quite unsuitable. The maximum permissible specific load depends primarily on the melting point of the anode material; hence, it is necessary to choose a metal with a high melting point such as tungsten ( $3350^\circ\text{C}$ ), which is in this respect the most suitable, whereas platinum (m.p.  $1770^\circ\text{C}$ ) and gold (m.p.  $1060^\circ\text{C}$ ) are less suitable. In addition to this, the thermal capacity and thermal conductivity of the anode are also important.

In general, tungsten is the most common anode material used. Anodes of the *stationary type* are usually made by embedding a tungsten target, only 2–3 mm thick, in a copper block, thus making use of the properties of high thermal conductivity and capacity of copper in conducting the heat rapidly away from the tungsten target (which is less efficient as a conductor) (figure 1.4).

*The part of the anode on which the electron beam impinges is known as the focus.* The focus, then, is the spot where the X-radiation originates and from where it diverges in all directions. We can compare this to a light source. The intensity of the radiation is equal in all directions except for the rays that pass very near the surface of the anode and thus form a very small angle (less than about  $5^\circ$ ). The X-rays that originate on the anode in the focus do not only leave the front of the anode (in an arc of  $180^\circ$ , that is half a circle), but similarly in the other  $180^\circ$  direction, into the anode material itself, where it is practically

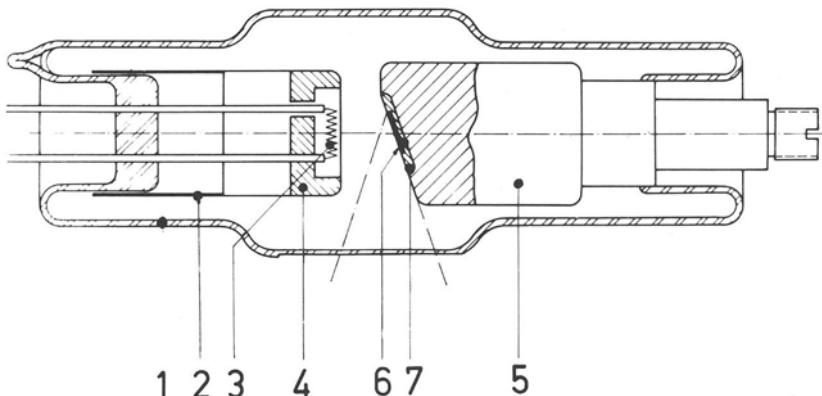


Figure 1.4 Section of an X-ray tube with stationary anode. 1. Glass tube or envelope; 2. cathode; 3. filament; 4. cathode cup for electrostatic focusing of electrons emitted by the filament; 5. anode, comprising solid copper block in which a tungsten target (7) is embedded; 6. focus; 7. tungsten target.

completely absorbed. Whereas one can optically focus (by means of lenses, etc.) light which originates from a light source, this is impossible in the case of X-rays. This is why we are obliged to use only a (small) part of all emitted rays and the rest is absorbed unused. The beam which in this case is meant to be used is in the shape of a cone, the top being the focus and the base the round window in the tube and tube housing, which allows the radiation to pass through.

Every X-ray image is a shadow image; it is therefore obvious that in order to obtain a sharp image the focus must be as small as possible. After all, if one wishes to produce sharply outlined shadow images the light source must be as nearly point-shaped as possible. If the electron beam, however, were to strike too small an area of the anode, the heat generated would be so intense as to melt the anode at that point. The focus, therefore, must have a specific size according to the load it should be capable of withstanding.

In the early X-ray tubes the angle between the surface of the anticathode (anode) and the electron beam was  $45^\circ$ , as illustrated in figure 1.5 (1). The particular ray that is perpendicular to the long axis of the X-ray tube (hence also to the electron beam) is assumed to be the *central ray* of the useful X-ray beam. This forms an angle of  $45^\circ$  with the anode; this angle is called the *anode angle*. The central ray is the axis of the cone-shaped X-ray beam and passes from the focus through the centre of the tube window. In all other aspects this central ray is no different from the remaining rays in the beam. It is obvious that in the direction of the central ray the focus appears to be smaller. After all, when one looks at a surface from an oblique angle, the surface seems smaller. This phenomenon, that is 'apparent' reduction in the size of the radiation source, contributes to greater definition.

Since the real focal spot assumes an increasingly elongated shape as the angle diminishes, this system is known as *line focus* or, in honour of the man who first applied this principle, *Goetze focus*. If in figure 1.5 (1),  $a$  is given as the width

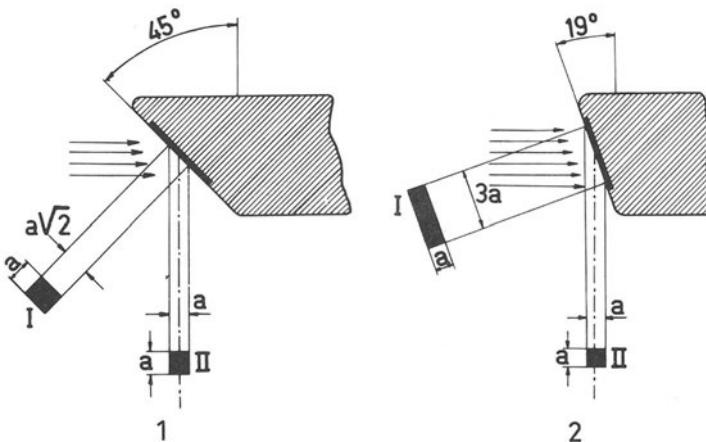


Figure 1.5 Real and effective focal-spot sizes associated with different anode angulations. 1. Anode angle of  $45^\circ$ ; 2. anode angle of  $19^\circ$ . The parallel arrows represent the electron beam. I. The real focus; II. the effective focus.

and  $a\sqrt{2}$  as the height of the actual spot on the anode, the width and the height of the apparent or effective focal spot at an anode angle of  $45^\circ$  (as seen along the central ray of the beam) will both equal  $a$ . With an anode angle of  $19^\circ$  (figure 1.5(2)) the real focus, in order to give an effective focus of  $a \times a$ , will be  $a \times 3a$ . It will be evident that the *actual* focal spots corresponding to anode angles of  $45^\circ$  and  $19^\circ$  with the same *effective* focal spot size of  $a \times a$  are  $a^2 \times 2$  and  $3a^2$  respectively. The ratio between the total loads is therefore  $a^2\sqrt{2} : 3a^2 = \sqrt{2} : 3$  = about 1 : 2.

The amount of heat due to electron bombardment, which a focus with anode angle of  $19^\circ$  can withstand, is more than twice that for the same size of the effective focus with an anode angle of  $45^\circ$ . This demonstrates the advantage of the Goetze focus. From this point of view, then, it would be reasonable to reduce the anode angle as far as possible in order to increase the specific load. However, if the anode angle were to be decreased too much, the radiation intensity immediately beside the anode would drop sharply. The emergent beam would then be weaker at the anode side, and with anode angles of less than  $5^\circ$  would lead to under-exposure on the side of the object which corresponds to the anode side. This would obviously restrict the cross-section of the useful beam. This decreased intensity of radiation which passes immediately next to the anode is known as the *heel effect* (one is, as it were, in the shadow of the anode). In cases where a smaller beam cross-section can be tolerated, one is therefore, not inconvenienced by the heel effect of the outer rays on the anode side, the anode angle can be made even sharper than  $19^\circ$  ( $10^\circ$  for example), making it possible to subject the effective focus to an even higher specific load. In recent years, X-ray tubes have been produced in which part of the anode makes an angle of  $19^\circ$  with the central ray, and part an angle of  $10^\circ$ . The smaller angle of  $10^\circ$  is reserved exclusively for small image fields or for use at large focus-film distances.

The useful beam cross-section at any given distance from the focus depends on the anode angle. As a rule, this angle is about  $45^\circ$  in therapy tubes and about  $19^\circ$  or  $10^\circ$  in diagnostic tubes. In practice, the ratio of useful beam cross-section to focus-film distance in therapy tubes is about 1:1, and in diagnostic tubes about 2:3. With a smaller anode angle ( $10^\circ$ ) this ratio becomes even less. From figure 1.5 (2) it follows that the object parts on the anode side of the central ray view the focus from a steeper angle (and hence smaller) than object parts on the cathode side. Thus, on the anode side the image is a little sharper than on the other side, but this difference is of no practical importance. In practice, a simplified notation is used to indicate the size of the focus. For example, an effective focus of  $1.2 \times 1.2$  mm is simply referred to as a 1.2 focus. Often, however, the loading capacity (power) is indicated as being the most important and one speaks of a 30 kW tube, for example.

### **1.5 MAXIMUM PERMISSIBLE LOAD ON THE FOCUS, $kV_p$ AND $kV_{R.M.S.}$**

The *maximum permissible load* or the *capacity* of a diagnostic tube of the stationary anode type is expressed in kilowatts. Formerly, the maximum permissible load that could be withstood by the tube for 1.0 s was indicated. With the much shorter exposure times of today, the maximum permissible load of the tube is now indicated by the load it can withstand for 0.1 s. The load of a tube for an exposure is expressed by the maximum permissible load multiplied by time and is indicated by  $kV_{R.M.S.} \times mA \times \text{time}$ , therefore in watt-seconds (Ws). Watt, the unit of power, is the product of the unit of voltage (volt) and the unit of current (ampere), or of kilovolt and milliampere (which is the same). However, a distinction must be made between direct current and alternating current. With direct current, the voltage is constant and therefore  $kV \times mA = W$ . With pulsating direct voltage the tube voltage is indicated by the maximum value of the voltage, that is  $kV_{\max}$  or  $kV_{\text{peak}}$  ( $kV_p$ ); the corresponding voltage for the thermal loading of this tube is expressed in  $kV_{R.M.S.}$ . For an alternating voltage that has been rectified in a simple manner (for example half-wave and four-valve apparatus  $kV_p = 1.4 \times kV_{R.M.S.}$ , or  $kV_{R.M.S.} = 0.7 \times kV_p$ .

Every irradiation, radiograph or fluoroscopic exposure imposes on the focus for a certain time a load which can be expressed in watt-seconds. Since this load is almost entirely converted into heat, reference is often made to 'heat units' (H.U.), which are based, however, on the peak value and not on the effective value of the voltage. The number of heat units, then, is equal to the product of  $kV$ ,  $mA$  and time (s). A load of, say,  $100 kV_p$  pulsating direct voltage (half-wave and four-valve apparatus) and  $25 \text{ mA}$  for  $5 \text{ s}$  thus amounts to  $100 \times 25 \times 5 = 12500 \text{ H.U.}$  (this corresponds to  $0.7 \times 12500 = 8750 \text{ Ws}$ ). If a continuous direct voltage is used (twelve-valve and capacitor apparatus), then the load will be 1.4 times greater, that is  $1.4 \times 12500 \text{ H.U.}$  (equal to  $12500 \text{ Ws}$ ).

*With the same maximum voltage, mA and time, therefore, the number of heat units produced with pulsating voltage is 0.7 times that with direct voltage.* This expression of the thermal load in heat units was introduced because, in practice, many half-wave and four-valve machines are still being used and these units dispense with the need for calculating effective voltages. On the present day tube

rating charts the maximum permissible tube load is usually again indicated in kilowatt-seconds, since three-phase apparatus (six- and twelve-valve rectification) is coming into vogue more and more, supplying a practically constant voltage which scarcely deviates from the peak voltage. For six-valve apparatus,  $kV_{R.M.S.}$  0.95  $kV_p$ ). Twelve-valve apparatus produces virtually direct voltage (constant peak voltage).

Steps must be taken to ensure that the focal area is large enough and the heat dissipation such that the tungsten is just prevented from melting when generating the required quantity of X-rays. Due to the limited direct conduction of heat in the anode material, care should be taken to ensure that the temperature of the entire anode remains under about  $1500^\circ C$  (which is already red hot). The quantity of energy which a tungsten focal surface area can support per  $\text{mm}^2$  before beginning to melt corresponds approximately to 200 W, provided this load is not imposed longer than 1 s. If, however, one applies the same load to the already hot focus in the following second then the focus would no longer be able to dissipate the heat fast enough and would therefore melt. Thus, what can be demanded of the X-ray tube in 2 s is less than that in twice 1 s with a sufficient cooling-off period between. The usual statement of the maximum permissible

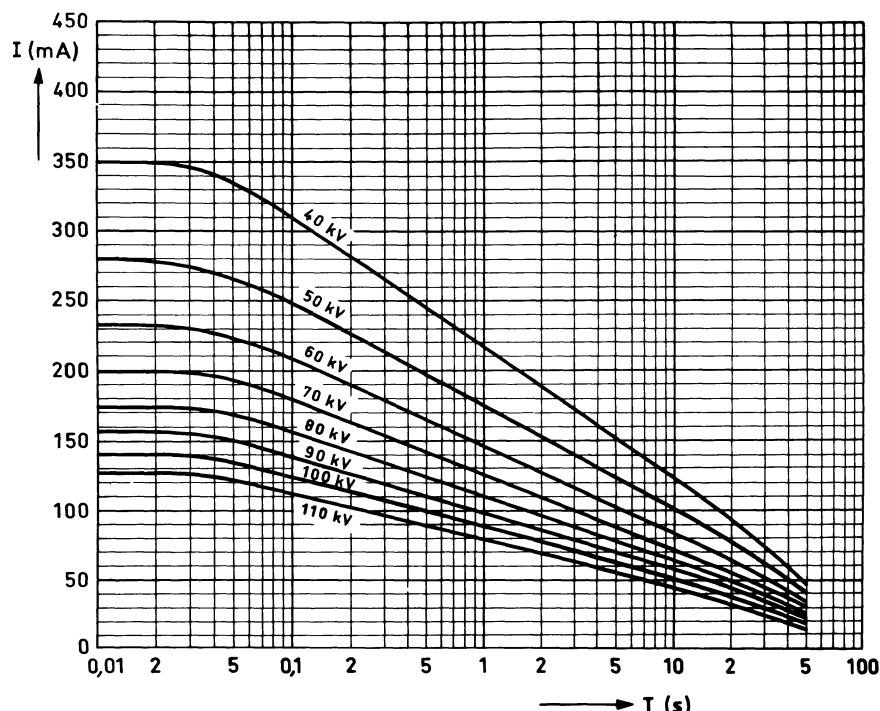


Figure 1.6 Graphic nomogram representing the permissible load of a 6 kW stationary anode tube connected to a two-pulse apparatus; 3.1 mm focus. This nomogram has been chosen for didactic purposes (see text); it refers to a tube that may now be considered as outdated, being of the non-rotating type (compare figure 1.7).

tube load is valid for a particular time (in s) and is not therefore valid for longer exposure times. If, for instance, the *permissible load* of a tube is  $200 \text{ W/mm}^2$  of the tungsten focal area for 1 s, then this means a maximum permissible load of  $3 \times 200 \text{ W} = 600 \text{ W/mm}^2$  of the effective focus. A 6 kW tube with a stationary anode with (Goetze) line focus has, therefore, an effective area of  $6000:600 = 10 \text{ mm}^2$ . If one assumes a square format (such as is usually the case in practically all effective foci) then this means that the linear dimension of the focus is  $\sqrt{10} \text{ mm}^2 = \text{about } 3.1 \text{ mm}$ . It is true that the diagonal of the square is larger (namely, about 4.4 mm), but in practice this is usually disregarded. The relationship between maximum permissible load of the tube and the exposure times is determined for every tube in a *nomogram* (tube rating chart).

Figure 1.6 illustrates a simple nomogram of a 6 kW stationary anode tube with the aid of which certain facts can be determined. First, the maximum permissible load at 1 s can be read off, namely,  $0.7 \times \text{kV} \times \text{mA}$ ; for example, with 70 kV it is  $0.7 \times 70 \times 125 = 5925 \text{ W} = \text{about } 6 \text{ kW}$ . With 0.1 s the maximum permissible load is higher, namely  $0.7 \times 70 \times 180 = 8820 \text{ W} = \text{about } 9 \text{ kW}$ . With 10 s the maximum permissible load decreases to  $0.7 \times 70 \times 70 = 3430 \text{ W} = \text{about } 3.5 \text{ kW}$ . With short and extremely short exposure times, therefore, the maximum permissible load of the tube is much higher than at long exposure times. The reason for this is that the focus, as it were, is (increasingly) less able 'to cope' with the applied energy. A continuous load only becomes possible when the point of equal energy uptake and energy dissipation has been achieved.

*In X-ray practice, the voltage is not usually expressed in kV<sub>R.M.S.</sub> but kV<sub>P</sub>.* It is indeed precisely the highest value of the voltage that corresponds with the maximum energy of the X-ray quanta, which produce the effects important for the medical application of radiation. From now on, therefore, kV, without any further qualification, will denote peak voltage.

The heat generated in the focus must be dissipated as rapidly as possible in order to prevent the melting point from being exceeded. This requirement is fulfilled in different tubes in various ways, as will be described in the next section. In this connection the thermal capacity of the anode also plays an important part.

## 1.6 TYPES OF X-RAY TUBES

There are two main types of X-ray tubes: therapy tubes and diagnostic tubes. Therapy tubes are used for administering treatment with X-rays. They differ from the tubes used in diagnostic radiology in their relatively low operating current, which usually ranges from a few mA to 20 or 30 mA. The voltages vary from 5 kV to hundreds of kV. As one does not aim for great definition in therapy, the size of the focus in these tubes is of less importance, generally speaking, than in diagnostic tubes, so there is no necessity for a very acute anode angle nor for a line focus. On the contrary, a fairly wide beam of rays is desirable in therapy and since, as we have seen, a steep anode angle sharply limits the useful beam cross-section on the anode side, the anode angle generally found in therapy tubes is 45°. In this way, the useful beam cross-section at a given distance from the focus can be made equal to that distance (ratio of beam cross-section to focus distance is 1:1). High demands are made on the cooling system of the therapy

tubes, owing to the necessity for almost continuous heat dissipation.

In diagnostic tubes used for fluoroscopic examinations and for producing radiographs we work in general with high current values, that is to hundreds of mA and up to 150 kV. The supply of energy takes place over a period of several seconds to minutes in fluoroscopy, and for radiographs only for short and extremely short times (even as short as 0.003 s). The focus in this case plays a very important part indeed; this will be dealt with at length in chapter 5 on *definition*.

Diagnostic tubes fall into two main categories: those with a stationary anode and those with a rotating anode.

### 1.6.1 Tubes with stationary anode

In these the target plate, containing the focal spot (see figure 1.4), is usually a tungsten disc embedded in a copper (copper being a good conductor of heat) anode. Such an anode can be cooled in various ways. Formerly, 6 and 10 kW tubes were very much favoured because of their high permissible load (for that time). Their large focus, however, entailed poor definition, and technical improvements have now led to the virtual disappearance of these tubes. Another tube frequently encountered even in those days was the dual-focus, with which the user had the choice between a large and a small focus, for example between a 3.3 mm (for 6 kW) and a 1.8 mm (for 2 kW) focus. In such a tube the cathode contains two separate filaments (and this is why the cathode cable is a three-core cable: both filaments have one core in common). Stationary anode tubes are now usually used in small apparatus only.

### 1.6.2. Rotating anode tubes

By means of a sophisticated construction the anode is made to rotate so that during exposure no part of the anode is heated to the maximum. Before the metal can melt from the bombardment by electrons it rotates so that colder material is brought in line with the focus (figure 1.7). These rotating anodes, as opposed to stationary anodes, no longer consist of copper in which a tungsten target is embedded, but comprise a mushroom-shaped disc made entirely of tungsten which rotates on its stem. The focal spot, then, lies at a position near the rim of the disc.

However, since tungsten is not a good conductor of heat, the sudden local sharp increase in temperature on the focal track and the irregular expansion and contraction give rise to tiny tears and cracks, so that the focal track becomes roughened and pitted and eventually fissures appear. Adding *rhenium* (about 10 per cent) to the tungsten produces an alloy that is more resistant to temperature change. However, since tungsten is heavy and the inertia thus is undesirably high (that is slow to reach great speeds), the main mass of the anode disc has been made of tungsten-molybdenum, a lighter alloy, and to this a relatively thin skin of tungsten-rhenium alloy is attached. The reduced inertia has proved to be a great advantage in the high-speed anodes (9000 r.p.m.). To improve these anodes still further, graphite is sometimes applied to the external surface of the focal track

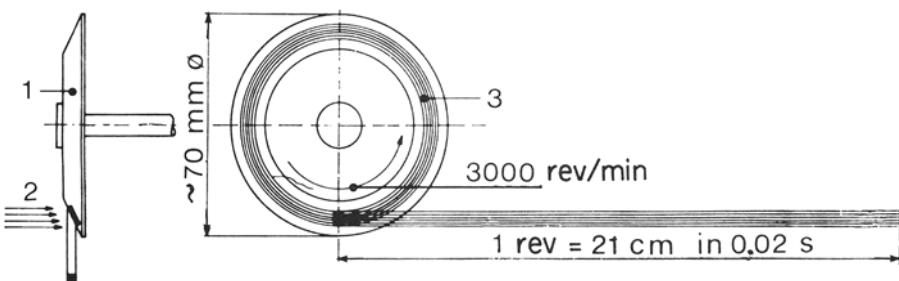


Figure 1.7 Left: side view of the mushroom-shaped anode of a rotating anode tube. Right: front view. 1. Anode disc (70 mm diameter) with anode stem or spindle; 2. electron beam directed onto the edge of the anode (indicated by arrows). At the edge of the disc the line focus is represented diagrammatically and under it the effective focus. In the figure on the right, the area (3) that is bombarded by the electrons during one revolution of the disc (the 'focal track') is clearly shown (the focal size being the same as in the figure on the left). If the diameter of the disc and the rate of rotation are increased, the track covered by the focus and, hence, the rating, is naturally also increased.

in order to obtain more rapid heat dissipation. These modern anodes with high loading capacities, therefore, reach a high speed more rapidly and their focal tracks are less affected. The latest constructions have built-in fissures in order to cope with expansion as it arises, and other metals (titanium, zirconium, etc.) are being tried for still greater efficiency and in some cases, have already been used in practice (figure 1.8a and b).

The anode must necessarily rotate very rapidly, its speed being about 3000 r.p.m. in a standard tube and about 9000 r.p.m. in a super tube (a tube with increased anode rotation speed). With a disc diameter of 70 mm, the length of the target track that is bombarded by the beam of electrons in 0.02 s is 21 cm at 3000 r.p.m., and as much as 63 cm at 9000 r.p.m. (One should realise that although the anode rotates, the focus does not; after all, the focus is the place where the beam of electrons hits and this remains at the same relative location!)

The extremely rapid rotation of the anode is a matter of considerable technical difficulty, for the anode rotates in a vacuum and hence, there is no opportunity for lubrication, nor for the use of normal ball-bearings. A lubricating grease introduced into a vacuum would at once generate gas, thus destroying the vacuum. At first, therefore, rotating anodes frequently seized up, thus rendering the tube useless. Today, the use of what are known as self-lubricating metal ball-bearings has improved rotation to such an extent that seizure of the anode is virtually unknown. Rotation is achieved by generating a rotating electromagnetic field around the glass X-ray tube, which causes the induction current in the *rotor* within the tube. This induction, which thus occurs through the glass and the vacuum of the tube, drags the rotor, to which the anode is attached, around with it. The field rotating is generated by means of a number of windings located outside the tube (*stator*), and thus achieves the fast rotation of the rotor mentioned above.

In the standard tubes a three-phase current field with a frequency of 50 Hz is used (mains frequency) which produces  $50 \times 60 = 3000$  r.p.m. (somewhat

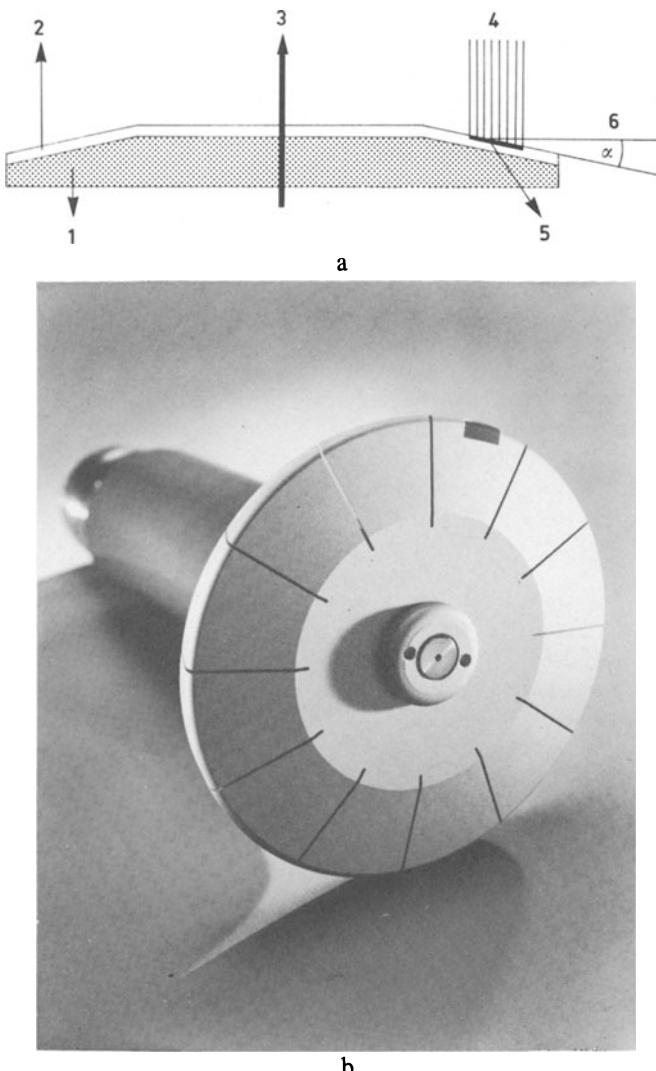


Figure 1.8 Construction of a rotating anode disc.

a. Section of a stratified anode disc. 1. Tungsten-molybdenum disc body; 2. tungsten-rhenium surface layer; 3. spindle or rotating axis; 4. electron beam; 5. focal track; 6. anode angle.

b. Anode disc with built-in radial expansion fissures, angled at 70° with respect to the surface (Philips Trinodex).

slower in practice). With tubes that have an increased rate of rotation, a three-phase current with a frequency of 150 Hz is generated in a special circuit (frequency multiplier). This produces a three-phase current field with the same frequency in the stator as a result of which the anode will rotate at three times the speed of the anode in a standard tube. The fact that the 9000 r.p.m. ( $150 \times 60$ ) is not quite achieved but is limited to, for example, 8800 r.p.m., is

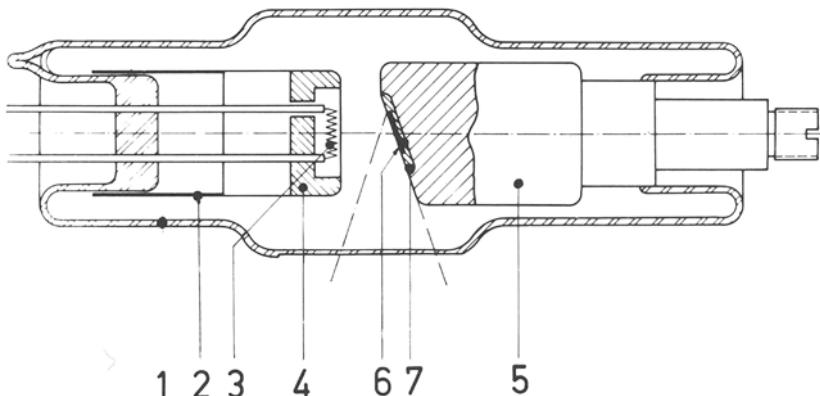


Figure 1.4 Section of an X-ray tube with stationary anode. 1. Glass tube or envelope; 2. cathode; 3. filament; 4. cathode cup for electrostatic focusing of electrons emitted by the filament; 5. anode, comprising solid copper block in which a tungsten target (7) is embedded; 6. focus; 7. tungsten target.

completely absorbed. Whereas one can optically focus (by means of lenses, etc.) light which originates from a light source, this is impossible in the case of X-rays. This is why we are obliged to use only a (small) part of all emitted rays and the rest is absorbed unused. The beam which in this case is meant to be used is in the shape of a cone, the top being the focus and the base the round window in the tube and tube housing, which allows the radiation to pass through.

Every X-ray image is a shadow image; it is therefore obvious that in order to obtain a sharp image the focus must be as small as possible. After all, if one wishes to produce sharply outlined shadow images the light source must be as nearly point-shaped as possible. If the electron beam, however, were to strike too small an area of the anode, the heat generated would be so intense as to melt the anode at that point. The focus, therefore, must have a specific size according to the load it should be capable of withstanding.

In the early X-ray tubes the angle between the surface of the anticathode (anode) and the electron beam was  $45^\circ$ , as illustrated in figure 1.5 (1). The particular ray that is perpendicular to the long axis of the X-ray tube (hence also to the electron beam) is assumed to be the *central ray* of the useful X-ray beam. This forms an angle of  $45^\circ$  with the anode; this angle is called the *anode angle*. The central ray is the axis of the cone-shaped X-ray beam and passes from the focus through the centre of the tube window. In all other aspects this central ray is no different from the remaining rays in the beam. It is obvious that in the direction of the central ray the focus appears to be smaller. After all, when one looks at a surface from an oblique angle, the surface seems smaller. This phenomenon, that is 'apparent' reduction in the size of the radiation source, contributes to greater definition.

Since the real focal spot assumes an increasingly elongated shape as the angle diminishes, this system is known as *line focus* or, in honour of the man who first applied this principle, *Goetze focus*. If in figure 1.5 (1),  $a$  is given as the width

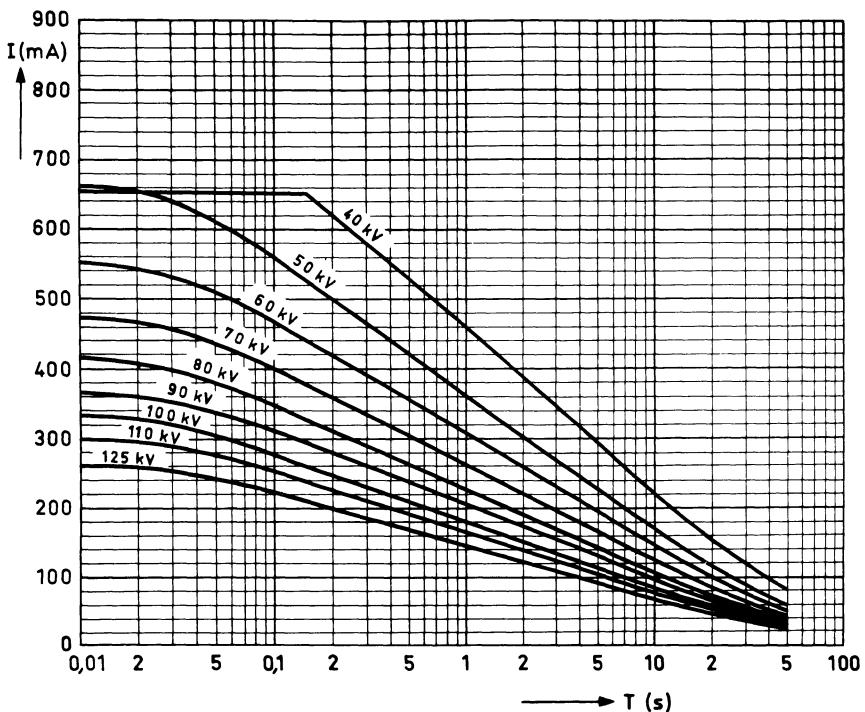


Figure 1.9 Nomogram for a rotating anode tube with a 1.2 mm focus (3000 r.p.m.) connected to a two-pulse voltage. The current ( $I$  in MA) is plotted on the ordinate and the exposure time ( $T$  in s) on the abscissa.

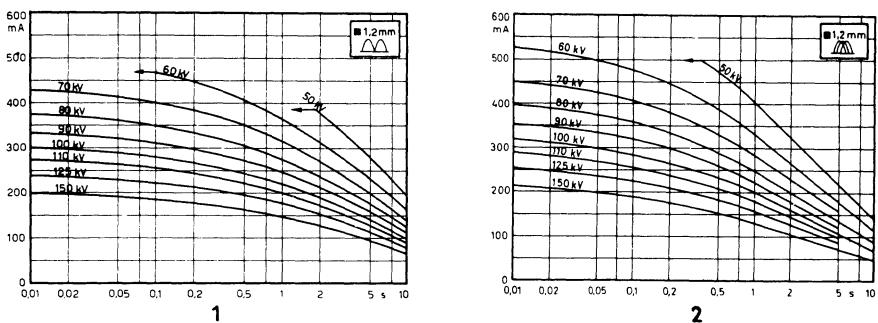


Figure 1.10 Comparison of loading and the capacity of a 1.2 mm rotating anode tube (3000 r.p.m.).

1. For two-pulse voltage. The loading is  $kV_p \times mA \times s$ , the number of heat units =  $(0.7 \times \text{number Ws})$ . The capacity for a particular time is  $kV_{\text{eff}} \times mA$ . At 70 kV and for 0.1 s the tube can cope with  $70 \times 400 \times 0.1 =$  about 3000 H.U. (capacity for 0.1 s is 21 kW); for 1 s about 24 000 H.U. (capacity for 1 s about 16 kW).

2. For six-pulse voltage. At 70 kV and for 0.1 s the tube can be loaded with 3150 Ws (capacity 31.5 kW for 0.1 s); for 1 s with about 23 100 Ws (capacity 23 kW for 1 s).

tube load with two-pulse voltage conforms with the facts mentioned in section 1.4, and is indicated in heat units. However, when constant potential is applied, virtually the same kV and mA values can be maintained whereby the value of the voltage is practically continuously equal to the  $kV_p$  value, which is also expressed in the loading ratio  $1 \text{ W s} = 1.4 \text{ H.U.}$

The fact that the tube rating for the same tube connected to a six-valve apparatus differs with the permissible loading when this tube is connected to a four-valve unit, is because the load on the focus increases during peak voltage periods with two-pulse voltage to the value of  $\text{kV} \times \text{mA}$ , which is thus 1.4 times as high as the average load on the tube. Moreover, when a rotating anode is used, the anode disc is unevenly heated due to the frequency of the peak voltages, causing uneven expansion of the anode disc. This can only be tolerated to a certain degree. For this reason the tube has a lower rating when it is connected to a four-valve apparatus.

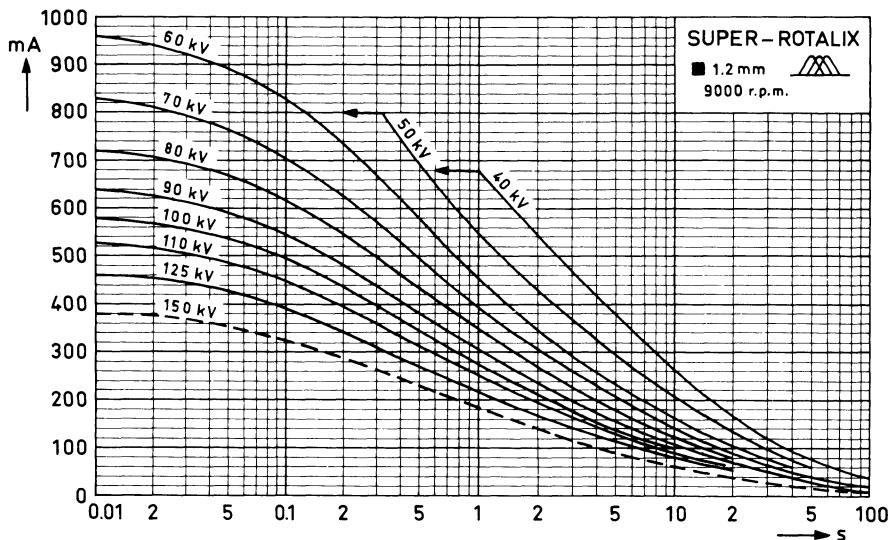


Figure 1.11 Rating chart of a tube with a super-fast rotating anode (9000 r.p.m.) and a focus of 1.2 mm connected to a six- or twelve-pulse apparatus. The current (in mA) is plotted on the ordinate and the exposure time (in s) on the abscissa.

The higher rating (= greater loading capacity) of tubes with a rotating anode (mentioned above) from raised r.p.m. is clearly expressed in their nomograms (figure 1.11). At 70 kV, the following applies:

At 0.1 s the loading capacity amounts to  $70 \times 700 = 49\,000 \text{ W} \doteq 50 \text{ kW}$ .

At 1 s the loading capacity decreases to  $70 \times 400 = 28\,000 \text{ W} = 28 \text{ kW}$ .

At 10 s the loading capacity has decreased even further to  $70 \times 140 = 9800 \doteq 10 \text{ kW}$ .

From the above one can conclude that, when very high loading capacities are unnecessary, one can also use the higher loading capacity per  $\text{mm}^2$  focal area for the application of smaller foci. This has indeed taken place, and use of the super-speed rotating anode tube with a focus of 0.6 mm, for example, is on the increase. For heavier loads a 1.2 mm focus is usually quite sufficient. Moreover, increased interest is again being shown in the 0.3 mm focus (macro-radiography) and even in a 0.1 mm focus.

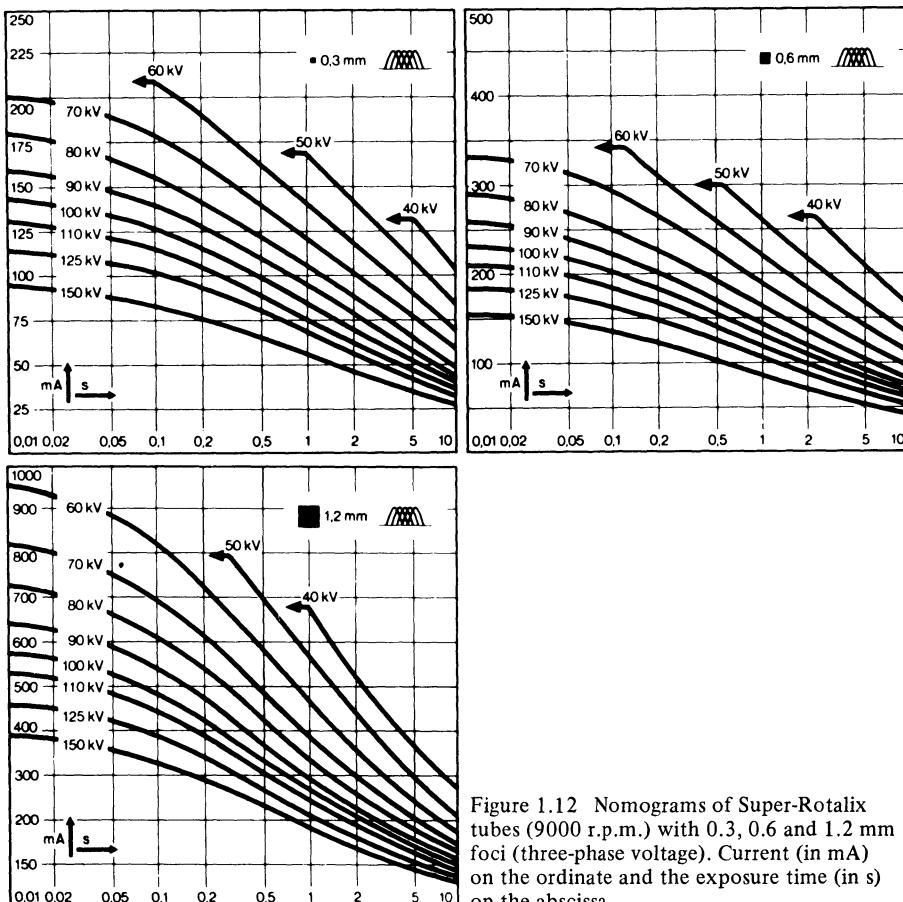


Figure 1.12 Nomograms of Super-Rotalix tubes (9000 r.p.m.) with 0.3, 0.6 and 1.2 mm foci (three-phase voltage). Current (in mA) on the ordinate and the exposure time (in s) on the abscissa.

The tube ratings for three foci can easily be read off from the three nomograms in figure 1.12 (three-phase voltage and 9000 r.p.m.). From these nomograms the following loading capacities (in round figures) can be read off:

	0.1 s	0.5 s	1 s	5 s
0.3 min focus	12.5 kW	10 kW	8 kW	5 kW
0.6 min focus	20 kW	15 kW	12 kW	9 kW
1.2 min focus	48 kW	35 kW	27 kW	14 kW

It appears from the nomograms and the above figures that for longer continuous loads the ratings of the different foci approach each other and will eventually reach the same value. For this reason, it is logical that in fluoroscopy the smaller of the two foci should always be used. Finally, figure 1.13 demonstrates the great gains made by the change to super-fast rotating anodes, especially for very short exposure times.

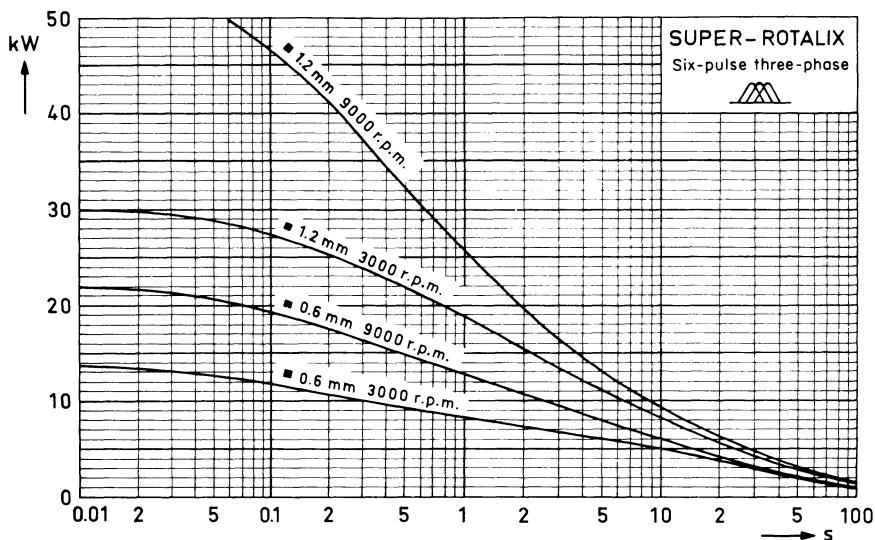


Figure 1.13 Comparison of the loading capacities for rotating anode tubes with 0.6 and 1.2 mm foci and speeds of 3000 and 9000 r.p.m. The loading capacity is expressed in kW (on the ordinate), and the exposure time in seconds on the abscissa. The curves apply for six-pulse three-phase voltage. The sharp fall in loading capacity at longer exposure times is very clearly seen.

#### 1.6.4 Nomenclature of tubes, focus tolerance

A common specification of tube type first mentions the name (usually patented) in abbreviated form (for example Bi = Biangulix), followed by the highest permissible voltage (for example 125 kV) and then the rating of the focus or foci (such as 30 kW for the fine focus, 50 kW for the broad). This (Siemens) tube is thus indicated by Bi 125/30/50; the dimensions of the foci do not follow from this, but are mentioned separately. The (Philips) tube with rotating anode and 'ordinary' r.p.m. (3000 r.p.m.), called the *Rotalix*, could be specified, for example, by Ro 12 31, that is a Rotalix tube with a loading capacity of 12 kW on the fine focus and 21 kW on the broad focus. These loading capacities apply (according to further specifications) for the 0.6 mm and 1.2 mm foci for an exposure time of 0.1 s. For tubes with higher r.p.m. (nominal 9000 r.p.m.) the prefixes super- or ultra- are used; for example the Super-Rotalix SRO 20 50, which can withstand 20 kW on the 0.6 mm focus and 50 kW on the 1.2 mm focus (for 0.1 s).

Incorrect indication of the dimensions of the focus leads to an incorrect appreciation of the tube rating. If, for example, the focus is really larger than indicated, then, as a consequence of underloading, exposure times which are too long would be necessary; this, together with the large focus, would cause the image to be very blurred. The effective focal dimensions, which are indicated by the manufacturer, may deviate a maximum of 30% from the real values according to the international regulations. Therefore, a focus indicated as 1 mm could actually prove to be a 1.3 mm focus.

We shall return to the details of the method of measuring the focus in chapter 5, section 5.1.

## 1.7 FURTHER STRUCTURAL DETAILS OF THE X-RAY TUBE, TUBE WINDOW, INHERENT FILTRATION

Of the quantity of radiation emitted from the focus, only a small part is used, namely that part which passes through the (usually round) *tube window*. The tube shield has an aperture, in line with the tube window, which also allows free passage of the rays. The remainder of the radiation is absorbed in the tube itself or in the tube shield. The useful beam is, therefore, a cone of rays, the apex of which is the focus. Although we often use the word *X-ray beam*, we should always remember that X-rays, unlike light rays, *cannot* be focused into a beam. The part we call beam, therefore, is the small portion of the radiation emitted by the focus, which can reach the outside through the tube window and the tube shield only. The tube window consists of a portion of the glass wall of the tube, which is made thinner to allow the rays to pass through with as little hindrance as possible.

*Every obstacle through which the rays must pass on their way from the focus to the object is known as a filter.* The first filter, therefore, is the glass of the tube window itself. Other substances may also be placed outside the window with the effect (intentional or unintentional) of further filtration of the beam. This filtration is always expressed in terms of the required thickness of a certain substance which would be needed to absorb the same amount of X-radiation under equivalent conditions. We thus speak of, for example, mm *aluminium equivalent* or mm *copper equivalent*. One should distinguish between:

(1) The filter (or the filtration) which is inevitable and cannot be separated from the tube (glass envelope, possible surrounding oil and tube shield aperture, etc.). Together these are called the *inherent filtration value* of the tube or *inherent filter* (sometimes these may be called the *fixed filter*). Usually, the inherent filtration value is expressed in mm aluminium equivalent.

(2) A possible *added filter* which, for example, consists of a thin plate of aluminium or copper, is placed in front of the tube window. For voltages up to 100 kV, added aluminium filters are used and copper for voltages above 100 kV. The aluminium filter, when combined with a copper filter, is placed on the patient's side of the copper filter in order to absorb as much as possible of the soft characteristic radiation produced in the copper by the X-radiation (see section 2.1).

The *total filtration* is naturally equal to the sum of the inherent and added filtration and is also expressed in mm aluminium or mm copper equivalent.

Finally, for certain purposes, namely the use of soft X-radiation, in order to keep the inherent filtration as low as possible, tube windows are made of materials with low atomic numbers. Formerly, these were the so-called Lindemann windows consisting of glass with lithium ( $Z = 3$ ) and boron ( $Z = 5$ ). Today, these have been superseded by beryllium ( $Z = 4$ ) windows which are now found in all modern tubes required to have low inherent filtration. A special tube used for contact therapy for example, has a beryllium window combined with a sheet of mica (which ensures a 'vacuum seal') and has an inherent filtration of only 0.03 mm aluminium equivalent. Heavier filtration, and thus also the use of an added filter, reduces the intensity of radiation and makes it 'harder', since the softest radiation is absorbed to a relatively greater extent.

## 1.8 TUBE AND APPARATUS CONSTRUCTION IN RELATION TO PROTECTION AGAINST RADIATION AND HIGH VOLTAGE

The design of X-ray tubes should take two hazards into account:

- (1) the radiation hazard,
- (2) the danger of high voltage.

X-rays produce a biological effect, that is to say they affect living tissue, and inexpert handling or negligence can give rise to serious injury (radiation damage). In the types of X-ray tubes formerly used, which can still be seen in museums, the radiation was emitted in all directions. Heavy and unwieldy wooden shields, lined with lead or lead glass, served to absorb this radiation, except that which was allowed to pass through a small opening in the shield. The shield was not without its dangers, since a leak was not immediately perceptible and it was possible to be exposed to primary radiation while believing oneself quite safe.

Later, protective measures were fixed to the tube itself either by partially substituting the glass envelope by a radiation-absorbing metal section (in which a glass window allowed the beam to pass through), or by fixing lead protection (also with a window) immediately next to the glass envelope. An example of the first type of construction was the Metalix tube (Bouwers, Philips), and the second construction was used by others (such as Siemens, with the Multix tube). Both types of construction in their time, when X-ray tubes were still often 'open' tubes (that is not protected against high voltage) meant a great step forward; however, since the introduction of protection against high voltage by means of earthed tube shields, these tubes have practically lost their importance. The X-ray tubes of today, which are built within the tube shields, are not themselves protected against undesirable radiation as this task has now been taken over by the tube shield.

As far as the danger of high voltage is concerned, it is fatal not only to touch simultaneously the naked high voltage leads to the anode and cathode, causing the entire potential difference to traverse the body, but also to touch just one of these wires or the open X-ray tube itself, when the voltage passes directly to

earth through the body. This danger of high voltage has been completely eliminated in modern X-ray units; the X-ray apparatus, high-tension cables and tubes have been made *shockproof*.

The first fully shockproof apparatus was demonstrated at the Third International X-Ray Congress in 1928 at Stockholm, and was regarded then as a revolutionary advance. The apparatus was the 'Philips Metalix Junior'. Very soon after that, complete protection (against both high voltage and undesirable radiation) was built into X-ray tubes and apparatus and, thus, as early as 1933 a fully protected (rayproof and shockproof) installation could be provided, even for a 200 kV (therapy) unit.

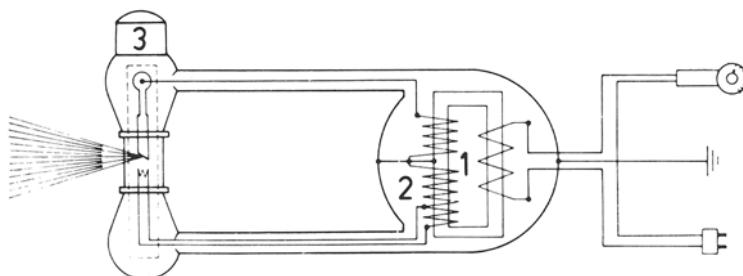


Figure 1.14 The principle of protection against high voltage. 1. Primary winding of the high-tension transformer; 2. secondary winding with filament current tap and earthing of the centre; 3. fan for air cooling of the X-ray tube. This diagram represent the scheme of the Philips Metalix Junior apparatus with which the era of total high voltage protection was introduced in 1928.

The principle of a protected installation is simple, and is represented in figure 1.14. In general, the following applies. The low voltage from the mains supply (220 or 380 V), together with a connection to earth, is fed to the primary windings of the high-tension transformer via a circuit with which the exposure time can also be regulated. A branch from the mains connection goes to the primary windings of the filament transformer. The centre of the secondary windings of the high-tension transformer is earthed. This earthing conductor is directly connected to the metal shield, which contains the transformer, (surrounded with oil), to the metal shield that surrounds the tube and also to the high-tension cables which run from the transformer to the tube. No matter how one approaches the transformer, the cables or the X-ray tube, one always meets with the earthed shield first, and one is therefore entirely protected against high voltage. If a defect occurs somewhere inside, for example a breakdown of the rubber insulation of the cable, then there will merely be a short circuit between the high voltage of the inner conductor and the earthed metal shield, without anyone who might be touching the apparatus, cables or X-ray tube, noticing (by means of a shock or otherwise).

*Every modern shockproof X-ray installation has a continuous, earthed metal shield within which the high voltage phenomena take place.*

## 1.9 INSULATION AND COOLING

The introduction of these protective measures against high voltage has involved far-reaching changes in the actual design of the X-ray tubes themselves, partly in connection with insulation and also cooling.

### 1.9.1 Air insulation, cooling by air

In the simplest forms of protection against high voltage, insulation is provided by the air in the space left between the tube and the shield. A fan was often also fitted (figure 1.14). However, in diagnostic X-ray tubes air insulation has been entirely replaced by oil insulation.

### 1.9.2 Cooling by means of water

When the anode is earthed, this can be connected to the mains water-pipes. This is used in some types of tubes (Senographe, C. G. R.). The copper anode is made in such a way that the water can circulate through it and this makes heat dissipation very efficient, and the tube can thus receive relatively heavy loads. The cathode, in this case, is raised to the full transformer voltage and is negative with respect to earth.

### 1.9.3 Oil insulation and oil cooling

The use of air insulation between tube and shield has now virtually given way entirely to oil insulation. Advantage is taken of the fact that oil (provided it contains no impurities) is a very efficient insulator. This allows the distance between tube and shield to be less than when air is used as the insulator. This means that oil-insulated tubes are less bulky than air-insulated ones. A further advantage is that the oil, which entirely surrounds the tube, also serves as a cooling agent.

Let us now take a closer look at the cooling of these oil-insulated rotating anode tubes. During 'heavy' exposure, the anode becomes very hot and even glows due to heat dissipation from the focus to the rest of the anode. At these high temperatures the heat is transmitted to the surroundings (glass, oil, shield) by radiation (heat radiation). This is why the anode is coated (except the focal track) with a thin black layer (a metal oxide) which increases the heat radiation. The heat radiation is to a large extent absorbed by the glass which becomes heated. The 'hard' glass of the tube is capable of withstanding a great deal of heat. The oil in contact with the glass is also warmed in its turn, and convection currents are produced in the oil carrying heat further to the metal wall of the tube shield. Space should be provided to allow for expansion of the oil.

In order to avoid decomposition of the oil and other insulating materials in the tube shield, the temperature of the oil should never be allowed to reach 100 °C. Apart from the oil, the tube also includes solid insulation material, for example for the connections to the tube. These connection sites are usually made in the form of sockets (made from porcelain, bakelite, etc.) into which the cables can be plugged. While in the case of electrical breakdown in a liquid (for example oil) the site of the breakdown is immediately filled up, the breakdown of a solid insulator

(in a socket, for example) leaves a permanent defect, which then needs repair or replacement.

It is technically very difficult to make anything 'oil-tight' and, oil-cooled tubes therefore sometimes feel rather greasy on the outside. This does not necessarily mean that there is a leak. Of course, if drops of oil appear, or if the outside becomes very oily, the tube must be investigated and repaired, since obvious loss of oil cannot be permitted. In practice, the consequence of the extreme purity requirements of the oil and tight oil seal is that the tube cannot usually be installed in the tube shield in the X-ray room, but in the factory. For this reason, it is advisable to keep a complete tube unit (that is tube complete with shield) in reserve. Another necessary and sometimes unwelcome consequence of the use of oil is that the inherent filtration of the tube is higher than that of tubes with air insulation, for, after passing the glass window of the tube, the radiation must first penetrate a layer of oil before it can emerge through the window in the shield. The inherent filtration of an oil-filled tube is generally about 1 mm aluminium equivalent. This in itself is not so serious, particularly not in fluoroscopy for which purpose a total filtration of at least 2-4 mm aluminium equivalent is desirable. In these protected tubes an extra aluminium filter of at least 1 mm aluminium equivalent is used.

Much more serious is the fact that the insulating media themselves, when penetrated by the radiation, give rise to additional radiation, that is, radiation which does not originate from the focus and has the effect, as it were of diffused 'light'. This unwanted additional radiation was a familiar phenomenon in old types of X-ray tubes, where it was caused by secondary electrons bombarding the anode stem and there generating X-rays. It proved possible to eliminate this nuisance by intercepting these secondary electrons within the tube, or by screening off the radiation caused by them. This is not possible when the secondary radiation is emitted from outside the tube but from within the tube shield by the insulating media. Analogous with the above, this radiation is also known as *stem radiation*, although it does not in fact originate from the anode stem. It would be better to call it *off-focus radiation*. Fortunately, the intensity of this radiation is very low compared with that of the primary focal beam and is therefore of no great consequence in practice. Its presence can be detected in fluoroscopy, however, without an absorbent medium, by the appearance of a faint butterfly-shaped glow at each side of any particular field defined by the shutters of the diaphragm.

## 1.10 METHODS OF COOLING BY MEANS OF OIL

### 1.10.1 Static natural oil cooling

With most diagnostic tubes the heat capacity of the oil within the shield is sufficient to deal with the heat generated by the tube (the shield in its turn dissipates the heat by conduction and radiation). We may refer to this as static natural oil cooling. In many cases the shield contains an expansion chamber (detail 1 in figure 1.15), which operates a contact switch (thermoswitch) when the heat and thus the expansion becomes excessive. This automatically protects the tube from the consequences of over-heated oil. In this way the tube is protected (thermal protection).

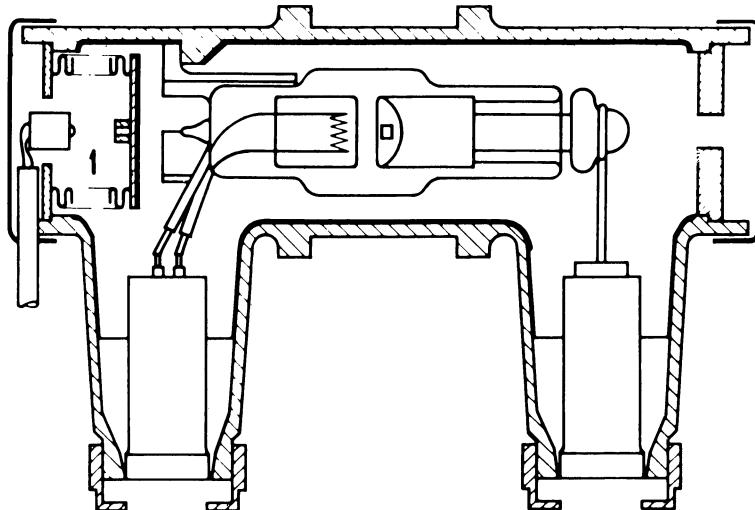


Figure 1.15 Protected X-ray tube with oil insulation. Static natural oil cooling. The tube insert, entirely surrounded by oil, is located within the shield. On the left, the expansion chamber (1) with thermoswitch. With oil insulation the dimensions can be much smaller than with air insulation. The cable connections are made to the lower projections of the shield.

### 1.10.2 Static forced oil cooling

The shield is sometimes additionally cooled by means of a built-in fan. This form of cooling is called *static forced oil cooling* (figure 1.16). If the heat generated is too great to be dissipated by static natural cooling (mainly in therapy tubes) then one can either cool the oil around the tube itself or keep cool oil continuously supplied to the tube (*forced oil cooling*). In the first case, a cooling spiral can be fitted around the tube in the oil and connected to the water mains (the spiral must, of course, be far enough away from the tube to prevent a flash-over). In this way the heated oil is cooled by the water flowing through the spiral. This too is called static forced oil cooling (figure 1.17).

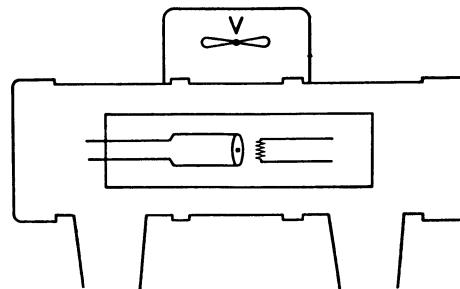


Figure 1.16 Static forced oil cooling (with fan). The air cools the shield and thereby also the oil which is located between the tube and the shield. V = fan.

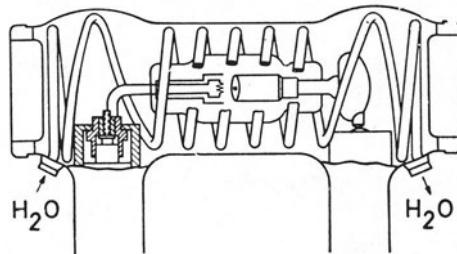


Figure 1.17 Static forced oil cooling (with water). The water cools the oil which is located between the tube and the shield.

### 1.10.3 Circulated forced oil cooling

In the second case, the oil around the tube is connected by two pipes to an oil reservoir with a radiator and pump, where the oil is usually additionally cooled by water. The oil is forced into the shield by the pump and back again to the reservoir. Although the oil circuit is in contact with the high voltage, the insulating properties of the oil prevent flash-over. This form of cooling is called *circulating forced oil cooling* (figure 1.18).

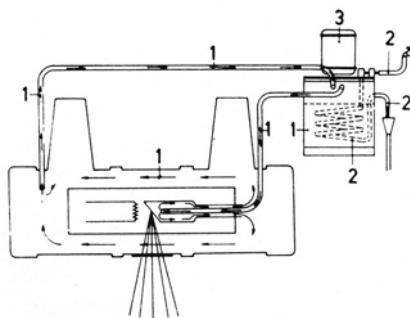


Figure 1.18 Circulating forced oil cooling. By means of the pump (3) the oil (1) is forced towards the anode in the direction of the arrows and then flows around the tube. The oil is additionally cooled by water at (2).

A drawback of oil cooling is that during its alternation from hot to cold, the oil can undergo certain chemical changes, which can lead to sedimentation (with obstruction of the oil circulation); carrying out repairs to the oil cooling system always makes a mess in the neat and tidy X-ray department. Moreover, the cooling properties of oil are relatively poor. The negative properties, however, are offset by the advantages, which have led to the fairly general use of oil in today's tube constructions.

Attempts have certainly been made to re-introduce gas instead of oil insulation, but there are several serious objections to the use of gas for this purpose: in order to prevent flash-over across a small distance, the gas must be under very high pressure, which means that the tube shield must again be stronger and heavier than

when oil is used. Also, there is always the danger of compressed gas escaping or exploding and, furthermore, gas is a much poorer conductor of heat than oil. We may, therefore, expect oil insulation and oil cooling to remain a permanent feature of X-ray tube constructions.

#### **1.10.4 Cooling by means of an earthed anode**

A few words about an unusual type of tube in which either the anode or the cathode is earthed and the other terminal, therefore, carries the entire high voltage. The earthed terminal can naturally be touched without danger. If the anode is earthed then cooling is very simple, as one can use circulating forced water cooling by connecting the anode directly to the mains water supply; this is in fact done in some therapy tubes (apparatus) and also in the special mammography tube with an molybdenum anode. The electrical insulation of the other terminal must be capable of withstanding the entire high voltage.

#### **1.11 TUBE SHIELD, HEAT DISSIPATION, COOLING-OFF PERIODS, ANODE DISC**

The modern protected tubes consist of the tube shield within which the actual tube insert is situated, surrounded by oil. Protection against radiation is almost entirely provided by the shield by means of a lead lining on the inside. The actual X-ray tube is not rayproof. This applies to all types of tube, regardless of the manner in which they are cooled.

Figure 1.19 shows a cross-section of a fully rayproof and shockproof diagnostic tube with rotating anode (with dual focus, thus two filaments), which is cooled by the static natural oil cooling method and provided with a thermoswitch, which ensures that the tube is switched off if the temperature rises too high. In addition to the single-core anode high-tension cable and the three-core cathode high-tension cable, two other cables lead to the tube, one for the thermoswitch and one for the

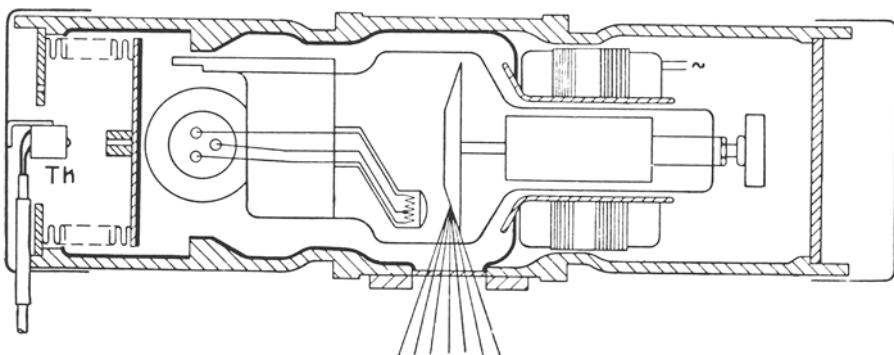


Figure 1.19 Protected dual-focus rotating anode tube with stationary natural oil cooling. Right: the anode disc and anode stem; around the tube insert the stator windings with mains supply connection (~). Left: both spiral cathode filaments with the three supply leads from the cathode cable; on the extreme left the oil expansion chamber with thermoswitch (Th).

stator that drives the rotating anode.

Apart from the heat generated by the electron bombardment of the anode, the heat given off by the filament must also be dissipated, as well as that caused by friction during the rotation of the anode. Compared with the number of joules produced by the electron bombardment, the heat from the filament, stator and anode friction can be disregarded in practice. In fluoroscopy the filament consumes about 40 W and the anode friction losses are even less, whereas the capacity of the anode may amount to 200 or 300 W. In radiographic exposures the heat dissipation may rise to 20 kW (for example, with an exposure of a lateral lumbar spine). With rapid sequence exposures the heat dissipation may be still greater and care should be taken that the thermal capacity of the tube is not exceeded.

It should again be emphasised that the tube rating charts should be studied carefully before enormously heavy loads are placed on the X-ray apparatus, which could be the case when (large size) rapid sequence series are carried out as, for example, in angiography. It should also be noted that in tubes with a stationary anode the heat is mainly dissipated by the anode stem, whereas in tubes with a rotating anode there is less heat conduction to the anode stem and the anode disc loses its heat mainly by direct radiation. It is obvious that with loads of short duration (radiographic exposures), the temperature of the focus undergoes a sudden enormous rise and then drops again. This gives rise to strains and stresses, which can cause cracks to appear on and around the focus; as a result the focus eventually becomes pitted and rough and forms a marked contrast to the beautifully polished surface surrounding it. If the focus becomes too rough, many electrons will collide in the cracks and fissures and the X-rays generated by them will make no contribution to the useful X-ray beam. The resultant drop in the *efficiency* of a tube, an ageing phenomenon, can sometimes be appreciable and may necessitate longer exposures. In order to lessen the roughening of the focal track to some extent, 5-10 per cent of a metal called 'rhenium' is added to the tungsten of the anode (see also section 1.6.2). A moderate roughening of the focal track will always be apparent eventually, even on targets of correctly loaded tubes. In the case of tungsten targets embedded in copper the stresses at the junction between the metals can become very considerable and the targets may even burn through or break away from the copper.

Thanks to the cooling provision every tube can 'dispose' of a specific quantity of heat; as we have seen, the specific heat rating can be found from the nomogram of the tube. For some tubes periods of rest are specified. For example, small X-ray units (for dental purposes, portable equipment, etc.) are provided with a time switch. The longest time that can be set on the time switch corresponds to the maximum load on the tube. With such equipment, one must never make two exposures in quick succession so that their total duration exceeds the longest time set on the time switch. Usually, it is not possible to switch to the maximum time more than once a minute.

Modern, large diagnostic tubes are rated for a continuous load of 150-350 W, depending on the size of focus, anode diameter and speed of rotation. For instance, a 0.3 mm focus with a rotating anode disc of 70 mm can be rated for a continuous load of 150 W, that is  $2 \text{ mA} \times 70 \text{ kV}_{\text{R.M.S.}}$ , or 2 mA at about 100 kV peak voltage, which is quite sufficient for fluoroscopy. The tube current usually needs to be no larger than 0.5 mA when screening with image intensifier and television.

## 1.12 BEAM CROSS-SECTION

From the focal spot the X-radiation is propagated in all possible directions, but the absorption in the anode generally restricts it to a hemisphere. However, the interior of the tube shielding is covered with an absorbing layer (generally made of lead), which absorbs all radiation in this hemisphere, except at the *window* where this absorbing layer is absent. The beam of X-rays leaving the tube is thus in the form of a cone with the focus as its apex and the tube window as its cross-section. We have already seen that the *angle* of the anode also plays a part in determining the size of the useful beam: too acute an angle gives a very narrow useful beam, that is a considerable loss of intensity on the side of the anode (*heel effect*).

In diagnostic tubes with anode angles of about  $19^\circ$  the ratio between the diameter of the useful beam and the focus-film distance is about 2:3. Consequently, for a focus-film distance of 80 cm, for instance, the maximum beam cross-section is  $2/3 \times 80 \text{ cm} =$  about 53 cm. Thus a film size of  $30 \times 40 \text{ cm}$  (diagonal = 50 cm) can be completely covered by the beam, with cut-off corners, if correctly centred.

It may be noted here that, in practice, both for obtaining better radiographs and also with a view to radiation protection, one always uses as small a beam as possible, compatible to the size of the object to be examined. A fixed or adjustable diaphragm (made of lead) is used to limit further the size of the beam emerging from the tube window, as desired. Naturally, if the anode angle is made even smaller (for example  $10^\circ$ ) the useful beam cross-section is reduced further, and is now only suitable for spot films (of certain details) at usually a relatively short focus-film distance. When the focus is situated at the end of a rod one can theoretically use an angle greater than  $180^\circ$ . In practice, however, this leads to difficulties. For diagnostic purposes a tube of this type has been constructed for panoramic exposures of an entire set of teeth (focus inside the mouth!) (chapter 12, section 12.1.11).

## 1.13 VALVES, RECTIFIERS, DIODES

### 1.13.1 Glass valves

A very important problem in X-ray apparatus is the rectification of the alternating current. The *valves* or *diodes* are similar to X-ray tubes in that they are built according to the same principle. They also consist of a high-vacuum glass envelope in which a cathode filament and anode are located (figure 1.20).

The electrons liberated from the hot cathode can only proceed to the anode when this is positive with respect to the cathode. With an alternating voltage, however, the anode is negative during one half of a cycle, so that this tube is then without current. The characteristic of every diode is that it allows current to pass through in one direction only. This is called (although not entirely correctly) *rectification*. In contrast to the X-ray tube, however, in which the transition of electrons from the cathode to the anode is made difficult and only occurs at high voltages (due to which they are given great speed and produce X-rays), in the valve the transition of electrons from cathode to anode is achieved at low voltages.

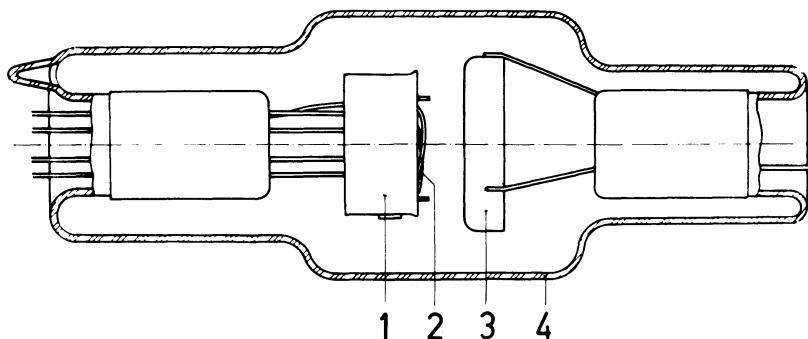


Figure 1.20 Diagram of a valve. 1. Cathode; 2. filament (tungsten with thorium oxide); 3. molybdenum anode; 4. glass envelope.

This is done by a high emission rate from the cathode and by means of specially constructed electrodes. With only a few kilovolts potential difference between anode and cathode the beam of electrons passes easily through the valve, and X-rays are not produced at the anode. A valve in the circuit thus produces little resistance and thus causes relatively little loss in voltage. It is important that:

- (1) The current is allowed to pass in one direction only (the function of the valve)!
- (2) The low voltage across the valve does not cause X-rays to be produced at the anode.

It should be noted that, according to convention, the electric current travels from 'plus' to 'minus', that is, from the anode to the cathode. In reality, the electrons move in the opposite direction.

Valves have undergone considerable changes in the course of their development. In earlier types of valves it sometimes happened that the cathode emission became too low, so that the current diminished as the resistance of the valve increased (more difficult transition of electrons) and the voltage drop across the valve in the circuit became greater. Since the valves are always in series with the X-ray tube there was less high voltage left over for the X-ray tube. The result was, therefore, undesirable X-radiation from the valve and too weak an X-radiation from the X-ray tube. Therefore, the emission of older types of valves (valve filament current) had to be very carefully adjusted or regulated. Special measures were taken to make valves rayproof in the event of X-ray emission (lead shielding, Metalix valves, etc.). Later, the so-called 'gas valves' were made based on the principle of the charge-carrying properties of gas ions in the valve. Actually, such a gas valve is an ion tube that operates at a low voltage. These gas valves have also been abandoned.

With the introduction of hard-glass X-ray tubes immersed in oil, valves have also been made of hard glass and their dimensions considerably decreased. Moreover, the cathode has been coated with certain substances (such as thorium oxide) that emit electrons profusely at a fairly low filament energy, thereby reducing the amount of heat developed and also avoiding the risk of a drop in electron emis-

sion. Furthermore, these valves are less dependent on temperature, which is an important advantage when transformers and valves have to operate in cold rooms.

Valves are used in both diagnostic and therapy equipment. In diagnostic apparatus they have almost entirely been replaced by *solid-state rectifiers*.

### 1.13.2 Solid-state rectifiers

These new types of rectifiers are based on the properties of semiconductors. They have long been used for rectification in low-voltage techniques, but are now also being used for high-voltage techniques (figure 1.21). Such a rectifier (semiconductor diode), also called a solid-state rectifier, consists of two layers of the same basic material (selenium or silicon), which, by the addition of traces of other elements (impurities), have different electrical properties. Between the two layers there is a boundary layer of which the most important characteristic is that it allows the electric current to pass through in one direction only. This layer is therefore called a *barrier layer*.

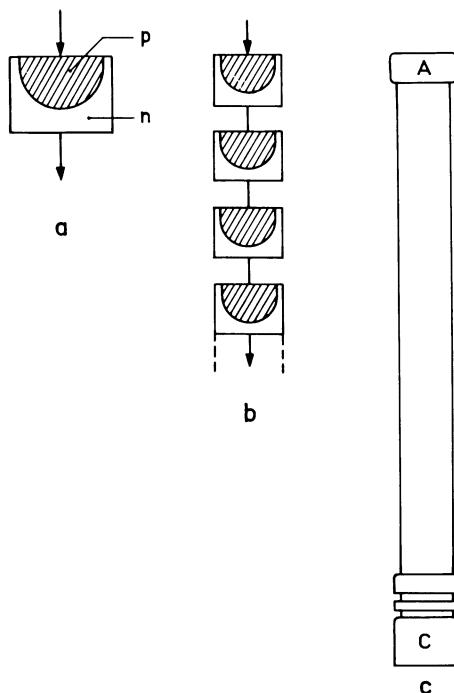


Figure 1.21 Semiconductor rectifier.

a. Diode element. The arrows indicate the direction of the electric current. The hatched part of the element represents the positive side (p material), the rest the negative side (n material).

b. Four diode elements in series, mounted in stack form.

c. A complete rectifying rod with anode connection (A) and cathode connection (C), suitable for rectifying 150 kV.

In general, these cells or elements are constructed in the shape of a little disc. A single cell can pass a heavy current (even as much as 1A) in the forward direction and can withstand a voltage of 250 V without allowing current to pass in the opposite direction. In order to block an inverse voltage of 150 kV (such as occurs in modern diagnostic equipment) it would be necessary to place  $150\ 000 : 250 = 600$  of these cells in series (assuming that one cell can withstand 250 V). For this purpose they are piled up like stacks of coins, joined to each other (by means of an insulated bolt, usually) and in this manner made up in the form of rods (with the cells in series). By connecting several of these rods in series the required rectification is achieved. It goes without saying that apart from having the correct number of cells one must be sure that they are of sufficiently high quality to prevent 'breakdown'. In this respect a silicon rectifier is better than a selenium rectifier, since the first does not depend on temperature to any great extent, it does not produce a serious drop in voltage and has a longer life.

The rectifier is mounted either in plate form inside the X-ray transformer or in a form which is very similar to that of a glass valve tube. In the latter case there is a choice between the use of conventional glass valves or modern semiconductor rectifiers. These modern rectifiers have the following advantages: they need no provision for filament current, therefore no filament transformer, and can never produce X-rays. They have a longer life than a valve. It should be mentioned, however, that in contrast to a gas-filled valve, they cause a certain loss in voltage in the forward direction. This can and must be taken into consideration when the transformer is constructed.

### 1.13.3 Symbols

Much use is made of simple symbols to indicate X-ray tubes, valves, solid-state rectifiers (these are all diodes). This is illustrated in figure 1.22:

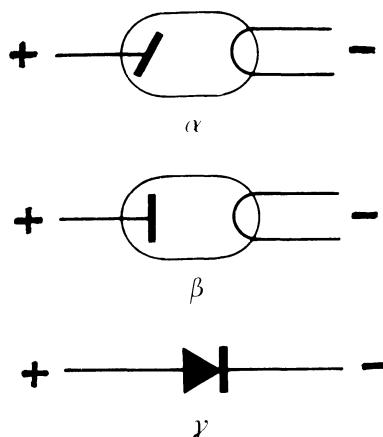


Figure 1.22 Diagrammatic representation of various diodes.  $\alpha$ . An X-ray tube;  $\beta$ . a valve;  $\gamma$ . a semiconductor rectifier. The anode (+) is on the left, the cathode (-) on the right. The arrow indicates the direction of the electric current (from + to -, that is, opposite to the direction of the electron flow).

$\alpha$  represents an X-ray tube. Facing the curved line (the filament) the straight oblique line indicates the anode.

$\beta$  is the symbol for a (glass) valve. Facing the curved line is a straight, vertical line and this indicates the anode.

$\gamma$  The arrow in this symbol indicates the direction in which the electric current flows (that is, opposite to the direction of the flow of electrons!). The point of the arrow in this case touches the cathode.

After the discussion in this chapter about the manner in which X-rays are produced and about the different types of tubes for use in diagnostic radiology, in the next chapter full attention will be given to the properties of X-rays.

## 2

# Formation and Properties of X-rays

X-rays form a part of the electromagnetic spectrum. They travel in straight lines (like light); this is known as rectilinear propagation. X-rays travel with the speed of light. There are, however, no methods of bending or breaking them (as can be done with light), and, therefore, their direction cannot be altered. Concentration or deflection of X-rays with lenses or mirrors (as can be done with light) is therefore not possible.

### 2.1 RELATIONSHIP BETWEEN TUBE VOLTAGE AND EMITTED RADIATION ENERGY

X-rays generated in an X-ray tube have different wavelengths, as do light rays that originate in a light bulb. This is because the energy of the individual electrons that collide with and are decelerated by the anode, is divided into varying amounts of heat and X-radiation.

A large energy conversion causes hard rays, and a small energy conversion causes soft rays. Every beam of X-radiation that is emitted from an X-ray tube contains a continuous spectrum of different wavelengths (*Bremsspectrum*) (*Bremsstrahlung*, German for ‘braking radiation’)

The highest voltage used (expressed in  $kV_p$ ) determines the greatest speed of the electrons and hence the highest energy or shortest wavelength that occurs in the radiation spectrum. The relationship between this shortest wavelength ( $\lambda_{\min}$ ) (formerly expressed in Å, now in nm), and the maximum voltage ( $kV_p$ ) is stated by the *Duane-Hunt Law*:

$$\lambda_{\min} = \frac{12.4}{kV_p} \text{ Å (old)}$$

or

$$\lambda_{\min} = \frac{1.24}{kV_p} \text{ nm (new)}$$

At 62 kV<sub>p</sub>,  $\lambda_{\min}$  therefore equals 0.02 nm, and at 124 kV<sub>p</sub> it equals 0.01 nm. There are usually differences in the intensity of radiation at different wavelengths in a beam. If one declares the intensity of a beam to be a function of the wavelength, then one speaks of a *spectrum*. A spectrum emitted by an X-ray tube ends abruptly at  $\lambda_{\min}$ . There is a maximum intensity in the vicinity of this shortest wavelength and a gradual decline towards the longer wavelengths. The maximum is at a wavelength we call  $\lambda_i$ , and is thus emitted with greater intensity than the others. With increasing voltage the spectrum spreads towards the shorter wavelengths. At the same time  $\lambda_i$  also shifts in this direction (see figure 2.1). However,  $\lambda_i$  cannot be calculated as easily as  $\lambda_{\min}$ . A good approximation is  $\lambda_i = 2/kV_{\max}$  nm.

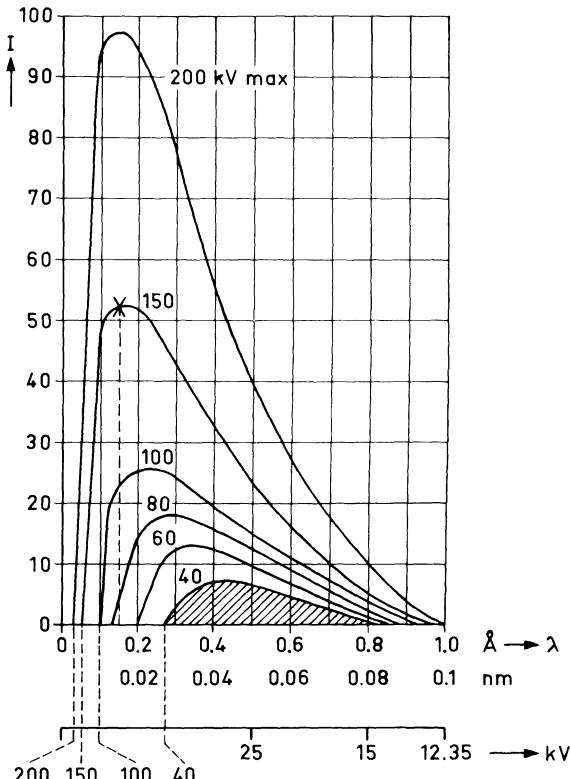


Figure 2.1 X-ray spectrum and radiation intensity for the various wavelengths at different kilovoltages. The ordinate represents the intensity I (in arbitrary units) and the abscissa wavelength (in nm and in Å). The area enclosed by the curve and the abscissa represents the total intensity. For 40 kV this is the shaded area. The sharp increase of intensity at a higher kilovoltage is clearly visible as well as the abrupt end of the curve at  $\lambda_{\min}$ . It can be seen that the intensity shifts towards the shorter wavelengths with increasing kilovoltage and  $\lambda_i$  also shifts in this direction. On the curve for 150 kV, the location of the highest emitted intensity is indicated with an X, which corresponds with  $\lambda_i$  on the abscissa for that kilovoltage.

We here point out the analogy with the emission of heat radiation, portrayed by the laws of Stefan-Boltzmann (at a higher temperature a great increase in the total intensity of radiation) and of Max Wien (at a higher temperature the wavelength emitted with the greatest intensity shifts towards the shorter wavelength side).

(N.B.: All radiations used in practice are therefore heterogeneous, consisting of hard and soft components and the radiation spectrum is continuous, that is it does not show any interruptions.)

When the electrons collide with the anode, another process takes place at the same time as Bremsstrahlung. Electrons travelling with sufficient speed, that is accelerated by a sufficiently high voltage, can dislodge electrons from their orbits in the anode material itself. A short time later the vacancy will be filled by an electron from another orbit. For every orbit (or shell) a very definite amount of energy is liberated, expressed by the emission of a quantum (photon)\*, with an energy of  $\hbar\nu$ . At sufficiently high electron speeds and high energy orbits, these quanta are X-ray quanta. These form, therefore, a very definite and, for the particular element of the anode, a completely characteristic spectrum. As practically all anodes of X-ray tubes are made of tungsten, characteristic radiation for tungsten is our main concern. The K, L and M orbits of this element have energies of 69.5, about 12 and 2.8 keV, respectively. At voltages lower than 69.5 kV, only interaction with the L and M orbits (and the orbit even poorer in energy, N orbit) can be attempted. The characteristic radiation of about 10–12 and 2.8 keV thus created is very soft and will be absorbed by the inherent tube filtration.

At voltages of 69.5 kV and over, the characteristic K-radiation appears with energies of about 57 keV (L-K jump or transition) and (emitted with much less intensity) of about 67.4 keV (the M-K transition). The K-radiation (at 57 keV energy,  $\lambda = 0.022 \text{ nm}$ ) is fairly hard and at voltages over about 70 kV makes an appreciable contribution to the intensity of the X-rays emitted. At increasing voltages the  $\lambda_{\min}$  and  $\lambda_i$  do shift towards the shorter wavelength side, but the characteristic radiations stay (of course) in their position. (One could compare the Bremspectrum with the continuous spectrum of light emission by light bulbs, for example, and characteristic radiation with the specific line emission spectrum of natural light.)

Monochromatic radiation, that is, radiation which contains only one sharply defined wavelength within the characteristic line spectrum, is sometimes used for special purposes (material and structural examinations). In such cases, the anode is made of a particular element, molybdenum for example. Also, the specially made mammography tubes with molybdenum anodes make use of the characteristic radiations of molybdenum ( $\lambda = 0.063$  and  $0.071 \text{ nm}$ ) that arise at low voltages and low quantum energies of 19.6 and 17.4 keV.

In the X-ray beam the characteristic radiation is superimposed on the Bremspectrum. With a molybdenum tube for mammography, the above-named, fairly long wavelengths are very intense (have a high intensity) causing the mammographs to gain appreciably in contrast.

---

\*The terms quantum and photon have the same meaning and both are still being used; for this reason, both terms are used in this book. Photon, however, is gradually replacing quantum.

Similarly, X-rays can also produce characteristic radiation by removing inner orbital electrons. For substances with low atomic numbers (Al with atomic number of 13, and human tissue with an effective atomic number of 7.3, etc.) the energy of the electrons in their shells, however, is very low and therefore the characteristic radiation very soft; they are readily and completely absorbed in a few mm of tissue and play no important role. Substances with a higher atomic number such as iodine ( $Z = 53$ ) that are being used in contrast media, or foreign bodies such as iron ( $Z = 26$ ), copper ( $Z = 29$ ), etc., can give rise to a somewhat harder characteristic radiation but these are also insignificant in practice.

With the use of copper filters, X-rays can produce characteristic copper radiation, namely, fairly soft radiation with an energy of about 10 keV. In order to prevent an effect upon the skin of the patient, an aluminium filter is added to the copper filter on the patient's side; this absorbs the copper radiation completely as well as emitting extremely soft characteristic aluminium radiation itself, but this can be totally ignored.

## 2.2 SOME FUNDAMENTAL CONSIDERATIONS

The following considerations concerning the changes that take place in an X-ray beam as it enters a body will enable us to understand the details of attenuation of radiation intensity. The energy of the incident rays (X-ray quanta) can, for example, be transferred to the molecules as a whole and this could, amongst other things, result in the production of heat. In practice, this heat cannot be measured and this thermal effect can therefore be ignored. One can imagine, however, that this slight heat is transferred to the peripheral electrons of the molecules and atoms, which in turn leave their orbits, thereby causing certain chemical reactions.

In general, it can be said that X-ray quanta, as they pass through matter, eject the electrons out of the orbits of the molecule or atom with which they collide and give them great speed. Ions are created in this manner (charged atoms or molecules), fast electrons and often X-rays with less energy as well.

We differentiate between four types of effects in association with these collisions of X-radiation with matter:

- (1) photoelectric effect;
- (2) classical scatter;
- (3) Compton scatter;
- (4) pair production.

### 2.2.1 Photoelectric absorption

When an X-ray quantum (X-ray photon) collides with an orbital electron and ejects it from the atom, giving it all the remaining energy, we speak of *photoelectric effect* (figure 2.2). The photon is in this case completely absorbed. The original energy of the photon is partly used to eject the electron from its orbit, and the remaining energy is given to the ejected electron as kinetic energy. This electron, called a *photoelectron*, travels with high or low speed through the surrounding matter. It can in turn, undergo collisions itself and, as described, again liberate electrons (*secondary electrons*). These can, if enough kinetic energy has remained, liberate tertiary, etc., electrons.

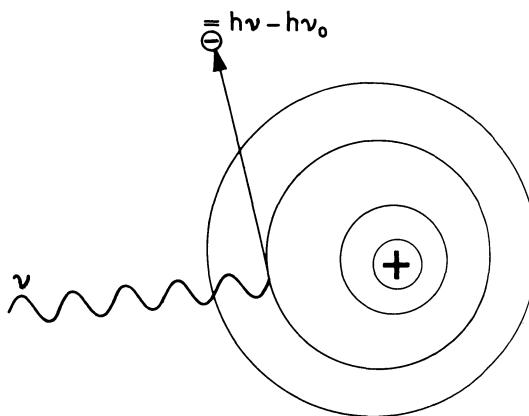


Figure 2.2 Photoelectric effect (true absorption). The X-ray photon of frequency  $\nu$  and energy  $h\nu$  liberates the electron from its shell. For this an energy equal to  $h\nu_0$  is required. The residual energy ( $h\nu - h\nu_0$ ) is transferred to the photoelectron.

The vacancies in the orbits, caused by this process, are almost immediately filled by electrons from the outer orbits or by electrons coming from outside the atom. Energy liberated in this manner causes the characteristic radiation.

The photoelectric effect, therefore, causes an entire absorption of X-ray photons and results in liberation of electrons (photoelectrons, secondary, tertiary, etc., electrons) and the production of characteristic radiation. This photoelectric effect is also called *true absorption*. The extent to which the radiation energy is absorbed in an absorbent material is expressed as the percentage of incident quanta that cause the photoelectric effect. Both the energy of the incident radiation and the atomic number of the irradiated element determine the degree of absorption. The higher the atomic number (third-power relation, that is proportional to the cube of the atomic number, when one compares it per gram of matter) and the lower the energy of the incident radiation, that is the lower the voltage or the longer the wavelength (also a third-power relationship), the greater the photoelectric absorption. Furthermore, absorption is proportional to the density of matter (atomic number remaining the same). Conclusion: photoelectric absorption is proportional to  $Z^3$  and  $\lambda^3$ , and the density of matter.

### 2.2.2 Scatter

In passing through matter, X-rays are attenuated not only by absorption but also by scatter. The following analogy will explain this. When light rays are passed through glass that has been slightly darkened (for example sunglasses), part of these rays will be absorbed by the glass and the remainder will pass through unhindered. Then, if one takes a pane of frosted glass, one realises that although much light passes through it, few direct light rays pass through. Thus, there is a great reduction in the amount of light that passes through the glass in straight lines. The light travels through the glass in a zig-zag path; a large proportion of the incident light rays is diffused or 'scattered' in all directions. Since this pane of frosted glass diffuses light in all directions, one could say that the pane itself has become a luminous object. The theory of this phenomenon is that each

particle struck by the radiation becomes the starting point for new radiation which is emitted in all directions.

There is a similar process in the case of X-rays. When X-rays strike an object, part of the incident (primary) beam is attenuated by absorption as described in the previous paragraph. Another portion of the radiation is scattered within the medium. It is this scattered radiation to which particular attention must be paid in practice.

### 2.2.2.1 Classical scatter

An X-ray quantum which has insufficient energy to eject a peripheral electron from its orbit could collide with a whole atom. No energy is lost by the photon, but it is deviated from its original direction, unchanged in wavelength. This constitutes scattered radiation produced by *classical scatter* that causes a loss of part of the primary radiation. Classical scatter plays a part only when both  $Z$  and  $\lambda$  are large. At X-ray photon energies greater than 15 keV, such as occur in diagnostic radiology, classical scatter is of no importance.

### 2.2.2.2 Compton scatter

An X-ray quantum could also collide with one of the electrons in an atom's outer orbit (or with an entirely free electron), liberate it, using part of its energy, and also give it some energy; some energy still remains. The energy with which the electron is bound to the atom in the case of an outer orbital electron is small compared with the energy given to the electron at the time of collision with the X-ray photon. Consequently, this electron is not only ejected from its shell, out of the atom, but is also given great speed; such an electron is called a *recoil electron* or *Compton electron*. Similarly, as has been described in the case of a photoelectron, a Compton electron can also liberate other electrons in the surrounding matter and, therefore, cause ionisation.

After the collision, an X-ray quantum is emitted with the remaining energy (less than the original quantum, and therefore, with longer wavelength) and in a direction that differs from the direction of the original photon. This phenomenon, in which the incident radiation is changed into a softer radiation with a different direction, is known by the name *Compton scatter* (figure 2.3). The amount of

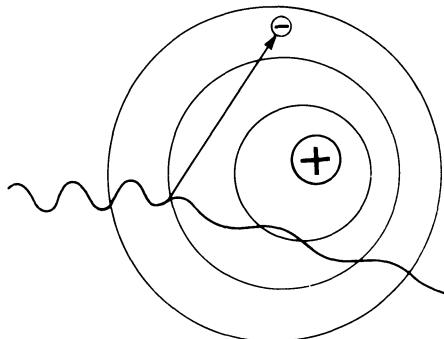


Figure 2.3 Compton effect. The X-ray photon liberates an electron from its shell. The residual energy is partially transferred to the electron and partially changed into a softer X-ray photon (with longer wavelength).

energy which the photon transfers to the orbital electron is determined by the energy possessed by the photon and by the geometry of the collision. The greater the energy of the photon, the smaller the portion of the available energy that is used to liberate the electron, the greater that is transferred as kinetic energy to the electron and the relatively greater the change of wavelength of the remaining photon. The smaller this change, the less the change in direction of the Compton scatter from the original direction. The geometry of the collision determines the direction in which both the recoil electron and the scattered photon travel with respect to the direction of the incident photon. It can be deduced from the laws that govern collisions, that the recoil electron will always be projected in a forward direction at an angle between  $9^\circ$  and  $90^\circ$ , while the new quantum, after collision with the electron, is directed either obliquely forward, sideways, or (with a head-on collision) even backwards. In this last case, the recoil electron will travel on, in the direction of the incident photon (figure 2.4).

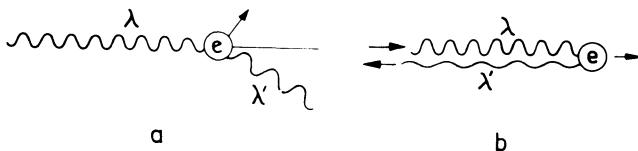


Figure 2.4 Change of wavelength as a consequence of the nature of the collision.

a. Oblique collision. The new quantum, with a somewhat longer wavelength,  $\lambda'$ , travels forward in an oblique direction, just like the electron  $e$ .

b. Head-on collision with the electron  $e$ . The new quantum with its wavelength,  $\lambda'$ , increased sharply, travels in a backward direction and the recoil or Compton electron travels straight on (in a forward direction). With this collision maximum energy is transferred to the electron and the relatively small amount of residual photon energy results in a maximum increase in wavelength.

When X-rays are attenuated by the Compton effect, part of the energy of the X-ray photons is transferred to kinetic energy of the electrons and the rest of the energy remains as X-ray photon energy in the form of scattered radiation of longer wavelengths (Compton scatter). When a photon is scattered in a backward direction as a result of a head-on collision with an electron, there will be the greatest increase in wavelength and the recoil electron is given a maximum amount of energy. Not only must the energy transferred to the recoil electron and the energy used to liberate it be considered as a loss of the incident radiation, but also the energy of the scattered radiation (even if this travels partly in the same direction as the primary beam), and, therefore, contributes to its attenuation or weakening.

Attenuation by the Compton effect depends to a lesser extent than the photoelectric absorption on the energy (wavelength) of the primary radiation. The energy of the Compton electrons increases in proportion to a decrease in wavelength and also, as the voltage increases, the scattered radiation becomes harder. Moreover, Compton scatter is more or less the same per gram of various materials (Compton effect is proportional to the number of electrons and this is more or less the same per gram of various materials); that is Compton scatter is proportional to the density of the material.

The term *scattered radiation* should strictly speaking mean Compton scatter (with a change in wavelength) and classical scatter (without a change in wavelength). We shall, however, in future, subscribe to the meaning attached to it in practice and that includes Compton scatter, classical scatter and the classical radiation that is produced in the body due to the photoelectric effect. A more exact, but less used collective term for these radiations is *secondary radiation*.

### **2.2.3 Pair production**

When an X-ray quantum or gamma quantum possessing an energy greater than 1.022 mega electron volts (MeV) enters the electric field surrounding an atomic nucleus, it may be converted into an electron–positron\* pair. In this process then, radiation is converted into mass. Conversely, the disappearance of mass (matter) and the production of radiation also occur. One calls this *annihilation* of mass, and the energy created from this, *annihilation radiation*.

For pair production, the energy of the quantum must be at least 1.022 MeV because the two particles so formed each have a mass equivalent to 0.511 MeV (511 keV). If the pair-producing quantum has an energy greater than 1.022 MeV the surplus energy is given up to the electron–positron pair as kinetic energy. It is obvious that this process will also have an attenuating effect on the primary radiation during its passage through matter. The quantum under consideration is completely absorbed. The probability of pair production increases with increasing X-ray energy, higher atomic number of the absorbing medium and is proportional to the density. As we have said, formed pairs can by means of annihilation be transformed into radiation again; this radiation may be emitted in any direction and, therefore, must be regarded as scattered radiation. *Pair production does not occur with the X-ray energies used in diagnostic radiology.*

In the foregoing, there has been repeated mention of distances travelled by electrons and ions after ionization, collisions, etc. Although these extremely small particles, just as atoms and molecules, are not visible (not even with electron microscopy), it has been made possible to make their tracks visible in super-saturated water vapour. This occurs in *Wilson's cloud chamber* where by sudden pressure reduction mist droplets are condensed around the ions that form the fast particles, thus creating an ion track or ion path. These tracks are rendered visible under intense illumination. The removal of nuclear particles (for example  $\alpha$ -radiation) can also be photographed and/or filmed in this manner.

## **2.3 THE MAIN PROPERTIES OF X-RAYS**

The properties which give X-rays their great value both in diagnostic radiology and radiotherapy, are as follows:

- (1) They are capable of penetrating matter (penetrating power).
- (2) They cause some materials to emit light (luminescent effect).
- (3) They produce an effect on a photographic emulsion, resulting in blackening after development (photographic effect).
- (4) They are capable of ionising gases (ionising effect).
- (5) They produce changes in living tissue (biological effect).

\*Instead of positron, one also comes across positon.

### 2.3.1 Penetrating power of X-radiation; attenuation

The great penetrating power of X-rays can be expressed in another way. One can also say that the intensity of an X-ray beam is relatively little attenuated as it passes through matter. While in the case of light rays, matter can be divided into transparent and opaque when, for example, the opaque one (even an extremely thin layer) absorbs light rays completely (think, for example, of screening from intense light by means of thin black paper), all materials are more or less penetrable by X-rays. A further difference is that light can be totally reflected or deflected, while this is not possible with X-rays.

When X-radiation penetrates an object of homogeneous composition, the intensity distribution across the diameter of the beam, at right angles to the direction of the radiation, does not change. Therefore, the intensity of the emergent beam is the same at every point equidistant from the focus, just as in the primary beam. One could also say that there are no radiation contrasts in the emergent beam. The situation is quite different, however, when the penetrated object is of heterogeneous composition and consists, for example, of materials that attenuate the radiation in varying degrees. Therefore, a piece of lead in a body will absorb the incident radiation almost entirely and the radiation intensity remaining, after emerging from the lead, is almost zero. If another part of the body causes very little attenuation, then the intensity of the emerging radiation is high. In this way, radiation contrasts are produced in the emerging radiation beam. This subject will be dealt with in greater detail in section 6.1.

The attenuation of X-radiation in a body depends on various factors:

- (1) nature of the substance, that is atomic number;
- (2) density of the substance;
- (3) thickness of the substance;
- (4) hardness (wavelength of the radiation).

#### 2.3.1.1 The attenuation depends upon the atomic number Z (per unit weight)

One could say. the heavier the atoms, the greater the attenuation. The physical state of the substance, whether it be a gas or a liquid, is not important (taking, of course, the same number of atoms or, what is the same thing, a similar density), as the absorption is the same.

The difference between light rays and X-rays is evident from the following example. Sulphur cannot be penetrated by light rays; carbon also absorbs all light rays. A mixture of sulphur and carbon is also opaque, but the compound carbon disulphide is a transparent liquid and therefore allows light rays to pass through. These facts are determined by chemical form.

The attenuation of X-rays in a mixture of sulphur and carbon is also the same as the attenuation by sulphur plus the attenuation by carbon. However, in contrast to the case of light rays, the attenuation of X-rays by the compound carbon disulphide is equal to that by the mixture of sulphur and carbon (the mixture containing the same quantities of both substances as the compound). Thus, in the case of X-rays, it does not matter in what sort of mixture or compound the atoms are present, nor whether the substances are hard, soft, liquid or gaseous. Their attenuation is determined by the nature and number of atoms and not by their chemical composition or physical state.

It is not the atomic weight, but the atomic number ( $Z$  = number of electrons) that determines attenuation. The substances that make up the human body are largely composed of hydrogen (H,  $Z = 1$ ), carbon (C,  $Z = 6$ ), nitrogen (N,  $Z = 7$ ), and oxygen (O,  $Z = 8$ ). The skeletal system consists mainly of calcium (Ca,  $Z = 20$ ). The attenuation of X-radiation is proportional to the third power of the atomic number, per gram of matter, if we consider photoelectric absorption exclusively (section 2.1). One gram of calcium absorbs  $20^3 = 8000$  times as much as a gram of hydrogen.

For the soft parts of the body, an average effective atomic number of 7.3 is accepted. This corresponds approximately to the effective atomic number of water. The effective atomic number of the skeletal system ( $Z_{\text{eff}}$ ) is about 14.

### ***2.3.1.2 The attenuation is proportional to the density of the material to be penetrated (with an equal volume and an equal atomic number)***

By the word density, one means the mass of 1 cm<sup>3</sup> of a material, expressed in grams; the density is numerically equal to the specific gravity, that is the weight of 1 cm<sup>3</sup> of the substance, also expressed in grams.) The greater the number of atoms per unit volume with the same atomic number (that is the greater the density), the greater the attenuation, the relationship being directly proportional.

In the human body this is demonstrated by the air-containing organs (lungs and intestines), as compared to the rest of the soft parts. Although the same average atomic number 7 (in round figures) is given to air and soft tissue, the specific gravity of air is 0.001293 and that of soft tissue almost 1 (therefore equivalent to water). This enormous difference in density explains the great difference in attenuation.

The simultaneous influence of the atomic number and density on attenuation is clearly expressed when one compares the attenuation in bony tissue (the skeleton) with that in soft tissue. The average atomic number of bony tissue is about 14, and that of soft tissue 7. At identical densities (per gram) the attenuation in bone would be  $2^3 (= 8)$  times greater. However, as the density of bone tissue is 1.85 times greater than that of soft tissue, the attenuation per cm<sup>3</sup> is an additional 1.85 times as great, that is  $(8 \times 1.85) = 15$  times greater (in total) than that in soft tissue. To simplify the calculation, the attenuation due to scatter is ignored, and it is assumed that the entire attenuation is caused by photoelectric absorption.

### ***2.3.1.3 Attenuation depends upon the thickness of the medium***

The thicker the layer through which the X-rays have to travel, the greater the attenuation to which they are subjected in this layer. When an X-ray beam undergoes 50 per cent attenuation by a 1 cm layer of a substance, it does not follow that the next 1 cm layer of that material will absorb the remaining radiation entirely. In the second layer, the remaining radiation is again attenuated by 50 per cent, so that after 2 cm there is still 25 per cent of the primary intensity left. The third layer of 1 cm attenuates again 50 per cent of the remainder, so that after 3 cm there is still 12.5 per cent remaining, etc.

This fact is expressed by the attenuation coefficient ( $\mu$ ). By the attenuation coefficient is meant the number which indicates the proportion of the radiation that 'disappears', that is, is absorbed, or scattered, in a 1 cm thickness. One can express attenuation by an exponential function. The exponential law of attenuation is

$$I_1 = I_0 \cdot e^{-\mu d} \quad (\text{only true for narrow monoenergetic beams})$$

where  $I_1$  is the intensity which remains of the primary  $I_0$  intensity, after passing through the layer  $d$ , which has an attenuation coefficient of  $\mu$ ;  $e$  is the base of the natural logarithms (about 2.71).

Strictly speaking, the attenuation formula applies only to monochromatic radiations, but in practice it is also applicable to heterogeneous radiations (actually, for every wavelength, a separate formula is valid, that is each with a different  $\mu$ ). With the aid of tables of attenuation coefficients and formulae, one is able to calculate the attenuation in a particular homogeneous material, and even in heterogeneous materials, exactly.

A particular form of attenuation is found to occur when, with increasing voltage, a wavelength is reached which is somewhat shorter than that which is emitted as characteristic radiation by the irradiated element. Attenuation by photoelectric absorption then suddenly increases very sharply. A (relatively small) part of the photon energy is used to liberate an electron from the particular orbit. As energy is liberated when the vacancy is filled, photons with this particular energy are produced and make up the *characteristic radiation* (for example K-radiation of tungsten).

Whereas, generally, with increasing voltage attenuation gradually diminishes, there exists for each element a characteristic wavelength (photon energy, voltage), a steeply raised absorption, which in the absorption curve is called the *absorption*

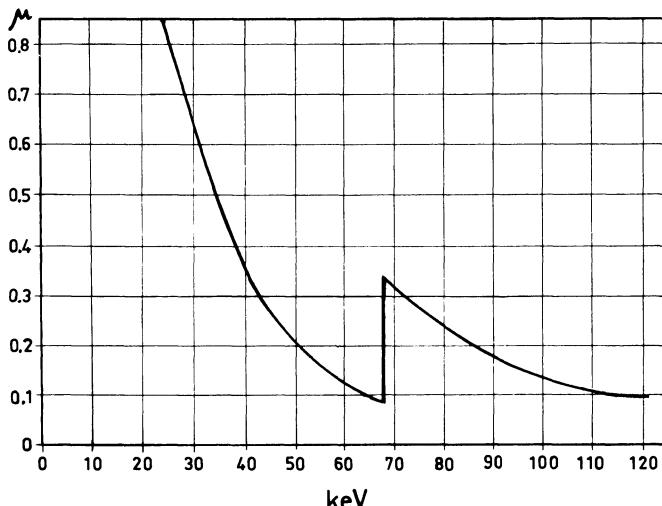


Figure 2.5 Selective absorption by tungsten as a function of the energy of the X-ray quanta in keV. With an increase in X-ray quantum energy, the absorption decreases more and more, then suddenly, at 69.5 keV, it increases sharply. See text.

edge. This raised absorption is called *selective absorption*. However, the voltages at which selective absorption arises for the elements that make up the human body are so low that selective absorption is insignificant in practice. Selective absorption does occur in foreign elements that may be found in the human body, such as tooth fillings (mercury, gold, silver) or foreign bodies such as shrapnel, metal splinters, bullets, etc., or contrast media (barium, iodine, etc.). Experiments attempting to make use of selective absorption in diagnostic examinations have not so far been successful. On the other hand, this selective absorption in materials which contain silver, tungsten, zinc, etc. (as in photographic emulsions of films and intensifying screens) is of marked importance.

The gradual decrease in absorption with increasing voltages is suddenly accelerated sharply on reaching a voltage of about 69.5 keV. This is due to the photon energy that forms the characteristic radiation for tungsten (57 and 67.4 keV) (figure 2.5).

### **2.3.1.4 Attenuation depends upon the hardness of the radiation**

The softer the rays (that is of longer wavelength) the greater their attenuation. The harder the rays (shorter wavelength) the less their attenuation and the more readily they penetrate matter. Penetration depends on wavelength, that is attenuation is directly proportional to the third power of the wavelength.

If we compare the penetrability of bones with that of soft tissue with a given wavelength, then this relationship changes completely with the application of either a harder or a softer radiation. With harder radiation the penetrability of bone tissue increases in relation to that of soft tissue (becomes more 'transparent'); with softer radiation, more is absorbed and bone becomes less penetrable.

Since the relationship between the transmitted radiation intensities (radiation contrasts) determines the contrast in the X-ray image, it follows that using harder radiation reduces contrasts. This effect is utilised in radiography in order to obtain transparent ribs in chest radiographs, using high voltages (hard X-ray technique).

The following tabulation indicates in percentages, the quantity of radiation which is transmitted by equal layers of soft tissue and bone tissue, at different hardnesses (in the case of monochromatic radiation). Soft radiations were purposely chosen to demonstrate the differences more clearly.

layer thickness	0.03 nm (40 keV)	0.05 nm (25 keV)
1 cm soft tissue	77 per cent	61 per cent
1 cm bone tissue	24 per cent	0.4 per cent
radiation contrast	77/24 = 3.2	61/0.4 = 152

### **2.3.1.5 Attenuation—summary**

In diagnostic radiology, radiation is attenuated by photoelectric absorption and scatter (as below 1.022 MeV attenuation by means of pair production can be ignored). Absorption increases sharply at higher atomic numbers and greater density, whereas it decreases sharply with harder radiation (proportional to  $\lambda^3$ ).

Attenuation due to scatter becomes more important with harder radiation. When radiation is soft, photoelectric absorption predominates and the total attenuation is almost equal to the absorption. When radiation is hard, absorption predominates also in materials with high atomic number (calcium, barium, iodine

and lead), but scatter predominates in materials with low atomic number (for example soft tissue). Therefore, one could say, in general, that *hard radiation is more scattered than absorbed and soft radiation is more absorbed than scattered*, when speaking of attenuation of X-radiation in the human body.

Scatter occurs as classical scatter ( $\lambda = \lambda$  of primary radiation), which is of little importance with the X-rays utilised, and as Compton scatter ( $\lambda$  is longer than  $\lambda$  of primary radiation). At low voltages the scattered rays are also soft, being mostly absorbed in the body and therefore their part in the total that emerges from the body is of little significance. At high voltages the scattered rays are also hard; fewer remain in the body and hence they form a large part of the total emergent radiation. As they usually travel in a more oblique direction than the primary radiation, they pass along a longer path and are relatively more absorbed. Because the object itself acts like a filter for the scatter that is produced, the soft components of the scattered radiation are filtered out and the average hardness of the emerging scattered radiation resembles the average hardness of the incident beam and can even be harder.

For a hard radiation of, for example, 0.0124 nm (100 keV) attenuation in water due to absorption accounts for only 1 per cent and that due to scatter 99 per cent. At 0.03 nm (40 keV), attenuation due to absorption accounts for 20 per cent and that due to scatter 80 per cent. At 0.06 nm (20 keV) attenuation due to absorption accounts for 70 per cent and that due to scatter 30 per cent. At extremely soft radiations of 0.1 nm (12.4 keV) attenuation due to absorption is more than 90 per cent. These figures are valid for monochromatic radiation. However, in practice X-ray beams produced in X-ray tubes consist of radiation composed of a great number of wavelengths (that form the continuous spectrum). In order to apply the figures to such beams, one must take as the average hardness of the beam the one that corresponds to a third of the highest (peak) voltage, that is  $kV_p : 3$ . Therefore, one can say that in practice for radiation up to a  $kV_p$  of 50 kV, photoelectric absorption is of importance. Between 60 and 90 kV, both photoelectric absorption and Compton scatter are important. At very high voltages (more than 1000 kV = 1 MV) and with gamma radiation of cobalt 60, or radium, the attenuation in all materials is very slight and is mainly caused by Compton scatter. This attenuation is generally not dependent on the atomic number but on the density. At voltages over 1.022 MV (1022 kV) pair production also plays a role and becomes more and more important.

### 2.3.2 The ability to cause light emission (luminescence)

Various substances such as zinc sulphide, calcium tungstate, caesium iodide and barium platino-cyanide, emit light when bombarded by X-radiation or fast-moving electrons. This phenomenon is known as *fluorescence*. Some of these substances continue to emit light for a certain length of time after bombardment by photons or electrons has ceased; this phenomenon is called *phosphorescence*. Both phenomena are included in the concept *luminescence*. It is the luminescent property of these substances that enables our eye to perceive the, for us, invisible X-rays. Not all the luminescent substances emit light of wavelengths to which our eye is sensitive. The spectral distribution of the emitted light also varies for different materials (see chapter 8, section 8.1.1).

Luminescence can be explained as follows. There are various minerals in crystal-line form (zinc sulphide, calcium tungstate, etc.) that do not emit light under normal circumstances. In such a substance an X-ray quantum can undergo photoelectric absorption or Compton scatter, and an electron (photoelectron or recoil electron, respectively) is ejected from an atom of one of the molecules. The vacancy left by the ejected electron is filled by another electron from one of the outer orbits; this coincides with the emission of another X-ray photon (secondary radiation). This photon, in turn, is again absorbed or scattered and produces again a fast electron, etc. Electrons produced in this manner travel with high energy, that is great speed, through the crystal. They leave a track (or path) of ionisation behind them, since they again collide with electrons of other atoms many times, which in their turn are ejected from their orbits and move themselves through the crystal. Calm returns when the moving electrons recombine with the empty orbits; this occurs while a light photon is emitted. This recombination is promoted by foreign atoms (deliberately brought in) or faults (permanently present) in the crystal structure, the so-called luminescence or F-centra (f from Farbe).

An absorbed radiation photon, therefore, causes many simultaneous processes that by means of photoelectrons, recoil electrons and secondary quanta ionise many atoms, and this leads to the emission of many light photons. If such light emission follows quickly (for example within  $10^{-10}$  second), this is called *fluorescence*. The recombination may take longer (even several or more minutes) and then causes what is called *phosphorescence* (afterglow).

In radiology, one makes use of luminescence in fluorescent screens; intensifying screens, input and output phosphors of image intensifiers and television screens (see chapter 8, section 1). Luminescence enables us to perceive X-radiation with the eye, photographically or electronically. A screen coated on the underside with a fluorescent substance is called a fluoroscopic screen. When the intensity of X-radiation is increased the luminescence is also increased. A fluorescent screen sends out more light from places which are bombarded by X-rays of greater intensity. In this way, therefore, a fluorescent screen converts an invisible X-ray contrast (radiation image) into visible contrast (fluoroscopy image), (see figure 2.6). We can as it were, see through objects with the aid of a fluorescent screen, hence the term 'screening'.

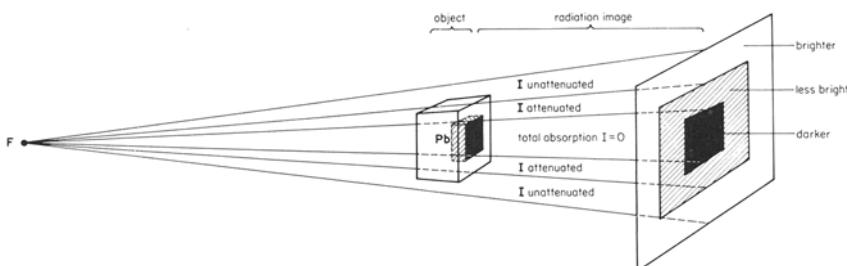


Figure 2.6 The production of a visible image on a luminescent screen. The radiation contrasts (invisible radiation image) present in the beam (behind the object) give rise to a visible image on the fluoroscopic screen. The greatest intensity causes the greatest brightness (for example the images of the lungs are bright and the barium-filled stomach is black). The image is positive. Compare with figure 2.7.

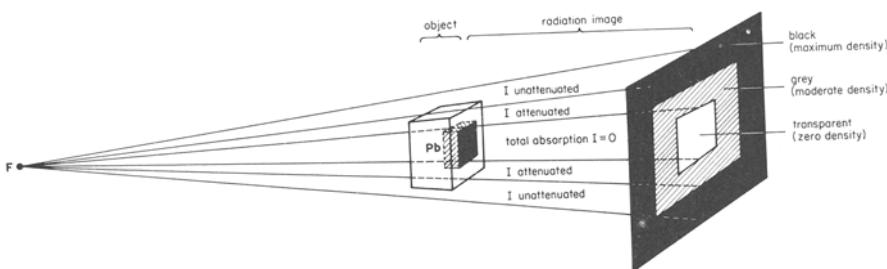


Figure 2.7 The production of a visible image by means of the photographic effect of X-radiation. The radiation contrasts (invisible radiation image) give rise to a visible image on the X-ray film (greatest intensity causes the greatest amount of blackening; for example the lungs dark, the stomach bright).

If, for example, an X-ray beam falls partly on a small piece of wood and partly outside it, then the portion of the beam that passes through the wood will produce a less bright fluorescence than the portion that passes outside it. We notice a difference in brightness on the fluorescent screen in the beam behind the wood and that outside it. If one now fixes a nail to this piece of wood, the difference in brightness with the surrounds (the wood in this case) is very noticeable. Because of great attenuation in iron, hardly any X-rays pass through the nail and a dark shadow is thereby produced on the screen. Therefore, one has here the contrast between nail and wood and between wood and air. If one covers the piece of wood and nail with a layer of iron, then one will see nothing of the wood nor the nail as all the rays will be absorbed in the iron plate. There will be no more contrasts and consequently no image either. This example with the nail and piece of wood is a simple form of diagnostic radiology. *Without differences in attenuation there are no radiation contrasts; one sees no image and one cannot make a diagnosis.* With the aid of a fluorescent screen one can see through objects.

### 2.3.3 Photographic effect of light rays and X-rays

As light rays, X-rays can act on a photographic emulsion in such a way that after development and fixation (the processing procedure) it exhibits blackening. A photographic emulsion contains silver bromide ( $\text{AgBr}$ ). A 'latent' chemical change (latent image) is produced by absorption of the energy which, after development is converted into a visible image. Metallic silver is deposited on the irradiated areas and this produces the 'blackening'. The greater the effect of the radiation, the greater the blackening. The non-irradiated silver bromide is removed in the fixer so that those areas become completely clear, that is transparent.

There is only a quantitative difference between the action of X-rays and that of light rays on a photographic emulsion. A light photon as well as an X-ray quantum is absorbed in the emulsion layer which contains  $\text{Ag}^+$  and  $\text{Br}^-$  ions. By the absorption processes of X-ray quanta and light quanta, electrons are ejected from their orbits (by photoelectric absorption). The  $\text{AgBr}$  grain is thereby converted into such a state that the developer can liberate the  $\text{Ag}$  atoms as metallic silver. One perceives this as the blackening.

A certain amount of energy is necessary to render the  $\text{AgBr}$  grain developable;

about 300 light quanta are necessary in the case of visible light. If the exposure is too little and only 200 light quanta strike the grain, for example, the grain is not developable and this happens especially to AgBr grains that lie deeper within the emulsion. If the required number of quanta is reached, only then does blackening become possible. This explains the *threshold value* of an exposure when light rays are used. In contrast, one X-ray quantum, even of the weakest X-radiation, has so much more energy than a light quantum, that it is always large enough to influence about 3000 AgBr ion pairs in an emulsion. Also, X-rays penetrate the emulsion to a greater extent than light rays, so that also the grains deeper within the emulsion become developable. Exposed AgBr grains subjected to visible light are most numerous on the surface of the emulsion and decrease in number deeper within. However, with the action of X-radiation, there is an even influence upon the AgBr grains in all emulsion layers. Thick emulsions, therefore, are of little or no use in ordinary photography, (in contrast to X-ray photography) and even have disadvantages.

In the foregoing, the action of X-rays upon photographic emulsions has been described and, by that, the impression given that a radiograph is produced in this manner. This, however, is only the case in an extremely small section of the field of radiography, that is dental radiography and non-screen film work.

Because of the great penetrating power, only a very small part of the incident rays are absorbed in the film's emulsion and the rest of the radiation may be regarded as lost. Radiography, especially in the case of thick subjects, would necessitate an impermissibly high radiation dose to the patient in order to obtain

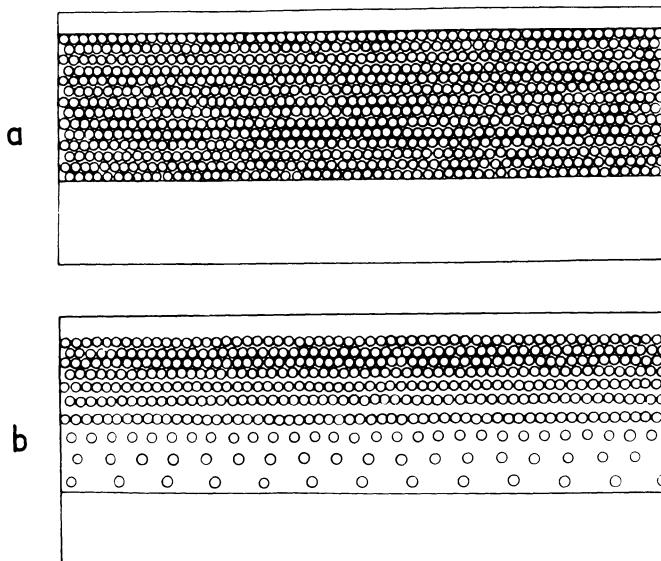


Figure 2.8 Influence of radiation on film emulsion.

- Uniform blackening of the emulsion under the influence of X-rays.
- The blackening of the emulsion by means of light rays primarily takes place in the superficial layers of the emulsion and gradually decreases towards the deeper layers. This is the case with exposure by means of intensifying screens.

sufficient blackening, and also demand an unacceptably long exposure time. For most radiographs by far, one makes less use of the photographic properties of X-ray themselves than of the luminescence that X-rays can produce in certain materials. By allowing the radiation image to act primarily upon luminescent screens (that are brought into intimate contact with the film's emulsion), one achieves exposure of the emulsion chiefly by means of light photons. The photographic effects of the few X-ray photons that are absorbed in the emulsion are thereby reinforced and, therefore, these luminescent screens are called *intensifying* screens (figure 2.8).

In contrast to the film used in photography with visible light, X-ray films have an emulsion on both sides, each of which is acted upon by an intensifying screen in direct contact with it (section 8.3).

### 2.3.4 The ability of X-rays to produce ionisation

By ionisation one understands the separation of electrons from atoms of molecules. The result of ionisation is always on the one hand free electrons, negatively charged, and on the other hand positively charged ions. Motion of electrons and ions means motion of an electrical charge and hence an electric current.

#### 2.3.4.1 Demonstration of ionisation, saturation current, saturation voltage

A gas or gas mixture, such as air, consists of molecules moving freely in space. It is an electric insulator, that is it does not conduct an electric current. The molecules have no electric charge, being electrically neutral under normal circumstances. If one connects a condenser, the plates of which are separated by air, into a series circuit with a direct current supply (for example a battery) and a galvanometer, no reading will be registered on the galvanometer. The neutral gas molecules between the condenser plates show no tendency to move to the positive or negative terminal (figure 2.9a). If the air is irradiated with X-rays, a

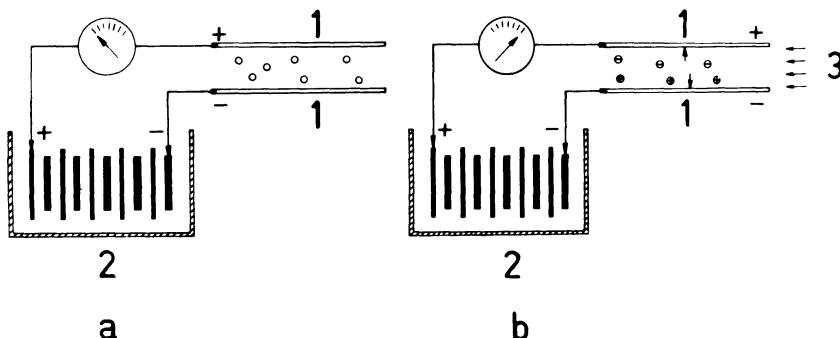


Figure 2.9 The ionising effect of X-radiation (principle of the ionisation chamber). 1. Electrodes; 2. voltage source; 3. X-radiation.

a. The gas between the electrodes is non-conducting (insulator) and no reading is registered on the meter.

b. X-rays give rise to ionisation of the gas, which therefore becomes conducting; now the meter does register a reading.

reading will be registered on the galvanometer which means that the air has conducted electricity; this has been made possible by the ionisation of the molecules; the air has been made conductive (figure 2.9b).

Ionisation occurs in the following manner. Some X-ray photons produce a photoelectric effect or Compton scatter in the gas. In both processes an electron is ejected from the atom, that is ionisation. The neutral substance is therefore split into positive and negative ions and electrons. The (primary) photoelectron and recoil electron may have sufficient energy to do the same, as was done to it by the X-ray photon, that is liberate a further electron from another atom (secondary electron), which, if it also has sufficient energy could give rise to a tertiary electron, etc. Further ionisation is not only caused by photoelectrons and recoil electrons that have sufficient speed, but also by the newly created X-ray photons which have less energy (scatter) which arise due to the Compton effect. These are essentially no different from the primary X-radiation and are equally capable of releasing secondary, tertiary, etc., electrons.

A given quantity of X-rays (number of quanta), a given hardness of radiation (size of quanta), a given quantity of gas particles (gas volume and gas density), induces a given number of separations or, in other words, a given amount of *ionisation*.

Because of the positive and negative charges on the condenser plates, the positive ions are attracted to the negative plate and the electrons to the positive plate. If the voltage is fairly low, more positive ions will unite with electrons to reform neutral gas molecules before they are able to reach the respective condenser plates (electrodes or poles).

If the voltage becomes higher, then the speed of the fast-moving particles increases and the total *recombinations* become less; the galvanometer will show a higher reading. In other words, a higher voltage across the electrodes produces a greater ionisation current. There is a limit to this increase, however. When the voltage across the electrodes reaches such a high value that practically no recombinations take place, but virtually all electrons and positive ions formed arrive at the electrodes, then a further increase in voltage will not result in an increase of the ionisation. The ionisation current has then reached its maximum possible value under these ionisation conditions and is called *saturation current*; the voltage across the electrodes with which this saturation current is reached is called *saturation voltage*. The voltage across the electrodes, therefore, has to be at least as high as the saturation voltage at the highest expected saturation current, depending on the capacity of the galvanometer (exposure meter, dose meter).

The saturation current then, can only be increased by a greater amount of ionisation. This can be achieved by

- (1) More X-rays (greater intensity, more mA) and/or more powerful X-rays (harder radiation by a higher kV, which contains photons with greater energy),
- (2) Increasing the number of available molecules that can be split or ionised or by a greater volume (more molecules in the irradiated area) and/or by a greater density of the gas (more molecules per unit volume).

#### **2.3.4.2 The unit of exposure, the röntgen (R)**

Wide use is made of the ionisation of gases to determine the quality and quantity of radiation in radiology. The term 'intensity' is a general physical measure that serves to represent the quantity of all kinds of radiations and is expressed in the

units  $\text{W}/\text{cm}^2$  and  $\text{W}/\text{m}^2$ . These units refer to the radiation energy per second that passes through an area of  $1 \text{ cm}^2$  or  $1 \text{ m}^2$ , perpendicular to the beam. For the measurement of X-radiation, ionisation in air produced by the radiation is taken as a basis, and not the measure of, energy. For this, the term exposure is used, for which the following simplified definition can be given: *By the exposure of a given small volume of air is meant the total charge on all ions of one sign, formed by all the electrons liberated by the photons in that volume and supposing that they travel their entire path through air, divided by the mass of that volume of air.* Exposure, therefore, can be said to be an electrical charge divided by a mass. The unit of exposure is the röntgen (R) and is equal to  $2.58 \times 10^{-4} \text{ C/kg}$ \*

Other units derived from the röntgen are the milliröntgen ( $1 \text{ mR} = 0.001 \text{ R}$ ) and the microröntgen ( $1 \mu\text{R} = 0.000001 \text{ R}$ ). We speak of photons (quanta). Therefore, the concept exposure and the "R" refer only to the ionising electromagnetic radiation, that is only to X- and gamma-radiation. The 'R' is therefore not valid for corpuscular radiation (beta-radiation, neutron radiation, etc.). Furthermore, the volume of air must be small enough so that the exposure is almost the same at various points in that volume. According to the definition, the size of the volume of air that is permitted depends upon how much the exposure varies with the position in the beam. Usually the volume of air concerned is about 1 ml and the mass of air in that volume is about 1 mg. In connection with this, the definition of the 'R' would correspond more closely to conditions in practice if it were defined as  $1 \text{ R} = 2.58 \times 10^{-10} \text{ C/mg}$ . Therefore, one of the conditions of the definition is that all liberated ions and electrons are measured. A condition for this is electronic balance (see section 3.3).

The fact that a unit of X-radiation has finally been based upon the ionising effect of the rays and not, for instance, upon the blackening of a photographic emulsion, is due to the simplicity and speed with which ionisation in air can be measured.

The expression exposure remains a physical term. Often, the term dose is wrongly used in place of exposure.

### 2.3.4.3 The röntgen and the rad

A medically useful unit, which expresses the quantity of absorbed X-ray energy, can be formulated. The quantity of absorbed X-ray energy per gram of tissue (muscle, bone, etc.) is approximately proportional to the biological effect. The International Committee for Radiological Units (I.C.R.U.) has chosen the expression *absorbed dose* for this medical dose. A simplified version of the definition is as follows: *By the absorbed dose in a certain area of tissue is meant the quantity of energy imparted to matter by ionising particles divided by the mass of matter in that area.* Therefore, absorbed dose equals energy divided by mass. *The unit of absorbed dose is the rad (1 rad = 0.01 J/kg)*†.

In this definition, ionising particles refers to both (electromagnetic quanta) and real particles such as electrons, protons, alpha particles, neutrons, etc., are meant.

\*The R no longer occurs in the system of SI units. It has been replaced by *coulomb per kilogram* ( $1 \text{ C/kg} = 3876 \text{ R}$ ).

†According to the SI system of units, in force since 1977, absorbed dose is measured in the new unit *gray* (symbol:gy). 1 gy = 1 J/kg, so that 1 gy corresponds to 100 rad.

This generalisation is intentional in order to define the concept of absorbed dose for all kinds of radiations (this is in contrast with the R). The above-mentioned tissue area must be sufficiently small so that the absorbed dose in that area can be considered equal at all points in that area. The size of the tissue area permitted by this definition corresponds to a mass of matter of the order of fractions of grams. (The rad, in practice, would be better defined as  $10^{-8}$  J/mg).

One cannot measure the absorbed dose in practice, but it is derived from the exposure. The relationship between R and rad is therefore extremely important. One R produces a total ion charge of either sign amounting to  $2.58 \times 10^{-10}$  C, in 1 mg of air. As the charge on each ion is known, ( $1.6 \times 10^{-19}$  C) one can simply calculate how many ion pairs (1 ion pair = 1 positive and 1 negative ion) are produced by 1 R per mg of air. With the help of this value one can now calculate how much energy the ionising radiation or particles emit per R per mg of air. The result is  $0.87 \times 10^{-8}$  J per mg air, or  $0.87 \times 10^{-2}$  J per kg air per R.

*1 R is equal to 0.87 rad in air that is electronically balanced.* 1 R is equal to 0.9–1.0 rad in all soft tissue (except fat) for all wavelengths used in diagnostic radiology. 1 R is 0.5–0.8 rad in fat and 1.5–4 rad in bone. Therefore, an exposure measured in R can simply be multiplied by 0.9 to calculate the absorbed dose in rads for soft tissue. This explains why the physical unit 'R' was so useful in medical practice, when it (quite wrongly) was still regarded as a *dose* unit of biological effect.

#### **2.3.4.4 Relative biological effectiveness (R.B.E.); the rad-rem relationship**

Different radiations have different biological effects with identical absorbed doses (the same number of rad). The reason for this is the fact that, ultimately, the biological effect is the result of the number of ionisations that arise and this varies for different radiations. One therefore compares the biological effect that is produced by a definite kind and/or quality of ionising radiation with the biological effects brought about by *standard X-radiation*. This standard X-radiation is 200–250 kV radiation (0.8 mm copper H.V.L.) used in conventional deep therapy, with which much practical experience is gained.

The photo- and Compton electrons, liberated by the standard X-radiation photons, produce ion tracks with an average ion density of 100 ion pairs per  $\mu\text{m}$  in soft tissue. It is the ion density that determines the biological effect to a great extent. Thus, for example, the effect of a dose (in rads) of alpha-radiation is ten times as great as an equal dose of standard radiation. One then assumes for alpha-radiation, a relative biological effectiveness (R.B.E.) of 10. For other radiations, the R.B.E. has other values. Thus, for example, the R.B.E. for cobalt 60 is 0.85. To simplify this in practice, the *quality factor* (Q) has been introduced; an outline of its values are: Q = 1 for all quality X-, gamma- and electron radiations; Q = 5 for neutron radiation; and Q = 10 for alpha-radiation.

The concept R.B.E. has been reserved for radiobiological considerations since 1962. To facilitate the comparison of the biological effect of the various radiations whose doses are expressed in rads and, above all, to prevent errors, the rem\* unit (röntgen equivalent, man) has been introduced as a *dose equivalent*

\*Although the rem is not an SI unit, it (as well as the R and the rad, for that matter) will still continue to be used in practice, for years to come.

*unit.* Dose equivalent (in rem) is equal to  $Q \times$  absorbed dose (in rads). Therefore, both the rad and the Q are assimilated in the rem ( $\text{rem} = Q \times \text{rad}$ ). Thus, a dose given in rem expresses a dose which is biologically equal to an identical dose of a 'standard radiation', with respect to every radiation with a Q of 1. One hundred rad X-radiation, gamma-radiation, electron radiation (also beta-rays) is therefore equal to  $1 \times 100$  rem X-radiation. Ten rad neutron radiation is equal to  $5 \times 10 = 50$  rem X-radiation; 10 rad alpha-radiation is equal to  $10 \times 10 = 100$  rem X-radiation.

### 2.3.5 Biological effect of X-radiation

There is no such thing as biological over-sensitivity, nor insensitivity to X-rays. In this respect X-rays differ from, for example, ultra-violet rays, to which individuals show considerable differences in sensitivity.

#### 2.3.5.1 Effect on living objects

X-Rays affect the following:

- (1) they inhibit growth;
- (2) they destroy tissue;
- (3) they cause inflammation.

It is evident then, that the action of X-radiation is not an improving or constructive influence, but a damaging one. When we make use of the biological effect of X-rays in the treatment of certain diseases (radiotherapy) this is only possible because we are able to damage the diseased cells to a greater extent than the healthy ones. Therefore, we can influence the battle that is being waged between the healthy and diseased cells, to the advantage of the healthy ones.

A radiation can only be biologically effective when it is absorbed in the tissue. This is expressed by the *fundamental biological law of Grotthus Draper*, which states that only absorbed energy can be biologically effective. It is quite logical that radiation which passes through a body without being absorbed, and therefore leaves the body unattenuated, cannot exercise any biological influence.

The simplest form of energy transformation that can occur in a body is the generation of heat. Other effects are known as *specific radiation effects*, such as electrical and chemical changes in the tissues, produced by certain kinds of radiation in particular. The absorption of ultra-violet light, for example, gives rise to photochemical reactions such as destruction or intensification of enzyme action; this can be partly due to the specific effect of the absorbed radiation and partly to the heat generated thereby. The biological effect can sometimes be augmented by the use of sensitizers, which, when added to a substance, make it capable of reacting to smaller amounts of energy than would otherwise be necessary. For example, the pigments eosin, haematoxylin, etc., are sensitizers for the action of light.

In the case of X- and gamma-radiation (for example radium), which is a radiation of much greater energy and able to penetrate atoms, we are mainly concerned with the emission of electrons. These electrons (both photoelectrons

and Compton electrons) can, depending on the energy they possess, liberate secondary, tertiary, etc., electrons. The number and type of chemical processes that will take place depends on the chemical circumstances and the amount of requisite energy. In the X-ray range of the electromagnetic spectrum, we are not directly concerned with the heating effect itself that is produced by the absorbed energy (as in the case of the infra-red range), but with the electron emission caused thereby, called the *radiochemical processes*. There are various theories concerning the biological effect of radiation, but we will mention one only, the *direct-hit theory*. This theory implies that a certain number of 'direct hits' (originated by ionisations) are necessary in order to cause damage. A direct hit is regarded as the combined effect of a group of ions. The chance that a biological effect is produced in a cell, therefore, depends on the chance of it being hit directly. The chemical radicals OH and O<sub>2</sub>H that could be produced would, just like O<sub>3</sub> (ozone), be particularly active. The results of calculations based on the theory of probability appear to agree to a reasonable extent with the experimental results.

The damaging effect of X-radiation is frequently only perceived after a short or longer latent period. The biological effect of X-radiation is divided into two kinds, *somatic* and *genetic* effects.

### **2.3.5.2 Somatic effect**

The consequences of irradiation can manifest themselves in an individual by pigmentation of the skin, non-functioning of sweat glands, cataract formation, X-ray ulcers, or even radiation carcinomas (radiation cancers), for example. Also, changes may take place in the blood-forming organs such as alterations in the blood's composition or disease of the blood, leukaemia, for example. Here we are concerned with change in the body of an individual, hence the name *somatic effect*. The gonads can also be damaged somatically by high doses of X-radiation, causing sterility. In this case the changes are not passed on to future generations and so remain a somatic damage. However, it is possible that the reproductive cells are only partially damaged and remain capable of reproduction. This leads us on to the second form of biological effect.

### **2.3.5.3 Genetic effect**

In 1927, Müller, while experimenting on the banana fly (*Drosophila*, a much-used insect in experiments), discovered that X-rays, besides affecting the fly itself, were also capable of influencing the hereditary factors in the nuclei of the reproductive cells. This was a discovery of great biological importance. These changes, known as *mutations*, are rarely favourable, and are generally adverse and may even eventually prove to be fatal, possibly in the next, or in a later generation (so-called lethal mutations).

The genetic effect of X-rays on the gonadal cells (sex glands) can be transmitted (latent) from generation to generation before manifestation. Manifestation occurs when the mutation itself is sufficiently serious or when, either in the same or in a later generation, new, additional damage occurs to the nuclei of the gonadal cells thereby causing an *accumulation* of unfavourable factors. It is precisely this cumulative effect of damage to the nuclei of the gonadal cells in one or more

generations (as observed by Müller) that has attracted attention to the genetic effect of ionising radiations and has led to a better insight into, and protection against, the undesirable effects of radiation.

While the biological effect of X-, gamma- and other ionising radiations is made use of in radiotherapy, it is an undesirable but unavoidable effect in diagnostic radiology. Therefore, also in the diagnostic radiology department should one be aware of the biological effects of X-rays, and carry out the radiographic examinations with as low an exposure as possible (low patient dose) and be capable of providing sufficient protection for all those working in the department (see chapter 3).

# 3

## Dosimetry, Radiation Hazards and Protective Measures

In diagnostic radiology one should be familiar with the radiation with which one works, the hazards connected with that radiation and with the measures that one can and must take in order to avoid these radiation hazards. Putting this knowledge into practice is summed up by the concept *radiation protection*.

### 3.1 METHODS OF MEASURING EXPOSURE AND DOSE

In order to understand radiation, one should know its intensity (amount of energy per unit time and per unit surface area), as well as its quality. It must be possible for these magnitudes to be expressed in size and number; certain specific units for these are laid down. In section 2.3 the complicated methods of measurement to that end, making use of ionisation in air, were discussed. At the same time, the *röntgen* (R) was described as a unit of *exposure* and the unit of radiation quantity, the *rad*, as a unit of *dose*. Exposure as well as dose play a part in diagnostic radiology; exposure in connection with the resulting physical phenomena (film blackening, for example), and dose in connection with the action upon the human organism (somatic and/or genetic effect, see chapter 2, section 3.5). The relationship between exposure (in R) and dose (in rads) has already been discussed. Again, it must be emphasised in this connection that it is the measurement of exposure that is almost exclusively undertaken and the dose derived from this. While using the firmly established terminology of dose, dosimeter and dosimetry, one should realise that one is actually concerned with exposure, exposure meter and the measurement of exposure. The correct terminology will be used as much as possible.

### 3.2 EXPOSURE, EXPOSURE RATE, DOSE, DOSE RATE AND INTEGRAL MEASUREMENT

An exposure meter can be constructed such that radiation intensity can be measured *directly* (*direct measurement*), and/or such that the total quantity of radiation used in a given time is indicated (*integral measurement*).

The value found by direct measurement is expressed in exposure per unit time (R/s or R/min, for example) and this is called the *exposure rate*. The value found in a given time (radiation remaining constant) is exposure rate  $\times$  time = *exposure* (for example ... R/min  $\times$  ... min = ... R).

The manipulation of the concepts exposure rate and exposure resembles what we do in road traffic every day. The reading on the speedometer indicates the length of road travelled per unit time: km/h or m.p.h. The kilometre or mileage recorder indicates the total distance travelled: km or miles. It is logical that the same relationship exists between the concepts dose rate and dose. Dose rate represents the applied dose per unit time (rad/min, for example), while dose is again equivalent to the product of dose rate  $\times$  time.

Most radiation measurements can be traced back to electrical measurements of ionisation. Ionisation produced by radiation results in electrons and positive charges, moving in opposite directions, in an electric field. This stream of electrons (an electric current therefore) can be used to discharge a positively charged electrometer, or it can (after amplification) be measured and read directly as current (figure 3.1).

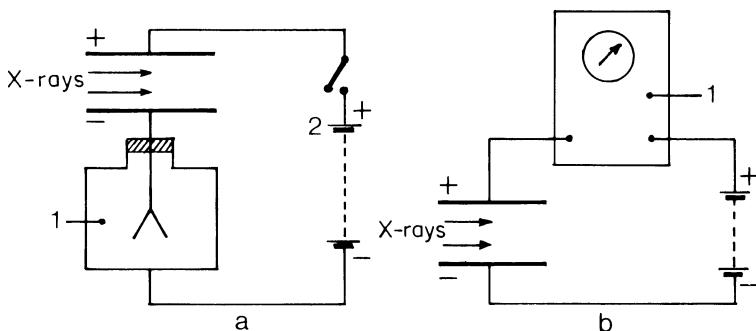


Figure 3.1 Measurement of the ionising current.

a. Indirect measurement by means of discharging an electrometer. 1. electrometer; 2. voltage source (integral measurement of current).

b. By means of direct measurement of the ionisation current. 1. direct current amplifier with meter.

Measurement of exposure rate amounts to the measurement of an electric *current* (that is the displacement of a quantity of charge). Determination of exposure amounts to the determination of an electric *charge* or discharge. The total charge conveyed to the ionisation chamber during the irradiation, in compensation for the charges lost due to ionisation, is proportional to the exposure. Direct reading of the exposure rate has the advantage of giving information about the strength of the radiation *at that moment*, at the point of measurement.

### 3.3 DOSEMETERS (EXPOSURE METERS), IONISATION CHAMBERS

A great variety of dosimeters exists, but they all consist, in principle, of the following essential parts:

- (1) a measuring chamber, the *ionisation chamber*, fixed or movable, connected to the meter or completely separate;
- (2) a charging system, in order to charge one of the electrodes;
- (3) a meter from which the ionisation produced can be read off;
- (4) a check or calibration system.

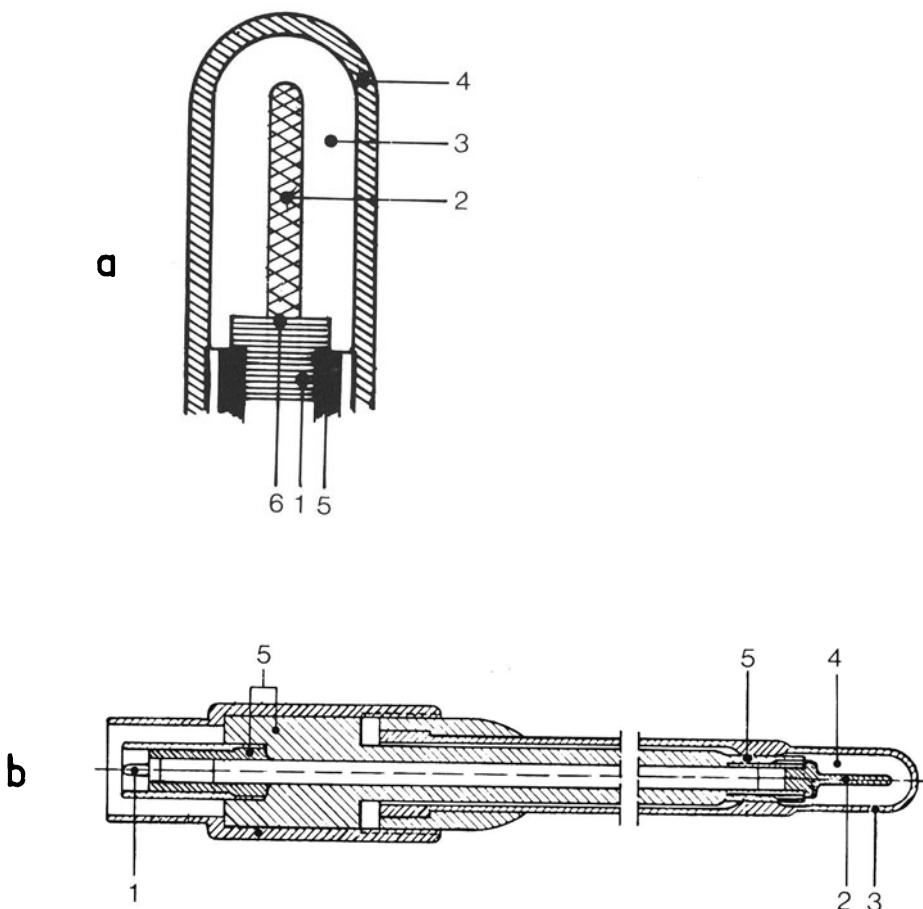


Figure 3.2 a. Fundamental principle of an ionisation chamber. Insulation (1) with supply wire (6) to the internal electrode (2), volume of air (3), chamber wall (4) with conducting internal layer connected with external electrode (5).

b. Thimble ionisation chamber. Connection (1) for internal electrode (2), chamber wall (3) of which the conducting internal layer is connected to the external electrode, measuring volume (4) insulation (5).

The electric charges and ionisation currents which are to be measured are extremely small—how small, may be gathered from a simple calculation:

At a dose rate of 1 R/s (60 R/min) and a volume of air with a mass of 0.001293 g (= 1 ml of air at 0 °C and 760 mmHg pressure) the ionisation current will be  $0.333 \times 10^{-9}$  A (= 0.3 nA). An instrument capable of measuring such small currents is an electrometer. The measurement can be carried out either indirectly by discharging the electrometer, or directly (after amplification) with the aid of a microammeter, as shown in figure 3.2.

The whole ionisation chamber must be placed in the radiation during measurement, so that the total volume to be measured is exposed to the ionising radiation. In order to determine the exposure correctly, a suitable ionisation chamber must be chosen. There are ionisation chambers of many designs and sizes in existence. One with a large volume contains many molecules of air which can be ionised. Even if only a small number of X-rays strike so large a chamber, there will still be measurable quantities of charge liberated by ionisation. This makes the large ionisation chamber especially useful for the measurement of low exposures (scattered radiation in diagnostic radiography, for example).

The choice of ionisation chamber is not infrequently determined by the situation in which one must take the measurement. For example, if one wishes to measure the exposure within the oesophagus during a radiological examination, then one will, of course, have to use a small ionisation chamber, even if the sensitivity of such a small chamber is not so great. *Thimble ionisation chambers* are therefore very suitable for such measurements. In these, the chamber wall (sometimes given conducting properties by the use of graphite) serves as one electrode and a central rod as the other. Its wall consists of materials which, although chemically considerably different from air, are still suitable for electronic balance (*air equivalence*). The volume of air, whose ionisation will be measured, is present between these electrodes. The materials of the walls must be chosen with great care.

The electrons that are liberated by ionisation of the air in the ionisation chamber and still have great speed so that they, in turn, can cause further ionisations (all of which will have to be taken into account for the measurement), will to some extent disappear within the walls or even pass through them and thus be lost to the measurement. In contrast, other fast electrons, which are created by ionisation both in and outside the walls, can penetrate towards the volume of air and contribute toward the measurement. It is therefore absolutely essential that during measurement there is a balance between the electrons that escape from the volume of air and the electrons that penetrate the volume of air from the walls (*electronic balance*). Therefore, the walls of the ionisation chamber should be made of a material which, as far as absorption is concerned, is equivalent to air (air equivalence) and, normally, be a synthetic which is coated with a layer of graphite. Without electronic balance, the measurement of the exposure will either be too great or too small (figure 3.2).

Choice of material and thickness of the chamber wall greatly influence the result of the measurement of exposure in another aspect as well. X-rays must of course be measured with ionisation chambers whose walls do not absorb too much, or else the radiation will not be able to penetrate into the volume of air

in its entirety. This is a difficulty, especially when measuring soft radiation. In this case one would measure too small an exposure, which, under certain circumstances, could create a dangerous situation. One might, in fact, wrongly think oneself well protected. Directions as to how measurements of radiations of a particular hardness must be corrected are usually given in the instructions that come with the chambers.

### **3.4 METHOD OF MEASURING WITH IONISATION CHAMBERS, THE CONDENSER CHAMBER**

The simplest method of measuring an exposure is with the aid of a condenser chamber, that is a chamber in which the electrodes serve as condenser plates at the same time. A known potential difference is applied between the two electrodes of the condenser chamber. The chamber is then disconnected from the

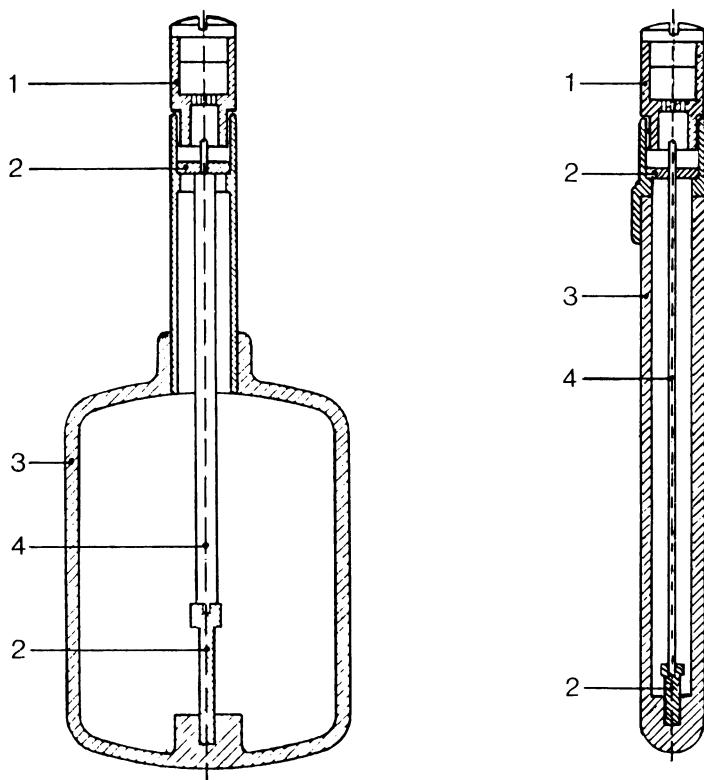


Figure 3.3 Diagrammatic reproduction of two condenser chambers with different ranges of measurement. Left: measuring range of 0.01 R (= 10 mR). Right: measuring range of 0.2 R (= 200 mR). 1. Cap, often containing a substance which absorbs moisture to protect the chamber against 'leaks'; 2. inter-electrode insulation; 3. external electrode of conducting synthetic material; 4. internal electrode of graphite-covered aluminium.

electric source and exposed to the radiation for a certain length of time. The radiation produces ionisation. The electrons and positive ions move themselves to the electrodes of the ionisation chamber, which consequently becomes more and more discharged. Ultimately, the remaining potential difference between the electrodes is measured. As the magnitude of the potential difference was known before ionisation and afterwards, and, since also the capacity of the condenser is known, the loss of charge can therefore be calculated from this. The loss of charge is a measure of exposure. The exposure meter may be calibrated in R. We are, therefore, concerned with an integral measurement in this case and the result is a number of mR, R and the like (figure 3.3).

This method of using the condenser chamber is not suitable for the determination of exposure rate, unless one has to deal with a completely constant radiation and one knows the exposure time exactly. Only then is the exposure rate (in R/s) = (exposure (in R))/(time (in s)). When measuring with other chambers, the thimble chamber, for instance, the ionisation chamber is kept connected to the exposure meter. During the irradiation of the air volume, the ionisation chamber loses charge. But, because it remains connected to the electric source (such as a battery), which is found within the exposure meter, a new charge is supplied immediately. In this way, a continuous current is conveyed to the ionisation chamber. This current does not have to be constant; there will, in fact, be variations in the strength of the current, since there are variations in the intensity of the radiation. Current strength is, from moment to moment, proportional to the exposure rate. The total charge that passes by, during the irradiation of the ionisation chamber, for the loss of charge due to ionisation, is proportional to the exposure. Usually, the scale of the exposure meter is calibrated in R/min, so that a direct reading is possible.

### 3.5 PRECAUTIONS IN MEASUREMENT

We shall now consider the points requiring special attention when carrying out a dose measurement 'free in air'.

(1) Scattered radiation should be avoided. In most cases this requirement can be fairly well satisfied by ensuring that there are no other objects in the beam besides the ionisation chamber. Diaphragms used to limit the X-ray beam to the necessary dimensions should be of flat lead of sufficient thickness, positioned perpendicular to the beam, and not a lead pipe through which the beam is conducted. Pipes or tubes generally cause a great deal more scatter, and possibly more characteristic radiation, than flat diaphragms of the same metal. The characteristic X-radiation of, say, a copper filter, can be reduced by placing an aluminium filter in front of it; that is, on the side where the ionisation chamber is located. The aluminium will then absorb most of the characteristic radiation of the copper, while the characteristic radiation of the aluminium is so soft that it is absorbed completely in a few centimetres of air (see chapter 2, section 2.1). If the X-ray beam strikes a wall or floor relatively close behind the ionisation chamber, the scattered rays may well influence the measurement. The chamber should therefore be set up as far away from other objects as possible. The points

at which the beam inevitably meets the surrounding walls or floor must be covered with sheets of lead, as lead emits considerably less scattered radiation than lighter materials.

(2) Thimble chambers must be fully exposed to the radiation; the beam must therefore be wide enough to encompass them (that is not collimated too much). This also applies to most other chambers. The dose is normally measured at a point in the central ray, and it is assumed that the point of dose measurement coincides with the centre of the chamber, unless stated otherwise. The measurement distance is the distance from the focus to this point of measurement. One can easily check with a fluorescent screen or film, placed behind the measuring chamber, whether or not it is positioned correctly within the beam.

(3) The measurement should preferably be made at the same location at which one wishes to know the exposure. If, for some reason this is not possible, the dose may be measured at a different distance from the focus and then converted by an inverse square law calculation. However, this is not always possible, as in many cases complicated associated phenomena make conversion with the inverse square law inaccurate. Thus, the inverse square law is not completely valid when the radiation is very soft (heavy absorption in air) and if stem radiation is present (which is usually the case with modern X-ray tubes).

(4) The dimensions of the ionisation chamber should be small in relation to the measuring distance, so that the distance from the focus to all points of the measuring chamber is virtually equal.

(5) One should always make sure that the ionisation chamber is suitable for measuring radiation of a particular quality and that, if necessary, corrections for the relevant H.V.T. (half-value thickness, the measured hardness of the radiation) are applied.

(6) The ionisation chamber should be calibrated and adjusted before use. This is done either electrically or with the aid of a radioactive calibrating substance.

(7) Lastly, it is important to adhere strictly to the safety precautions and to avoid carefully both the primary beam and the scattered radiation.

### **3.6 MEASUREMENT OF THE QUANTITY OF RADIATION**

The relationship between the kilovoltage applied to an X-ray tube and the radiation emitted, as well as the factors that influence the quantity and quality of that radiation, has already been discussed in chapter 2. Measurement of the radiation intensity, expressed by the exposure rate ( $R/s$ ,  $R/min$  or  $R/h$ ), is always carried out at a particular distance from the source of radiation. This distance must be known exactly, but it may be arbitrarily chosen, provided that the attained ionisation is neither too low nor too high for an acceptable and exact measuring time. For every arbitrary distance the result can then be converted by means of the inverse square law.

The completed measurement is, therefore, exclusively related to *this* particular radiation, that is produced by *this* particular kilovoltage (kV) and *this* particular current (mA) and *this* particular filtration. It appears by varying the factors,

- (1) that the exposure rate (strength of the radiation) is directly proportional

to the strength of the tube current (twice the mA produces twice the exposure rate);

(2) that the exposure rate is proportional to the square or third power of the kilovoltage;

(3) that by heavier filtration the rate of exposure decreases due to radiation absorption in the filter.

The change in the exposure rate is simple to predict when the mA is altered, but this is not so when the kV and/or the filtration is altered, as it requires measurements and calculations and/or readings from known tables.

The problem concerning the most suitable filtration of radiation is especially important. In practice, too soft a radiation mixture loses an unnecessarily large amount of radiation in the body itself, which does not contribute towards image formation, but does have a biological effect; that is it is harmful. Too hard a radiation mixture produces too little contrast in the radiation image, causing loss in diagnostic value of the resulting radiograph. Knowledge of the quality of radiation used (expressed in  $kV_p$ ) and the total filtration is therefore important.

### 3.7 DETERMINATION OF THE QUALITY OF RADIATION

The penetrating power of X-radiation increases with increasing voltage; in other words, the attenuation decreases. The energy of an X-radiation can best be characterised by plotting its attenuation in a particular material, on a graph. The attenuation curve expresses the relationship between the intensity of the radiation (in percentages) and the thickness of the material. For voltages higher than 100 kV, it is customary to specify the absorption in copper, and for voltages of 40–100 kV, aluminium is taken as the standard absorbing medium. For still lower voltages, aluminium or water may be used.

#### 3.7.1 Monoenergetic (monochromatic) and other radiations

The attenuation curve of a radiation is completely different when it concerns a radiation where photons of one energy (monoenergetic) are emitted, than when it concerns a radiation which contains photons with various energies (*polyenergetic*). Whereas in these expressions, which are used more and more (especially in therapy), the *energy* of the photon is proposed as the most important, one does still encounter the indication where the *wavelength* is the most significant.

Here, monoenergetic is similar to monochromatic and polyenergetic to polychromatic (or non-monoenergetic). The expressions homogeneous and inhomogeneous, which sometimes lead to confusion, are much used. Actually, these expressions mean no more than that the intensity of a radiation is the same (or not the same, respectively) over an area perpendicular to the central ray of the beam. However, these expressions are still being used in the sense of monoenergetic or polyenergetic, respectively.

The attenuation of a monoenergetic radiation in a particular material complies completely with the law of attenuation:  $I = I_0 \times e^{-\mu d}$  (see chapter 2, section 3),

where the attenuation coefficient,  $\mu$ , has a constant value. This means that every following layer of equal thickness attenuates the rays that fall upon it by the same percentage. If, for example, 1 cm of a substance attenuates the intensity to 50 per cent, then in the following additional cm there will be a further 50 per cent attenuation, after which, therefore, 25 per cent of the original radiation remains. The next additional cm will reduce this to 50 per cent of 25 per cent = 12.5 per cent, etc. (figure 3.4).

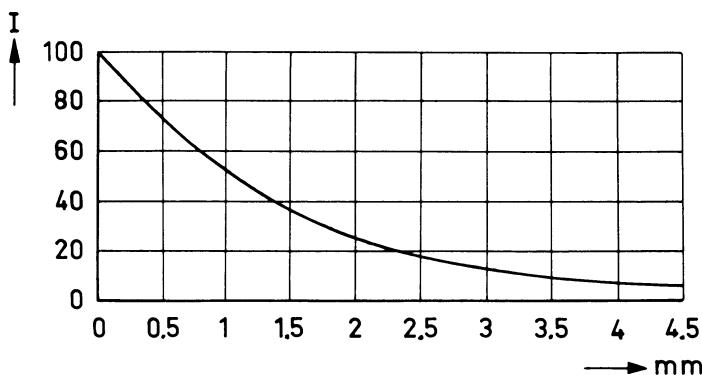


Figure 3.4 Simple diagram representing the attenuation of a monochromatic beam of X-radiation in an absorber. An attenuation of 50 per cent through 1 mm is assumed. The scale in the diagram is linear.

The attenuation curve is completely different for a non-monoenergetic radiation. Every layer that is penetrated attenuates the soft radiation that is present in the beam to a greater extent than the hard components. This filtration has, as a consequence, the effect that the average radiation becomes increasingly harder, and that the composite absorption coefficient does not remain constant, but becomes gradually smaller. In other words, the next added layers, which attenuate an equal percentage of the radiation, become gradually thicker.

### 3.7.2 Half-value thickness (H.V.T.)

Instead of plotting the complete attenuation curve, it is usual to indicate the 50 and 25 per cent points of the curve. The 50 per cent point represents what is known as the first half-value thickness (first H.V.T.). *By H.V.T. is meant: that thickness of a substance which reduces the intensity of a radiation to one half.* The thickness of a substance, which reduces the intensity that remains after passing through the first H.V.T. again to one half, is called the second H.V.T. By both the complete attenuation curve and the 100 per cent, 50 per cent and 25 per cent points, can the distribution of energy be completely defined. A radiation with a different energy distribution cannot have the same attenuation curve, nor the same values for the H.V.T.s: for a monoenergetic radiation, the first H.V.T., the second H.V.T., the third H.V.T., etc. (see figure 3.5).

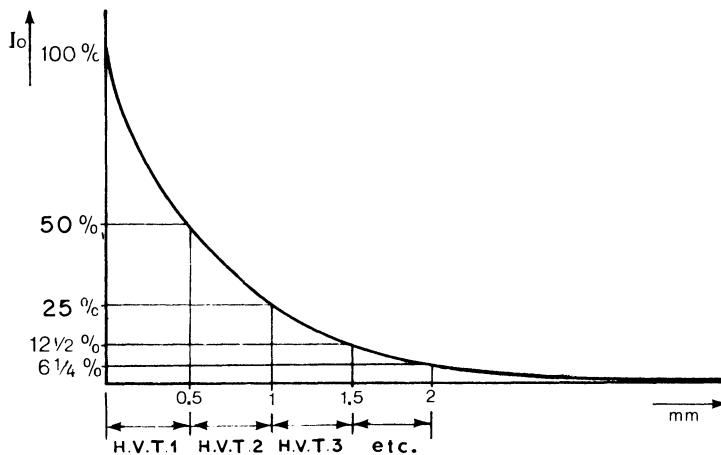


Figure 3.5 Half-value layers with a monochromatic radiation. Here, the 50 per cent of the curve corresponds to the 0.5 mm of the attenuating material (H.V.T.1), the 25 per cent point corresponds with a thickness of 1.0 mm. The difference from the 50 per cent point (thus,  $1.0 - 0.5 = 0.5$ ), indicating the H.V.T.2, is again 0.5 mm and therefore equal to H.V.T.1, etc.

### 3.7.3 Influence of filtration; degree of heterogeneity

We have already seen in section 7.1 that every additional layer of equal thickness attenuates a non-monoenergetic radiation to a lesser extent than the previous layer. By this method of filtering radiation, an alteration occurs in the spectral distribution of the radiation, namely a shift towards the shorter wavelengths. The effect of a filter is clearly seen in figure 3.6: the relative hardening of the beam, by which the beam approaches the behaviour of a monoenergetic beam (homogenisation),

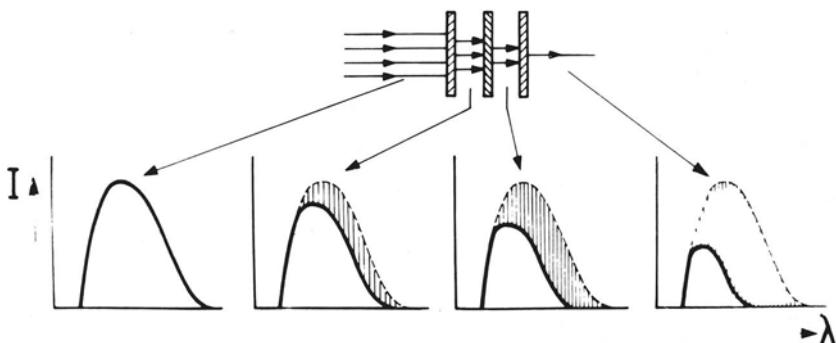


Figure 3.6 Hardening (homogenisation) of a polyenergetic (non-monoenergetic) beam by means of filtration. The shaded areas represent those portions successively absorbed by the filters. The non-shaded areas represent the residual radiation, which has been sharply reduced by the filtration.

a purely internal affair of this beam, as it were. *This hardening of the beam by means of filtration does not mean that harder rays are produced than were originally present in the primary beam, but only that the average hardness of the radiation increases.* It is also clear from the figure that by means of filtration the total intensity of the rays is greatly reduced. This increase in (average) hardness of the heterogeneous radiation by filtration finds expression in the absorption curve, and/or in the half-value thicknesses.

When a particular thickness of a substance reduces the intensity of a heterogeneous radiation by one half, this thickness represents the first H.V.T. (H.V.T.1). To reduce again the now harder radiation by one half, a greater thickness is necessary. In other words, the H.V.T.2 is thicker than the H.V.T.1, and the H.V.T.3 is thicker than the H.V.T.2, etc. However, these differences become steadily less, because the radiation behaves increasingly like monochromatic radiation. It is then said to approach homogeneity (figure 3.7). The limiting situation arises with a monoenergetic radiation with a constant H.V.T., but then the intensity of the radiation has also descended to zero.

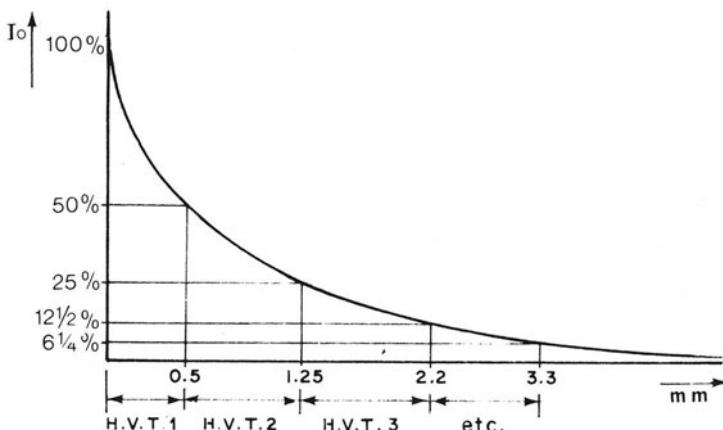


Figure 3.7 Attenuation curve of a non-monoenergetic or heterogeneous beam.  
 $H.V.T.1 = 0.5 \text{ mm}$ ;  $H.V.T.2 = 1.25 - 0.5 = 0.75 \text{ mm}$ ;  $H.V.T.3 = 2.2 - 1.25 = 0.95 \text{ mm}$ ;  
 $H.V.T.4 = 3.3 - 2.2 = 1.1 \text{ mm}$ ; etc. The half-value layers increase with decreasing individual differences. Finally, when a monochromatic radiation is virtually achieved, the H.V.L. would reach a constant value.

The ratio between H.V.T.2 and H.V.T.1 is known as the degree of heterogeneity. Naturally, the degree of heterogeneity of a monoenergetic radiation is 1, and that of a non-monoenergetic radiation is always greater than 1. When the radiation contains more soft components, such as with extremely low filtration in the tube, the degree of heterogeneity is so much the greater. If, for example, the H.V.T.1 of a radiation is 0.3 mm aluminium and the H.V.T.2 is 0.7 mm aluminium, then the degree of heterogeneity is  $0.7/0.3 = 2.3$ , that is this radiation is only slightly homogeneous. On the other hand, if the H.V.T.1, for example, is 0.6 mm copper and the H.V.T.2 is 0.8 mm copper, then the degree of heterogeneity is  $0.8/0.6 = 1.3$ . In other words, the radiation is much more homo-

geneous\*. In the above discussion, scatter has been ignored, and this is permitted with thin metal filters. Where scatter is considerable, as it is in the human body, for instance, then the softer Compton radiation counteracts the homogenising effect.

In radiological practice it is usually sufficient merely to indicate the H.V.T.1, certainly when additional information such as the tube kilovoltage is known. For diagnostic purposes the radiation is very rarely characterised by the H.V.T.1. Normally, only the voltage is given (highly inadequate), and not even the filter is specified. The situation is improved in therapy, and is, moreover, more essential. The quality of a radiation can be very well specified by giving the H.V.T.1 and the H.V.T.2, or by giving the H.V.T.1 and the degree of heterogeneity. Quite often the voltage and the filter used are also mentioned, although this is not really necessary.

### 3.7.4 Measurement of the H.V.T.

The method of measuring the H.V.T. is indicated in figure 3.8. One measures the exposure rate in R/min in a particular point in the X-ray beam. Next, one places filters of various thicknesses in succession in the radiation, and one then measures the corresponding exposure rates. The resulting values are plotted on a graph as shown in figure 3.7, for example. When the original exposure rate is indicated by 100 per cent, the 50 and 25 per cent levels of this graph, which correspond to the H.V.T.1 and H.V.T.2, can then be read off.

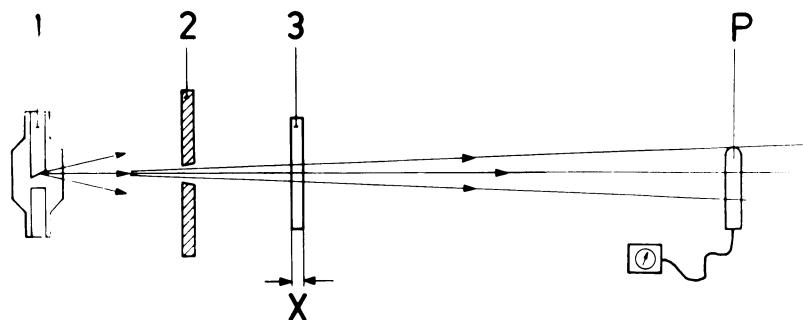


Figure 3.8 Method of measuring the H.V.T. or attenuation curve. 1. X-ray tube; 2. diaphragm; 3. filters (interchangeable) of thickness X (in this case placed in front of the diaphragm); P. position of ionisation chamber (connected to the dosimeter).

\*As in much of the literature the concepts homogeneity factor, degree of homogeneity, degree of non-homogeneity, degree of heterogeneity and so on, are being used for the same purpose, this may lead to confusion.

Following from the logical notion that a greater difference between H.V.T.2 and H.V.T.1 represents a greater non-homogeneity (heterogeneity), we have reserved the concept degree of heterogeneity (degree of non-homogeneity), for the relationship H.V.T.2: H.V.T.1, which is always represented by a number equal to or greater than 1.0. If one wishes to maintain the concept degree of homogeneity, then one takes the reciprocal value of the above, that is H.V.T.1/H.V.T.2, and this is always represented by a number smaller than 1.0.

This method of measuring the H.V.T. of an X-radiation by means of drawing up a complete absorption curve is very exact, when the details mentioned in section 3.5 are taken into consideration. One could, of course, try to find just those filters that reduce the radiation to one half, or one quarter of the initial value. Usually, however, one would be unlikely to possess such a range of filters, and it is quite unnecessary when using the graphic method described above. The distance from the focus at which the measurements should be carried out can in general be chosen at any convenient value, except when measurements of very soft radiations are taken, as these will be appreciably hardened by the air between the focus and ionisation chamber.

### **3.8 SKIN DOSE AND INTEGRAL ABSORBED DOSE IN DIAGNOSTIC RADIOLOGY**

The determination of radiation exposure is an important matter in all radiology, because of the relationship between absorbed radiation and potential biological consequences. One can check the magnitude of the radiation dose received in diagnostic radiology on the skin at the centre of the radiation beam, on the bone marrow of the ribs, and on the gonads, for example. Also, the staff, the radiological workers who carry out an examination, may wish to know how large an exposure or dose is at a certain point, such as on the right arm, on the forehead, or on, or behind the lead-rubber apron. It is already clear from these examples that the radiological dose concept is of a localised character; that is, when one discusses dose, the part of the body one is talking about should be mentioned. In this way, one speaks of bone marrow dose, gonad dose, skin dose, etc. The radiation dose is expressed in rad, thus indicating how much energy is absorbed per gram of tissue.

#### **3.8.1 Skin dose**

The most noticeable, but virtually unconsidered effect of radiation in diagnostic radiology, is a potential skin reaction. This is created by absorption of the rays in the skin, by the *skin dose*, therefore. By measuring the exposure on a particular point on the skin (in R), one also knows the skin dose at that point (in rad). As, however, an applied dose is not 'digested' by the body (which is usually the case when drugs are used), a new supplementary dose adds itself to the previous dose as it were, etc. Because of this *accumulation of dose*, a high total dose over one's lifetime is by no means imaginary. Further discussion about the effects that are related to this accumulation, such as subdivision (fractionation), low dose rate, (protraction), etc., falls outside the scope of diagnostic radiology.

One would be on the safe side, however, if one begins at the complete accumulation of the applied doses. With a total skin dose of hundreds of rads, erythema (redness), dryness, loss of hair, non-functioning of sweat glands, horn formation (hyperkeratosis), and, in the end, a *radiation skin* may occur or develop. By means of malignant degeneration, chronic radiation ulcers and even skin cancers may develop. These changes never occur immediately but only after a latent period, which may vary from days to years. There are, however,

extremely rare, and only may occur after very gross blunders, injudicious actions and fatal mistakes. Normally, no-one suffers skin damage, in whatever form, from radiographic examinations. However, in view of the cumulative effect, the radiologist should try to limit the dose severely (rapid examination, use of highly sensitive materials, etc.) when a particular patient is examined frequently.

### 3.8.2 Integral dose (I.D.) or volume dose

By the concept integral dose (integral absorbed dose) is meant the amount of converted radiation energy (the absorbed dose) in the irradiated volume, or in the irradiated amount of tissue. The integral absorbed dose is not only of significance in therapy and by relatively large doses, but also when it concerns lesser quantities of radiation, such as occur in diagnostic examinations. Even a small I.D. can have a highly undesirable and dangerous effect upon the very sensitive tissues and organs, such as bone marrow and the gonads (even if these lie outside the primary radiation). The absorbed dose differs from point to point (by local differences in density, intensity etc.) and the integral absorbed dose may be considered as the sum of many tiny doses. Each tiny dose represents the absorbed dose in a tiny portion of tissue (so small that the dose therein may be considered constant), represented by the mass of this portion, multiplied by the active quantity of rads. *The unit of integral absorbed dose is the kilogramrad (=  $10^{-2}$  J).* Often a smaller unit is used, the gramrad (=  $10^{-5}$  J). If, for example, the average absorbed dose in 1000 g of tissue is 2 rads, then the I.D. is 2000 gramrads = 2 kilogramrads (2 kgrads). In order to know the I.D. following an examination, one should, as it were, multiply all the grams of tissue that lie in the irradiated area by the rads that have been absorbed by these grams of tissue, and add all this together. Not only is this impossible in practice, but it would be inaccurate, as the tissues affected by scatter and the rads absorbed thereby, would be ignored.

A better method would be to measure the X-ray energy that enters the body, and subtract from that the energy that leaves the body. The difference then is the energy that is absorbed in the irradiated body tissues, the I.D. However, this method is also impossible in practice. In view of the fact that for the image formation, the radiation leaving the patient is relatively very little, one makes a small, but well-justified, mistake if one presumes that the radiation leaving the body is nil, and that the radiation energy present in the primary beam is completely absorbed in the body. One needs to do no more than to measure the energy of the beam emitted from the tube, and passed through the diaphragm, in order to gain a good impression of the integral absorbed dose. As both the non-absorbed radiation that is emitted from the body and the scatter have been ignored, the result obtained is too high. This measurement actually represents the *maximum possible integral dose*. The real absorbed dose is always less than the dose measured in this way, and one is therefore certainly on the safe side.

### 3.8.3 Measurement of the integral dose

The problem of measuring the energy of the beam that has passed through the diaphragm has not (yet) been solved satisfactorily for application in practice. If one knew this energy (expressed in joules), then, from that, the maximum

absorbed dose could easily be determined, based on the following formulae:  $1 \text{ Ws} = 1 \text{ J}$ ,  $1 \text{ mWs} = 0.001 \text{ J}$ .  $1 \text{ rad} = 0.01 \text{ J/kg}$ , and, therefore  $1 \text{ kgrad} = 0.01 \text{ J} = 10 \text{ mWs}$ . (In SI units:  $1 \text{ kg gray} = 1 \text{ kgGy} = 1 \text{ J} = 1 \text{ Ws}$ .)

In practice, a simpler method has been introduced which can give a satisfactory impression of the applied volume dose. Here, a special, large, flat ionisation chamber is used, a type of flat box, whose walls absorb very little of the radiation. This is fixed onto the diaphragm cover of the X-ray tube (figure 3.9). This ionisation chamber makes possible the measurement of the rays that enter during screening and radiography (see figure 14).

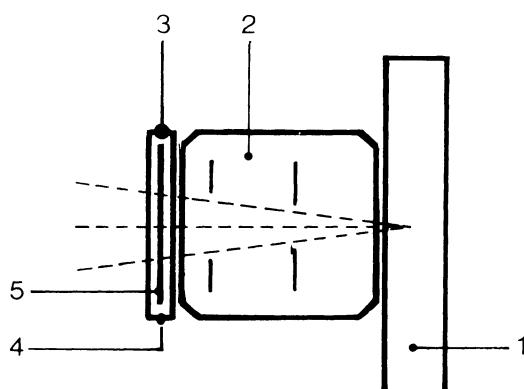


Figure 3.9 Diagrammatic representation of the ionisation chamber of the diagnostic dosimeter. 1. X-ray tube; 2. light-beam diaphragm; 3. flat ionisation chamber of which the internal wall is connected to 4; 4. external electrode; 5. insulated internal electrode.

The air volume of the flat ionisation chamber is only partly within the beam. As the beam becomes larger, a larger portion of the air volume will be in the radiation. The area of the ionisation chamber is so large that even with a completely open diaphragm the beam will not fall outside the air volume. The accompanying measuring apparatus indicates the product of the exposure (in R) and the beam area (in  $\text{cm}^2$ ) used. Naturally, this area is measured on the part of the ionisation chamber that is perpendicular to the central ray of the beam. At greater distances from the focus, the exposure decreases (according to the inverse square law), but the area of the beam increases in proportion to the square of the distance, so that the measured 'dose', (expressed in  $\text{R cm}^2$ ) remains constant everywhere in the beam.

It is clear that this measurement in  $\text{R cm}^2$  takes into account both the quantity of the radiation (from which the intensity is determined by means of the kV, mA and the filtration used) as well as the field area. Naturally, the time of exposure also plays a part and is expressed by the product  $\text{R cm}^2$ . As expected, the volume dose is directly proportional to the field size, whereby the importance of beam limitation is brought to our notice.

The diagnostic dosimeters that are in use indicate the number of  $\text{R cm}^2$  of every examination measured. Conversion into integral absorbed dose (in kgrd) is pos-

sible (chapter 15, section 15.2), but is not usual. The biological meaning of a number of kg rad is, for that matter, completely different for different parts of the body, as it depends whether sensitive or insensitive tissues are irradiated. Therefore, a high I.D. in an insensitive area, such as the extremities, would be less significant than a low volume dose in a sensitive area such as the gonads.

The value of diagnostic dosimetry, such as the determination of  $R\text{ cm}^2$ , does not lie in its (nearly impossible) biological interpretation, but in the fact that the radiologist and radiographic staff become more 'dose conscious' with respect to both the patients and themselves. One is reminded daily, as it were, that one must be 'thrifty' with radiation. Dosimetry can contribute much, so that neither the danger of radiation is underestimated, nor a tendency towards radiation phobia is induced.

### 3.9 OTHER FORMS OF DOSIMETRY

Ionisation of air is virtually the most often used aid for the measurement of an exposure as a preamble to the determination of the radiation dose. There are many more forms of exposure measurement. *Photographic dosimetry* and *thermoluminescent dosimetry* are also of importance in diagnostic radiology. Both these forms of exposure measurement offer the possibility of determining the radiation exposure only, and not the exposure rate. They are, therefore, integral methods of measurement. Both forms of dosimetry make use of materials that are not tissue equivalent, and in both cases fairly complicated procedures are involved that demand regular verification of methods.

#### 3.9.1 Photographic method; film badges

One can find a relationship between the cause (radiation) and the effect (blackening of film) by the influence of X-radiation upon photographic material. Although the relation between X-ray dose and film density is far from simple, being subject to many different factors including radiation quality, a method has nevertheless been devised for measuring radiation both quantitatively and qualitatively with serviceable accuracy. It is especially useful for demonstrating and measuring small quantities of radiation. Tiny films are used for this purpose, which fit into a special miniature cassette (known as film badges) and can be carried on the person or hung up somewhere in the space to be monitored. The film badge can be provided with several different filters (aluminium, copper and lead), mounted in step-wedge fashion, to allow analysis of the radiation quality. It sometimes contains several types of film with varying sensitivity and dependence upon wavelength.

Monitoring by means of film badges is usually a service provided by some central organisation (this varies from country to country), whose function it is to provide, develop and analyse monitoring films of this kind. Film badges are worn for 2–3 weeks, usually. The densities are compared with standard films. Of course, all films must be of the same emulsion and developed under the same standard conditions. The regular reporting of the results to the persons concerned, contributes to more careful attention to the radiation protection rules. In places where a film-

badge service does not exist, an impression of the exposure can be obtained by making a few test films with the aid of known exposures, for example of, 0.01, 0.02, 0.05, 0.1, 0.2 and 0.3 R, with the same filters and kilovoltages.

### 3.9.2 Thermoluminescent dosimetry (T.L.D.)

Increasing use is being made of the changes produced in certain crystals, such as calcium sulphate ( $\text{CaSO}_4$ ) and lithium fluoride (LiF) by X-rays. Electrons in the substance change into a state of greater energy. They sometimes remain in this 'cocked' state for years, if the substance is kept at room temperature. If one heats the crystalline substance, then the cocked electrons return to their old state, which is accompanied by a liberation of energy in the form of light (hence the name thermoluminescence). One therefore places the thermoluminescent material upon the area where one wishes to measure radiation, and later heats the substance in a special oven, at which time the light produced is measured. The dosimetry is based upon the direct relationship between the quantity of light emitted and the radiation dose. The crystalline substance can be re-used. The principle is shown in figure 3.10.

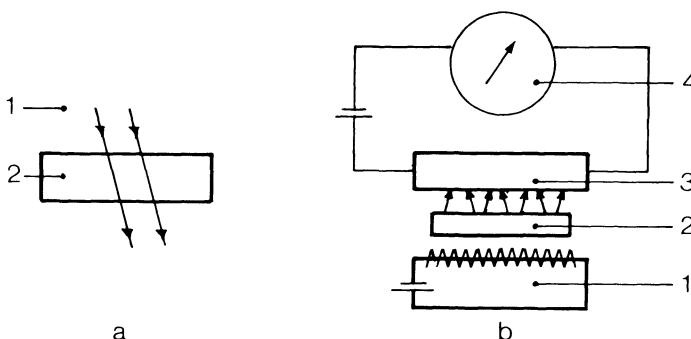


Figure 3.10 Diagrammatic representation of thermoluminescent dosimetry.

- Irradiation of the crystalline material: 1. X-radiation; 2. thermoluminescent material.
- Heating (glowing) of the crystalline material and measurement of the light produced:  
1. heating; 2. thermoluminescent material; 3. light sensitive cell; 4. a meter which can be read.

Thermoluminescence with lithium fluoride is used for the measurement of extremely small X-radiation doses, but also gives correct results for greater and even very large doses. The substance is heated to  $\approx 300^\circ\text{C}$ . Thermoluminescent dosimetry demands the use of very special apparatus. The method has great advantages, if many measurements have to be made, and is also useful in diagnostic radiology and radiation protection. The crystalline substance can be prepared in all forms, such as a powder (possibly encapsulated in Teflon), rods, slices, etc. It is therefore also suitable for dose measurements within the body, as the radiation meters can be of small dimensions. Grateful use is made of this in radiotherapy.

Thermoluminescent dosimetry, like photographic dosimetry, is a purely integral method of measurement and will probably increasingly replace the latter.

### 3.10 RADIATION HAZARDS AND PROTECTION

Having become acquainted, in the preceding paragraphs, with the methods whereby radiation can be detected, measured and qualified, we shall now consider the kinds of radiation to which we are exposed and how these can be minimised.

#### 3.10.1 'Natural' and other radiations

Each one of us is subjected to the effect of unavoidable 'natural' radiation, to which is added radiation of medical origin. The latter is more or less avoidable or can be limited. The natural radiation to which we are exposed averages about 0.13 rem (= 130 mrem) per year.

This radiation consists of:

- (1) *cosmic radiation*, originating from interstellar space. It is more intense at high altitudes than at low levels (for example the intensity at 4000 m is four times greater than at sea level).
- (2) *terrestrial radiation*, which varies with the composition of the soil. It is caused mainly by the radioactive elements  $^{40}\text{K}$ ,  $^{232}\text{Th}$ ,  $^{239}\text{U}$  and varies from 50 mrem per year per inhabitant to several rem per year (this latter in the state of Kerala in India);
- (3) *atmospheric radiation*, originating from gaseous radioactive decomposition products of radium and thorium (radon and thoron). Radon has a  $T_{1/2}^*$  of 3.8 days and thoron has a  $T_{1/2}$  of 1.91 years;
- (4) *natural radiation in our bodies*, caused by the presence of  $^{40}\text{K}$  (activity  $6 \times 10^{-9}$  Ci/g of potassium) and further by  $^{14}\text{C}$ . The latter is formed in the air by the effect of cosmic radiation which enters the biological environment of every living being (in man 2 mrem per year). There is also radiation emanating from  $^{226}\text{Ra}$ ; this varies greatly with the nature of the food taken (namely 100 nCi per day with a vegetarian diet and 5 nCi in the case of Western-type diets).

The radiation of medical origin that has to be considered together with 'natural' radiation is caused mainly by medical techniques used in examination and treatment; thus, mainly diagnostic radiology and radiation therapy. However, radiation is also added by industry in the form of luminous dials and figures (watches and indicating instruments), television sets, etc. Furthermore, the use of nuclear reactors and the testing of nuclear weapons (radioactive fall-out) should also be mentioned.

As far as medical radiology is concerned, a few figures may serve as a general guide to the gonad dose in the male and female, imparted in a number of examinations:

	gonad dose (mrem)	
	male	female
for a full-size chest radiograph	0.2	0.45
stomach examination	90	300
pelvic radiograph	1300	1500
intravenous pyelogram	390	4500

\*By  $T_{1/2}$  is understood the time needed for the radioactivity of an element to fall to one-half of its original value.

In a gastro-intestinal examination the blood-building organs receive 500 to 700 mrem, and in a thorax study 40 mrem.

For the population as a whole, medical radiology raises the dose imparted by natural radiation by some 20-100 per cent. One should, however, set against this disadvantage the progress achieved in public health care as a result of better diagnosis made possible by the use of radiation. The quota that radiotherapy adds to the 'population dose' is relatively small (only 4.5 mrem per year) and, moreover, it relates predominantly to persons over the age of forty. That is to say, a group with waning or rapidly disappearing genetic influence.

### **3.10.2 The radiation hazard**

The biological effect of ionising radiation has already been discussed at some length in chapter 2. As we have seen, a particular characteristic of such radiation is the latent period, that is the time that elapses between exposure and the onset of a specific effect. The latent period following exposure to high doses is relatively short, being between a few days and a few weeks, whereas for low doses regularly administered it may last twenty-five years or more before certain effects, such as carcinoma and leukaemia, begin to manifest themselves. It is this long latent period, during which a cumulative dose is built up, that gives the radiation hazard its insidious and treacherous character. The cumulative effect of many small doses of radiation spread over a long period was the reason for the numerous grave and often fatal radiation injuries suffered by the pioneers of radiology. When the harmful effect appears years later it is often too late to procure complete or even partial recovery of the damaged parts of the body.

Among the organs and tissues most sensitive to ionising radiation are the haematopoietic organs, the skin and the gonads. For these, damage by the chronic effect of radiation is to be particularly feared. In earlier times, radiation injuries to the skin, mainly of the hands, were quite common, owing to the habit, then all too prevalent among radiologists, of testing the hardness of the rays (especially from ion tubes) by holding the hand in front of the fluorescent screen. The long-term result of this practice was often the formation of a carcinoma, usually of the squamous type. It is therefore essential never to expose the hands to doses which may, by accumulation, lead ultimately to a permanent skin injury. Nowadays, a localised radiation injury incurred in the diagnostic application of X-rays must be considered a serious professional blunder, showing the want of a proper regard both to one's own safety and to that of others.

The haematopoietic system, or blood-forming system, which includes the bone marrow, the lymph glands and the spleen, can also be irreparably damaged by the chronic effect of radiation; the outcome may be leukaemia, a fatal condition in which there is hyperplasia of the tissues that produce white cells. The real cause of leukaemia is as little known as that of cancer. We do know, however, that the chance of someone contracting the disease is greatly increased by the chronic effect of ionising radiation, and its incidence among radiological workers\* is higher than in other groups, although the absolute incidence is in any case

\*The term *radiological workers* is always used in codes of practice, etc., to denote persons who by reason of their profession come into regular contact with ionising radiation.

fortunately small. It is not known whether leukaemia is preceded by any demonstrable change in the blood, but however this may be, persons who come into regular contact with ionising radiation should have regular blood checks to ascertain whether the radiation is having any effect on the blood.

The chronic effect of radiation on the gonads (ovaries and testes), resulting from relatively small doses, may lead to reduced fertility or to sterility. The gonads must therefore be regarded as particularly 'critical' tissues from a genetic point of view. Ionising rays are capable of causing gene mutations that are generally deleterious to future generations. Gene mutations also occur in nature 'spontaneously'; exposure to X-rays increases the chance of their taking place, depending upon the dose received. It is therefore essential to keep this chance as low as possible, the more so now that a greater percentage of the population is being exposed to ionising radiation. Every dose of X-ray received by the gonads of sexually mature persons contributes to an increase in the number of damaged genes in the population. The results of such mutations, which may be felt many generations later, are still the subject of much conjecture and experiment, but there is no doubt of the danger inherent in all gene mutations in that sooner or later they will have their effect and be the cause of reduced vitality and fertility. As far as the genetic effect is concerned, the only factor of importance is the total dose received by the gonads of the total sexually mature population, and not how this dose is distributed among the individual members of this population.

As regards the chronic effect of radiation on the eye, radiological experience does indicate that the lens is sensitive to X-rays with respect to cataract formation, but in the first place it must be considered as a critical tissue because of its high sensitivity to fast neutrons. Physicists exposed to neutrons have developed cataracts without appreciable skin changes or permanent loss of hair.

The incidence of cataract among the survivors of atom-bomb raids has been high. Cataracts, however, have also been produced in patients given large doses of X- or gamma-rays to treat cancer in the neighbourhood of the eye. To be on the safe side, the radiosensitivity of the lens of the eye should be considered the same as that of the blood-forming organs.

### 3.10.3 Permissible dose

A question of primary importance is whether the dose rate can be so greatly 'reduced' as to produce no, or at least no demonstrable, biological effect. This is in fact possible, as it has been proved that throughout the centuries (since before the discovery of X-rays) humanity has long been exposed to the ionising action of cosmic and other kinds of natural radiation. This dose rate appears to be well tolerated, although what humans would have been like if they had not been exposed to these radiations is an open question.

The question now arises: does there exist a safe dose rate, which a normal person, exposed for an indefinite period to ionising radiation, may receive in addition to the background radiation without the risk of his suffering appreciable bodily harm at any time during his life? This risk is called 'somatic radiation hazard' as distinct from the 'genetic radiation hazard', which by gene mutations may become manifest in later generations.

As long ago as 1925, Mutscheller carried out extensive investigations to determine the maximum permissible exposure for radiological workers and arrived at a tolerance exposure of  $10^{-5}$  R/s over a 40 hour working week, which amounted to a total weekly exposure of about 1.25 R per week. For the gonadal dose it was assumed, quite arbitrarily, that only one tenth of this exposure was permissible, namely 0.125 R per week.

These tolerance doses were later lowered by the International Committee for Radiological Protection (I.C.R.P.), while the rules were also extended by taking the relative biological effect of the various ionising radiations used for medical purposes also into account. The tolerance doses were thus expressed in rem, the rem being the unit of dose equivalent, equal to the product of the absorbed dose in rads and the relative biological effectiveness (or the quality factor, Q). In the diagnostic range of wavelengths the  $Q = 1$  and so 1 rad is equal to 1 rem.

The tolerance dose for radiological workers is now determined by the following rules.

(1) The maximum permissible dose that can be received by the blood-forming organs, the gonads and the lens of the eye is 3 rem in 13 successive weeks, that is 12 rem per year, but the dose received must also fulfil the conditions that the accumulated dose,  $D$ , is never greater than  $5(N - 18)$ , where  $N$  is the age of the person concerned in years. This formula  $D = 5(N - 18)$  therefore indicates that a person under 18 years of age may not work regularly with ionising radiation, while, for example, the maximum dose that can be received by someone aged 25 is  $5 \times 7 = 35$  rem. Radiological workers are not allowed to receive more than an average of 5 rem per year, starting from the age of 18. These 5 rem do not include the dose caused by natural radiation and the dose administered in radiological examinations or treatment of the worker concerned. It should be remembered, however, that this refers to the dose received by the organ in question. The dose in rem to which the body as a whole (the skin) can be exposed is thus much greater.

(2) The local skin dose, apart from the organs mentioned above, may amount to 8 rem in 13 successive weeks and 32 rem per year; the skin dose on the hand, underarm, foot and ankle may, however, be twice this amount: 15 rem in 13 successive weeks and 60 rem per year.

(3) The maximum permissible dose for the internal organs, apart from those mentioned in (1) above, is 4 rem per 13 successive weeks and 16 rem per year.

Since radiological workers only make up a very small percentage of the population, it is logical that the maximum permissible dose determined by the rules given above is higher than for the general population, excluding patients. For such persons, the maximum permissible dose is 0.170 rem per year for the blood-forming organs, the gonads and the lens of the eye (which for radiological workers is 5 rem per year).

While it is believed on the grounds of extensive experiments that the values above guarantee the safety of the individual and of generations to come, it is nevertheless advisable that all measures should be taken that might reduce to an absolute minimum the dose received by patients and by all those whose work

brings them into contact with ionising radiation and radioactive substances, that is if possible, to a much lower value than quoted above.

### **3.11 PROTECTION OF X-RAY PERSONNEL**

Persons working with X-rays must never under any circumstances expose themselves to primary radiation; this rule is easily observed by keeping out of the way of the useful beam.

The location and dimensions of the useful X-ray beam are indicated by the tube diaphragm (if not the light-beam diaphragm). Beyond the limits so defined there must be no X-radiation (direct). National and international regulations exist on the protective measures required, such as the lead equivalence of tube housing, and for the old high-tension rectification valves which can also emit X-rays (even if in small quantities).

Personnel should always avoid the useful beam even when they are protected by a lead-rubber apron. It is never really necessary to step into the beam, and the lead equivalence of the protective material is generally not sufficient to protect against primary rays. Moreover, the useful X-ray beam should never be directed on to a wall of partition behind which people are working, unless, of course, the lead equivalence of the barrier provides adequate protection.

In fluoroscopy the radiologist cannot always avoid being in the path of the useful beam (unless remote control is used, as described in chapter 15, section 15.11), but in these cases he is always behind the fluoroscopic screen, the serial changer or the image intensifier, all of which are furnished with sufficient lead shielding (2 mm lead equivalent up to 100 kV and 0.01 mm lead equivalent extra for every kV up to 150 kV). Care should be taken that the shielding is designed for the highest voltage that can occur, although it goes without saying that the radiation is usually attenuated by the patient before it reaches the fluorescent screen. Fluoroscopy should be carried out with the smallest possible field and the lowest possible current. For palpation in the useful beam the hand must either be protected by a lead-rubber glove, or a distinctor must be used.

It cannot be stressed strongly enough that not only the radiologist but also his staff should never put their hand in the primary beam, for example to hold an object in position. In particular, when making dental exposures on patients of low intelligence, or for immobilising a baby during the taking of a radiograph, one is often tempted to 'do it oneself just for a moment', under the impression that this 'moment' cannot do any harm. However, the cumulative dose received in this way over the years may finally be enough to lead to lasting injury, even death; such an action must thus be regarded as definitely out of the question.

If someone is needed to help in immobilisation, then one should always choose someone who does not come into regular contact with X-rays, preferably someone over 45 years of age such as a patient from the waiting room.

Not only the useful beam but scattered radiation too is dangerous. As previously explained, scatter is emitted in all directions from the irradiated object and also

strike those outside the primary beam. The measure of protection required is determined by the quantity or quality of the scattered radiation. More protection is therefore necessary if the irradiated volume is large and the primary rays are harder than when the beam is small and the primary rays are soft. It is difficult to mark a boundary between soft and hard rays in this connection, but it can be said that below 60-70 kV the scattered radiation constitutes a hazard only in the *immediate* proximity of the irradiated object. Above this kilovoltage, scattered radiation increases rapidly in intensity and range. It is therefore quite unnecessary when making 'on the spot' exposures of, say, the extremities with small X-ray units, to take elaborate precautions such as standing far away. At higher kilovoltage (stomach investigations, bucky exposures, colon investigations, etc.) one should take special care to avoid the scattered radiation at the side of the main beam by means of extra shielding or by standing far away; for example, during a bucky exposure one should never stand unshielded right by the side of the table. The operator's place behind the control desk should also be shielded, either by placing the control desk in a separate cubicle or by means of a lead or lead-glass partition.

Lead-rubber aprons and gloves intended to provide protection against scattered radiation (not against primary rays) should have a lead equivalence of 0.25 mm up to 100 kV and 0.5 mm up to 150 kV; the lead equivalence should be indicated on these objects. Lead-rubber has a tendency to split and tear easily, though imperceptibly; in addition to always hanging up lead-rubber aprons (never folded), both protective aprons and gloves should be regularly inspected and tested (by screening or radiographs). Screening stands must also be provided with adequate protective material outside the limits of the fluorescent screen or image intensifier to shield against scattered rays. Especially when image intensifiers and television are used and the observer is not entirely behind the stand, care should be taken to provide sufficient shielding.

### **3.12 PROTECTION OF THE PATIENT**

In view of the great increase in radiological examinations nowadays, the protection of the patient is assuming ever greater importance. Patients are often repeatedly exposed to ionising radiation, and it is therefore necessary to keep the total dose as small as possible. Of course, the radiation hazard must be weighed against the health of the patient, if one foregoes a radiological examination. It is the responsibility of the radiologist to ensure that all possible means have in fact been employed to keep the dose to the patient as low as is consistent with the information required from the examinations.

In fluoroscopy, the focus-skin distance may not be too short. In certain countries, a minimum distance of 35 cm is permitted, but most modern fluoroscopy stands have a focus-table distance of 45-50 cm. The extra filter must absorb enough soft radiation. A total filtration of 2 mm aluminium equivalent is sufficient for voltages up to about 90 kV; at higher voltages a total filtration of 4 mm aluminium or 0.1 mm copper plus 1 mm aluminium is recommended. Figure 3.11 shows the exposure rate, free in air, at 50 cm from the focal spot of a rotating anode tube with inherent filtration of 1 mm aluminium equivalent, operated

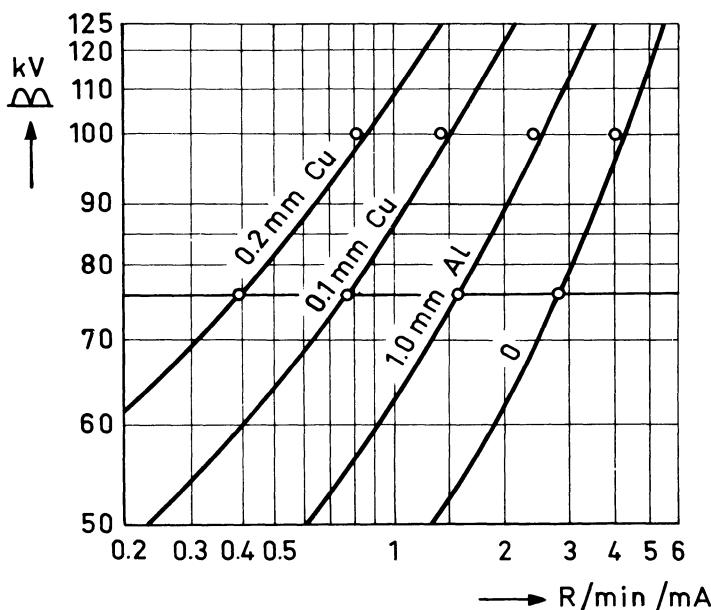


Figure 3.11 Exposure rate by means of fluoroscopy. The curves indicate some orientative values for the exposure rate (in R per min per mA), at a distance of 50 cm from the focus, measured in free air at various voltages (50–125 kV, four-valve voltage) and with different added filters (1.0 mm aluminium (Al), 0.1 mm copper (Cu) and 0.2 mm copper). The values are measured when a rotating anode X-ray tube is used with an inherent filtration value of 1 mm aluminium equivalent.

at voltages of 50–125 kV, and with various extra filters; the four curves give the exposure rate in R per min per mA.

At a current of 2 mA, normally employed in fluoroscopy (if no image intensifier is used), the patient receives, during a stomach examination lasting 10 min at 90 kV (0.1 mm copper extra filter and 50 cm focus-skin distance), an exposure of about 25 R. Without additional filtration the applied dose would have been about three times as high; with the use of an image intensifier, however, 10 min of fluoroscopy at 80 kV, 0.5 mA and an additional filter of 1 mm aluminium equivalent only requires about 10 R.

Apart from the surface dose, the integral absorbed dose has to be taken into consideration. This can be reduced by restricting the cross-section of the beam, together with the measures discussed above. A narrow beam cross-section is essential in fluoroscopy, not only with regard to safety, but also to improve the quality of the image. It is self-evident that fluoroscopic examinations must be carried out in the shortest possible time, and with the lowest possible tube current. The importance of the image intensifier, in this respect, cannot be overestimated.

Essentially, the same holds true for radiography as for fluoroscopy, although the doses concerned are generally much lower. Screening with, for example, 90 kV and 2 mA for 2 min, results in as high a dose as six radiographs at 90 kV and 40 mAs each. However, in a colon examination, for example, the dose

required for the radiographs represents an appreciable part of the total dose administered.

*It should, therefore, always be realised that even though the photographic results of over-exposure can to a certain extent be corrected in the processing room, such over-exposure leads not only to a certain reduction in image quality, but also to an unnecessarily high dose of radiation to the patient.* For similar reasons, maximum beam limitation is a sign of a responsible working technique.

The protection of the gonads is a further requirement in diagnostic radiography. In male patients this can generally be easily afforded by using special lead shields or lead pieces on the scrotum. With women, shielding of the ovaries is often impossible without losing important details on the radiograph. Besides localised shielding, it is of great importance to keep the irradiated volume as small as possible, as then the amount of scattered radiation reaching the gonads through the body is reduced.

Most radiographs entail a skin exposure of between 0.1 and several röntgen. The skin dose is relatively high for radiographs of the abdomen and vertebrae and for contact- and macro-radiography, whereas for radiographs of the chest and extremities it is relatively low.

The means of reducing the dose to the patient are, therefore: beam limitation, the use of fast films and intensifying screens, higher kilovoltages, addition of extra filters, and greater focus-skin distances. This decrease of the dosage by the use of harder radiation (higher kV) concerns mainly the skin dose; the advantage is considerably less as far as the total absorbed dose and the gonad dose is concerned.

In this connection, a distinction must be made between those cases where the gonads are in the primary radiation and where they are not. With abdominal exposures, where the gonads often are in the primary radiation, the highest possible voltage is the best with a view to reducing the gonad dose. With lung exposures, on the other hand, it is true that a high kilovoltage reduces the amount of radiation needed, but the scattered radiation formed will be harder, and will thus penetrate more easily through the body to the gonads than the scattered radiation from a softer primary beam.

Special care is called for in the case of abdominal exposures and fluoroscopy of sexually mature women, where irradiation of the gonads should be avoided as much as possible, and in addition, the possibility of pregnancy considered, even if this is not outwardly apparent. During the first months of pregnancy the foetus is highly sensitive to radiation. A dose of 40-60 rem received by a one-month-old foetus can cause abortion or malformation. In order to take this into account, it is advisable to give the date of the last menstruation on the request form for a radiological examination, and in cases of possible pregnancy to wait for the next menstruation, unless the case is urgent.

### **3.13 PROTECTION OF THE ENVIRONMENT**

Apart from the protective measures which must be observed within the X-ray department, the department as a whole must not be a hazard to the environment.

The harder the radiation, the greater the demands for protective measures. This is particularly clearly brought to our notice in the building of modern therapy departments, where energies of several megaelectronvolts (MeV) are employed, and for which the name *therapy bunkers* is already established.

The demands are much smaller for the radiation energies (to about 150 keV) used in diagnostic departments. By incorporating a protective layer of sufficient lead equivalence in the walls, doors, floors and ceiling, practically all radiation into the environment can be prevented. A great deal of experience, recorded in specialised books, already exists in this area; this one can make use of when building or making alterations. In many countries, stringent laws and controls for their observance are laid down.

### 3.14 CONTROL OF PROTECTIVE MEASURES

It is not sufficient merely to adopt protective measures; they must also be checked at regular intervals to see that they are serving their purpose.

Lead-rubber aprons may develop dangerous cracks, X-ray valves may be emitting unlawful doses of X-rays, a broken lead-glass screen may have been thoughtlessly replaced by panes of ordinary glass, and so on. Constant supervision and systematic checks are necessary to prevent abuses and to detect anomalies in good time. The supervisory measures required comprise:

- (1) checking of the equipment,
- (2) radiation monitoring (dose measurements, that is exposure measurement),
- (3) regular medical examination of personnel.

Regular inspection of the X-ray apparatus, auxiliary equipment and protective accessories, etc., can be carried out in several ways, namely, with a fluorescent screen, with films and with dosimeter. The first method is quick and efficient, but can only be used if the room is completely darkened. Modern fluoroscopic screens are so sensitive that with well-accommodated eyes they can be seen to fluoresce at very low exposure rates. Faint fluorescence need not, therefore, be itself any cause for alarm. The fluoroscopic screen is especially useful for detecting the presence of small radiation leaks.

As discussed in section 3.9.1, small amounts of X-radiation can also be demonstrated photographically. The most accurate measurements are carried out with dosimeters. For personal radiation monitoring, wide use is made of condenser chambers in the form of fountain pens, which like film badges can be worn on the person. There are also very sensitive instruments known as dose monitors, which give a direct reading of the exposure rate, even of soft scattered radiation, in milli- or micro-röntgen per unit time.

There are also various instruments for checking the dose received by patients during a diagnostic examination. The dose timer built into the control desk, which records the exposure time and gives a warning signal after a certain length of time has passed, was a first step on the way to dose-consciousness in radiography. More efficient is the  $R\text{ cm}^2$  meter, which adds up the incident exposure during the examination and multiplies it by the field size. An impression of the

dose absorbed in the body is given by the measurements of the total X-ray energy needed for an investigation. This energy can be expressed in mWs, from which the approximate absorbed dose in kgrad can be derived. Medical examination aims at detecting the presence of an incipient radiation injury in time. Haematological tests (blood counts) are especially important in this respect, the haematopoietic organs being pre-eminently sensitive to ionising radiation. Regular blood counts (that is the determination of the number of erythrocytes and leucocytes) enable an incipient radiation injury to be detected at a stage when no other symptoms are apparent and when it is still possible to effect a complete recovery.

The effects of ionising radiation may appear in the blood in the form of a drop in the number of erythrocytes (anaemia), a drop in the number of leucocytes (leucopenia), or a drop in the number of thrombocytes (thrombopenia).

On the one hand, it is questionable whether the absence of abnormalities in the blood is a reliable indication that the person concerned is not regularly receiving a higher dose than is permissible. Although blood counts are doubtless efficient for the purpose of ascertaining gross infringements of the permissible weekly dose, they are probably not suitable for detecting minor, but none the less unallowable infringements.

On the other hand, every change in the blood pattern of X-ray personnel should not be automatically attributed to the influence of radiation. There are many other causes, some unknown, of sudden and temporary changes in the blood; a change in the blood count is frequently a normal variation and reversible. For this reason, new personnel in an X-ray department should be subjected to a pre-employment examination including a blood count, so that the presence of possible disorders can be ascertained and not wrongly ascribed to over-exposure to radiation.

### **3.15 CONCLUSION**

Research concerning the protection against radiation is going on continuously and some, though very restricted, results have already been obtained. Also, immediate radiation reactions without a latent period (a decrease in the intra-dermic pressure) have been described. It is now still an open question, whether one will ever find a means, which can be administered like a medicine, to prevent local or even generalised radiation effects. As long as such prophylactic or curative drugs are not available, the greatest attention should be paid to those precautionary measures that are possible in the physical and technical fields.

Primarily, irrespective of regulations and automatic devices, it is one's moral duty to protect others and oneself against unwanted radiation. If this duty is disregarded, the great sacrifice of the pioneers in radiology will have been in vain.

# 4

## Methods of Image Formation and Laws of Projection

### 4.1 FORMATION OF THE INVISIBLE RADIATION IMAGE

The most important property of X-rays, without which they could not be put to diagnostic use, is their ability to penetrate matter to a greater or lesser extent. All degrees of transmission are possible, ranging from complete transmission of the radiation to complete impenetrability. It is due to this penetrating power of X-rays that we are able to use them to gain a visual impression of the internal constitution of the human body, in as much as the parts of the body differ in the amount of radiation they absorb. The laws that govern the attenuation of X-rays in matter have already been discussed. Differences in degree of attenuation are thus obviously to be expected in the human body, owing to differences in the density and atomic composition of the various tissues as well as in the thickness of the layers which have to be passed through.

The parts of the body which are distinguishable radiologically are the skeleton, the soft tissues and the pneumatic organs and cavities, the sequence of permeability from maximum to minimum being air, fat tissue, muscles, connective tissue, bone and metal. The soft parts, including the body fluids, consist largely of water together with certain organic substances such as carbohydrates, mainly composed of the elements hydrogen (H), carbon (C), nitrogen (N) and oxygen (O) (of atomic number 1, 6, 7 and 8, respectively). Their effective atomic number is approximately equal to that of water, 7.42.

Since they also have about the same density as water (= 1) there is scarcely any difference in absorption between these soft parts of the body. Fatty tissue has a lower density, and is distinguished by a greater permeability (greater density on the film) than, for example, the demonstration of a kidney in a pyelographic investigation, or glandular and connective tissue in a radiograph of the breast. Air

also has roughly the same effective atomic number of 7.42 as the soft parts, consisting largely as it does of the elements nitrogen and oxygen. Its density however, is considerably lower (about 1/775) for which reason pneumatic tissue is in contrast to the tissue containing no air. For example, in lung tissue (which contains air) an infiltration (containing no air) can be distinguished because the density of the lung is, for example, 1/3, while that of the infiltration is about 1. It is self-explanatory that gases or air present in the body, whether pathological or not, differ considerably from their environment in their lower degree of absorption and so cause radiolucency in parts of the body.

The skeleton contains many calcium salts, such as calcium carbonate and calcium phosphate. The atomic numbers of phosphorus and calcium are much higher than those of the soft parts, namely 15 and 20. It is this difference in atomic structure, in conjunction with the fairly high density of bone tissue (about 1.8), that explains the great difference in absorption between the skeleton and the soft parts so characteristic of a radiograph of the human body.

If we therefore pass a beam of X-rays through a part of the body, the emergent radiation will show differences in intensity, which are known as radiation contrasts. The whole set of contrasts contained in the emergent beam results in a shadow pattern of the subject, which is called the radiation image. This radiation image is invisible, and suitable means have therefore to be found to convert it into a visible image.

## 4.2 MAKING THE RADIATION IMAGE VISIBLE

The radiation image can be made visible by the use of the following properties of X-rays:

- (1) Their ability to make certain substances luminescent. This property is made use of in fluoroscopy, radiography with intensifying screens and also in photofluorography.
- (2) Their ability to act upon photographic emulsion. This property is used in radiography without intensifying screens. In radiography where intensifying screens are used the direct influence of the X-radiation on the actual film is practically negligible.

The different radiological methods that are employed to make the radiation image visible are outlined in the following paragraphs.

### 4.2.1 Fluoroscopy

In fluoroscopy the radiation image is immediately converted into a visible image on a fluorescent screen (figure 4.1). This makes it possible to observe directly any movement which may occur. A characteristic of the fluoroscopic image is its very low brightness, thus making it necessary to carry out examinations in a darkened room. Moreover, the eyes of the investigator must be adapted to this low level of illumination, so as to be sufficiently sensitive to fluorescent light. In modern fluoroscopy use is made of electronic image intensification, where smaller radia-

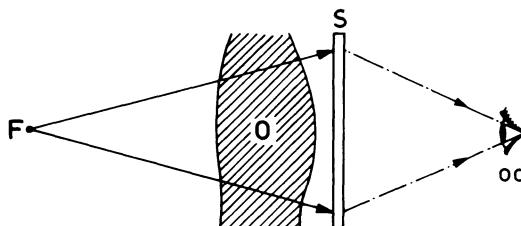


Figure 4.1 Diagrammatic representation of fluoroscopy. Diverging from the focus (F) the X-rays penetrate the object (O) and reach the fluoroscopic screen (S). The image is perceived with the eye (oc).

tion intensities give a much brighter picture. It is then no longer necessary to adapt one's eyes to the darkness, and the room need not be completely darkened. Moreover, with these brighter pictures the perceptive power of the eye is much greater. This modern method of fluoroscopy has certainly surpassed the old (classical or conventional) fluoroscopy.

#### 4.2.2 X-ray photography

In X-ray photography, the radiation image is converted into a 'latent image' in a photographic emulsion, which becomes visible only after development. Thus, in fluoroscopy, a continuous picture is obtained of the object, whereas, this radiograph gives merely an instantaneous picture.

Since, at the tube tensions concerned, the thin film-emulsion absorbs very little of the X-radiation to which it is exposed, excessive radiation doses (for both patient and X-ray tube) would be needed to produce adequate photographic density on the film. Hence the very wide use made of intensifying screens in radiography. These are luminescent screens, which are in close contact with the

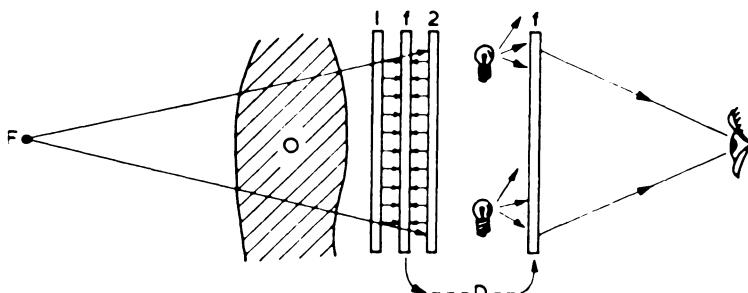


Figure 4.2 Diagrammatic representation of the taking of a radiograph with the aid of intensifying screens. The film (f) is exposed by the X-rays which emerge from object (O) but both emulsions are exposed to a much greater extent by the luminescent light produced in the intensifying screens (1. front screen; 2. back screen) by the X-rays. For the sake of clarity, the intensifying screens are not shown as they are in reality (namely, in intimate contact with the film). After the development procedures (D) the film is viewed in front of a viewing box (represented by the light-bulbs).

film during exposure and which, by their light emission, add to the photographic effect of the incident X-rays (the film density produced by their luminescence is many times greater than that produced by the direct X-radiation) (figure 4.2). X-ray photography, with or without intensifying screens, always produces a large image on a 'full-size' film.

#### 4.2.3 Screen image photography

In screen image photography (called either X-ray photography or photofluorography), a photograph is taken of the fluoroscopic image by means of lens or mirror cameras.

##### 4.2.3.1 Classical fluoroscopic screen

The fluoroscopic screen is of large size (for example  $40 \times 40$  cm) on which an entire thorax can be X-rayed. This fluoroscopic image is reduced in size by the camera (figure 4.3). The resultant negatives are usually  $70 \times 70$  mm, or  $100 \times 100$  mm, and after development they are generally viewed either by means of a magnifying glass or by projection.

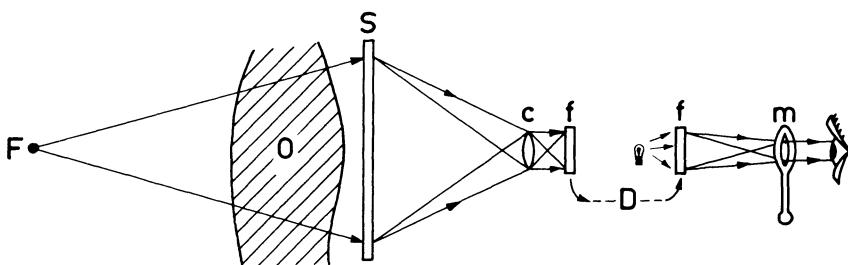


Figure 4.3 Diagrammatic representation of conventional photofluorography. The fluoroscopic image of object  $O$  appearing on screen  $S$  is recorded on a film  $f$  by means of a camera  $c$ . After development ( $D$ ) the film is viewed with the aid of an optical magnifier ( $m$ ) against an illuminator.

##### 4.2.3.2 Image intensifier fluorography

A special, and increasingly commonly used form of screen image photography is image intensifier photography. Here, the image that is produced on the secondary screen of an image intensifier unit is photographed (figure 4.4). Large format photos, however, are superior since the reproduction of details by use of intensified fluorography is still not as good as it should be.

#### 4.2.4 Television

With the advent of television cameras it was found that television could be advantageously combined with fluoroscopy. It is possible to record the TV image on magnetic tape and to play it back later. During televised fluoroscopy, the fluoroscopic image is taken by the television camera and projected onto the television monitor. This form of fluoroscopy has become the method of choice.

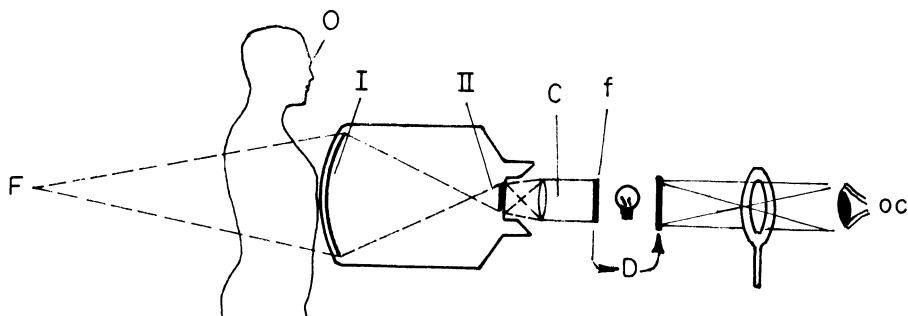


Figure 4.4 Diagrammatic representation of image intensifier fluorography. The X-ray image of object O on the primary screen (I) in the image intensifier is intensified and reproduced in a reduced form on the secondary screen (II). This image is photographed on, for example, a 70-mm film by means of a camera (C). After development (D) the film is viewed (usually in an enlarged form). oc = eye.

The image that appears on the television monitor can be photographed. However, direct photography of the television picture is rare because of the poor reproduction of detail: the filming of televised pictures (kinescopy) also has little application, for the same reason.

With the use of magnetic tape the television image can be permanently recorded. This procedure involves receiving the video signal rather than direct photo-

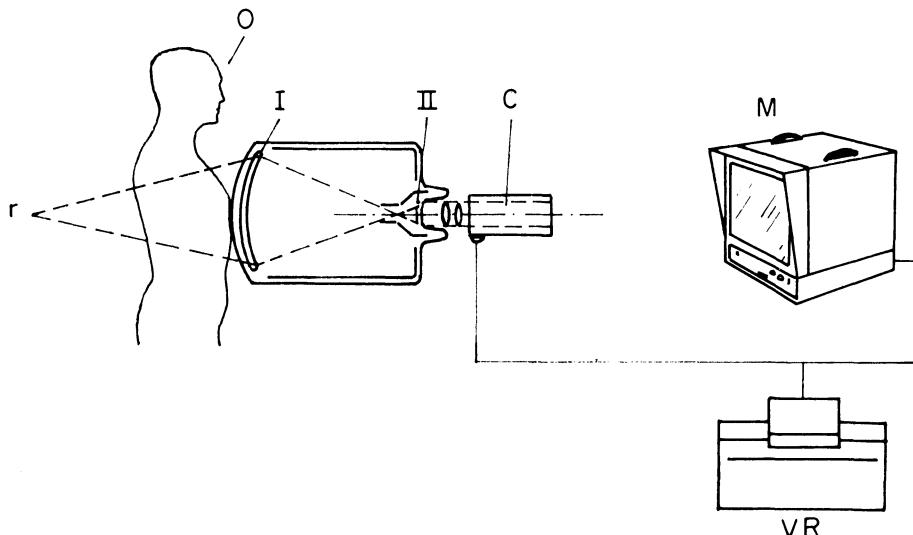


Figure 4.5 Image production on a television monitor and a video recorder. The fluoroscopic images of object O on the primary screen (I) in the image intensifier are intensified and reproduced in a reduced form on the secondary screen (II). The television camera (C) converts these images into a video signal which is transformed into visible images in the television apparatus, which become visible on the monitor (M). The video signal may also be fed into an apparatus which records the images on a magnetic tape (video recorder, VR).

graphy of the monitor image (figure 4.5). The tape can then be 'played back' and the image (images) can be studied. This is also known as video recording, which in everyday life can be illustrated by the televising of a football game that was actually played earlier rather than at the time it is being shown. Video recording is a very valuable method of temporarily recording X-ray exposures for later inspection and for educational purposes.

### **4.3 QUALITY OF THE VISIBLE IMAGE**

Characteristic of every visible X-ray image are its contrasts and its sharpness. The contrast means the relationship between light and dark areas. Only where a contrast exists are we able to see anything in the picture: we distinguish in this way any object that stands out from its surroundings. We call that a component detail.

The quality of a radiographic or fluoroscopic image depends upon the perceptibility of the details in it. The quality of the images produced by the different radiological methods is found to differ. The quality of the image produced on the normal fluoroscopic screen is poor.

By means of phantom tests, detail perceptibility can be accurately analysed and expressed in degree and number; in this way the various radiological methods of producing X-ray images can be compared and assessed as to their merits. This occurs best through the determination of the modulation transfer function (see chapter 7, section 7.4).

### **4.4 COMPOSITION OF THE IMAGE**

The representation of details in the X-ray image is largely dependent on their mutual position in the object with respect to the focus and the plane of projection (screen or film).

#### **4.4.1 Superimposition**

Generally speaking there is not only one part of any object in the path of the rays, but the same ray passes through several successive parts of an object, in each of which a certain amount of absorption takes place. What then remains of the primary ray (disregarding scattered rays in this context) produces the image on the film. When, therefore, we see a radiograph which is, for example, a lateral projection of the sella turcica on which a revolver bullet is visible, we must realise that this bullet need by no means be actually in the sella itself. All we can deduce from this radiograph is that the bullet is somewhere in the path of the rays; hence it may be in the sella, in the left or right wall of the skull, in the scalp, or in the intervening tissue. It could even be entirely outside the skull, somewhere between the focus and the film.

This phenomenon in which all images in a particular projection fall one above the other is called superimposition. In the case of complex structures, such as the skull and the spinal column, it calls for a considerable amount of skill to analyse the composite lines of the superimposed image.

#### 4.4.2 Parallax and parallactic shift; orientation in space

Parts of an object that lie at different points along the same X-ray will be superimposed in the fluoroscopy image. Such details can be separated by moving the X-ray focus sideways with respect to the beam of X-rays (figure 4.6). The angle subtended by these details at the focus is called the parallax (in the case of superimposition, the parallax is  $0^\circ$ ). The extent to which the parallax of the details changes when the focus is shifted allows us to determine their distance from the image plane. In radiological practice, neither the parallax itself nor the change in angle when the focus is shifted is measured. What is measured is the displacement of the details of the projected image, and it is the difference found in this way which is called the parallactic shift. As the parallactic shift increases, the particular detail must be further from the projection plane, that is from the image plane.

In case the image of an object detail does not undergo any parallactic shift when the focus is moved, the detail is placed in the plane of projection. It is then placed directly on the screen or on the film and the object-film distance ( $Of$ ) is zero. Whenever the images of two object details do undergo parallactic shift, one at a time, it means that they both lie in a parallel plane at the plane of projection (the same object-film distances).

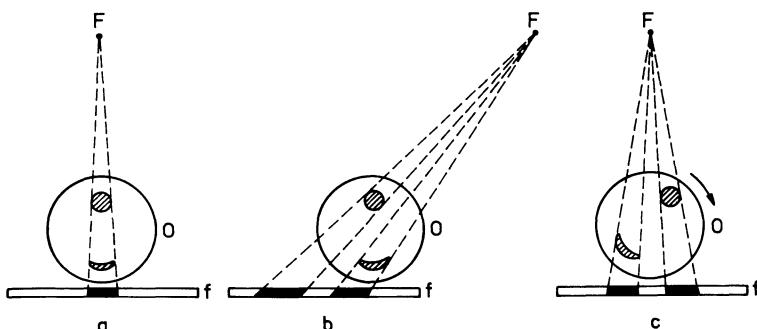


Figure 4.6 The separation of projections by shifting the position of the focus or by turning the object.

- a. The projections of two superimposed structures in object O coincide on film f.
- b. After shifting the position of the focus (F) the structures become separately projected.
- c. By turning the object (to the right or to the left), while the focus remains stationary, the superimposed structures will also be projected separately.

The same parallactic shift can be produced by displacing or rotating the object instead of moving the focus (figure 4.6c). This method is often used in fluoroscopy to give a three-dimensional effect, that is, to demonstrate what is in the front and what at the rear. For this purpose, the patient is turned to the left and/or to the right. Apart from the extent to which the patient is turned, the direction in which he is turned is also important. If the patient is turned to the right (the left shoulder coming forward, towards the screen, and assuming that the patient is facing the screen), everything behind the axis of rotation will also move to the right (seen from the place of observation of the fluoroscopy screen), while everything in front of this axis will move to the left on the screen.

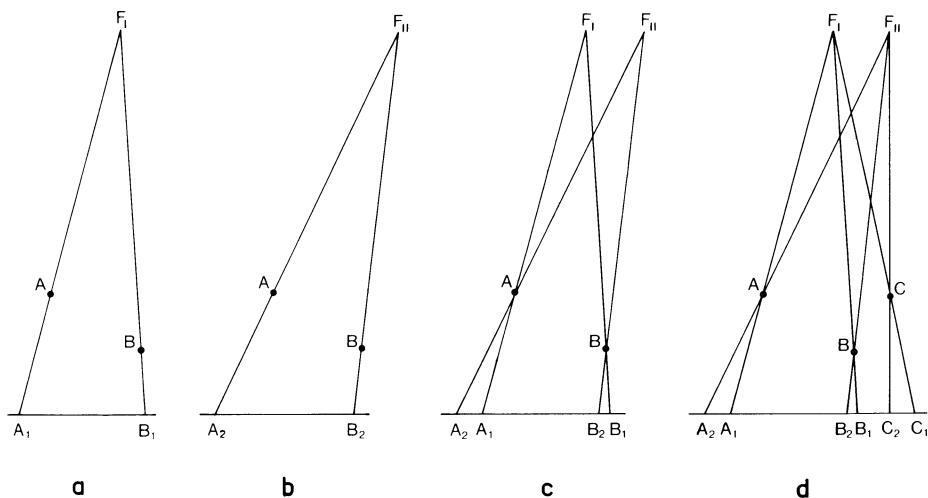


Figure 4.7 Parallax and parallactic shift.

- a. In the first position of the focus ( $F_1$ ) the object details A and B have a parallax (= angle)  $AF_1B$ . They are projected on the film as  $A_1$  and  $B_1$ .
- b. The same details with respect to a different position of the focus ( $F_{11}$ ). The parallax (= angle)  $AF_{11}B$  is now different from angle  $AF_1B$ . The projections are now  $A_2$  and  $B_2$ . The distance  $A_1A_2$  and  $B_1B_2$  is the parallactic shift.
- c. Combination of a and b. The parallactic shifts of the projections of A and B are different:  $A_1A_2$  is larger than  $B_1B_2$ . The further a detail is from the film f, the greater the parallactic shift.
- d. Addition of an object detail (C) situated at the same distance from the film as A. Now the parallactic shift for both details is equal; therefore  $A_1A_2 = C_1C_2$ .

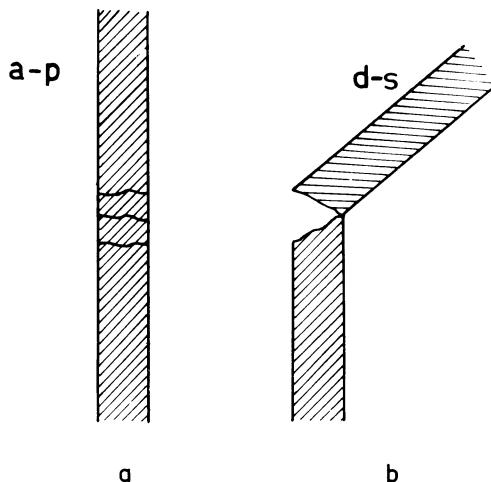


Figure 4.8 Imaging in two directions. The necessity of taking radiographs in different directions is shown here.

- a. View of a fracture in an a-p direction; apparently no dislocation.
- b. The same fracture in a view at right-angles, that is lateral (dextro-sinister, d-s) direction; there appears to be considerable dislocation.

Naturally, this displacement on the screen will be greater the further away the detail in question is from the axis of rotation.

Displacement of the focus or rotation of the patient is also made use of, to obtain radiographs which give us a spatial impression of the object, and show how the various details are situated with respect to one another. The concept of parallax is of great importance for stereoscopic investigations (see chapter 12, section 12.2).

Another method of investigation which makes use of displacement of the focus or rotation of the patient is tomography (see chapter 12, section 12.1).

A very common method of orientation in depth consists in taking two X-ray photos of the object in two mutually perpendicular directions. This is particularly necessary for locating foreign bodies (for example splinters of metal) and for judging the relative positions of the two pieces of a fractured bone. For example, it is possible that a dislocation is not noticed in a radiograph taken from one direction only, while it shows up very clearly in the radiograph taken at right-angles to the first (figure 4.8).

#### 4.4.3 End-on effect

It is possible that a given detail is invisible when the X-ray photo is taken in a certain direction, but shows up well in another direction. This is particularly the case when a detail is thin and only has large dimensions in one given plane. If we consider a thin membrane (for example the pleura), here the absorption of X-rays will generally be so slight that no contrast is produced with respect to the sur-

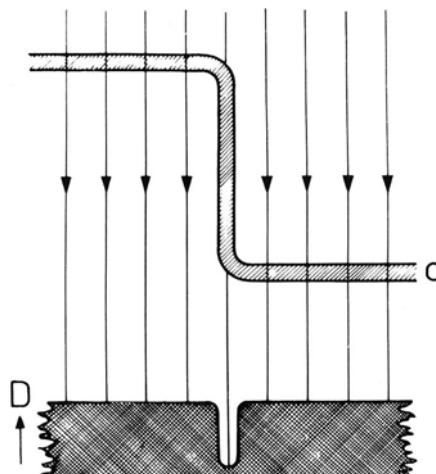


Figure 4.9 The end-on effect. The thin membrane, d, (shown in cross-section) does not show up clearly on the radiograph if it lies parallel or at an angle with respect to the plane of the film as the absorption is much too low. However, the membrane is well-visualised if it lies parallel to the direction of the rays, that is 'end-on'. The shaded strip, D, represents the photographic density. Where the membrane is parallel to the direction of the rays (in this case perpendicular to the film) the absorption of the X-rays is much greater and is shown on the film as a thin white line.

roundings, that is the membrane is invisible. Where, however, it is parallel to the direction of the X-rays (for example in a bend), it causes greater absorption and hence shows up on the film (in the case of the pleura like an interlobar line).

Similarly, even a thin sheet of paper can show up as a line, but only in one particular direction where it is completely in line with the radiation (figure 4.9). This phenomenon is often met with in radiography, and is known as the 'end-on' effect. The X-ray of an egg shell is a good example of this end-on effect: the egg is shown as an egg-shaped line, as the result of the stronger absorption in those parts of the shell which happen to be parallel to the X-rays. A similar effect is found with gall-stones when they only have a thin calcareous wall. The end-on effect can also be negative; for example, in the case of a fracture of a thin bony structure, as often occurs in fractures of the skull. The absorption difference to the surroundings, showing the fracture as a dark line, is only apparent in the projection where the fracture is parallel to the X-rays over a sufficient distance. A very large number of photos are thus necessary to exclude the possibility of such a fracture, but in practice one limits oneself to a few, taken at different angles.

Other examples are to be found in radiographs of the lungs, with the small blood vessels and bronchi. When these vessels and bronchi are parallel to the film, they are practically invisible, but when they are parallel to the X-rays they show up as round spots or circles, as a result of the larger thickness of tissue which the X-rays must pass through in this direction. Much of the lung detail in a radiograph of the chest must be explained as being caused by the end-on effect of blood vessels and bronchi. The well-known 'calcium sickle' in the aorta by no means indicates a local deposition of calcium, but is due to the end-on effect of a thin calcareous layer deposited on the wall of the aortic arc over a considerable distance. One can also project the falx cerebri through this end-on effect. When a rod-shaped or annular detail (blood vessel, bronchus) is pictured by rays parallel to its length (that is end on) one speaks of an orthogonal or axial representation.

#### **4.4.4 Inverse square law**

If the divergent X-ray beam leaving the round window of the tube is regarded as a cone, the apex of which is the source of radiation, (that is the focus), then the further one moves away from the focus, the weaker the radiation becomes.

Stereometrically this is easy to understand and to express quantitatively. Imagine the cone to be cut perpendicularly by two planes, the one at a distance  $a$  and the other at a distance  $2a$  from the focus. If the radius of the circle constituting the first plane is  $r$ , then the radius of the second circle is  $2r$ . The area of the first circle is  $\pi r^2$ , of the second circle  $\pi(2r)^2 = 4\pi r^2$ ; the latter is thus four times larger. It is evident that the radiation passing through the first circle must also pass through the large circle; hence the intensity of radiation in the large circle is four times less. This may be expressed by saying that at twice the distance the intensity is four times lower, or, in general terms: when the distance to a source of radiation is increased  $n$  times, the intensity of the radiation at that distance is  $n^2$  times less (and conversely: an  $n$  times smaller distance means an  $n^2$  greater intensity). This phenomenon is known as the inverse square law, a law which plays an extremely important role in radiography and in radiotherapy (figure 4.10).

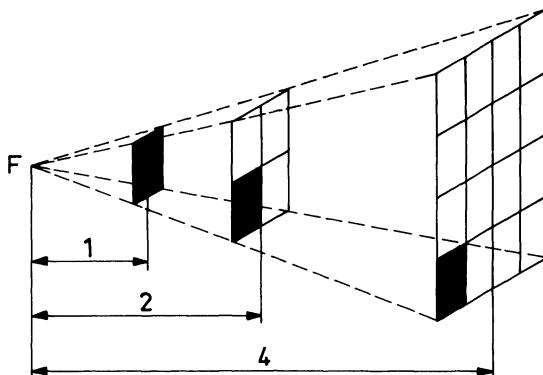


Figure 4.10 Representation of the inverse square law. For the sake of clarity, the X-ray beam is shown in the shape of a pyramid instead of a cone. At twice the distance, the intensity is reduced to one quarter, at four times the distance the intensity is reduced to 1/16.

#### 4.4.5 Magnification and distortion

Since X-rays are emitted from an extremely small source, the focus, which for the sake of convenience we shall assume to be a point focus, the image of an object in the path of the rays is formed according to the laws of central projection.

The object situated in the divergent beam of rays, casts as it were a shadow on the projection plane (fluoroscopic screen or film) and the shadow is normally a magnified image of the object. Only when the object is placed directly against the screen or film (object-film distance,  $Of = 0$ ) there is no magnification and an image of true size is formed.

From a simple plane drawing (figure 4.11) we see that the ratio of the size of the image of an object to the true size is the same as the ratio of the focus-film distance ( $Ff$ ) to the focus-object distance  $FO$ . Taking this ratio as the measure of magnification ( $M$ ) we find  $M = Ff/FO$ . The image of an object situated midway

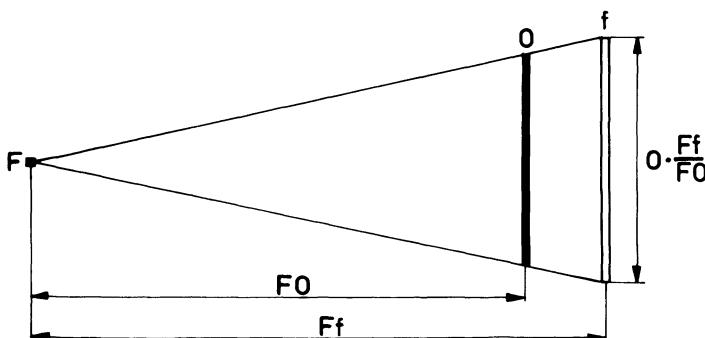


Figure 4.11 Magnified image resulting from central projection.  $Ff$ , focus-film distance;  $FO$ , focus-object distance; Object  $O$  is magnified in the ratio  $Ff/FO$ .

between focus and film is  $FO = \frac{1}{2}Ff$ . The magnification factor ( $M$ ) is then  $Ff : \frac{1}{2}Ff = 2$ , and the image will be twice the size of the object.

Later we shall see whether and under what conditions it is possible to use such magnified images (see chapter 12, section 12.3). Since, however, an object has a certain thickness, it contains parts lying at varying distances from the film (by film we refer here either to the X-ray film, to the classical fluoroscopic screen, or to the primary screen of the image intensifier). The magnification of these parts is not identical, so that their images on the film not only fail to correspond to the true size but also fail to indicate the true relationship of the parts to each other (figure 4.12). This unequal magnification of different object parts is called distortion.

When the focus-film distance is small and the object-film distance relatively large, the distortion can be quite considerable.

For example an X-ray photo of a pregnant woman lying on her back with  $Ff = 1\text{ m}$ , may show the skull of the foetus (at which  $FO$  is relatively small) magnified so much that it looks as if it cannot possibly pass through the pelvis (at which  $FO$  is relatively large) although in fact the relation between the

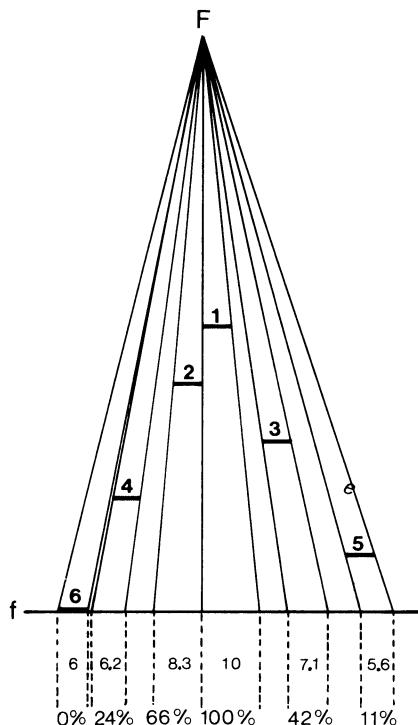


Figure 4.12 Distortion: uneven magnification. In the illustration, details 1, 2, 3, 4, 5 and 6 are all the same size (for example 5 mm), but are situated at different object-film distances, 50, 40, 30, 20, 10 and 0 cm, respectively, from the film with the focus-film distance being 100 cm. They are projected with unequal magnification; namely, as 10, 8.3, 7.1, 6.2 and 5.6 mm. Only detail 6 is projected in its true size (5 mm). The magnifications are 100, 66, 42, 24, 11 and 0 per cent, respectively.

dimensions of skull and pelvis is quite normal. Strong distortion can thus give rise to incorrect conclusions, as in chest radiographs, for example, when comparing the size of the heart to the width of the thorax (see section 5.2).

## 4.5 SOME APPLICATIONS OF DIFFERENT FOCUS–FILM DISTANCES

By using different focus–film distances, the magnification factor,  $Ff/FO$ , and also the detail perceptibility can be influenced.

### 4.5.1 Orthodiography and orthodiametry

When it is required to determine the true dimensions of an organ (at right-angles to the direction of the X-rays), an exposure could be made using only the central part of the X-ray beam. In practice, a very narrow beam around the central ray is used. The fluorescent screen is kept stationary, while the focus is moved (parallel to the screen) so that the beam, visible on the screen as a spot of light, just follows the contour of the object in question (the heart, for example). This moving central beam remains parallel to itself, since the ultimate image thus obtained is due to the parallel rays, originating, as it were, from infinity.  $Ff$  as well as  $FO$  are also  $\infty$ , so that the magnification factor = 1, and the image reproduces the true size.

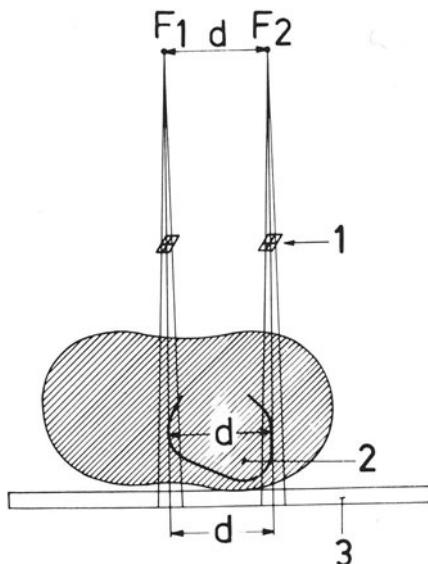


Figure 4.13 Principle of orthodiametry. The contour of the heart (2) is traced on the fluoroscopic screen (3) by means of a diaphragm with a crossed-wire marker (1) and a narrow X-ray beam directed perpendicularly to the screen. Object and screen remain stationary and only the X-ray tube is moved. In order to measure the width of the heart the tube is moved over a distance  $d$ . The projection of the crossed wire also moves over a distance  $d$  and, thus, corresponds exactly to the diameter of the heart.

This contour can be traced in its true size on a piece of tracing paper placed on the screen. Since this procedure can be carried out for all parts of the object (for the outline of the thorax, for example) an undistorted image of the true size is obtained. This method is called orthodiography, and its principle is illustrated in figure 4.13. The central beam is 'marked' either by limiting its extent or by using a wire cross. In drawing only a number of lines in this way, which are then measured, one speaks of orthodiametry.

A necessary condition in the application of this method is that the tube should be able to be moved independently of the screen; but hardly any modern stand allows this. In particular, and for reasons of safety, preference is given to a construction in which the beam remains centred on the middle of the fluorescent screen, and tube and screen move simultaneously, parallel to one another. With this set-up is neither orthodiography nor orthodiametry possible, and it is for these reasons that these methods have been abandoned.

In the following section we shall discuss a method which can be used in practice to give a life-size projection without distortion.

#### **4.5.2 Teleradiography**

When it is necessary for certain reasons to obtain an image of practically true size with the parts in their true proportions, that is with the smallest possible distortion, it is necessary to resort to long-distance radiography, which is known as teleradiography. This method is used most commonly for judging the size of the heart. If such a radiograph were taken from a relatively small distance (say 1 m) the heart, lying close to the film, would make a falsely favourable image (too small) in postero-anterior projection. With larger exposure distances, distortion decreases and the true proportions can be judged more closely. The principle of teleradiography is based on the concept that, regardless of the object-film distance, it is possible to obtain an X-ray image of true size with a beam of 'parallel' rays. This condition is satisfied in teleradiography by the use of a large focus-film distance (for example 2 m). Of course, the X-ray beam is still not thereby made parallel, but magnification and distortion are reduced to almost negligible proportions (figure 4.14).

There is little point in taking teleradiographs at distances of 4 m or more, as practised by some, because it can be shown by means of a simple calculation that the gain in the dimensional accuracy of the image is very small compared with that at a distance of 2 m. In fact, this 4 m distance has the disadvantage that it entails a four-times higher tube load, that is an exposure four-times longer than at 2 m, quite apart from the problem of space involved. In order to avoid blur due to movement, the X-ray unit needed must be powerful enough to allow a short exposure in spite of the large focus-film distance. This may necessitate the use of high-tension exposure techniques.

Teleradiography is mainly used for demonstrating the heart, the vertebrae (for orthopaedic purposes) and the jaw (for orthodontic purposes).

A telecardiogram is generally understood as being a postero-anterior view of the thorax taken at a distance of 2 m with the purpose of measuring the dimensions of the heart with respect to the thorax (figure 4.15).

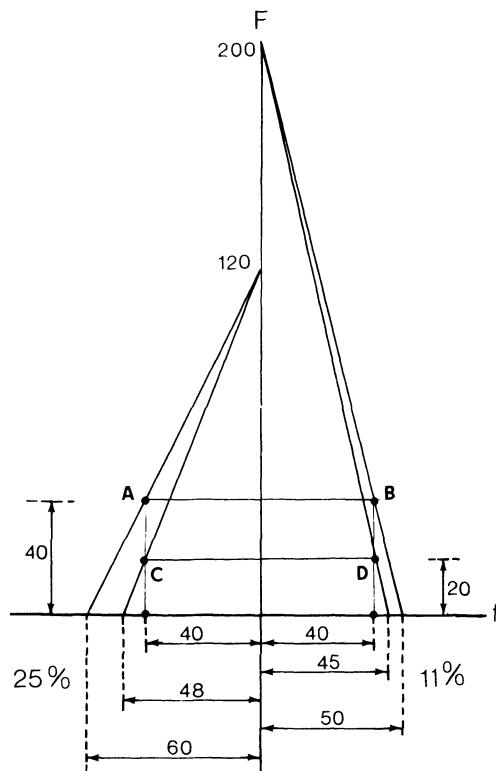


Figure 4.14 Improved proportions (less distortion) with greater focus-film distances. An object AB with a cross-sectional diameter of 40 mm at a distance of 40 cm from the film ( $Of = 40$  cm), and an object CD of the same size at a distance of 20 cm, is given. These objects are radiographed with the focus in two different positions, that is with an  $Ff$  of 200 cm and an  $Ff$  of 120 cm. With  $Ff = 200$  the projected half sections (on the right) are 50 and 45 mm, respectively, with a relative difference of 11 per cent. With  $Ff = 120$  cm, the projected half sections (on the left) are 60 and 48 mm, respectively; therefore, with a greater relative difference, 25 per cent in fact. It should be noted that, for the sake of clarity, the projection dimensions of the distances are ten times as great as those for the object (namely, cm and mm).

#### 4.5.3 Contact radiography; contact exposures; exposures with a small focus-object distance

In certain cases, good use can be made of projection distortion. By bringing the tube very close to the object and the object very close to the film, the object details in the immediate proximity of the film are made to show up on the film in approximately their actual size and true relationship to each other. Other parts of the object will be all the more magnified and distorted the farther they lie from the film, and may even become so blurred as to be indistinguishable. Such parts, which might otherwise give rise to troublesome superimposition, now have no part in the image formation, owing to their magnification and distortion.

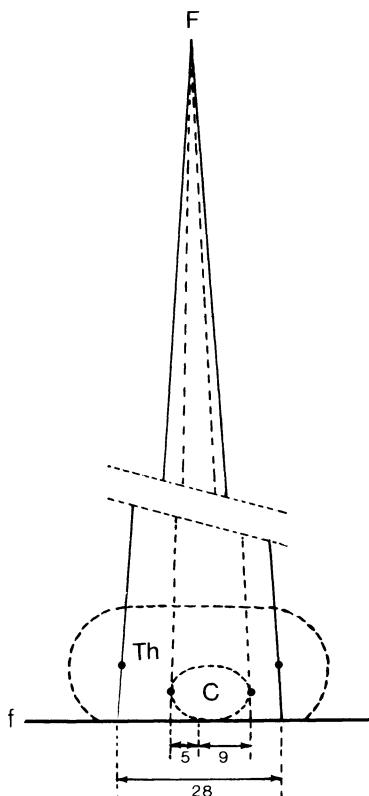


Figure 4.15 Telecardiogram. With a distance of 200 cm the magnification of the dimensions of the thorax (Th) are only slightly greater (due to the greater object-film distance) than the magnification of the dimensions of the heart (C). Therefore, it is permitted to draw conclusions from these measurements, which would not be the case with shorter focus-film distances. In the diagram, a situation has been assumed where the heart is somewhat enlarged (the diameter of the heart in this case is half the transverse section of the thorax). For the sake of clarity the beam is illustrated as interrupted lines.

Other details will be projected beyond the radiograph by the great divergence of the beam (figure 4.16).

A contact exposure of the capitulum mandibulae (by Parma's method) gives a good picture of the capitulum next to the film, while the one on the tube side, and other interfering parts of the object, are made unrecognisably large, faint (by geometrical blurring) and distorted and are projected out of the picture. Contact radiography is also useful when taking a distal eccentric view of the mandible (where superimposition upon the other side can be completely avoided), when taking a sternum, and when making a postero-anterior view of the patella, with the tube in the hollow of the knee.

It must always be kept in mind that in contact radiography the X-ray dose on the skin on the tube side is much larger than with the normal radiographic tech-

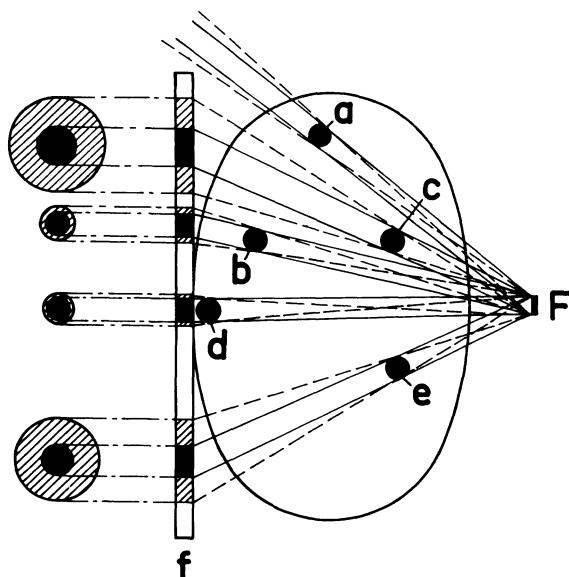


Figure 4.16 Principle of contact radiography. Details a, b, c, d and e, all of the same size, are projected in different sizes and varying degrees of definition. Detail a is projected off the film, c and e are blurred, and only b and d are sharply projected.

nique because of the relatively shorter distance of the focus to the skin. It is true that the thickness of the object is the same with both distances, but in contact radiography it takes up a larger part of the total focus-film distance. For this reason the integral absorbed dose in contact radiography is somewhat higher than in normal techniques. In many radiology institutions contact exposures are the exception rather than the rule. Instead use is made of zonography (see chapter 12, section 12.1.3).

#### 4.6 SELECTION OF THE DIRECTION OF PROJECTION

We have already seen that, owing to superimposition, it is extremely difficult to provide an accurate analysis from a single radiograph, and even impossible when it is a question of accurately localising any given object seen on it.

In the majority of cases in radiography use is made of two or more projections. Where possible the object is X-rayed in two projections which are at right-angles to each other, that is to say one from back-to-front, or front-to-back, and one laterally. The front-to-back direction (antero-posterior) is known as the a-p projection, and sometimes as the v-d (ventro-dorsal) projection. The back-to-front direction is called the p-a (postero-anterior) or d-v (dorso-ventral) projection. Lateral radiographs are termed lateral, transverse, or profile projections, the path of the rays often being further specified. If the left side of the object is against the film (that is with the beam passing from right to left) the radiograph may be termed a transverse d-s (dextro-sinister) projection. If the right side is against the

film, the radiograph is an s-d (sinistro-dexter) projection. In general it is possible to obtain sufficient information from an a-p or a p-a and a lateral radiograph for the purposes of localising or diagnosing anomalies.

In X-ray diagnostic technique much depends on the positioning of the tube, patient and film, in order to obtain the best possible view of the detail to be examined. The lumen of a bone canal, for example the bony auditory meatus, is best demonstrated when the X-ray beam passes in the direction of the long axis of the canal. A true impression of the pelvic inlet is obtained only if the X-ray beam is perpendicular to its horizontal cross-section. The contours of the sella turcica (pituitary fossa) also cannot be judged accurately unless the beam has passed directly laterally through it.

Moreover, there are certain structures which can only be made visible by very special projection. The thin membrane which is stretched between two pulmonary lobes can only be demonstrated if it coincides with the direction of the X-rays: known as the interlobar line. This is because of the 'end-on' effect. It is evident therefore, that any specific structure will stand out more distinctly the more it is projected away from supervening shadows.

#### **4.7 STANDARDISED PROJECTIONS AND SPOT-FILM TECHNIQUES**

Long experience and knowledge of anatomy have led to the application of definite projections for X-ray exposures for specific parts of the human body and their details.

##### **4.7.1 Standardised projections**

Many projections can be looked upon as being standardised. This is particularly the case with exposures of the skull where visible or palpable bodily 'landmarks' (for example the outer canthus of the eye) are used as a guide. The methods are usually referred to by the names of their originators. For example, the names of Schüller, Stenvers, Mayer and Chaussé are connected with certain views of the petrous bone, Liliénfeld, Towne and others with certain cranial projections, Rhese-Goalwin with a projection of the foramen opticum, etc. The useful standard projections for the entire human body are described in detail and with illustrations in many books dealing with 'positioning'.

In any standardised projection one must, if possible, take individual anatomical variations (for example an asymmetrical skull) into account, as otherwise the X-ray photo as taken before may not give the projection expected. A thorough knowledge of the standard positions, theoretical as well as practical, is one of the most important points in the diagnostic training of radiological technicians.

##### **4.7.2 Exposures under fluoroscopy**

In opposition to these standard projections with their constant factors (angles, distances, etc.) are the spot-film techniques, where the optimum position is selected visually by means of a fluoroscopic examination before the radiographic exposure. This allows one to choose the best position for the particular object,

even when it is anatomically abnormal and thus unsuitable for the necessarily 'shot-in-the-dark' method of the standardised projection. The radiographic exposure is then made immediately after the tube has been positioned by the fluoroscopic inspection. Mostly, one speaks of 'exposure under fluoroscopy' or of 'exposure with a serial cassette' (this is the instrument with which these exposures are taken). The most important application of this technique is in 'barium meal' examinations of the alimentary tract, where hardly any standardised projection can come into consideration, but where it is important that a certain view be seen during fluoroscopy (for example bulbus duodeni with the patient in a certain oblique position and at a certain phase of movement) and that it should be taken immediately when it is seen.

In view of its many advantages, and in particular its speed and efficiency, exposure with fluoroscopy is being used more and more, especially for the modern, greatly improved methods of fluoroscopy using an image intensifier and television. For example, exposures of the gall bladder, of details of the skull, of the contrast medium in hysterosalpingography, myelography, etc., have already become routine methods instead of 'blind' standard projections.

# 5

## Sharpness and Unsharpness

As sharpness is an abstract idea that cannot be expressed in dimension or number and can, moreover, never be realised in practice, we prefer to speak about the lack of definition or unsharpness.

We shall now examine the causes of unsharpness and the means by which it can be limited.

Unsharpness in a radiographic or fluoroscopic image can arise in different ways. In the first place there is the unsharpness already present in the radiation image, that is before it has been converted into a visible image; this is caused by the finite size of the focus (geometric unsharpness) and by movement during the exposure (movement unsharpness).

In the second place there is the unsharpness that appears when the X-rays are converted into a visible image, and which is due to the typical structure of the fluoroscopic screen, or intensifying screen and film (intrinsic or material unsharpness).

### 5.1 GEOMETRIC UNSHARPNESS

Geometric unsharpness occurs because the source of radiation, the focus, is not a point (that is, is not infinitely small) but has a finite size.

In the laboratory the dimensions of the focus are determined by a ‘pinhole camera’, which comprises a lead plate with an extremely small hole (for example 0.1 mm). When this plate is placed midway between focus and film, the image of the focus appears on the film in its true size. (What actually appears is the image of the pinhole, but this is so blurred by geometric unsharpness that its size is exactly that of the focus at this distance.)

As a result, we see the same phenomenon that appears when a luminous surface (say a frosted-glass lamp) is taken as the source of light instead of, for example the sun, which may be regarded as a point source. In the latter case the shadows are sharp, whereas with the frosted-glass lamp we perceive a region of half-shadow, or penumbra, that is a region of gradual transition between full shadow and the illuminated area outside it. Precisely the same penumbral region is formed in the projection of an image by the focus of an X-ray tube, no matter how small the focus may be. If the focus were a point, the shadow cast by the edge of a lead plate, for example, would be perfectly sharp. With the finite foci of X-ray tubes, however, we see in the image of the edge produced on a film, a region which no radiation has reached and a region of half-shadow from light to dark; in other words, the edge is no longer sharp black-white but has become indeterminate (from black via grey to white). The width of this half-shadow region, or penumbra, on the film is called the geometric unsharpness ( $U_g$ ). Because it is caused by the focus, it is also referred to sometimes as ‘focus unsharpness’.

### 5.1.1 Formulae for $U_g$ \*

Geometric unsharpness may be expressed by a simple but important formula (figure 5.1).

Let  $F$  be the size of the focus (linear dimension),  $O$  the object,  $f$  the film,  $FO$  the focus-object distance and  $Of$  the object-film distance, then  $U_g: F = Of : FO$ , or  $U_g = F \times Of / FO$ . If the projected focus is, for example, 2 mm across, the focus-film distance 100 cm, the object-film distance 20 cm, and hence the focus-object distance 80 cm, we have  $U_g = 2 \times 200 / 800 = 0.5$  mm.

The equation

$$U_g = F \times Of / FO \quad (1)$$

for the geometric or focus unsharpness is very important. A small algebraic conversion gives us a second, simple formula for geometric unsharpness. This is as follows. From figure 5.1 it follows that  $Of = Ff - FO$ . If we substitute this in equation 1, we get

$$U_g = F \left( \frac{Ff - FO}{FO} \right)$$

Further development of this gives us

$$U_g = F \left( \frac{Ff}{FO} - 1 \right)$$

or

$$U_g = F \left( \frac{Ff}{FO} - 1 \right)$$

Now, the magnification factor  $M$  is equal to  $Ff/FO$  (see chapter 4, section 4.5),

\*N.B. To remember more easily,  $a$ ,  $b$ ,  $c$  and  $d$  will not be used, but rather letters with meaning:  $F$  = focus,  $f$  = film,  $O$  = object,  $Ff$  = focus-film distance, etc.

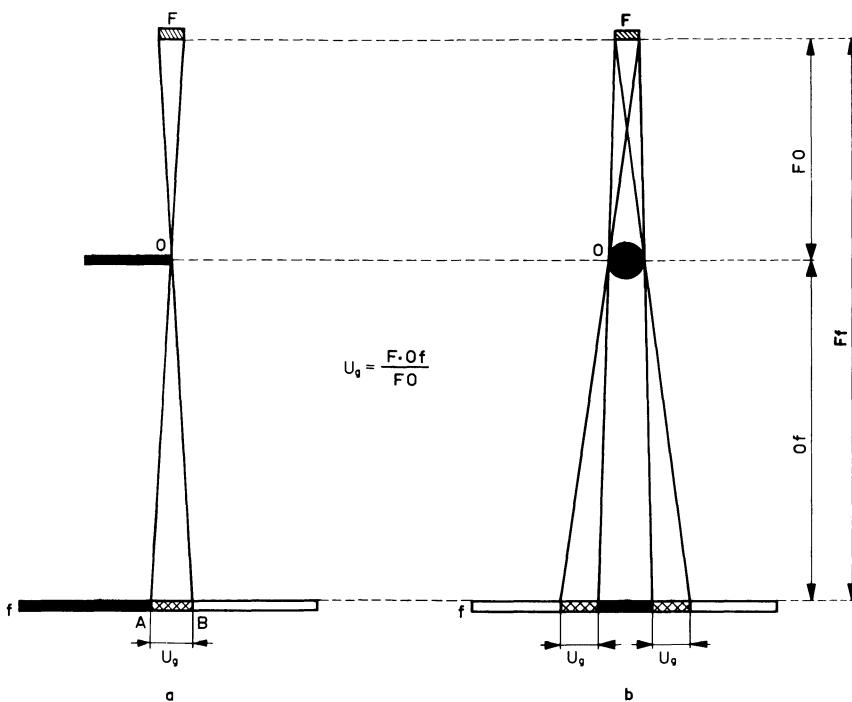


Figure 5.1 Unsharpness, caused by the dimensions of the focus: geometric or focus unsharpness. F. focus; f. film; O. object; Ff. focus-film distance; FO. focus-object distance; Of. object-film distance;  $U_g$ . geometric unsharpness.

and thus it follows that

$$U_g = F(M - 1) \quad (2)$$

It is obvious that all variables mentioned in the equations have to be expressed in the same units, mm, for example.

### 5.1.2 Given and actual size of the effective focus

The focus size that the manufacturer states is the length of the side of the square that is formed by the projected focus. For example, with a tube of 1.0, the projected (= effective) focus is  $1.0 \times 1.0$  mm. The largest measure of the focus is given by the diagonal of the square, which will be 1.4 times larger than the side (in this case, 1.4 mm). If the size of the focus lies in the upper limits of the maximum permissible tolerance (see chapter 1, section 1.7) an additional 30 per cent will be added. Therefore the diagonal measurement will actually have to be considered as being 1.8 mm. In practice, the diagonal measurement of the focus is hardly ever dealt with.

### 5.1.3 Practical considerations concerning $U_g$

From the above formulae it follows that

- (1) Geometric unsharpness is directly proportional to the size of the focus ( $F$ ). The smaller the focus, therefore, the less the geometric unsharpness.

(2) Geometric unsharpness is directly proportional to the distance between object and film ( $Of$ ). This distance must accordingly be kept as small as possible, especially when using a large focus. Thanks to the construction of smaller foci (0.3 mm, for example) the object-film distance is no longer so important, and may, in fact, be deliberately increased without greatly impairing definition.

(3) From equation 2 it follows that the geometric or focus unsharpness is equal to  $(M - 1)$  times the size of the focus. With a magnification factor of 2, the  $U_g$  will be equal to  $(2 - 1) \times F = 1 \times F$ , and therefore equal to the size of the focus.

Since every part of the body to be radiographed has a particular thickness, the various details are not equidistant from the film and do not, therefore, appear with equal geometric unsharpness. The parts farthest from the film are the most affected. With the large foci formerly used it was possible to see at once from the radiograph which side of the object had been closer to the film, namely the side with the smaller unsharpness.

(4) Geometric unsharpness is inversely proportional to the distance between focus and object ( $FO$ ). Thus, the farther the object is removed from the focus the less will be the geometric unsharpness.

The following practical rules for obtaining as low as possible a geometric unsharpness follow from the above:

- (a) Choose the focus as small as possible.
- (b) Keep the object-film distance as small as possible, that is bring the object as close as possible to the film. (For example, for gall-bladder photos the film should be in front of the patient, and for kidney photos behind.)
- (c) Make the focus-object distance as large as possible.

If we consider these three points further, we see that they are to a certain extent impossible to realise in practice.

#### 5.1.4 $U_g$ and the limits of tube load

If one wishes to have the smallest possible focus one must also keep in mind the permissible load of the focus. The drawback of smaller foci is that they are unable to withstand the same load as larger foci. This necessitates the use of, for example, less current at the same tube tension and this involves longer exposures, while maintaining the same density. This, in turn, can result in greater movement unsharpness. A large focus threatens to interfere with the  $U_g$ .

All this presupposes that the focus is always optimally loaded. The importance of optimum loading is sometimes not fully appreciated. It is known that overloading will damage the tube, but there is still too little awareness of the fact that underloading means loss of definition: the same smaller load could have been given with a smaller focus, thus reducing the geometric unsharpness. The conclusion follows that the optimum load on the focus is the maximum permissible load. Considerable underloading is to be regarded not as a reasonable economy but as a misunderstanding of the rules of radiographic definition. For this reason many modern X-ray machines are designed to ensure that full load is automatically applied to the tube in every setting.

The distance between object and film can only be reduced as far as the body permits. For example, the sella turcica, which lies in the middle of the cranium, cannot be brought closer to the film than by half the transverse section of the skull, that is about 8 cm ( $Of = 8$  cm).

If we include this  $Of = 8$  cm in the focus-film distance of  $Ff = 100$  cm, then the  $FO = 92$  cm. By using a 2 mm focus the  $U_g = F \times Of/FO = 2 \times 80/920 = 16/92 = 0.17$  mm. The maximum  $U_g$  can be (according to section 5.1.2):  $1.4 \times 0.17 = 0.24$  mm (diagonal measure). This increases by 30 per cent (maximum tolerance) and gives a  $U_g$  of  $1.3 \times 0.24 = 0.3$  mm.

Now what will happen if we double the distance between focus and object? The result will be that the geometric unsharpness will be halved. According to the inverse square law, however, twice the distance requires four times the exposure energy, that is an mAs product four times as large at the same kilovoltage. We cannot quadruple the duration of exposure(s) without increasing movement unsharpness; we must therefore use four times the milliamperage. But this in turn requires four times the area of focus, that is, a cross-section twice as large, and if the linear focus size is doubled, the geometric unsharpness will be just as great.

Thus, with optimum load on the focus, the duration of exposure being unchanged, definition is not improved by increasing the focus-object distance because of the necessary increase in focus size.

## **5.2 MOVEMENT UNSHARPNESS ( $U_m$ )**

Everyone who has ever taken an ordinary photograph knows that unsharpness of the photo will result when either the photographed object and/or the camera is moved. This is the same phenomenon as movement unsharpness in a radiograph. It arises from the fact that the projection of the object on to the film is moved with respect to the film during exposure, so that the image is 'spread out' over certain areas.

There is relative movement between projection and emulsion when either

- (a) the focus moves,
- (b) the object moves,
- (c) the film moves,
- (d) any combination of a, b, or c.

In the particular case that the movements of the focus and of the film are in opposite directions and in specific proportions, then the object details in a certain plane will not transpose their projection onto the film. Therefore, there will be no movement unsharpness (see chapter 12, section 12.1).

A radiograph will be completely free of movement unsharpness only if there is perfect relative immobility of focus, object and film during exposure. Focus and film can usually be adequately immobilised, but the many movements of the object (the human body) can only partially be suppressed.

The amount of movement unsharpness ( $U_m$ ) is equal to the number of mm over which the projection becomes displaced during exposure. If it takes place in one direction only and at a uniform rate, the displacement is equal to the rate of displacement (in mm/s) multiplied by the duration of exposure (in s).

If, however, the object moves in the direction of the X-ray beam, the projection remains almost stationary (as long as the object does not move a great distance, when the magnification will gradually change). Movement unsharpness is relatively most severe when there is movement parallel to the plane of the film, but much depends upon whether the movement is close to the film or at some distance from it. The farther from the film the worse are its effects (figure 5.2).

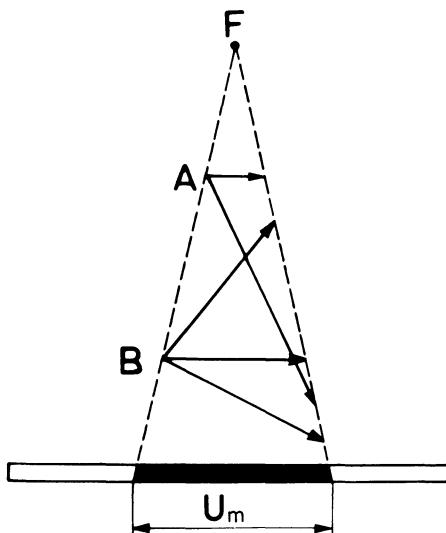


Figure 5.2 Effect of the direction of the movement and the distance from the film, where this movement takes place, on the movement unsharpness. All the movements indicated in the diagram (see arrows) of object details A and B produce the same amount of movement unsharpness, namely,  $U_m$ .

It is evident that in order to reduce movement unsharpness the aim will be to reduce both the rate of movement and the duration of exposure. The movement can only be slowed down or eliminated if it is a voluntary one and if the patient is able to cooperate. A number of fixation devices can also be used, such as sandbags, compression bands, etc. The problem becomes more difficult when the movements concerned are partly involuntary, such as respiration. It is advisable to get the patient to practice breathing control beforehand, until one is sure that he can hold his breath when told to do so during the taking of the X-ray photo. Movements that cannot be suppressed are those of the internal organs (oesophagus, stomach, intestines, heart, arteries) and those made by patients with neurological disorders (for example, tremor senilis, Parkinson's disease). In such cases, fixation is almost impossible and only very short exposures can keep movement unsharpness to a minimum. Whereas an exposure of some hundredths of a second is

generally adequate for radiographs of stomach and chest, even shorter exposures may be desirable for struggling infants, dyspnoeic patients and for radiographs of the vascular system. In this respect, exposure times as short as 0.003 s (3 ms) or even 1 ms are now possible. The necessity of such short exposure times as a few hundredths of a second for the alimentary canal can be simply demonstrated. It is true that many involuntary movements, such as stomach peristalsis, are fairly regular and slow, but these are often accompanied by a more sudden movement, such as the emptying of the bulbus duodeni, the peristalsis of the oesophagus, etc. If the exposure coincides with one of these sudden movements the result will be severe unsharpness and it is often precisely these movements that we wish to capture in the radiograph.

Movement unsharpness is sometimes deliberately introduced in radiography in order to obtain a better image of a specific part of the body. In exposures of the upper cervical vertebrae in a-p projection, for example, the jaw is made to move up and down (requires preliminary practice), so that it becomes blurred in the radiograph and allows better perception of the vertebrae. In tomography, parts of the body which would normally give rise to troublesome superposition are blurred by moving the focus and film.

### **5.3 INTRINSIC OR MATERIAL UNSHARPNESS ( $U_i$ )**

The X-ray image contains certain arranged information that depends on the size of even the smallest detectable detail. These are fixed due to the intrinsic unsharpness caused by the material with which the image is constructed (for example, intensifying screens, film, fluorescent screens). This is why it is also known as material unsharpness.

One can explain intrinsic unsharpness by the grid pattern that is used for the negatives for the printing of photos. Such a photo exists due to the gathering of points. If the grid used is rough, as it is with newspaper photos, then the points are relatively far apart from one another and only large details are relatively visible. With art paper one uses a finer grid and the points lie closer together, thus restoring the smaller details. A rough grid can be compared with a high intrinsic unsharpness on a radiograph or fluoroscopic image. This unsharpness can also be compared with a sieve that does not stop details that are smaller than a certain minimum size.

#### **5.3.1 Intrinsic intensifying screen unsharpness**

When intensifying screens are used the radiation image is usually first converted into a light image, which then acts upon the photographic emulsion. This conversion of X-rays into light is a further source of unsharpness, which is due to the thickness of the intensifying screen and also to the nature of the fluorescent material. A high luminous output depends upon a relatively thick screen because it intercepts more X-ray quanta. A thick screen, however, has the disadvantage of causing severe unsharpness.

This is because in a thicker screen there is a greater distance between the grains and the photographic emulsion. The light which leaves the grains in all directions, now diverges over a greater area of the film and causes additional unsharpness.

The size of the luminescent grains in the fluorescent layer, amounting to only a few tenths of microns, plays no significant part in the unsharpness caused by intensifying screens.

Thick screens, with their high luminous output, are known as fast screens. A fast screen, therefore, has a relatively high intrinsic unsharpness. Thin screens, with their low luminous output, are called slow screens. The terms 'fine grain' and 'coarse grain', which we have just seen are incorrect, strictly speaking, but are often used to describe slow and fast screens, respectively. The slow screens produce less unsharpness.

The notion of 'grain' explains clearly that one is speaking of the absolute bottom limit for portraying the smallest visible detail, whereas a detail smaller than the grain can not be portrayed.

The intensification factor of fast screens is large, and of slow screens small. The intensification factor of an intensifying screen is defined as the ratio of the exposure needed for a film without screen to that needed with a screen (see chapter 8, section 8.3).

As in the case of geometric and movement unsharpness, intensifying screen unsharpness can also be expressed in mm. The following list gives an impression of the intensification factor and intrinsic unsharpness of some commonly used types of intensifying screens.

Type	Intensification factor	Intrinsic unsharpness ( $U_i$ )
slow	6-7	approx. 0.2 mm
standard	approx. 10	approx. 0.3 mm
fast	15-20	approx. 0.4 mm

The figures given are not fixed but are subject, among other things, to the kilovoltage used; the intensification factors are ratios with respect to a standard screen, for which the factor taken is 10\*.

Naturally the intensifying screen unsharpness can, for a certain group of exposures (thin objects), be avoided entirely by making exposures without intensifying screens. Here use is made of non-screen films (see chapter 8, section 8.2.11).

The application of this requires a longer exposure time which also increases the chance of movement unsharpness.

### 5.3.2 Intrinsic film unsharpness

This inherent unsharpness of the X-ray film is very slight compared to the other sources of unsharpness, and can therefore generally be neglected.

The film grains are much too small (about  $1.5 \mu\text{m}$ ) to be noticeable in unmagnified film; it is only when the film is very strongly magnified by optical means that these grains become noticeable, and then they look like grains of rice (tapioca effect). The other factors that can cause film unsharpness are the thick-

---

\*There is again a stormy development occurring concerning intensifying screens. Here, the intensifying factors as well as the intrinsic unsharpness are made visibly better. This is due to the use of luminescent materials made with elements of the lanthanoid series (rare earths) (for example, lanthanum, see chapter 8, section 8.3.6).

ness of the emulsion and the presence of two layers of emulsion. When X-rays strike the film obliquely, there will always be a slight local difference in the image produced by a solitary object detail on both the front and the back of the film. The unsharpness which results is directly proportional to the total thickness of the film.

### **5.3.3 Cassette unsharpness**

We may also mention here another type of unsharpness found sometimes, which is easy to detect and to cure: unsharpness due to the cassette. This is caused by the fact that the intensifying screens are not in good contact with the film locally, so that the fluorescent grains can spread their light further over the film than when there is good contact. At such points, the film is noticeably blurred. This can be due to wear of the felt in the cassette, or to the fact that the cassette does not fasten properly.

The characteristic of cassette unsharpness is that it is local, and that it shows up on the same spot on each photo. It can easily be demonstrated by making a photo of a piece of metal gauze laid on top of the cassette.

This unsharpness can be temporarily suppressed by placing a piece of card-board between the felt and the intensifying screen, but it is better to replace the felt or the whole cassette.

In contrast to the three types of unsharpness mentioned above, cassette unsharpness can always be completely eliminated.

## **5.4 LAW OF UNIFORMITY**

The intensifying screen unsharpness together with the film unsharpness and even the cassette unsharpness, can all be grouped together under the title material or intrinsic unsharpness ( $U_i$ ).

In practice the total unsharpness is caused by the three contributory unsharpnesses: geometric unsharpness, movement unsharpness and intrinsic unsharpness. We should therefore endeavour to ascertain what part each of these three will play in an exposure and how they can be limited. It is important to remember that reducing the influence of one may often increase the influence of the other. The best solution to obtain optimum results is to seek a compromise, because he who wants to avoid the Scylla will fall as irrevocable sacrifice to the Charybdis.

It has been found theoretically and from practice that the total unsharpness is smallest when the individual unsharpnesses are not merely at a minimum but are in fact equal to each other. The total unsharpness can accordingly be calculated from the following formula

$$U_{\text{total}} = \sqrt[3]{(U_g^2 + U_m^2 + U_i^2)}$$

or, if there is no movement during exposure, from

$$U_{\text{total}} = \sqrt[3]{(U_g^2 + U_i^2)}$$

or, when the photo is also made without intensifying screens, from

$$U_{\text{total}} = \sqrt[2]{U_g^2 + U_{\text{g}}}$$

(here the film unsharpness is neglected).

As an explanation the following examples are given:

(1) Should we wish to study very small details, we need high-definition screens, provided the movement of the object permits the exposure time necessary with these screens. If the exposure time is unimportant, the object being perfectly still, we can take a non-screen film, thus entirely eliminating movement and screen unsharpness. The geometric unsharpness can also be reduced by increasing the focus-film distance (which again entails a longer exposure time), or (and) by using a very fine focal spot.

(2) The object to be radiographed is in violent movement (struggling infant, oesophagus during swallowing). A very short exposure is therefore of prime importance. For this purpose we use fast screens and a short focus-film distance. True, the fast screens cause more screen unsharpness and the short focus-object distance more geometric unsharpness, but in this case they are by no means as troublesome as the movement blur that would have resulted from the use of slow screens and a normal focus-object distance.

## 5.5 INTRINSIC UNSHARPNESS OF FLUORESCENT SCREENS

A fluoroscopic screen causes relatively much more unsharpness than an intensifying screen. Having regard to the dose to the patient, it is necessary to use coarser grains (a thicker layer of fluorescent material) in order to obtain the highest possible luminous output. The intrinsic unsharpness of the fluorescent screen may be as much as 1 mm without causing trouble during viewing at the very low illuminations used (rod vision). A fluorescent screen is therefore quite unserviceable as an intensifying screen and, inversely, an intensifying screen, owing to its relatively low luminous output, is unsuitable for fluoroscopic examinations.

The intrinsic unsharpness of the fluorescent screens used in photofluorography is smaller than that of screens for fluoroscopy. The intrinsic unsharpness of both receiving and viewing screens in an image intensifier, however, is still considerably lower, as will be discussed later (see chapter 8, section 8.1.2). At the same time another factor will be discussed which can also interfere with the sharpness, namely the 'noise'.

# 6

## Contrast

Contrast is as important to an X-ray film as sharpness. Contrast is a ‘relationship’; it can be, for example, the ratio between two radiation intensities, that is radiation contrast, or the ratio between two densities, in which case we speak of a visible contrast.

Image formation presupposes the existence of a radiation contrast and of a medium which converts this radiation contrast into a visible contrast.

### 6.1 THE RADIATION CONTRAST

The X-ray beam emerging from an object is composed of the remaining primary rays and scattered radiation arising from the object. This remaining radiation is what has been left of the primary radiation falling on the object by the locally different absorption in it. It thus contains radiation contrasts and would itself represent—if not mixed with scatter rays—a faithful radiation-absorption image of the object. The greater the absorption differences and hence the greater the radiation contrasts, the ‘clearer’ will be the radiation image (though still invisible to our eyes).

It should be noted that a great absorption difference between an object and its surroundings can appear when a detail has its biggest dimensions in the direction of the X-ray beam (end-on effect). In this way the nasal septum, interlobar lines, folds in clothing or bandages, etc., can reveal themselves (often accidentally) in one direction when the X-rays pass through them longitudinally, whereas in another direction they can remain absolutely invisible (see chapter 4, section 4.4.3).

The absorption differences may be increased by the choice of a lower tension, the absorption being proportional to the third power of the wavelength and the latter inversely proportional to the tension (the kilovoltage). The lower the tension the larger the radiation contrasts. However, we cannot decrease the tension without reaching a limit; firstly because the object will no longer be penetrated, the radiation being completely absorbed; secondly because lower tensions imply a much higher radiation dose (long exposure times, high load for the tube, high skin dose for the patient) necessary to obtain the required exposure dose on the film. The more the absorption, the larger is the difference between the intensity of the primary radiation beam and the intensity of the emerging part of the primary beam, that is, between the radiation dose at the tube side of the patient and the required exposure dose at the film side.

Thus for every object there is a minimum tension which requires an exposure time and a tube load that can still be considered reasonable. Here we perceive at once the influence of the features discussed in the preceding chapter, for we also have to keep in mind the definition of the images and ask ourselves every time: What effect has this tension and that exposure on the  $U_g$ ,  $U_m$ , and  $U_i$ ?

We have already discussed the importance of contrast as regards detail perceptibility or image quality in this chapter. We shall now consider more extensively the laws governing the formation of contrasts and examine the means used to heighten contrast in the X-ray image.

The absorption (attenuation) which the X-ray beam undergoes in passing through the object is given by the formula

$$I_1 = I_0 e^{-\mu d}$$

where  $I_1$  = intensity of the emergent radiation

$I_0$  = intensity of the incident radiation

$\mu$  = linear attenuation coefficient of the object

$d$  = thickness of the object

e = base of natural logarithms

Radiation contrasts are relationships in intensity in the emergent beam. Although other definitions are possible, a radiation contrast is defined here as the difference of the logarithms of two different intensities, for example  $I_1$  and  $I_2$ , which emerge from the object at two different points

$$\text{contrast} = \log I_1 - \log I_2 = \log (I_1/I_2)$$

Substituting the absorption formula in this expression we get ( $\log e = 0.43$ )

$$\begin{aligned} \text{radiation contrast} &= \log I_0 e^{-\mu_1 d_1} - \log I_0 e^{-\mu_2 d_2} \\ &= \log e(\mu_2 d_2 - \mu_1 d_1) \\ &= 0.43(\mu_2 d_2 - \mu_1 d_1) \end{aligned}$$

(1) For an object of equal  $\mu$  but different thickness, the radiation contrast will be  $0.43 \mu(d_2 - d_1)$ . The contrast is therefore directly proportional to the difference in thickness. The greater the difference the greater the contrast.

(2) The same difference of thickness in an object will give rise to a greater contrast the higher the coefficient of attenuation.

(3) For two objects of equal thickness but of varying  $\mu$  we may, by analogy, write

$$\text{radiation contrast} = 0.43 d(\mu_2 - \mu_1)$$

The contrast is therefore directly proportional to the difference in attenuation coefficient. The greater the difference the greater the contrast.

(4) Moreover, the same difference in attenuation coefficient will give rise to a greater contrast the thicker the layers which differ in  $\mu$ .

In general, a lower tube tension means a higher coefficient of attenuation. Very slight differences of thickness in an object can therefore only be converted into perceptible contrasts if extremely low tensions are used. A higher tube tension gradually means a lower  $\mu$ . The extent to which  $\mu$  decreases varies considerably, depending upon the attenuation coefficient of the different kinds of tissue in the body. It has been ascertained that at 50–125 kV and more, the  $\mu$  of tissues with a high atomic number (bone tissue) decreases relatively much more than the  $\mu$  of tissues with a low atomic number, such as muscles and fat. This means that at rising kilovoltages the contrasts in the bone, and the contrasts of the bone with the surrounding soft parts, decrease much more than the contrasts in the soft parts themselves, or in the soft parts containing air. Good use is made of this in radiography of the lungs. Exposures made at high kilovoltages (high-voltage technique) show the ribs as fairly transparent (loss of contrast) behind which the lung structure is still 'contrasty' enough to be clearly visible. (See chapter 14, section 14.7.1.5).

## 6.2 THE ADVERSE EFFECT OF SCATTERED RADIATION UPON CONTRAST

Although radiation contrast depends upon the relative absorption of the X-rays in the object (and this in turn depends upon the tube tension used and upon the atomic number), there is nevertheless another important factor to be considered, namely scattered radiation. Raising the tension from 50 to 150 kV results in a relatively large increase in scatter, particularly from substances of low atomic number. Scattered rays traverse the object in all directions (hence the name), and are neither image-bearing nor image-forming. They blacken the film, however, and are therefore troublesome. Figure 6.1 illustrates two film images (a and b), one with scatter (b) and the other without (a). The scattered rays set the radiation image, as it were, on a uniformly dense base (fog). Figure 6.1c shows a similar picture, that is with scattered radiation as in b, but with the same average density as in a. Comparison of c with a clearly shows the lack of contrast due to scattered radiation.

The phenomenon may also be expressed numerically. Assume that the radiation emerging from the object (the true radiation image) has two intensities, that is 50 and 100. The contrast is then  $\log(100/50) = 0.301$ . To this is added scattered radiation with an intensity of 50, so that the contrast becomes  $\log(150/100) = 0.176$ . The resultant loss of contrast is therefore 0.125.

It should be pointed out in this context that as regards general views of the chest (65 kV) the intensity of the emergent scattered radiation is roughly equal to the intensity of the emergent primary radiation, whereas with radiographs of the abdominal organs at 125 kV, the scattered radiation may have three or four times the intensity of the emergent primary radiation:

Scattered radiation is enemy number 1 of good X-ray photos. It is therefore very important to limit it as much as possible.

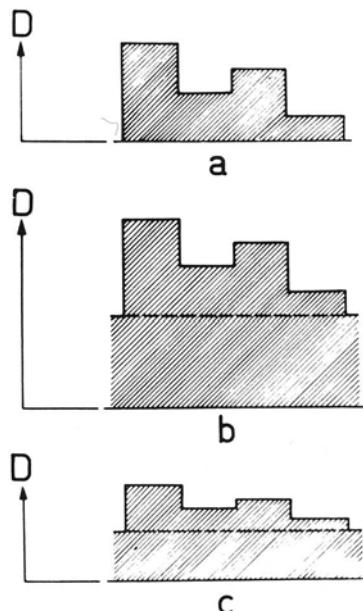


Figure 6.1 Loss of contrast due to scattered radiation.

- a. Diagrammatic representation of the density on the film, of an object with four different thicknesses without scatter (correct exposure).
- b. As in a, but this time with scattered rays, which uniformly increase the density of the film by a certain amount (this radiograph will, apart from this, be over-exposed).
- c. The same as b, but the exposure is adjusted to compensate for the scatter; the greater density is the same as in a. Compared with diagram a, however, there is a distinct loss of contrast. D = density (or blackening).

### 6.3 METHODS OF OVERCOMING SCATTERED RADIATION

In view of the many advantages to be gained by using higher tensions in X-ray diagnosis, means other than reduction of the voltage have to be found in order to limit scattered radiation as far as possible and to eliminate its adverse effect upon image quality. This can be done in a number of ways, which are usually combined, but, if this is impossible, are applied separately.

#### 6.3.1 Beam limitation

By limiting the cross-section of the X-ray beam we reduce the irradiated volume and thereby reduce the number of scattered rays. This method is so efficient that it enables contrasty radiographs to be obtained, even of thick parts of the body, without other measures having to be taken. The beam is limited by means of diaphragms or with the aid of applicators of appropriate cross-section.

We can easily see the value of a narrower beam by screening successively with a large and a small diaphragm and noticing the part of the screen that is shielded off by the diaphragm. We shall see that, as a result of scatter, this part lights up

more for a large field than for a small field. Moreover the contrasts in the image with a large field will naturally be less than with a small field, especially when the object is thick. By limiting the beam one gives the patient a much lower exposure to radiation (volume dose).

### **6.3.2 Compression**

It is often possible to reduce the irradiated volume by reducing the thickness of the object, that is by means of compression. It is clear that compression should always be combined with as much beam limitation as possible. Compression can be effectively applied to obese parts of the body, particularly the abdomen.

Muscle tissue, on the other hand, cannot be so well compressed as fatty tissue. Compression has the further advantage of contributing to immobilisation (respiration) thereby lowering the risk of movement unsharpness. One can also use a shorter exposure, thus reducing not only the movement unsharpness ( $U_m$ ) but also the radiation dose received by the patient.

### **6.3.3 Increased object-film distance, or Groedel technique**

By placing the object at a distance from the film, the quality of the contrast can be improved due to the reduction of scattered radiation incident on the film.

There are two reasons for this. First, the increased distance influences the intensity of the scattered radiation (of which the origin is in the object) much more than it influences the intensity of the primary beam since its origin is the focus which is much further away. In the Groedel technique the primary radiation will take a bigger part in the relationship primary:scattered radiation than in the normal technique. Consequently the contrast of the image will be increased.

A simple formula illustrates this point. In the first example we will assume a focus-film distance of 100 cm and the object will be placed 5 cm from the film (that is  $Ff = 100$  cm and  $Of = 5$  cm).

In the second example we will place a film 20 cm further away.  $Ff = 120$  cm and  $Of = 25$  cm. The scattered radiation that reaches the film will be  $(25/5)^2 = 5^2 = 25$  times weaker than in the first example. The primary radiation decreases by only  $(120/100)^2 = (1.2)^2 = 1.4$  times.

Expressed in a simple way: the improvement in the contrast is due to the fact that by increasing the object-film distance a larger portion of the scattered radiation passes by the film rather than hitting it.

The draw-back of the increased object-film distance is the greater geometric unsharpness it entails. The method can therefore only be used efficiently in conjunction with a large focus-object distance or a small focus. The method of increased object-film distance to decrease the amount of scattered radiation reaching the film was described around 1925 by Groedel, especially for lung radiographs with higher voltage. In the technique of radiological image magnification, an increased object-film distance also makes a positive contribution to the contrast of the X-ray image (see figure 12.25).

### 6.3.4 Filters

The scattered radiation can be attenuated to some extent by inserting a sheet of copper or tin foil between patient and film, or, exceptionally, a thin lead foil of, for example, 0.1 or 0.15 mm thickness. The scattered rays for the most part pass obliquely through the foil and thus have to travel a longer path than the primary rays. Moreover, the scattered rays are somewhat softer and are thus more readily absorbed.

To achieve any appreciable attenuation the filter must, however, be relatively thick, which naturally will attenuate the primary rays as well. For this reason, the filter method is rarely used in diagnostic X-ray technology.

### 6.3.5 Slot diaphragms

An effective method of combating scatter is to make use of a flat diaphragm with an adjustable aperture (slot diaphragm) placed above and beneath the patient.

During the exposure both slots, which are no more than a few centimetres wide, are moved parallel to the film such that the lower slot always passes all the primary rays that enter the object via the upper slot. At the same time, the focus is moved together with the slots, so that a narrow beam round the centre of the X-ray beam passes through the whole object. In this way we get an image that corresponds precisely to the true size of the object, that is without magnification or distortion; this is known as an orthodiagnostic or orthogonal image (see chapter 4, section 4.5.1).

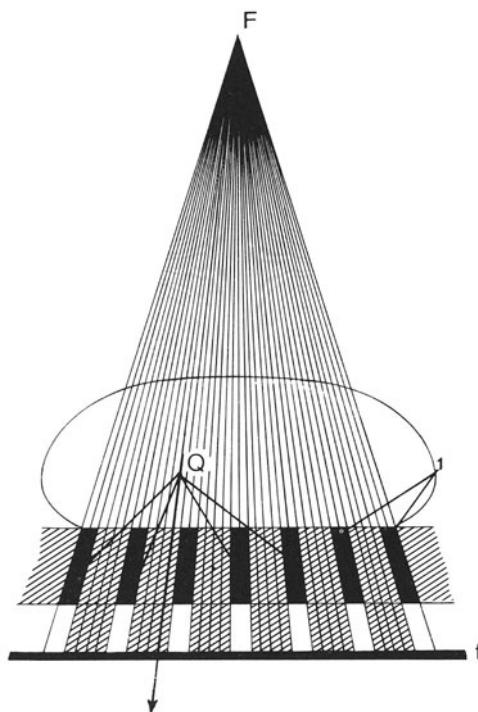
The use of small slots reduces scattered radiation very considerably. Nevertheless, this method is almost never used in radiological practice because it demands a very high tube load. It should be noted, however, that neither the skin dose nor the integral absorbed dose for the whole exposure is any greater than normal, since each strip of skin (and each corresponding section of the body) is exposed to the same amount of radiation as when exposed in normal technique.

### 6.3.6 The scatter grid

The use of a scatter grid is one of the most useful methods of eliminating scattered radiation. It makes use of the fact that scattered rays, as opposed to primary, image-forming rays, leave the object in all directions.

#### 6.3.6.1 *The structure of the grid*

The grid, which is placed between patient and film, consists of a number of very thin strips of lead, assembled edgewise and interleaved with material of low absorption (such as wood, a purely organic plastic, or, in some cases, a light metal), the purpose of which is to keep the strips properly spaced and in position. The strips of lead are so angled that when viewed in end elevation they converge to a straight line which is midway across the width of the grid. The distance to this straight line from the grid is called the focal distance of the grid. The X-ray tube focus is normally centred to the midpoint of both length and width of the grid, at this focal distance. These grids are called directional or focused grids. The image-forming primary rays pass between the lead strips at any point of their length (unless they hit the thin strips end on), whilst the scattered rays, as long as the angle they make with the primary rays is not too small, are intercepted and absorbed by the strips.



**Figure 6.2** Improvement of contrast by means of a grid. The lead strips (I) are directed towards the focus (F) and are held together by a radiolucent material. Most of the primary rays pass through the grid and reach the film (f). The scattered rays, from point Q for example, are mostly absorbed by the lead strips, and a small amount (indicated by the direction of the arrows) still reaches the film.

Grids can be focused at, for example, 80, 100, 150 and 200 cm. Figure 6.2 is a schematic illustration of a scatter grid.

#### **6.3.6.2 Stationary grids**

For radiographic use a stationary grid must have a much finer structure than for fluoroscopic use, because the intrinsic unsharpness of intensifying screens is lower than the  $U_i$  of fluoroscopic screens, and the strips become invisible on the radiograph. Also due to the high luminosity of the viewing box where the film is examined, the perception of details—in this case the strips—is much better than at the poor level of luminosity in fluoroscopy, where the strips may be unobserved. At the high luminosity, however, in intensified fluoroscopy they may become visible. When the intrinsic unsharpness is small, as it is with intensifying screens, stationary grids always produce a line image on the radiograph. Depending on the case this line pattern may be accepted (for example for a rough diagnosis of a fracture) or rejected (if small details should be seen).

### 6.3.6.3 Movement of the grid

To prevent the shadow of the lead strips from showing up on the film, the grid is moved in a direction perpendicular to the strips during the exposure. Movement causes the image of the strips to disappear. A grid which moves in this manner, together with moving mechanism, is also known as a Potter-Bucky diaphragm (often simply called a 'bucky').

The finer the grid, the less the distance the grid must move in order for the strip shadows to become sufficiently blurred (mainly by movement unsharpness).

Although considerable progress has been made in the construction of very fine grids (up to 40 strips/cm) until now there is no grid which produces such a line-free image that movement is superfluous for normal radiographs.

### 6.3.6.4 Stroboscopic effect

Generally a moving grid does not show the strips on a radiograph. Nevertheless, under certain conditions, even with a moving grid, strip shadows may appear. This occurs if pulsating high tension is used and if the frequency of the pulses and the frequency at which the same part of the film becomes regularly shadowed by the lead strips are related to each other as whole numbers. In other words, this

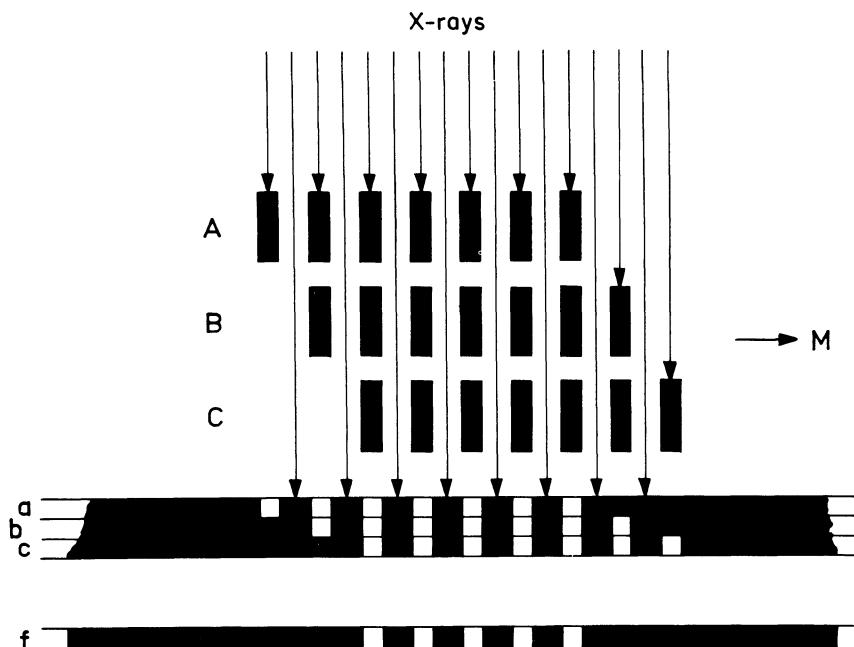


Figure 6.3 Stroboscopic effect. A. Position of the lead strips of the grid during the first pulse of current. a. The density produced by this pulse. B. Position of the lead strips during the second pulse of current. b. The density produced at that moment. C. Position of the lead strips during the third pulse. c. The density thus produced. f is the film, showing the sum of the densities a, b and c. The result is a distinct image of the lead strips of the grid on the film (as white lines). The distance between the lines is equal to that between the lead strips. M indicates the grid, which moves in the direction of the arrows.

means that a given spot on the film is always just covered by a strip of the grid at the moment that a current pulse is produced. In this way the radiation cannot reach any of such places on the film during any of the current pulses (50 or 100 per second with alternating voltage), so that the film is not blackened at these points. This is known as the stroboscopic effect\*. There are several forms of stroboscopic effect, depending on the rate of motion of the grid, the number of strips, the exposure time, and such. An example of this phenomenon is given in figure 6.3.

#### ***6.3.6.5 Different movements of the grid***

The motion of the grid can be realised in various ways. The drive mechanism may be a spring construction which is put under tension before the exposure and automatically released during the exposure, so that the grid is moved (catapult-bucky). The rate at which the spring gives up its stored energy can be regulated by means of a valve, and should be chosen so that the time during which it maintains the grid in motion is slightly longer than the exposure time. If the spring did not keep the grid in motion for as long as this, the grid would be stationary for part of the exposure and the lead strips would show up on the film. If the motion of the grid continues for much longer than the exposure time, the grid will not be moving fast enough during the exposure for the strips to be sufficiently blurred.

Modern constructions have an 'oscillating' drive mechanism, which moves the grid to and fro during the exposure. Since a stroboscopic effect is possible here too, a 'reciprocating' motion is superimposed on this regular motion. This reciprocating motion is also a to-and-fro motion, but in this case rather slow in one direction and very fast in the opposite direction. The exposure is automatically timed to begin during the high-speed motion. With oscillating and reciprocating motion, knowledge of the exposure time is unnecessary, which makes this design particularly suitable for automatic exposure techniques.

#### ***6.3.6.6 Focusing and types of defocusing***

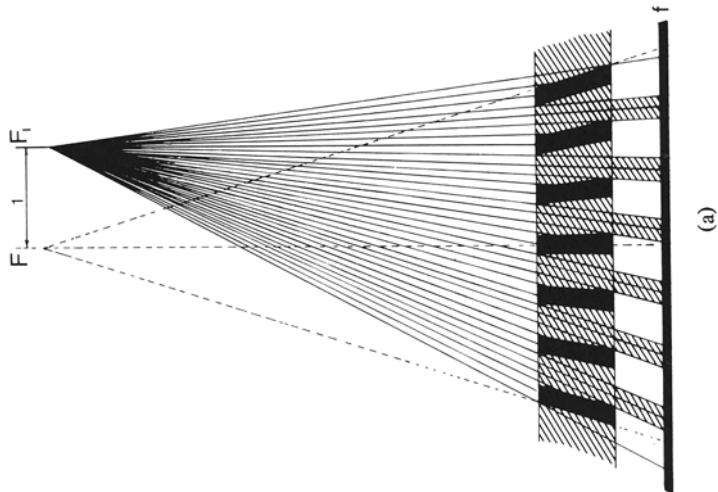
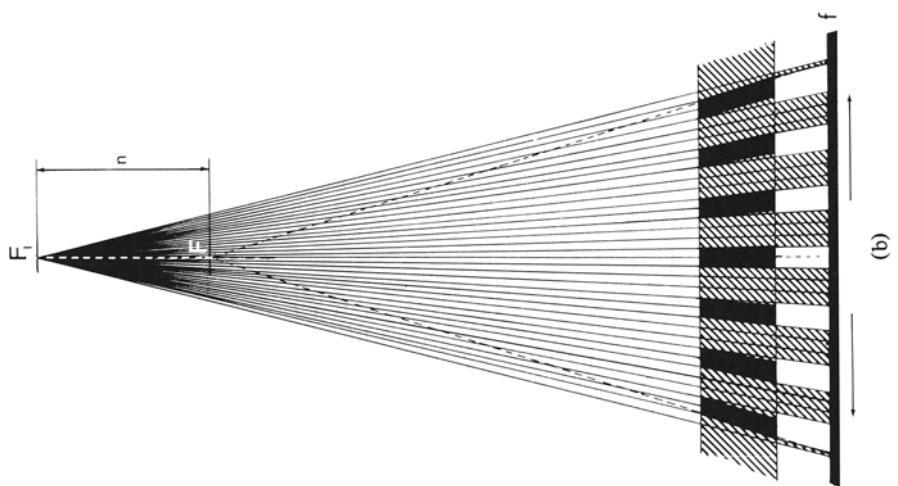
By far the most commonly used scatter grids are flat and are moved parallel to the film. The direction of the motion is perpendicular to the strips. The grid is only in the central position when it is also used at the correct distance, exactly directed on the focus. The 'focused' position allows the maximum amount of primary radiation through the strips. The defocusing and the attenuation it entails will not seriously affect the X-ray image, if the grid is moved only a few centimetres to the right or left.

There are more possible positions of the grid (which also occur in practice) whereby the focused position can change. The most common are:

- (1) Lateral defocusing (see figure 6.4a) perpendicular to the strips of the grid. As the focusing becomes more lateral fewer primary rays are allowed through the spaces between the strips. If one leaves the exposure unchanged with respect to

---

\*The stroboscopic effect can also be very elegantly demonstrated by running a film of, for example, a moving car, when the successive frames all come just when the spokes are in the same position. The car then appears to be moving forwards with stationary wheels (or, with a slight phase difference, even with the wheels turning backwards).



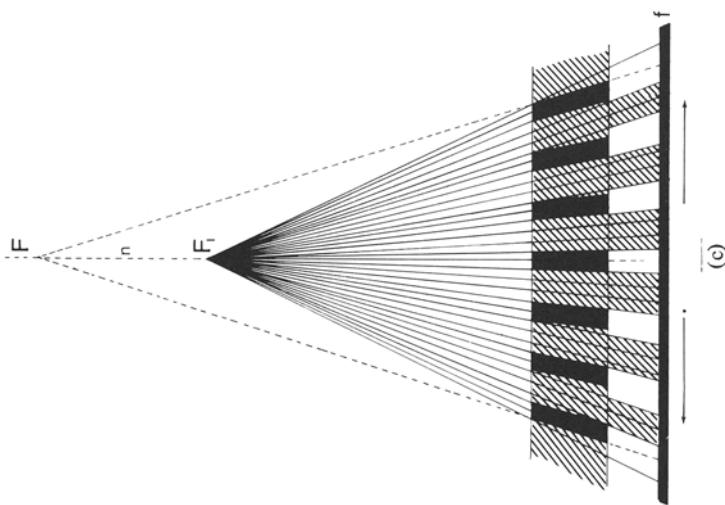
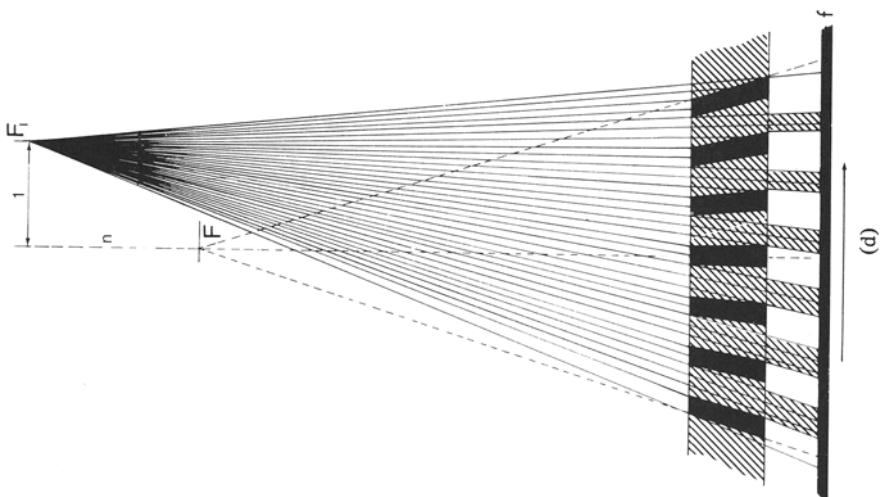


Figure 6.4 (see p. 125 for caption)

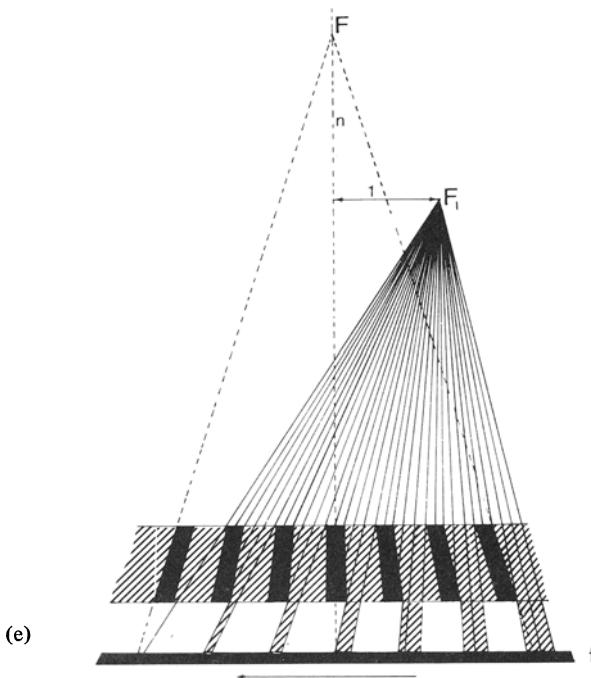


Figure 6.4 Effect of various types of grid defocusing; vignetting. F. The correct position of the focus with respect to the grid; f. the film. The black areas represent the lead strips, and the oblique shading indicates the emerging primary rays. In b, c, d and e the direction of the arrows indicates the increase in vignetting.

a.  $F_1$ , focus with grid defocused sideways over a distance  $l$ . Result: uniform attenuation of the transmitted beams (compare figure 6.2).

b.  $F_1$ , focus with grid defocused over a distance of  $+n$ . Symmetrical vignetting effect.

c.  $F_1$ , focus with grid defocused over a distance of  $-n$ . Symmetrical vignetting effect (more marked than in b).

d.  $F_1$ , focus with grid defocused sideways over a distance  $l$  and over distance  $+n$ .

Asymmetrical vignetting.

e.  $F_1$ , focus with grid defocused sideways over a distance  $l$  and over distance  $-n$ . Asymmetrical vignetting more marked than in d.

the focused position, then it follows that the under-exposure will be equal. With slight lateral defocusing, as is true with a moving grid which always appears during a portion of the exposure time, a similar under-exposure is hardly ever noticed. When taking stereo X-rays (see chapter 12, section 12.2.3) the lateral defocusing amounts to  $1/20-1/10$  of the focus-film distance. The amount of radiation lost in the defocused position must then be compensated for by a slightly greater exposure value.

(2) Defocusing caused by an increase in the distance from the grid to the focus (see figure 6.4b). There is no uniform weakening of the beam but rather an unpleasant bilateral weakening which increases from the centre outwards. The further the strips are from the centre the greater is the chance of hitting the strips. This causes an undesirable lateral decline in the blackening of the film called the vignette effect. This is of even greater concern with:

(3) Defocusing caused by a decrease in the distance from the grid to the focus (see figure 6.4c). The smallest deviation from the correct distance can create a very bothersome vignetting effect and render the film useless.

Tolerance is less for too small a distance from the focus than it is for too large a distance. If, for example, the correct distance is 100 cm, a decrease of 25 per cent (75 cm) causes a more serious vignette effect than an increase of 25 per cent (125 cm).

In practice the grid must be exactly centred and used at the correct distance so that a combination of the results of a and b or a and c do not occur. Small deviations have little effect, but large deviations cause the vignetting effect. The vignetting effect is not symmetrical but one-sided. Figure 6.4d and e illustrate this effect very clearly.

#### **6.3.6.7 Grid quality, grid factor, ratio**

The efficiency of a grid is expressed as its selectivity, which is the ratio of the percentage of transmitted primary rays to the percentage of transmitted scattered rays. Thus, the greater the selectivity of a grid the more efficient it will be.

A new measure of the quality of a grid is the contrast-improvement factor,  $K$ , proposed by Hondius Boldringh. This factor, which is very important in practice, is the ratio of the contrast in the radiation image acting on the film with a grid to the contrast in the radiation image acting on the film in the absence of a grid.

Apart from the above-mentioned factors, the exposure time should also be taken into consideration. For if we prolong the exposure we introduce greater movement unsharpness, thereby impairing the quality of the image.

In practice there is a further factor to be considered, namely the relation between the exposure times with and without a grid, which we call the bucky factor or grid factor. This factor depends mainly on the construction of the grid.

Selectivity and the grid factor are also dependent upon kilovoltage. The harder the primary radiation the harder will be the scattered rays, and therefore more lead will be needed to absorb them. Apart from the amount of lead per square centimetre of grid area—which is the most important factor—the distribution of the lead is also decisive as regards selectivity. The angle at which the scattered rays can enter the grid without being absorbed by the lead strips depends both upon the spacing between the strips and upon their height. The ratio of the height of the strips to the spacing between them is called the grid ratio (see figure 6.5).

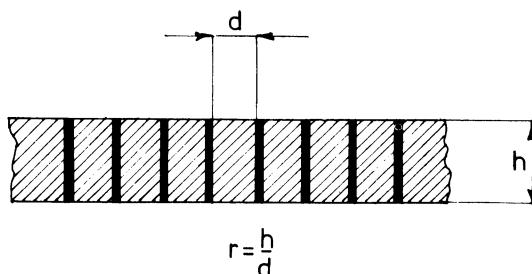


Figure 6.5 Factors which determine the ratio.  $r$ . Ratio;  $h$ . length of the lead strips;  $d$ . distance between the lead strips.

A higher ratio means better selectivity, since then less-scattered radiation can get through the grid. The grid ratio rises when at the same height the number of strips per centimetre is increased. Moreover, the shadows thrown by the strips are then less troublesome and more easily avoided. The extent to which the thickness of the strips can be reduced is mainly limited by difficulties in the manufacture of the grids.

As has been mentioned above, extra loss of primary rays can occur when using a grid as a result of:

(1) A deviation from the distance at which the strips of the grid are centred, whence a vignetting effect appears consisting of under-exposure towards the edges of the film. The degree of this under-exposure is dependent on the ratio, on the size of the deviation and on the size of the film.

(2) A lateral deviation of the focus, that is the central ray is not directed to the centre of the grid but beside it. This deviation results in under-exposure which appears evenly over the entire image field. In using moving grids this deviation will occur continuously during at least part of the exposure time. The under-exposure thus produced is dependent on the average lateral focus deviation and on the ratio of the grid.

Figure 6.6 shows a graph from which the percentage loss ( $V$  per cent) of primary rays can be defined for a grid with ratio  $r$ . Suppose one uses a grid focused at 100 cm with a ratio of 7. The average lateral deviation is 14 mm, as is roughly the

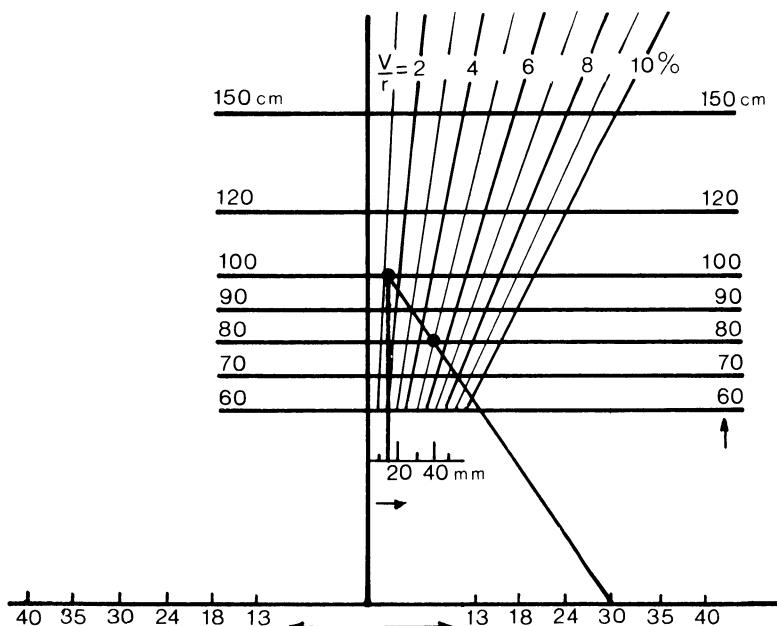


Figure 6.6 Calculation of the loss of radiation with defocusing. Graphic representation of the percentage loss of primary radiation with the focus at an incorrect position (both in height and in a sideways direction). For explanation see the text.

case, for example, with an oscillating bucky with a maximum amplitude of 25 mm to both sides. If one uses this grid at a distance of 80 cm, we find the percentage loss of primary rays for a film width of, say, 30 cm as follows. On the horizontal line for 100 cm (focus-grid distance) one marks the lateral deviation of 14 mm and joins the point thus obtained to the image width of 30 cm (at the lower right in the graph). The intersection with the horizontal line of 80 cm gives a value of about 5. This number, multiplied by the ratio 7, gives a percentage loss ( $V$ ) of 35 per cent. From this we clearly see the under-exposure due to incorrect centring, both in height and in the lateral direction, especially in grids with a high ratio.

#### **6.3.6.8 High-ratio grids and crossed grids**

In view of the fact that high tensions are often used, in which case the proportion of scattered radiation is high, grids have been constructed with a high ratio (15, for example). The relatively stronger absorption of the rays in this case demands longer exposure times. This disadvantage can be overcome, however, by the use of higher voltages. This voltage increase can be made so great, while the contrast remains the same as with a normal voltage and a normal ratio (7), or even increases, that both the exposure time and the dose received by the patient are not increased.

The use of such scatter grids with high ratios make it possible to take advantage of the specific properties of hard X-rays, for example to obtain the relatively low contrast in bone structures while the contrast between air and the soft parts is maintained, without having a fog caused by scattered radiation over the whole film.

High-ratio grids need to be centred very accurately, however, and are very sensitive to changes in distance.

Scatter grids with perfectly spaced strips are, as it were, focused on 'infinity'. In practical use each will contribute a certain amount of vignette effect. A grid with a low ratio is used when the desired image formation is not too great and the distance is not too small (greater than 60 cm). These grids are often used for taking X-rays in the emergency department or in the operating theatre.

Scatter grids with parallel lead strips, or strips focused on a given straight line, only intercept the scattered radiation which falls on the lead strips at an angle, the scattered radiation travelling in planes parallel to the strips pass through.

These scattered rays can, however, be held back by means of 'crossed grids' (cross-hatch grids), which in fact consist of two normal grids placed one above the other so that the strips of the two grids cross each other. Crossed grids are to be preferred when exposures are made simultaneously in two directions at right-angles to one another as, for example, in 'bi-plane' angiography. The moving of crossed grids places particular demands on avoiding the image of the strips or the influence of the crossed points. Crossed grids are hardly ever used.

### **6.4 COMBINED METHODS**

Since none of the methods described enables us to eliminate scattered rays entirely, the obvious thing to do is to use a judicious combination of methods.

When working with a grid, for example, we should still make the irradiated field as small as possible. Using a compressor with a small field, such as that used with a serial changer in stomach examinations, and limiting the beam accordingly, we can improve the contrast. Moreover, the (slightly) increased distance between object and film contributes to this improvement. In view of the disadvantages inherent in some of the methods discussed, such as the possible presence of strip shadows when using a grid and the greater geometric unsharpness caused by increasing the object-film distance, it will be necessary to decide from case to case which combination of methods is most suitable.

### **6.5 THE INFLUENCE OF FILM, INTENSIFYING SCREENS AND FLUORESCENT SCREEN UPON IMAGE CONTRAST**

The conversion of the radiation image into a visible image on a film involves a change in contrast according to the relationship film contrast =  $\gamma \times$  radiation contrast where  $\gamma$  is the gradation of the film. (This will be discussed in detail in chapter 8, section 8.2.6.) If the film gradation is less than 1, the radiation contrasts will be lowered; if  $\gamma$  is greater than 1, they will be increased. A combination of film and intensifying screens is best regarded as a single entity with its own gradation: film contrast =  $\gamma$  of film-screen combination  $\times$  radiation contrast. The gradation of film-screen combination is generally 2-3, which represents an appreciable heightening of contrast.

Efficient processing and exposure technique also play an important part in the formation of film contrasts. As regards processing technique, the method of development recommended by the manufacturer should be followed carefully.

As regards exposure technique, we know from the characteristic curve of a film that over-exposure and under-exposure always involve a loss of contrast (see chapter 8, section 8.2.5). Only correct exposure of the film can give optimum contrasts. It may perhaps be possible to remedy the damage to some extent by photographic intensification or reduction in the processing room, but it is better to avoid the error altogether. This is now really impossible with automatic developing.

The fluorescent screen, which directly converts the radiation image into a visible image, does not increase the contrast. Moreover, owing to the low level of screen brightness, the contrasts present are by no means all perceptible. Subjective contrast can be improved by boosting the tube current and by good dark adaptation of the eye. The image intensifier does not increase the visible contrast either, but owing to its higher level of luminance it greatly improves subjective contrast. If the image intensifier is combined with television, it is then possible to increase the contrast of the TV picture.

### **6.6 CONTRAST MEDIA**

To make an organ or part of the body visible, which in a natural state does not show any absorption differences with the surroundings, it should be filled with substances. The contrast media employed are:

(1) Those containing substances with a high atomic number, which are distinguished from the soft parts by their greater absorption of X-rays. One speaks here of positive contrast. The substances concerned are chiefly compounds of iodine and barium, the atomic numbers of which are 53 and 56, respectively.

(2) Air, or pure oxygen, which, although it has about the same effective atomic number as the soft parts, nevertheless has a much lower density and therefore absorbs less X-rays (density of air = 1/775 of the density of water or of the soft parts of the body). In this case we speak of negative contrast.

Whenever a positive and a negative contrast media (for example, barium and air) are used at the same time, one speaks of a double-contrast method.

Contrast media can be introduced into the body in several different ways and at several different points. This will be discussed further in chapter 13.

# 7

## Perceptibility of Detail in the Radiographic Image; Image Quality

Before discussing the various methods of using X-rays for diagnostic purposes we shall first consider what is understood by detail perceptibility in the X-ray image, and the factors that determine this. A detail in a fluoroscopic image or radiograph (*image detail*) is the projection of a detail in the object (*object detail*).

It had long been known that much more could be seen on a radiograph than on a fluorescent screen, and with the further development of ever new methods of producing radiographic images it was found that the images thus obtained could differ appreciably in detail. How can the quality of these different images be described and expressed?

A detail on a film or fluoroscopic screen can only be perceived if it contrasts with its environment. The presence of a certain amount of contrast does not necessarily signify that this can be seen with the eye. It is a characteristic of a sensory organ such as the eye that it only reacts to a stimulus, when this exceeds a particular limit or *threshold value*. A possible contrast, which has to be determined with a measuring instrument, must cross the perceptibility threshold before it can be differentiated subjectively.

### 7.1 LIMIT OF PERCEPTIBILITY OF AN IMAGE DETAIL

The perception threshold is variable and depends upon the following factors:

- (1) the quality of the detail,
- (2) the degree of adaptation of the eye,
- (3) the visual power of the eye.

Details which are not visible are called *infraliminary details*, that is to say they lie below the threshold of perception. Visible details are called *supraliminary*. In order for the eye to perceive the greatest possible number of details, the threshold value must obviously be as low as possible. Let us now consider what requirements this imposes on the three factors mentioned above.

### 7.1.1 The quality of a detail

The following factors determine the quality of a detail:

- (1) the size of the contrasting detail,
- (2) the contrast of the detail,
- (3) the degree of detail unsharpness,
- (4) the brightness of the detail.

We shall now examine these factors in turn (figure 7.1).

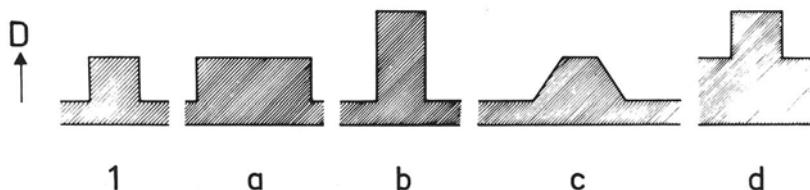


Figure 7.1 Density diagrams of different image details. The diagrams of a single object detail (a small recess in a Perspex phantom) have been obtained in various ways. The density (D) is shown vertically and the diameter of the detail horizontally. As compared with the ideal image in 1, the image detail is enlarged in a, richer in contrast in b, unsharp in c and poorer in contrast in d.

#### 7.1.1.1 The size of the contrasting surface or size of detail

The smaller the detail the less readily it can be perceived. Apart from the absolute size, the optical angle at which the detail is viewed is of importance, for the further the detail is removed the more difficult it will be to discern it; in other words, the smaller the angle the poorer the perception.

When viewing an X-ray image, we automatically choose the smallest distance at which we can see sharply without effort. If the details can no longer be perceived with the naked eye, optical magnification could be appropriate. Usually, however, the intrinsic unsharpness is an absolute barrier, which cannot be overcome by using a magnifying glass, etc. In that case macroradiography can perhaps offer a solution.

#### 7.1.1.2 The contrast of the detail

A detail becomes visible only when its contrast with respect to its background exceeds a certain minimum value. If the contrast is less than this minimum value, then the detail will have to be larger in order to be still discernible to the eye. Conversely, a greater contrast enables a smaller detail to be seen.

The importance of the size as well as the contrast of a detail is demonstrated in a convincing manner by a *contrast-detail diagram*. Such a diagram can be obtained after passing X-rays through a 'phantom' such as that designed by Burger, Janker, etc. (see figure 7.4, p. 136). An X-ray phantom is an artificial subject containing a variety of details that are of radiological interest; when these are reproduced in various ways and under different conditions, they can be tested for perceptibility.

Such a phantom can, for example, consist of metal wires of gradually decreasing thickness and spacing, encapsulated in a plastic such as Perspex (Perspex has the advantage that its scattering and absorption of X-rays are practically the same as those of human tissue). The thick wires, spaced widely apart, will still be visible even when the viewing conditions are poor. To each line that is caused by a wire also belongs a distance to the next line (that is the space between) to be compared with a 'negative line'. In most phantoms the line thickness and the distances between the lines in a particular group are made equal to each other. If the thin, closely spaced lines can also be seen, then the detail perceptibility is high. This is expressed as: the resolving power is so many line pairs (or periods) per cm.

The detail perceptibility of the image on X-ray television is less than that on radiographs. By certain modifications in the signal in the television chain the contrast of small details can be enlarged specifically. In this manner, the detail perceptibility of the television image is increased, but it cannot surpass that of the radiograph.

#### 7.1.1.3 Degree of unsharpness, contrast transitional zone, Mach effect

The contrast and the width of the transitional zone are particularly important; together they determine the *contrast gradient*. The contrast gradient is a measure of the slope of the line which links the two density levels (of the detail itself and its background) in the density diagram. Expressed mathematically, the contrast gradient is the tangent of the angle which the line connecting both density levels makes with the horizontal axis. The angle should always be chosen smaller than 90°. A broader transitional zone with equal contrasts means a smaller (or flatter) contrast gradient. With a transitional zone of the same width but with greater contrasts, the contrast gradient is steeper.

The following physiological phenomenon, peculiar to vision with the eye is of great importance in a transitional area between different photographic densities: the dark area becomes darker and the bright brighter than outside this transitional area (*Mach effect*). This phenomenon can be perceived on the radiograph of a step wedge, part of which is illustrated in figure 7.2. With a decrease in definition the contrast gradient becomes less steep. Essentially, unsharpness is a blurring of image detail; the detail becomes spread out over a certain area. This gives rise to a transitional zone at the edges, which is known as penumbra (or half-shadow or boundary unsharpness). The width of the penumbra indicates the degree of unsharpness, which is usually expressed in tenths of millimetres. If the penumbra is small compared with the size of the detail, little harm is done to detail perceptibility. But, if the details are small, the same degree of unsharpness may transform the whole detail into penumbra; no nuclear (or central) shadow remains and even a loss of contrast occurs (figure 7.3). This loss of contrast in the centre can be so

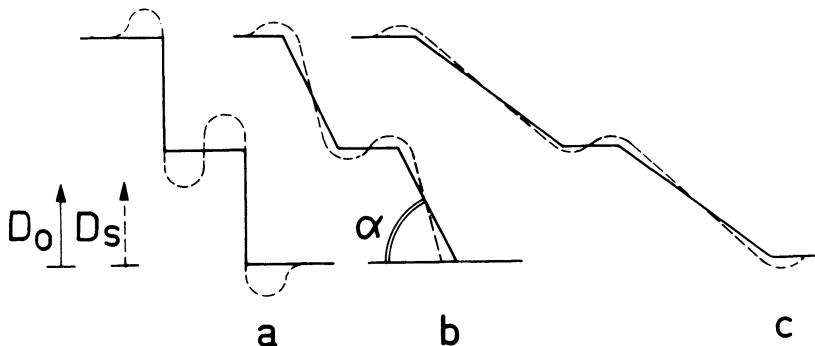


Figure 7.2 Objective and subjective contrast. Diagrammatic representation of a step-wedge radiograph. The solid line represents the objective density ( $D_o$ ), the interrupted line represents the subjective density ( $D_s$ ).

- Owing to the abrupt transition between the different density zones, the subjective contrast is much greater than the objective contrast. The Mach effect is most pronounced.
- Subjective contrast decreases with decreasing contrast gradient (represented by the angle  $\alpha$ ).
- Small contrast gradient; the subjective contrast is practically no greater than the objective contrast.

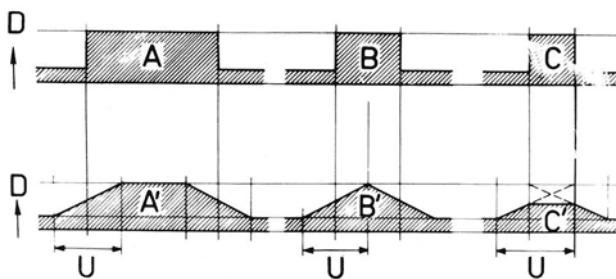


Figure 7.3 Effect of unsharpness upon details of different size. Top: Diagrammatic representation of the density (D) of three details of decreasing size (A, B and C) with ideal definition. Bottom: Effect of the unsharpness (U) on the three images. Image detail A' is larger than U; the edges are blurred, but there remains an unaffected region of total density, which is not affected by the unsharpness. Detail B' is the same size as U; the edge unsharpness extends to the centre of the detail. Detail C' is smaller than U; the region of total density gives way to lesser density and contrasts less with the surrounds.

great that the image detail becomes completely indistinguishable.

In the first place, therefore, unsharpness affects the finer details such as bone structure. This being so, a certain degree of unsharpness can be represented as a limit, as in the case of intrinsic unsharpness; details, which have a smaller diameter than this limit, can no longer be distinguished from their background. Obviously, this limit depends on the detail contrast; the limit is lower at higher contrasts and vice versa. In practice, a radiograph is described as 'sharp' when it shows bone structure clearly.

### 7.1.1.4 The brightness of detail

The significance of the brightness level clearly emerges from observations concerning detail perceptibility at different brightnesses (brightness levels). In this way, one ascertains that detail perceptibility at greater brightness (at least up to a certain level) improves. If we compare the detail perceptibility on a fluoroscopic screen with that on a radiograph, then we see that the former is much inferior.

Fluoroscopy, at any rate with a conventional fluoroscopic screen, is therefore, a rather rough method of investigation. It is true that a much better image would be obtained by boosting the tube current, but this would expose the patient to excessive radiation, and would overload the tube. It would also be possible to increase the brightness level by raising the kilovoltage, but since this again involves loss of contrast, the choice of a higher kilovoltage does not necessarily lead to improved detail perception. The image intensifier, in this respect, has brought about an essential improvement, especially in combination with X-ray television. Another factor closely related to the brightness of the image is the degree of adaptation of the eyes, which is discussed in the next section.

## 7.2 THE DEGREE OF ADAPTATION OF THE EYES; CONES, RODS

Optimum contrast sensitivity of the cornea is attained only at a specific level of illumination. Over-exposure and under-exposure decrease the perception of contrasts (subjective contrast). The fact that the eye is still able to see well in spite of the many variations in the brightness of daylight is due to the pupillary reflex, which accurately controls the quantity of light falling on the retina. This explains why, when a film is held against a viewing box, detail perception is reduced if one is blinded by the light surrounding the film. The relatively high luminous flux reaching the eye causes the pupil to contract, with the result that too little light from the film gets through to the retina. As soon as the light around the film is shielded, the pupil dilates and the contrasts on the film at once appear to be greater.

At intensities a great deal lower than daylight intensity, as in a fluoroscopic screen, the light is too weak to stimulate the nerve cells of the retina—the *cones*. These cones enable us to see in intense light but not in weak light. In the latter case, we would see nothing if it were not for the fact that another set of highly sensitive nerve cells in the retina—the *rods*—now take over the function of the cones at low light intensities. These rods are normally found in the deeper layers of the retina. With weak light they rise towards the surface just far enough to ensure that they are affected by the light and, thus, make contrast perception possible.

This physiological process, which is known as *dark adaptation*, takes longer than the pupillary reflex; about half an hour must elapse before the eyes are thoroughly adapted to the dark. This has already been pointed out when the importance of detail brightness was explained. As is evident from the above, the ability to perceive is even less when the eyes have not been adapted to the dark. For fluoroscopic examinations with a conventional screen the period of adaptation should be at least 15–20 min before the screening is started. If it becomes necessary to leave the darkened diagnostic screening room for a few moments,

the observer can retain his state of adaptation to some extent by wearing special dark (usually red) glasses (adaptation goggles).

Since there are practically no rods in that part of the retina with which we fix our gaze—the macula lutea or ‘yellow spot’—with dark adapted eyes it is better not to look at the detail of interest itself, but rather to let one’s gaze wander around it, as it were.

In fluoroscopy with an image intensifier rigorous adaptation is less important, because the intensifier screen is many times brighter than the conventional fluorescent screen.

The degree of adaptation generally plays no part in the examination of radiographs on a viewing box. The image in this case is usually bright enough to allow us to see by means of the cones. Moreover, a stronger light source—a *spot light*—can be used to advantage if the radiograph is very dark in parts, as otherwise the light transmitted by the dark areas will be too weak for good perception of detail.

### 7.3 VISUAL POWER OF THE EYES

Visual power naturally plays an important part in the observation of radiological images, especially of the relatively poor fluoroscopic image. It has been found that visual power differs from person to person. The factors that explain the considerable differences in perception are partly psychological (lack of concentration) and partly physical (poor adaptation, owing to lack of vitamin A, for example). However, there are a few individual differences in the speed with which one can adapt from brightness to darkness, but one can greatly improve the concentration on particular details and increase the speed of interpretation of those details with practice.

Figure 7.4 can serve to illustrate the great individual differences in the percep-

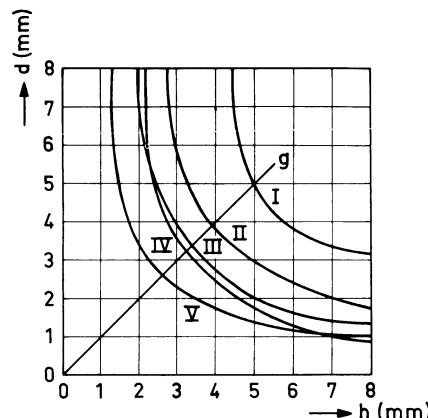


Figure 7.4 Contrast—detail diagram illustrating the perceptual differences of five persons of the same fluoroscopic image of a perspex phantom with drilled holes of different diameter ( $d$ ) and depth (= internal height  $h$ ). The individual results vary greatly. With the same objective contrast (holes of 5 mm depth) viewer  $\bar{V}$  sees holes of 1.5 mm diameter, whereas viewer I only sees holes with a diameter greater than 5 mm. Line  $g$  indicates the holes of which the depth (= internal height) is equal to the diameter ( $d$ ).

tion of details; the perception of five different examiners is shown in a contrast-detail diagram. The depths of the holes in a Burger phantom are plotted on the abscissa and the diameters of the holes are plotted on the ordinate; the measurements are expressed in mm. From this image it is obvious that one examiner is able to gather much less information from a fluoroscopic image than another examiner; in fact, many details may even be overlooked. Obviously, the curves illustrated in the diagram are by no means constant (they more or less represent images of the situation at that particular moment), and the poor perception by examiner I could have been entirely due to excessive fatigue.

#### 7.4 THE MODULATION TRANSFER FUNCTION (M.T.F.); IMAGE QUALITY

The explanation in the previous section clearly indicates that for ultimate visualisation of an object detail, size and contrast of the image detail are of primary importance. To be visualised, a small object detail should possess a rather high contrast in relation to its environment, whereas a larger object detail can still be visualised with less contrast in the image. Both entities, definition and contrast perceptibility, are closely related as far as detail perceptibility is concerned; it is cumbersome, when one wishes to indicate the image quality of a particular system, always to have to measure and describe both. This is the case when one determines the detail perceptibility by means of phantoms with details of various sizes and different contrasts (for example a sheet of Perspex with drilled holes of various sizes and depths, representing the object details in figure 7.4). Moreover, another disadvantage of the so-called contrast-size diagram is that it is only possible to evaluate an 'imaging' system in its entirety (that is the complete chain from the focus via image intensification via the optical system to the film). When changing one of the components of the chain (for example by choosing another focus) the *entire* system has to be measured again in order to evaluate the influence of this new component. This method of measurement and description has been steadily replaced by another, with which every component, as it were, keeps playing its own part, independently.

A combined method of describing the quality of lenses, mirrors, etc., has long been known in optics (the theory of light). The *modulation transfer function* (M.T.F.) defines the image quality in radiology, when certain conditions are fulfilled. A short explanation of the modulation transfer function follows.

One can present an image (signal), consisting of stripes placed at a certain distance apart and which vary in brightness according to a sinusoidal pattern, to an optical system. The minimum and maximum brightness, which could also be called the *minimum* and *maximum amplitudes*, are fixed at certain values. This contrast of the incident signal is set at 100 per cent. If we represent the maximum brightness (amplitude) of the signal by  $I_{\max}$  and the minimum brightness (amplitude) by  $I_{\min}$ , then the depth of modulation (expressed as a percentage) is equal to the difference between maximum and minimum brightness, divided by the sum of these brightnesses, multiplied by 100. Therefore

$$\frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \times 100 \text{ per cent}$$

Since with photographic reproduction one deals with density the depth of modulation is best expressed by the definition

*The modulation depth is the difference between the maximum and minimum density divided by the sum of the maximum and minimum density multiplied by 100 per cent*

Thus

$$\text{modulation depth} = \frac{D_1 - D_2}{D_1 + D_2} \times 100 \text{ per cent}$$

One is now able to measure the contrast of the emerging signal, which is still present in the image after passing through the optical system. The contrast will have decreased, for example, to three-quarters of its original value due to various causes (scattering of light, faults in imaging). It is then said that the *modulation transfer* for this distance between the stripes is 75 per cent. The distance between the stripes can be expressed by the number of 'black' and 'white' lines per cm, also called *frequency* or number of periods per cm. One can determine the modulation transfer for every frequency. In this way one obtains a number of values of the modulation transfer, which can be plotted against the frequency as a function (modulation transfer function).

This method is also applied to radiographs, although the stringent theory is based on the sinusoidal brightness variations in the object and image, and in practice it is difficult (if not impossible) to vary the X-ray transmissibility in a purely sinusoidal manner. Use is therefore made of metal-wire grids or (even better) lead-foil grids, which vary in frequency. Under ideal circumstances, that is without loss of definition and contrast, such a lead-foil grid or metal-wire grid would be reproduced as a pattern with perfectly sharp edges and great contrast (figure 7.1a and b; figure 7.5).

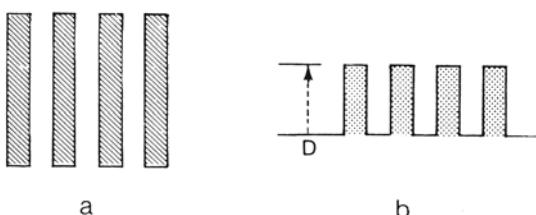


Figure 7.5 The image of a grid. Under ideal conditions, the production of an image of grid (a) with a certain frequency would take place without unsharpness and without loss of contrast, as is shown in (b) in which the density changes abruptly from low to high values. D = density.

In practice, however, the edges of the image will not be as sharp since they are affected, for example, by geometrical unsharpness, intrinsic unsharpness, etc. The unsharpness implies that the transition from an exposed to an unexposed part in the image is gradual and in this way takes up a certain amount of space. If the wire is thin, then the transitional areas on both sides could overlap and then there would not be the lucidity (or sharpness) in the centre of the wire image that

would have been there if an ideal imaging system had been used (figure 7.3). If the wires of the grids described lie close together, then the transitional areas of one wire overlap those of the adjacent wires and one will not find a density, which should have been the ideal density between the images of two wires.

In short: unsharpness entails a loss of contrast in an object with small detail such as in the above example of thin wires that lie close together (figure 7.6). The grid constant of a wire grid, when the distance between the wires is equal to the diameter of the wires, is described as line pairs per cm (spatial frequency of the object).

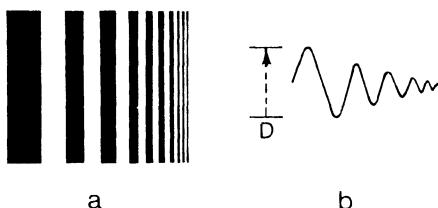


Figure 7.6 Test phantom comprising a metal grid. Frequency increase from left to right ( $D$  = density).

- a. The grid.
- b. Its reproduction as a sinusoidal pattern with decreasing amplitude.

The above can be summarised as follows: in general, by means of an imaging system, the higher frequencies in an object are reproduced with less contrast than the lower frequencies.

Let us suppose we have a number of objects in which the thickness varies sinusoidally, each time with a particular frequency, and in which the variation rises from 0 to the value  $A$  (figure 7.7). If the frequency of the sinusoidal pattern is extremely low, then the reproduction will be 'ideal' and will show an image of a sinusoidal pattern in which the contrast varies between 0 and  $B$ . This contrast (or modulation depth), according to the above definition, is equal to the difference of the amplitudes divided by their sum, multiplied by 100. In this case, therefore, this means that contrast  $= (B:B) \times 100 = 100$  per cent.

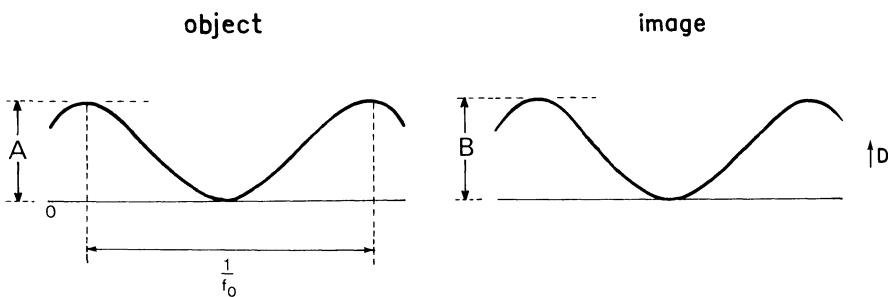


Figure 7.7 Reproduction of a very low frequency. Left: object with variations in density with respect to X-rays. The frequency  $f_0$  is very low; the wavelength  $1/f_0$  is correspondingly long; the amplitude is  $A$ . Right: image of this object. The amplitude of the density is  $B$ ; the contrast (= modulation depth) is  $B/B = 100$  per cent.

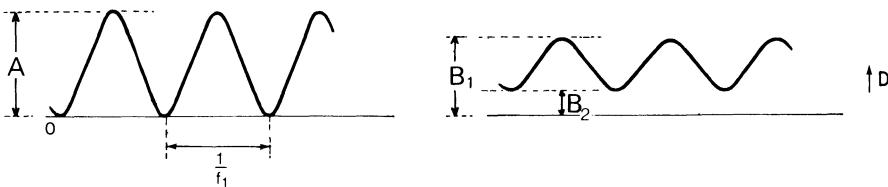


Figure 7.8 Non-ideal reproduction of frequency  $f_1$ . Left: object as in figure 7.7 but with higher frequency,  $f_1$  (wavelength  $1/f_1$ ). Right: image of this object. The greatest density is  $B_1$ , the smallest  $B_2$ . The contrast is  $(B_1 - B_2)/(B_1 + B_2) \times 100$  per cent and is less than in figure 7.7.

A reproduction (or image) of an object with frequency  $f_1$  will also show a sinusoidal pattern which, however, will vary between  $B_1$  and  $B_2$  due to the loss of contrast caused by deviations from the 'ideal system'. The contrast, according to the above definition is equal to  $(B_1 - B_2)/(B_1 + B_2) \times 100$  per cent (figure 7.8). A third sinusoidal object with a still higher frequency,  $f_2$ , in which the variation also rises from 0 to the value  $A$ , will be portrayed as a sinusoidal pattern, which varies between  $B_3$  and  $B_4$ , in which the contrast between  $B_3$  and  $B_4$  is less than that between  $B_1$  and  $B_2$ . The contrast of the image with a frequency of  $f_2$  is therefore smaller than that with a frequency of  $f_1$  (figure 7.9).

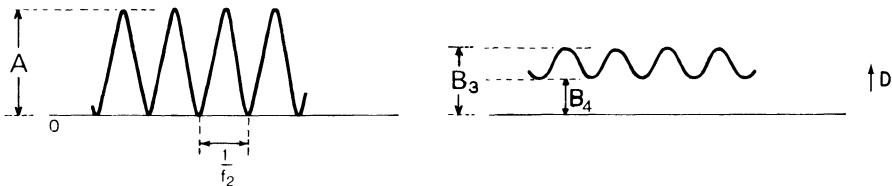


Figure 7.9 Reproduction of a still higher frequency than in figure 7.8. Left: object as in figures 7.7 and 7.8 with a still higher frequency,  $f_2$  (wavelength  $1/f_2$ ). Right: image of this object. The greatest density is  $B_3$ , the smallest density  $B_4$ . The contrast is still less than in figure 7.8.

(N.B.: In figures 7.7-7.9,  $I$ , in the left-hand diagrams, represents the variation in density of the X-rays and in the right-hand diagrams the density in the corresponding images. The modulation transfer function of a particular imaging system describes the loss of contrast that occurs with the 'imaging' for every spatial frequency in the object, whereby the contrast with the lowest frequencies is equivalent to 1 or 100 per cent. The size of the modulation transfer is shown as a curve on a graph (the M.T.F.) with the spatial frequency on the abscissa and the contrast, in percentages, on the ordinate, which is subdivided logarithmically. A characteristic example of this can be seen in figure 7.10.)

In order to be able to measure with ease and speed, the metal grids and similar test phantoms are constructed in such a way that the width and the distance between the metal strips both decrease equally (figure 7.6). In this manner there are many spatial frequencies present in one object and the modulation transfer function can be determined from this.

An advantage of the determination of the M.T.F. is that it provides a decisive answer covering the entire contrast range from 100 to 1 per cent, as opposed to the earlier determination of detail perceptibility. In this way, for example, the

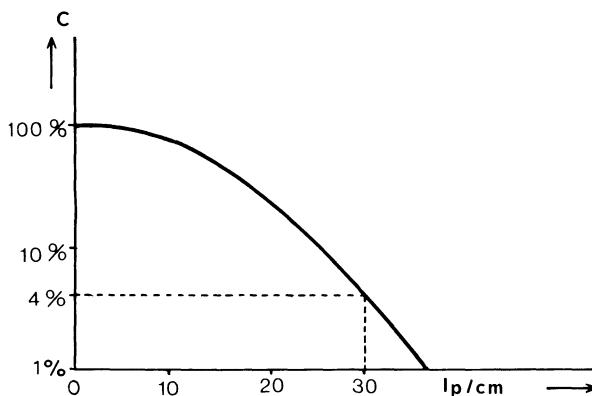


Figure 7.10 Modulation transfer function (M.T.F.) of a sinusoidal pattern with increasing frequency. The contrast is 100 per cent at frequency 0. The curve covers the entire contrast range from 100 to 1 per cent. As the human eye can perceive 4 per cent contrast, a frequency of 30 line pairs per cm would be distinguishable. The frequency (lp/cm) is plotted on the abscissa and the contrast (C) on the ordinate.

contrast sensitivity of the eye can be expressed by means of an M.T.F. curve. From this it is evident that a contrast of 4 per cent under normal conditions of illumination can still be easily perceived. It appears from the curve (figure 7.6) that this is possible for details to 30 periods (thus 30 line pairs) per cm. Thus, every line (a black and a white) has, moreover, a width of  $1/60$  cm = about 0.16 mm. Formerly, this was called a resolving power of  $1/6$  mm.

The most important advantage of an M.T.F. curve is that the M.T.F. can be determined individually for every component of the imaging system, and then combined as necessary. One needs only to multiply the loss of contrast in the various components (always at a particular spatial frequency). The quality of the components, expressed by the loss of contrast, which they introduce, is easily compared in this manner. An individual M.T.F. can be determined for all the factors that determine image quality, such as focus, geometrical enlargement, movement of the object, screens, image intensifier, optical and electronic image transfer, optics and, to a certain extent, the influence of photographs on film and of television. The M.T.F. of the entire system is then the product of the individual M.T.F.'s of these factors. The reverse takes place when one of the factors is left out: the M.T.F. of the entire system is then divided by the M.T.F. of the omitted component. This multiplication and division of M.T.F. is made still simpler by representing the loss of contrast logarithmically on the graphs. In this way, one can carry out multiplication by simple addition and, instead of division, subtraction. The determination of the M.T.F. has proved to be a useful aid for the search for better materials and better methods, such as the search for better luminescent materials for all types of screens, etc. Although the determination of the M.T.F. is certainly not a task suitable for a normal diagnostic radiology department, but belongs in a research and factory laboratory, X-ray personnel should still be familiar with the above facts.

It is a great pity that noise, which influences image quality in a manner that is difficult to define, cannot be expressed in an M.T.F. curve. When predicting detail perceptibility, one should, however, keep the noise factor in mind, and not base

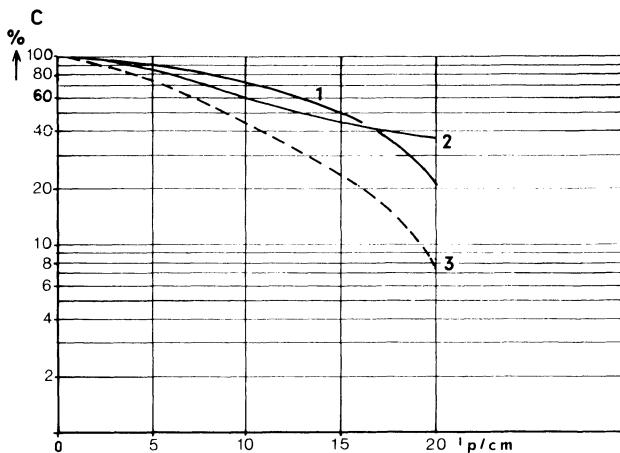


Figure 7.11 Modulation transfer function of a large (full-size) radiograph. Focus-film distance 100 cm; focus 2 mm; focus-object distance 80 cm. The multiplication of the M.T.F. curve for film and screens (1) and the M.T.F. curve of the 2 mm focus (2) produces the resulting curve (3). The ordinate is subdivided logarithmically and indicates the contrast in percentages (= modulation depth). The frequency is shown on the abscissa.

one's determinations on M.T.F. curves exclusively. In figure 7.11 the M.T.F. curves for X-ray photography are reproduced and added according to the technique indicated.

## 7.5 SUMMARY

The above explanations show clearly that the perception of detail on an X-ray image is a complicated and many-sided problem. To summarise, small details will be visible only if a radiograph has good definition and good contrast. Small details are vital if the radiograph is to provide the maximum information.

Definition and contrast are not independent from each other: unsharpness affects the subjective contrast, while an improvement in contrast can lead to a reduced subjective unsharpness.

The concepts, unsharpness and contrast, have been dealt with in chapters 5 and 6. The purpose of the above explanation is to demonstrate the mutual connection between both concepts. These concepts and their relationship are contained in the concept of modulation transfer function (M.T.F.). With low brightness, such as occurs with the conventional fluoroscopic screen, it can happen that objective contrast and sufficient sharpness still do not provide sufficient detail perceptibility, not even after full adaptation. In this case, it is theoretically preferable to increase the brightness rather than improve the contrast and definition. Therefore, the prime requirement of a fluoroscopic screen is high luminous output and not a low intrinsic unsharpness.

Since perception is a physical process, it goes without saying that, apart from the factors related to the materials used, such as choice of focus, screen and film, purely physiological factors such as adaptation, visual power and power of concentration may also play a part.

# 8

## Properties of Fluoroscopic Screens, Radiographic Films, Intensifying Screens and Cassettes

### 8.1 THE FLUOROSCOPIC SCREEN

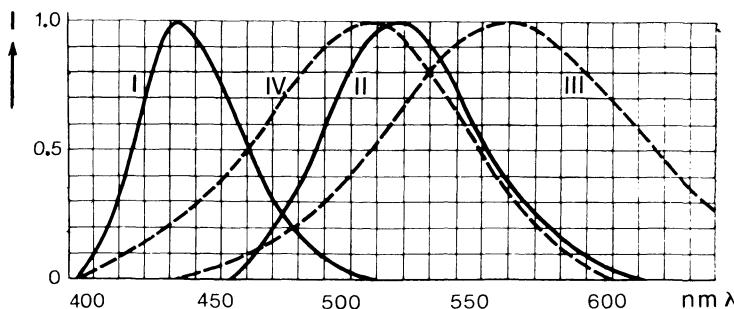
#### 8.1.1 The luminous efficiency of the fluoroscopic screen

In fluoroscopy, or ‘screening’ as it is called, the X-ray image is immediately converted into a visual image on a fluorescent screen. As opposed to radiographic methods, fluoroscopy is a process that extends over a relatively long period of time, usually several minutes, and it therefore entails the risk of exposing the patient to a relatively high dose of radiation. To reduce this risk to a minimum, the luminous efficiency of the fluorescent screen (or fluoroscopic screen) must be as high as possible, that is to say, it must convert the X-rays into the maximum amount of visible light.

The fluorescent material most commonly used for fluoroscopic screens is zinc cadmium sulphide or zinc sulphide, which has the useful property of emitting a yellowish-green light when bombarded by X-rays. Our eye is most sensitive to light of this colour. Figure 8.1 shows the spectral sensitivity curve of the human eye, both for high and low luminance of the field of vision; the high luminance is perceived chiefly by the cones in the retina and the low by the rods. At very low luminances the curve shifts towards the shorter wavelengths and, as may also be seen from the diagram, the spectral distribution of the greenish light emitted by zinc sulphide corresponds fairly well with the sensitivity curve of the eye.

The luminescent layer of a fluoroscopic screen should be thick enough for an optimum amount of the X-radiation to be absorbed and thus converted into light. The layer must not be too thick, as then the light originating in the deeper layers

of the screen would not be able to penetrate the supervening levels to reach the eye. Moreover, this light would cause a great intrinsic unsharpness. For this reason, there is a certain optimum thickness for a fluoroscopic screen. Since the absorption depends on the quality of the incident radiation, it is best to choose an average thickness (usually about 0.5–1 mm) that is suitable for all voltages commonly used in radiology (diagnostic).



**Figure 8.1** Spectral distribution of the light emitted by blue and green luminescent screens and the colour sensitivity of the eye at high and low brightness levels of the image. The intensity of the emitted radiation is plotted on the vertical axis and the wavelength plotted on the horizontal axis. I represents the relative intensity of the light as well as the relative sensitivity of the eye (a top value of 1 is assumed for both). I. Blue luminescent screen; II. green luminescent screen; III. sensitivity curve of the eye at high brightness levels (perceived by the cones); IV. sensitivity curve of the eye at low brightness levels (perceived by the rods). The diagram illustrates that the light emitted by a green screen is well adapted to the sensitivity of the rods; these rods are much less sensitive to the light that is emitted by a blue screen.

In spite of the best possible luminous efficiency at the conventional milliamperages used in screening, the luminance of fluorescent screens is still very low, amounting to a mere  $10^{-2}$  cd/m<sup>2</sup> (1 candela/m<sup>2</sup> = unit of luminescence), which corresponds to the brightness of a landscape seen at night by a full moon. The luminance of the fluoroscopic screen during an investigation of the abdomen is in fact no more than  $3.10^{-4}$  cd/m<sup>2</sup>, that is about 30 times as small. For this reason, fluoroscopy with the use of an ordinary screen is carried out in a completely darkened room. Moreover, the radiologist is obliged to allow his eyes sufficient time to adapt themselves to the darkness, in order to perceive sufficient details of the image on the fluorescent screen; if the eyes are not adapted, hardly anything will be seen during a fluoroscopic examination.

The intensity of the fluorescence is proportional to the intensity of the radiation up to very high values. At still higher radiation intensities saturation point is reached. For reasons of safety (of both patient and tube), continuous high intensities in fluoroscopy are not permissible; 2–4 mA tube current generally represents the limit.

An enormous improvement in luminous efficiency is obtained by using an image intensifier, the principles of which are described in chapter 10.

### 8.1.2 Structure of the fluorescent screen

In fluoroscopy, the radiation emitted from the tube strikes first the patient and then the fluoroscopic screen. The radiologist is situated behind the screen. The fluorescent material, which is coated onto a base opaque to light, is on the side of the screen facing the observer.

#### 8.1.2.1 *The conventional fluorescent screen*

The base of the conventional fluoroscopic screen is usually made of cardboard which is impregnated with a water repellent. Between the base and the fluorescent layer there is a further layer consisting of a white substance, magnesium oxide or magnesium carbonate, the function of which is to enhance the brightness of the image by reflecting that part of the fluorescent light that is emitted backwards, that is in the direction of the base.

The luminescent substance, usually zinc cadmium sulphide, held by a bonding material, contains traces of an activator (for example Cu or Cd) which increases the light emission in the green-yellow colour range. The size of the grains (crystals) is of the order of  $30\text{ }\mu\text{m}$ . However, these crystals are deposited in a relatively thick layer, which makes the intrinsic unsharpness rather high (about 0.6 mm). Phosphorescence is very undesirable, here, the luminescence must virtually all be fluorescence.

Whereas some manufacturers add an organic substance to the luminescent powder to protect the layer from damp and wear, others provide the fluorescent layer with a protective coating. Apart from being moisture-resistant, a coating of this kind also affords some protection against daylight, which, if excessive, can seriously reduce the luminous output of the screen. *All screens which do not have this protective layer should therefore always be shielded against daylight when not in use.*

Since the fluorescent screen does not absorb all the X-rays impinging upon it, the observer is protected by a lead-glass sheet interposed between him and the screen. In most countries there are rules concerning the thickness of this sheet, expressed in lead equivalence. Usually, 1.5 mm lead equivalent is required for voltages up to 70 kV, 2 mm lead equivalent for voltages up to 100 kV, and 0.1 mm extra for every 10 kV over 100 kV.

#### 8.1.2.2 *The screen used in conventional photofluorography*

The luminescent image that appears on the screen of the photofluorographic apparatus is photographed by a photofluorographic camera. In screening for this purpose, one does not view the fluoroscopic image itself and, therefore, spectral emission is not adapted to the sensitivity of the eye but to that of the photofluorographic film (usually sensitive to the blue or violet range). A high luminous efficiency is also desirable for these screens, but here also a suitable compromise must be found between luminous efficiency (thick layer:large  $U_i$ ) and sufficient sharpness (thin layer:lower  $U_i$ ). A certain amount of after-glow on this screen is not troublesome: on the contrary, since the radiation, after a short burst, is switched off, the fluoroscopic image does not move. This after-glow (phosphorescence), causes a welcome extra exposure of the film. As the protective shielding is usually built within the photofluorographic casing, the screen itself is not covered with lead glass.

### ***8.1.2.3 The input phosphor of the image intensifier***

The input phosphor (primary screen) of the image intensifier differs from the conventional fluoroscopic screen. The outermost luminescent layer is applied to a support at the inner side of the glass envelope of the image intensifier. The second layer is applied to the inside of this layer and is in intimate contact with it; this forms the photocathode. The X-radiation causes the creation of light in the luminescent layer, which itself is not perceived, but liberates electrons from the photocathode. Thus, the 'radiation image' is transformed into an 'electronic image'.

The function of the primary screen (input phosphor) is therefore not to act upon the eye or film emulsion (as mentioned in previous paragraphs), but to create an emission of electrons as intense as possible, with as little unsharpness in the electronic image as possible.

In the past, zinc cadmium sulphide (atomic numbers of the elements are taken as 30, 48 and 16, respectively), was used for the luminescent layer as well as for the conventional fluoroscopic screen. Intensive research has now led to the choice of crystals of the compound caesium iodide (CsI) for luminescence. This compound produces a very high luminous efficiency due to the higher X-ray absorption (because of the higher atomic numbers, 55 and 53, respectively) and the greater density with which they can be incorporated within the luminescent layer. The luminescent layer can, therefore, be made thin, whereby the intrinsic unsharpness is much less than that of the zinc cadmium sulphide screens used earlier. The greater sharpness attained hereby has come into its own in photo-fluorography with image intensification and in cinematography especially.

### ***8.1.2.4 The secondary screen of the image intensifier***

The output screen (also called output phosphor or secondary screen or viewing screen) of the image intensifier has the function of transforming the electronic image into a visible image. The electronic image is carried by the electrons, which, after liberation with great speed from the photocathode, move themselves through the vacuum of the image intensifier and strike the output phosphor on the other side of the tube. The energy of the electrons is liberated on collision and causes the screen to luminesce. A mere 1/20 mm, that is extremely thin, luminescent layer is sufficient in this case, as here we are concerned with the absorption of a corpuscular radiation and not, as in the case of the primary screen, with the absorption of X-ray photons (electromagnetic radiation). This means that the intrinsic unsharpness of the secondary screen is very low, so low that it can be disregarded in comparison with the unsharpness that is present in the electronic image (which originates in the primary screen).

The image on the secondary screen (electronically reduced and intensified as regards the image on the primary screen) can be used for:

- (1) viewing with the eye by means of an optical system: fluoroscopy with image intensifier,
- (2) photography by means of an optical system with a photographic or cine camera,
- (3) viewing with a television camera for a direct television image and/or a magnetic image recording (video tape).

### 8.1.2.5 The television screen

The television screen, just like the output screen of the image intensifier, does not have the problem of having to absorb X-ray quanta. It does, however, luminesce in a similar manner, due to the transfer of energy of the electrons during the collision. The luminescent image on the output phosphor of the image intensifier is caused by a complete electronic image. In the case of television, however, the image is transferred by an extremely narrow beam of electrons, the electron beam (this occurs in all television images). This beam of electrons is moved to and fro at tremendous speed, so fast that it strikes each spot of the screen every 0.04 s. It describes a number of horizontal lines in succession, in fact.

It is usual to utilise the generally applied 625 number of lines, although other line numbers are also used. The gradation of brightness (white, black, and a number of grey steps) is accomplished by varying the strength of the beam. It is true that the luminescence of the screen is very fast (practically no phosphorescence), but the slowness of our eye prevents us perceiving the individually moving point of light that is created by the beam of electrons. It is this very slowness that enables us to see the complete image on the screen.

The use of a television system introduces a certain extra unsharpness, by which the screen of the camera tube, the frequency limitation of the connection, and the diameter of the beam of electrons in the monitor are the critical factors. Moreover, the system contributes extra noise—electronic noise—in the image. The final result of a reproduction onto a television screen is always accompanied by a certain loss in perceptible detail. The fact that the television system is capable of specific contrast intensification of the image, can facilitate the perceptibility of adequate details. This does not mean, however, that the below-the-limit details can cross the perceptibility threshold. In general, the X-ray television means improved perceptibility of the larger details, but a loss in the region of the smaller details. In comparison with radiographs (provided that they are of good quality), one will be able to perceive fewer details with an X-ray television system.

## 8.2 THE X-RAY FILM

In diagnostic radiography, both the actual X-ray films (two emulsion layers) and the ordinary photographic type (one emulsion layer) are used. Glass plates, used until the 1920s, have been abandoned completely.

### 8.2.1 Structure of X-ray film

As the film emulsion absorbs only a very small part of the incident X-radiation, which, moreover, passes easily through the base material that carries the emulsion, both sides of the X-ray film are coated with emulsion. The back layer absorbs practically the same amount of energy as the front layer.

The film base formerly used was cellulose nitrate (celluloid), but this had the disadvantage of being extremely inflammable; it has therefore been replaced by cellulose acetate which is non-inflammable, and now especially by a polyester base (safety film). The base of double-coated (or double-sided) film is transparent and normally about 0.15 mm thick. Obviously, the two layers of emulsion must lie

very close together to avoid parallax when viewing. A *bonding* layer, or substrate (substratum layer), ensures that the emulsion adheres well to the base. The emulsion layers are also given a very thin protective coating (supercoating) on the outside so that the film is less easily damaged. The film must still be handled with utmost care. Double-coated films are used in radiography both with and without intensifying screens.

The sensitive layer of a photographic film consists of a suspension of silver bromide crystals in gelatin. The crystals or grains, as they are called, are formed by mixing solutions of bromide salts and silver nitrate to produce a precipitation of silver bromide. By mixing this with a solution of gelatin, the resulting suspension is subjected to a ripening process, during which the silver bromide particles agglomerate and crystallise into the requisite grain size, which determines the ultimate sensitivity of the emulsion. The size of the crystals is chiefly determined by the duration of the ripening process and by the temperature at which it is carried out. After ripening, the emulsion is cooled, and when it has set to a stiff jelly it is cut into shreds and these are washed before being melted again in order to undergo an 'after-ripening' process. During this process the sensitivity is increased considerably, owing to the addition of impurities; a small amount of sulphur, for instance, plays an important part in making the grains more developable. The emulsion thus obtained is finally liquefied and is then applied very uniformly to both sides of the base (with bonding layers) (figure 8.2).

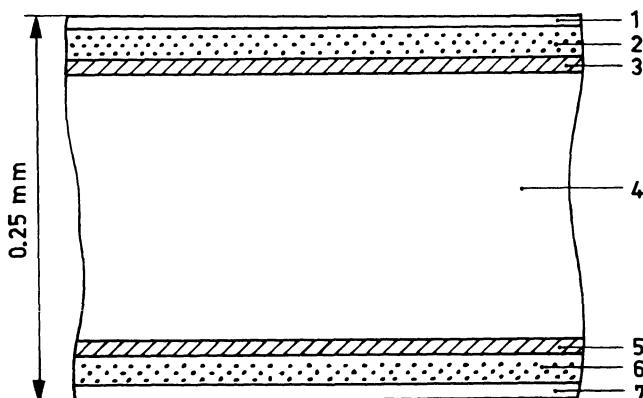


Figure 8.2 Cross-section of a double-coated film. 1, 7. Protective supercoating; 2, 6. emulsion; 3, 5. bonding layer (substratum); 4. base.

### 8.2.2 Photographic density

When the film is exposed to X-radiation the silver bromide particles absorb energy, form a *latent image* and become capable of photographic development. This means that when the 'exposed' silver bromide grains are brought into contact with a reducing agent, they are reduced to metallic silver deposits, the density of which will be greatest at the parts that have absorbed the greatest amount of energy. Silver is naturally opaque and when finely distributed gives the impression of being black. The opacity of the image is greatest where most silver has been

deposited, that is the places that received the greatest amount of illumination.

The *opacity* of a film after development is defined as the ratio of the intensity of light incident upon the film,  $i_0$ , to the intensity transmitted by the film,  $i_1$ .

*Blackening* ( $D$ , density) is defined as the logarithm to base 10 of the opacity; therefore  $D = \log(i_0/i_1)$ .

When the transmitted light is 1/10 of the incident light, the opacity is 10, and the density  $D = \log 10 = 1$ . If 1/100 of the light is transmitted, then the opacity is 100 and the density  $D = \log 100 = 2$ . If 1/1000 of the light is transmitted, then the opacity is 1000 and the density  $D = \log 1000 = 3$ . If all the light is transmitted (the film completely transparent), then  $i_0/i_1 = 1$ , the opacity is 1 and the density  $D = \log 1 = 0$ .

The density depends, of course, on the number of silver bromide crystals reduced to metallic silver. At low X-ray intensities the density is approximately proportional to the intensity. This proportion is valid only if the time of exposure is always constant (the concept 'exposure' will be explained further in section 8.2.5). This is understandable, since every new X-ray quantum affects one or more still unaffected silver bromide crystals. As we've said before, in the case of low X-ray intensities, that is low densities, one might therefore easily compare the X-ray intensities  $i_1$  and  $i_2$  by the ratio of the densities they produce:  $D_1 : D_2 = i_1 : i_2$ .

The total density of a film, however, is the sum of the inherent fog  $F$  (see section 8.2.4) and the density caused by the radiation. The ratio between the density and the radiation intensities is therefore actually  $(D_1 - F_1) : (D_2 - F_2) = i_1 : i_2$ , and in order to calculate the intensities from the densities, the amount of fog must first be known. This simple proportion applies to intensities which produce densities of up to about 1.7. It is no longer valid in the case of high intensities. The density curve begins to bend away from the straight line (shoulder region of the curve). The number of cases where more quanta strike the same silver bromide crystal is considerably increased. Thus the increase in density is less than that of the intensity.

At extremely high intensities the silver and bromide partially recombine when a quantity of silver has already been precipitated, and the result is then a reduced density with additional radiation (phenomenon of *solarisation*).

An instrument for measuring density is called a *densitometer*. A wide range of densitometers are available. These instruments, while differing in design and accuracy, are all based on the same principle, that is the measurement of the transmitted light through the film by means of a photo-electric cell or some other light-sensitive indicator, or by optical comparison with a calibrated scale of greys (a transparent phantom with gradually increasing density).

The density is determined from the ratio between the intensities of the transmitted and incident light. The instrument is therefore often constructed in such a way that a direct reading of the density is possible, since density is proportional to the logarithm of the intensity of the transmitted light and with a certain known intensity of the incident light. The density so measured indicates the total density, including density due to fog. The inherent base density, which, for the sake of convenience, is included with the fog, varies according to the type of light source employed in the densitometer. For instance, a yellow light source will give rise to greater absorption in a blue base and so give a higher density reading than a white light originating from a brighter source with less yellow.

The inherent base 'density' and the 'density' due to fog can be determined as follows. An unexposed and undeveloped film is fixed, thus making it transparent.

The densitometer then measures the density of the base alone. An unexposed film is then developed by the normal method, fixed and its light absorption measured with the densitometer. The value thus found gives the base density plus fog density. The density due to fog alone can then be found by taking the difference of the above two results. For use with X-rays films, a densitometer should have a measuring range to at least density 3.

### **8.2.3 Base density**

As the base never transmits 100 per cent of the incident light, it also contributes to the total opacity or total density of the film. There are two types of base: the *clear base*, which is colourless, and the *blue base*. The density contributed by the clear base is usually no more than 0.06, while that of the blue base may reach a reading of 0.2 on the densitometer, if measured with a yellow light. As has already been mentioned, when determining the real density of a photographic emulsion (that is that caused by radiation), it is necessary to deduct base density as well as fog density from the total density measured. In practice, however, one is concerned with the sum of both densities, that is 'fog'.

The type of base preferred is mostly a matter of personal taste; the image sometimes appears to be brighter and sharper when using a blue-base film, but detail perceptibility is in fact not improved (see also section 8.2.12).

### **8.2.4 Fog density**

It is a familiar phenomenon in photography that if an unexposed film is developed, a certain amount of metallic silver will nevertheless be formed. The density thus produced is known as *fog*, and is equal to the sum of the two densities mentioned in section 8.2.3.

The production of fog is influenced by various factors:

(1) The sensitivity of the film. A sensitive film will as a rule have large grains, and a spontaneous change in the silver bromide grains during storage is more likely than with a less sensitive film. For this reason, sensitive films should never be stored for long periods. On the other hand, less sensitive films can be stored for longer periods. The date at which the film must be considered to be fogged too much, that is, the expiry date, is stamped on each carton (usually in code). It is advisable to use films before this expiry date. Moreover, all films have a limited shelf life and one should always see to it that fresh film is provided. If in doubt, it is advisable to subject a sample to a fog test, that is, by developing an unexposed film in the usual manner but in complete darkness.

(2) Storage temperature is also important. High storage temperature and/or high humidity, encourages fog formation. *Films must therefore be stored in a cool and dry environment.*

(3) Unexposed films must be stored in a place where they cannot be reached by X-rays or by ionising rays from radioactive substances such as radium, cobalt-60, caesium-137, etc. Premature exposure to such radiations would obviously ruin the entire stock of films. One can easily check whether or not the

storage area is rayproof by fixing three non-screen films (partly covered on both sides with lead, in such a way that the free part on one side corresponds with the covered part on the other side) onto a wall inside the storage room, so that they are perpendicular to each other. If, after several months, the images of the lead mats are not shown on the film after development, the room can be considered safe from radiation. If an image does show, then, from the position of the film, the direction from which the unwanted radiation originates can be determined.

(4) The ionising effect of cosmic radiation may also give rise to fog density on films stored for too long a period. This radiation is so hard (so penetrating) that protection against it is practically impossible. However, the intensity is so low that fog density resulting from this is only manifested after long storage periods.

(5) In general, fog density increases when development time is too long or the developer temperature is too high.

The above factors are not the only ones that cause film fog. Different developers can have different effects upon the same emulsion, and can cause varying amounts of fog. Moreover, incorrect darkroom lighting can also lead to fogging.

Although the maximum permissible fog density is not standardised, a value of 0.2 may be used in practice; films with a fog density above 0.25 should be regarded as useless.

### 8.2.5 The characteristic curve

The characteristic curve of a film gives the relationship between the exposure and the resulting density for that film. Figure 8.3 shows an example of such a characteristic curve.

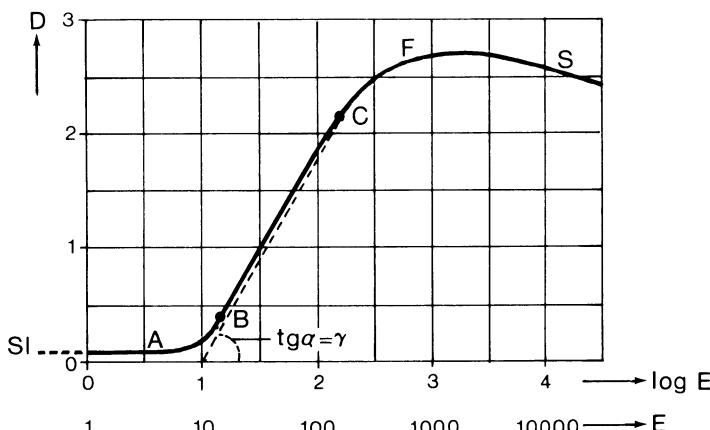


Figure 8.3 The density curve (characteristic curve). The characteristic curve of a particular film shows the relationship between the energy absorbed by the film during exposure ( $E$ ) and the resultant density ( $D$ ). The curve begins at the fog value ( $S_1$ ). The slightly curved portion on the left is known as the toe (A) which passes, via a straight-line portion (BC), into the shoulder (F). After the shoulder the curve falls again, into the region of solarisation (S). The exposure is set out on a logarithmic scale.

By exposure, we understand: the product of the luminous intensity and the exposure time. The exposure ( $E$ ), or rather the logarithm of the exposure ( $\log E$ ), which gives a more useful curve, is plotted as the abscissa and the density ( $D$ ) as ordinate. Density is expressed by the logarithm of a proportion, because the human eye sees, as it were, logarithmically. The difference in brightness between intensities 10 and 100 makes the same impression on the eye as that between 100 and 1000. (This is known as the *Weber-Fechner law*.)

A logarithmic division of the abscissa provides a good range of widely differing exposures, the values 1-10, 10-100, 100-1000, 1000-10 000, etc., being of equal distance on the abscissa.

At an exposure of 0, the density on the film is called the *fog*. This fog, as described in the previous paragraph, represents the sum of the 'base density' and the fog density of the emulsion; the characteristic curve begins at this level.

In the toe area, density increases slowly with an increase of the exposure. There is a definite difference between the characteristic curve produced by exposure to X-rays and that produced by exposure to light. Each X-ray quantum absorbed in the emulsion gives rise to at least one developable grain of silver bromide, whereas an emulsion exposed to light requires a great many quanta of light rays to render a grain developable. The characteristic curve for visible light (III in figure 8.4) begins with a portion practically parallel to the abscissa, and corresponds to the fog level up to a considerable exposure value. At a particular value on the abscissa, called the *threshold value* of the exposure, the curve begins to rise to higher ordinate values. It rises in an almost straight line and later flattens out and finally curves in a downward direction, to relatively lower values. The characteristic curve for X-rays begins at a point on the ordinate which represents the fog (= density at exposure 0) and rises immediately (that is there is *no threshold value*).

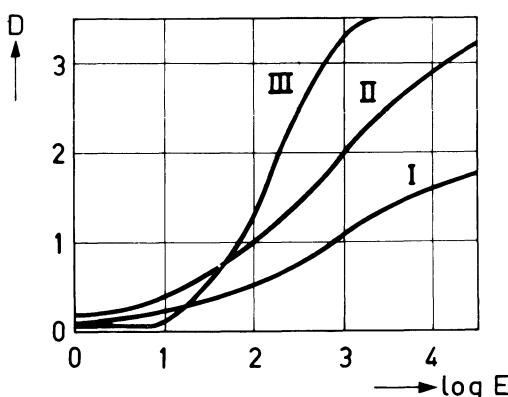


Figure 8.4 Characteristic curves of single- and double-sided photographic emulsions.  
I: Single-coated film exposed to X-rays; no threshold value; curve is rather flat. II: Double-coated film exposed to X-rays; steeper curve. The fog level has been taken to be somewhat higher. No threshold value. III: Double-coated film exposed to visible light of the intensifying screens. The fog level is the same as in film I; threshold value on exposure  $\log E = 1$  and the curve rises steeply.

### 8.2.6 The gradation of film

The slope of the linear part of the characteristic curve is called the *gradation*, *gradient* or *gamma* of the film\*. It expresses the amount of density increase as a function of the logarithm of the exposure.

The numerical value of the gradation at a point on the characteristic curve is equal to the tangent of the angle alpha ( $\alpha$ ) which the line tangent to that point makes with the logarithmically graduated abscissa. Therefore, gamma ( $\gamma$ ) = tangent alpha ( $\tan \alpha$ ). The slope or gradation is usually greatest in the straight line portion of the curve. *When speaking of gradation of a film, one means the gradation of the straight line portion. Gradation is determined at a point on the curve lying at density 1 above fog level.* This point always lies on the straight line portion of the curve (figure 8.5). Gradation 1 corresponds to a slope of  $45^\circ$  ( $\tan 45^\circ = 1$ ). This means that the density increases at the same rate as the exposure.

The more silver bromide contained in the emulsion (whether by means of larger grain size or thicker emulsion layer), the steeper the gradation of the emulsion. An equal exposure renders more silver bromide developable and therefore gives greater density. In practice, however, emulsions that are too thick are avoided, as the developer cannot penetrate the deeper layers sufficiently. An

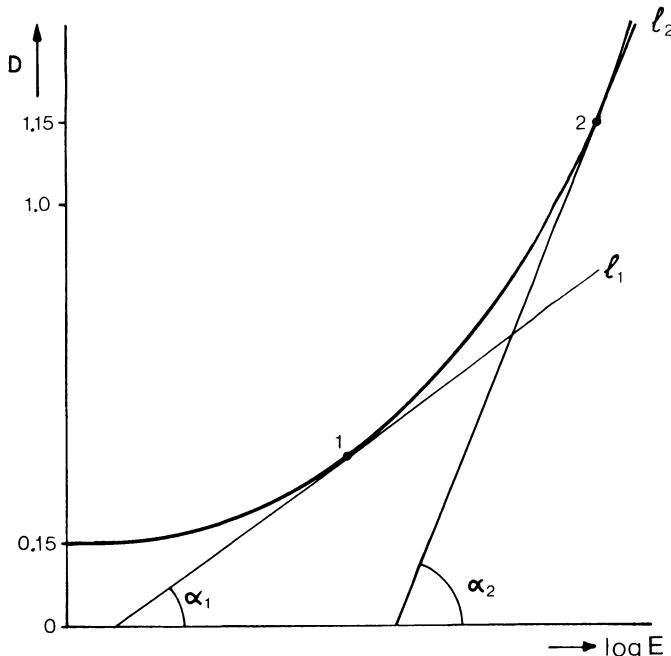


Figure 8.5 Gradation. The lower portion of the characteristic curve is shown in an enlarged form. The tangent  $l_1$  has been drawn through point 1; the gradation at that point is  $\tan \alpha_1$ . The tangent  $l_2$  has been drawn through point 2 (density 1 above fog level). The gradation of this film is therefore  $\tan \alpha_2$ . D, density; E, exposure.

\*Other names, such as *average gradient* and *contrast factor*, both relating to the 'straight-line' portion of the curve, are being increasingly used.

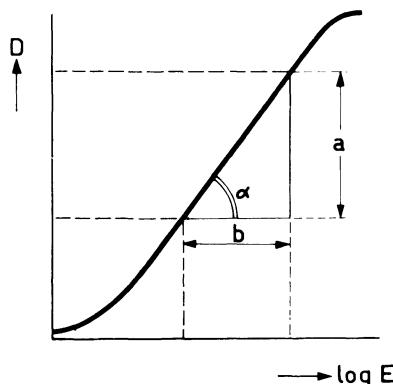


Figure 8.6 Visible contrast. Difference in density =  $\gamma \times$  radiation contrast. A difference in exposure,  $b$ , is converted into a density difference,  $a$ , on the film.  $\tan \alpha = \gamma = a/b$ , thus  $a = \gamma \times b$ .

attempt in this direction, by development for a longer period, would lead to an unacceptably high fog level. The advantage of a higher gradation without the disadvantages described, can be achieved by the use of double-coated films (see also figure 8.6).

*Radiation contrast* is expressed by the logarithm of the ratio between two exposures. The densities caused by these different exposures are different. This

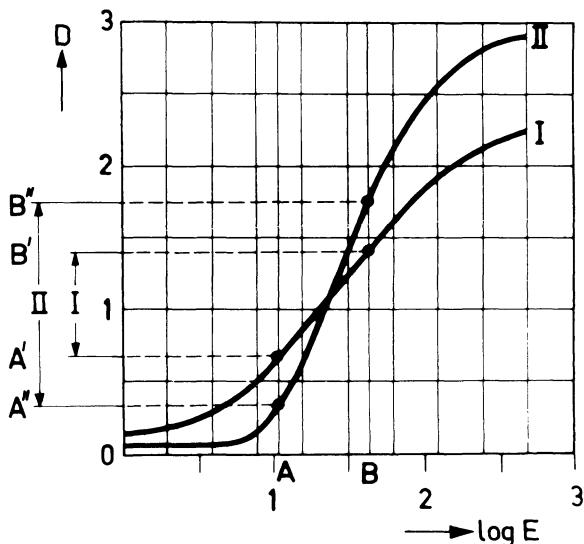


Figure 8.7 Fog, threshold value, gradation. I: High fog density level; practically no threshold value; flat gradation; radiation contrast  $AB$  produces visible contrast  $A'B'$  (= I). II: Low fog density level; high threshold value; steep gradation; radiation contrast  $AB$  produces visible contrast  $A''B''$  (= II).  $D$ , density;  $E$ , exposure.

(visible) density difference is the *visible contrast*. Therefore: visible contrast = gamma × radiation contrast. A comparison of two films with different gradations, based on the characteristic curves, is shown in figure 8.7. The gradation of film II is steeper than that of film I. A difference in exposure, AB, causes a smaller density difference, A'B' (contrast), on film I than on film II, A''B''. A film with a steeper gradation changes a certain radiation contrast (difference in exposure) into a greater density difference than a film with a flatter gradation. In other words: a 'steep' film is 'contrasty'—it enhances contrast—and a 'flat' film gives a less contrasty image.

The non-linear portions at each end of the curve—the toe and the shoulder—have a flatter gradation and are therefore less suitable for radiographic purposes. If an exposure has a value that lies in these regions, then the developed film will show little contrast. In photographic terminology, the lower portion of the curve (the toe) is called the region of under-exposure, and the upper portion (the shoulder) the region of over-exposure, and both cases involve loss of contrast.

In ordinary photography, a photograph with a great deal of contrast is said to be 'hard', whereas a picture with little contrast is called 'soft'. In radiography, an image lacking in contrast is usually caused by a hard radiation, and therefore the image is called 'hard'. This has nothing to do with the quality of the emulsion, but with less radiation contrast when using hard radiation. An image rich in contrast is usually the result of soft radiation and is called 'soft'. (N.B.: Photographically soft is radiographically hard, and vice versa, that is radiographically soft is photographically hard.)

The total density,  $D_{\text{tot}}$ , is equal to the sum of the densities of the first and second emulsions in a double-coated film. The density of the first emulsion reduces on viewing the intensity of the incident light from  $i_0$  to  $i_1$  and the density  $D_1$  equals  $\log(i_0/i_1)$ . The intensity  $i_1$  reaches the second emulsion, which allows  $i_2$  to pass through. Density  $D_2$  is equal to  $\log(i_1/i_2)$ . Hence

$$D_{\text{tot}} = \log(i_0/i_2) = \log(i_0/i_1)(i_1/i_2) = \log(i_0/i_1) + \log(i_1/i_2) = D_1 + D_2$$

In short

$$D_{\text{tot}} = D_1 + D_2$$

On exposure, intensity  $i_1$ , that remains after producing density  $D_1$  of the first emulsion, produces density  $D_2$  on the second layer. Due to the fact that the first emulsion does not attenuate the X-radiation enough to be worth mentioning, a double-coated film receives almost twice the density of a single-coated film, with the same X-ray exposure. Consequently, the gradation of a double-coated film is roughly twice that of a single-coated one.

### 8.2.7 Film sensitivity

The sensitivity of a film can be denoted by the reciprocal of the exposure needed to produce a density of 1 above fog level. The smaller the exposure needed, the greater is the sensitivity of the emulsion. For example, 1/5 of the radiation is necessary if the sensitivity is 5 times as great.

Film sensitivity depends to a great extent on the size and number of the emulsion grains. Coarse-grained emulsions are generally more sensitive, but at the same time their gradation is less steep. Compared with films that have emulsion on one side only, double-coated films, with the same gradation, have an obvious greater sensitivity, for each separate layer can have flatter gradation and therefore be more sensitive. Gradation as well as sensitivity has a bearing on the quality of the film. When two films have equal sensitivity (both have a density of 1 above fog level after identical exposure) the gradation could still differ appreciably. In practical radiography, however, there is little difference in the gradation of films.

In ordinary photography, film sensitivity is denoted by a certain number (ASA or DIN). This is not so in the case of X-ray film; here one speaks of fast (coarse-grained) emulsions, normal emulsions, or slow (fine-grained) emulsions. These are available under various trade descriptions.

### **8.2.8 Film quality**

Both gradation and sensitivity determine film quality, the definition of which follows. Let us consider the relationship between the kilovoltage across the X-ray tube during exposure, the energy of the incident radiation upon the film, the portion of energy that is absorbed by the film, and, finally, the contrast on the film. The higher the kilovoltage across the X-ray tube, the greater will be the intensity of X-rays leaving the tube and the greater the energy that reaches the film. If the tube current is constant, the photographic effect of the radiation increases by the 3rd to the 5th power of the kilovoltage, because, amongst other things, the penetrating ability through the object increases also with an increase in kilovoltage. At the same time, however, a decrease in contrast appears in the X-ray image, due to scatter especially. These two factors, therefore, the greater photographic effect and the lower contrast, have an important bearing on the quality of the film to be used.

We will consider two films, both of which have a density of 1 above fog level after identical exposures, but which differ in gradation. If film A has a steeper gradation than film B, this means that the radiation contrast is converted into greater visible contrast by film A than by film B. If we now wish to produce on film A the same contrast as on B, we must reduce the radiation contrast when making the exposure. This can be done by increasing the kilovoltage across the X-ray tube. The increase in kilovoltage must be such that the radiation contrast is decreased to an extent, which, taking into account the steeper gradation of film A will result in the same contrasts as produced on film B by the original, lower kilovoltage. Film A with its steeper gradation may therefore be used with a higher kilovoltage. However, the photographic effect on the film increases sharply, which means that for the same tube current and exposure time (mAs), film A will be subjected to over-exposure. Therefore, when raising the kilovoltage, we can at the same time shorten the exposure time (lowering mAs) by an amount that will ensure that the original density is preserved. As already mentioned, the photographic effect increases in proportion to a power (greater than 1) of the kilovoltage. The tube current can be decreased by the same amount in direct proportion (the exposure time remaining constant) to the photographic effect. This means a lower total load on the tube for film A, as the load on the tube is of course directly propor-

tional to the first power of the kilovoltage and tube current. If we consider the smaller amount of energy that must be emitted by the anode, in order to produce a density of 1 above fog level, with equal visible contrast as a basis for film quality, then film A is superior to film B.

### 8.2.9 Comparison of film quality

A simple method of comparing two kinds of films in practice is to make a density step-wedge. To do this one takes a radiograph of a phantom, that is an aluminium step-wedge with plates 2 mm thick, the wedge increasing in thickness stepwise, for example from 2 to 36 mm. A block of lead, at least 5 mm thick is adjacent to the thick end of the wedge. The films to be compared are then placed side by side, inside a cassette with intensifying screens, and the aluminium step-wedge and lead block placed upon the cassette, symmetrically in relation to the line dividing the two films. A correct exposure of X-radiation of sufficient energy is applied, whereby the image of the step-wedge and piece of lead is portrayed on both films to be compared (at a certain distance and an exposure time of 0.1 s, for example). Next, the films are simultaneously developed for exactly the same length of time or passed through an automatic processor. By comparing the images on both films, a difference in sensitivity, gradation and fog (under the lead) can be determined with the eye. It is more exact to measure the densities thus obtained with a density meter (densitometer). This method has an imperfection. The radiation emitted by the various steps differs in quality. The average radiation is harder with a greater thickness of a step. In practice, however, this does not appear to be an objection.

If one does not possess such a phantom, then both films may be compared by a simultaneous exposure of the same object, such as a radiograph of a pelvis, thorax, phantom, etc. Because of the influence of gradation, one should compare the films not just at one, but at several, kilovoltages. A lower fog level always means a point in favour for the film examined, as this aids contrast. A test of this kind where also factors such as the composition of the developer tend to play a role, can be considered as approximate information.

Whereas the *Schwarzschild effect* often plays a role in ordinary photography, this may virtually be ignored in radiography (except in tomography). This effect points out the difference in density which an identical exposure can produce on similar films. An identical exposure can be applied for a short time with high intensity, or for a long time with low intensity. The high intensity is more effective; this is expressed by the formula  $D = (\gamma) \log It^p$ , where  $p$ , the exponent, has the value 0.8–0.95. In radiography, however,  $p$  has a value of 1 for X-rays themselves, whereas in practice, the difference in intensity of the visible light created in the intensifying screens is not large enough to cause a noticeable Schwarzschild effect. Only when a certain mAs product is achieved by a low intensity and a long exposure time (tomography) does Schwarzschild effect play a role.

*Sensitometry*, used in light photography, where widely different exposures are chosen and the resulting densities are measured, can only be carried out in radiography with special instruments. Sensitometry then, in comparison with the step-wedge phantom method, is less used. Methods to obtain complete objective data about film quality lie outside the reach of a radiological department's capabilities, and can only be carried out in a well-equipped laboratory.

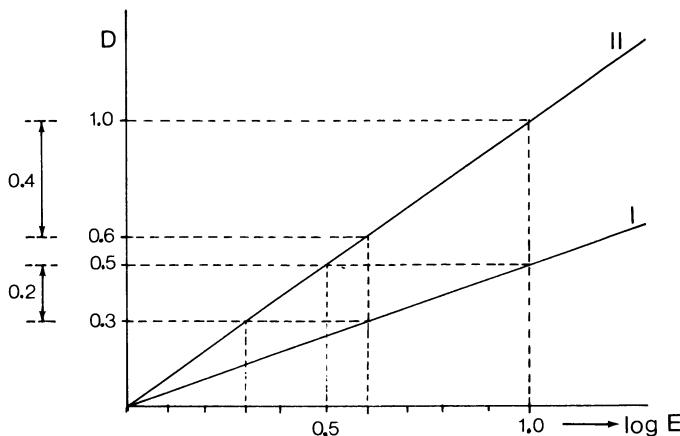


Figure 8.8 Increased contrast and increased sensitivity with double-coated films. If we assume that a given radiation contrast with exposures 1.0 and 0.6 produces the densities 0.5 and 0.3 (visible contrast = 0.2) on film I (with one emulsion), then the second emulsion on film II with the same exposures would add the same densities once again and thereby become 1.0 and 0.6 (visible contrast = 0.4). For the densities 0.5 and 0.3 the double-coated sensitive film would only require low exposure values (that is 0.5 and 0.3). With respect to the single emulsion film, the gradation and the sensitivity are, therefore, doubled. D, density;  $\log E$ , (relative) exposure.

### 8.2.10 Density range, object contrast range and exposure range (exposure latitude)

As we have seen, the useful area in the characteristic curve of a film is that part which rises in a practically straight line. The difference in density between the extreme points of this straight line portion is called the *useful density range*. The correct exposure range is closely related to this. It is limited by the two exposure values, which produce the two ultimate values of the density range respectively, and is called the *exposure range* or *exposure latitude*. The steeper the density curve the narrower is the exposure range, which is determined by the limits of the useful density range. This means: a steeper gradation has a narrower exposure range.

It has already been explained above that, in order to obtain a radiograph which is as distinct and has as much contrast as possible, the portions of the beam, including the ones with the maximum and the minimum intensity, that are emitted from the object are just included within the exposure latitude of the film. If the portion with the minimum intensity falls outside the exposure latitude, then a part of the radiograph will be under-exposed. Likewise, over-exposure is possible when the maximum intensity oversteps the ultimate value. The logarithm of the ratio between the maximum and minimum intensity in the invisible radiation image is called the *object contrast range*. The object contrast range is another method of expressing a certain radiation contrast (see section 8.2.6).

The object contrast range must be smaller than the exposure range of the film if the entire object is to be adequately demonstrated in the places where there is great, as well as in places where there is little, attenuation of X-rays. In radio-

graphy of the human body, the object contrast range is often very large, that is great local differences in absorption. The difficulty in demonstrating the thoracolumbar vertebrae, for example, is that the X-rays in the region above the diaphragm undergo much less attenuation than those below. If one has chosen the correct exposure for the lumbar vertebrae, then the thoracic vertebrae will be over-exposed; if the thoracic vertebrae are correctly exposed, then the lumbar region will be under-exposed (figure 8.9).

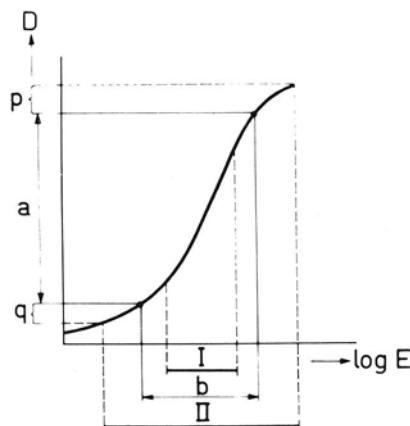


Figure 8.9 Density range, object contrast range, exposure range. The film with this characteristic curve has a density range  $a$ , corresponding to the steep line portion of the curve. An exposure range  $b$  corresponds with this. Object contrast range I falls easily within the exposure range but not the object range II. In this latter case only part of the object will appear on the film with good contrasts. The parts that absorb the least X-radiation will appear in the image in the over-exposed region (p), and those parts that absorb the most X-radiation will appear in the under-exposed region (q).

If the object contrast range covers the exposure range exactly, then the exposure must be chosen very carefully to ensure a good radiograph of the whole object. A small error leaves part of the radiation image (the part with most or least absorption) outside the useful density range, which decreases the image contrasts and makes detail perception more difficult. Since the correct exposure range is narrower for a 'steeper' film than for a 'flat' one, the exposure must be chosen more accurately for a film with a steep gradation.

If the kilovoltage is increased, the object contrast range is reduced as a result, as the difference between the maximum and minimum intensity in the visible image is reduced. The contrasts in the image are thereby also lowered. It depends, therefore, on what we wish to achieve in a given case, whether to demonstrate reasonably well the entire object, with its full range of contrasts—but all of them lowered (that is a low object contrast range)—or whether to show only a part of the object with optimum contrasts (a high object contrast range).

The terms object contrast range, density range and exposure range can be well explained (and remembered) by means of pictures (radiographs) of an aluminium

step-wedge. By the use of various kilovoltages, a large or small number of steps in the density range can be demonstrated. Naturally, the contrast between the steps is less in the first case than in the latter.

Density range and gradation are determined by film and screen combination. These, together with darkroom technique determine the exposure range. In radiography, films with a steep gradation are nearly always used for ordinary radiographs. If, in a given case the exposure range is too narrow to portray the object in question, the voltage can always be increased. By doing this, the object contrast

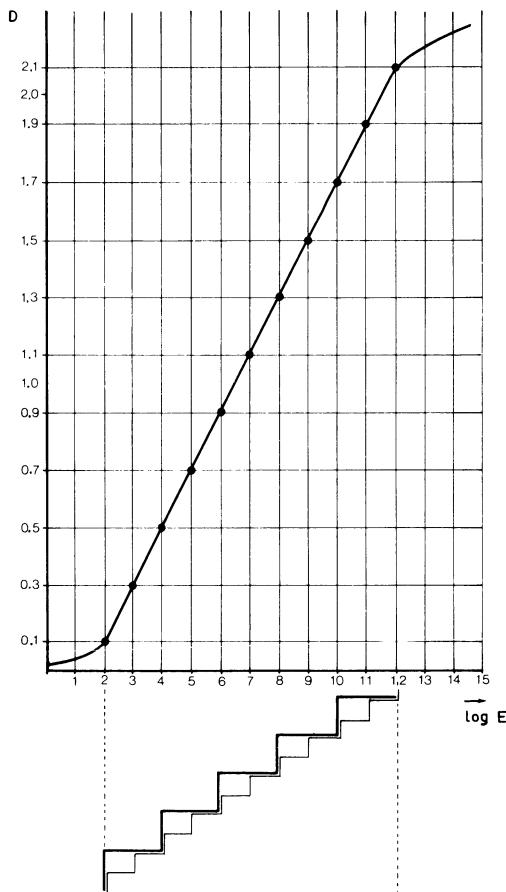


Figure 8.10 Density range, object contrast range when a step-wedge is radiographed. The density curve is diagrammatically reproduced. The density curve shows a density range of  $2.1 - 0.1 =$  visible contrast of 2.0, corresponding to a radiation contrast of  $12 - 2 = 10$ . There is a step-wedge phantom with ten steps. With a radiation contrast of 1 per step the object contrast range is such that the images of the ten steps are precisely shown in the density range (thin lines). With a radiation contrast of 2 per step the object density range is such, however, that only five steps are shown (heavy lines). In the first case a density contrast of 0.2 is available per step. With great object contrast range a (greater) density contrast of 0.4 per step is available; the remaining five steps now fall outside the useful density range.

range is of course decreased. This, for example, is the case in a lateral view of the thoraco-lumbar vertebral region.

Similarly, one could also lower the voltage when using a film with flat gradation, in order to increase the object contrast range, if this is smaller than the exposure range. This makes better use of the exposure range. However, lowering the voltage has disadvantages, in particular, that of an increase in the exposure time and a higher skin dose.

A very efficient method of reducing the object contrast range is the addition of a 'levelling' filter, or wedge filter, on the thinnest part of the object. The thickness of the filter should vary in accordance with the variation of absorption of the object at different sites. To avoid its disturbing image it may be moved during exposure, or its thickness variations made more gradual. Thus, for the thoraco-lumbar region mentioned already a wedge filter is thick on the thoracic side and thin on the lumbar side.

(N.B.: *A narrow object contrast range means low radiation contrasts and a wide object contrast range means high radiation contrasts.*) It is paradoxical and leads to confusion that, amongst other things, in figure 8.10 with a wide object contrast range, only five steps are shown and with a narrow object contrast range ten steps. This means that with a wide object contrast range a *smaller* portion of the object can assert itself and vice versa.

### 8.2.11 Non-screen film

The fact that the use of intensification screens brings with it a greater intrinsic unsharpness has already been discussed (see chapter 5, section 5.3.1).

Very sharp radiographs of bone structure, for example, can be obtained by omitting the intensifying screens. In such a case *non-screen films* are used. Each film of this type is packed in a separate light-tight envelope. The emulsion of non-screen films is basically identical with that of other X-ray films, but the emulsion layer is made somewhat thicker (to ensure more absorption of X-rays, which is in this case the only source of the photographic effect). Because of this thicker emulsion, non-screen films normally need a longer developing time than the films for use with intensifying screens.

Non-screen film is practically exclusively used for thin objects with great absorption differences, such as the extremities, because, on the one hand, the dose received by the patient is much higher (for example 10 times) than when a film-screen combination is used and, on the other hand, these films show a flat gradation because the photographic effect is exclusively due to X-rays. The intensity differences in the invisible radiation image must therefore be great (wide object contrast range).

The side that must face the focus is usually indicated on the envelope. *In order to prevent fog caused by back-scatter from the support used (table, stretcher, etc.), a non-screen film should always be placed on lead or lead-rubber during exposure.* For some time now, few non-screen films are being produced, except for dental films and special films for mammography. The reason for this is that it doesn't pay to produce them any longer, since most radiographs which were formerly done on non-screen films are at present being done with fine-grained intensifying screens. It is true that there is some loss of sharpness, but both the improved contrast and the smaller radiation dose are the deciding factors.

### 8.2.12 Colour X-ray films

An interesting new development, from which the first practical results are still too early to predict a wider application in the future, is the introduction of coloured emulsions in radiology. Whereas ordinary black and white film recognises differences in density only, colour film affords wider possibilities. *Medichrome* film (Agfa Gevaert), which is already available, has a blue colour, a particularly fine grain and a steep gradation. Nevertheless, the exposure range is wide, as the highest and lowest *usable* density give a much wider 'density range' than in the case of black and white films. By fitting special filters and/or a special light cabinet (viewing box), the contrast can be varied appreciably over the entire density range (both increased and decreased), including both the toe as well as the shoulder portion of the characteristic curve. The deadlock, 'high contrasts mean a narrow exposure range', described for black and white films, is thus broken. The adjustable contrasts make a wide exposure latitude possible. Because of this, it would seem that two films (one with steep and one with flat gradation) have been combined into one type as it were.

An advantage of these films is that they can be manually or automatically processed (except for the use of a special developer) and viewed in the normal manner. To come into their own completely, however, a special method of viewing (with colour filters, variable light intensity, etc.) will have to be used. The sensitivity of these films is still much lower than that of the customary black and white films, but their evolution is by no means yet concluded. The improved visual perception with colour vision could also lead to an improved perception of detail.

## 8.3 INTENSIFYING SCREENS

The principle of the effect of intensifying screens has already been discussed (see chapter 2, section 2.3.3).

### 8.3.1 Intensification factor

One of the most important characteristics of intensifying screens is the intensification factor. *The intensification factor is defined as the ratio between the exposure needed to produce a certain density on an X-ray film by X-radiation alone, and the exposure needed to produce that same density on an identical film with the use of intensifying screens.* However, the intensification factor is not a fixed number, but may vary due to several external conditions. The absorption of the X-rays by the intensifying screen crystals depends on the thickness of the object and the kilovoltage employed, that is in general it depends on the hardness of radiation that reaches the screen. At greater hardness (higher kilovoltage), the intensification factor increases. Actually, particular (and different) intensification factor values should be taken into account for particular kilovoltage ranges, and this certain manufacturers do recommend. In practice, this is somewhat complicated and three average intensification factor values have been indicated, which serve as useful informative numbers.

Screens with a high intensification factor require a short exposure time (when

tube current and kilovoltage remain constant). Therefore, screens with a high intensification factor are called *fast* screens and screens with a low intensification factor are called *slow* screens. The intensification factor is intimately related to the intrinsic unsharpness of the intensification screens  $U_i$ . The greater the  $U_i$ , the greater the intensification factor.

The classification of the three types of screens is as follows:

(1) *Slow screens* with an intensification of about 6-7 ( $U_i$  low). With these, as little unsharpness as possible is added to the unsharpness of the radiation image and therefore the visible image is as sharp as possible.

(2) *Universal screens* with an intensification factor of 10-12 ( $U_i$  higher). Of course, this higher intensification is obtained at the cost of increased unsharpness.

(3) *Fast screens* with a very high intensification factor of about 15-20 ( $U_i$  is high). These are used in cases where factors other than  $U_i$  (fast movements, large  $U_m$ , for example) decrease the sharpness most.

In the case of non-screen films the latent image is formed by the absorption of X-rays in the sensitive emulsion; with the use of intensifying screens the latent image is mainly formed by the visible light which the X-rays that are absorbed in the screens are capable of producing.

The light output from the X-radiation absorbed in the screens is not particularly large; at 90 kV only 5 per cent of the incident X-radiation is converted into photographically effective light. The gain in density obtained with intensifying screens is not, therefore, derived from a better exploitation of the energy of the X-ray quanta, but is due solely to the fact that far more quanta are absorbed in a film-screen combination than in a film alone. The intensification factor depends not only on the thickness of the screen, but also upon the energy of the incident radiation and the nature of the luminescent substance, or, in other words, the intensification factor depends upon the wavelength.

With X-ray films coated on both sides (double-coated films) use is made of a pair of screens, a front and a back screen. These can differ to such an extent that the layers of film emulsion receive equal exposure, that is equal photographic density is obtained on both. Thus, the front and back screens must each absorb such a quantity of X-rays that they both emit an approximately equal amount of light towards the film emulsions. Since the radiation that reaches the second emulsion is attenuated by the front screen and also (to a much lesser extent) by the first film emulsion, the intensity reaching the second emulsion and back screen is less. To compensate for this difference the back screen can be provided with a thicker luminescent layer so that the amount of light emitted by the back screen becomes more or less equal to that of the front screen and the exposure of each emulsion is practically identical.

Two screens that belong together in this way are called *combination screens*. The fairly thin front screen must be on the side of the film that faces the tube, and the (thicker) back screen on the side of the film that faces away from the tube. In comparison with a pair of screens of graduated thickness, the combination screens described have the advantage of a little more efficient use of the X-rays and along with this a certain decrease in dose to the patient.

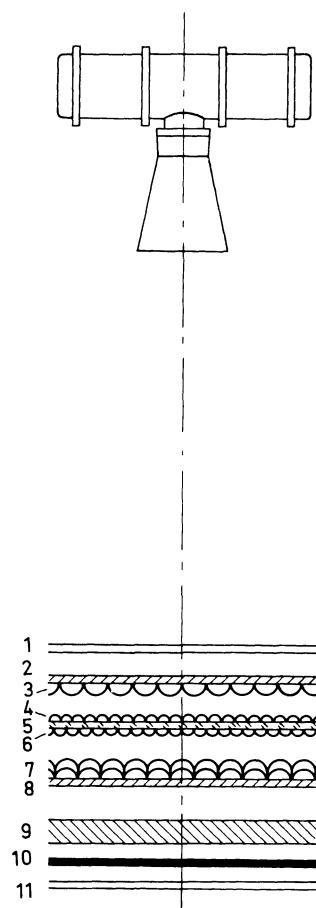


Figure 8.11 Diagrammatic representation of the path of X-rays through the cassette.  
 1. Tube side of the cassette; 2. base of the front intensifying screen; 3. fluorescent layer of the front screen; 4. front emulsion of the film; 5. transparent base of the film; 6. back emulsion of the film; 7. fluorescent layer of the back screen; 8. base of the back (in this case thicker) intensifying screen; 9. felt; 10. lead foil (not always present); 11. lid of the cassette.

#### *Remarks*

- (1) The luminescent layer must not be too thick, since the fluorescent light from the deeper layers would be partly re-absorbed in the more superficial layers and thus not reach the film, and the remainder would cause too large a spot of light over too large an area instead of a point, resulting in an unsharp image.
- (2) The fluorescence produced may be prolonged by phosphorescence, as this after-glow can mean a welcome extra exposure of the film.
- (3) Interchanging the front and back screens has disastrous results. Owing to the greater absorption in the thick screen, now functioning as the front screen, very much attenuated radiation reaches the thinner, less-intensifying screen (now

back screen). The light emission of the second screen is then too low and has little effect on the back coating of emulsion and thereby reduces the total density and the film is therefore distinctly underexposed. The path followed by the radiation in the cassette through the intensifying screens and film is shown diagrammatically in figure 8.11.

The difference in thickness between the front and back screen is of much less importance nowadays with thin (slow) intensifying screen combinations. At present, even screen combinations with a front and back screen of identical thickness are most usual. In this case, the interchanging of front and back screen is of no consequence.

*Graduated screens* are a special form of intensifying screen. They are made in such a way that they do not have the same thickness all over and therefore do not have the same intensification factor everywhere either. The higher intensification is indicated on the outside by a + sign usually, and the lower intensification by a - sign. These screens with a 'graduating' factor (graduated screens) are of great advantage for certain radiographic projections, for lateral spine projections, for example, with high object contrast range and usually too high a radiation contrast. The lowest (-) intensifying part of the intensifying screens is then placed in the area of lowest radiation absorption (for example above the diaphragm), and the (+) side in the area of greatest absorption (below the diaphragm). The least intensifying part of the screen then fulfills the role of the wedge filter, as it were (see section 8.2.10). There are even screens on the market with three different intensifications, graduating from + to - to +, for example.

### 8.3.2 Gradation of the film-screen combination

The density curve of a film shows a steeper incline when it is influenced by visible light than when the densities are produced by X-radiation. This is due to the threshold value that the luminous energy must exceed before the silver bromide grains can be rendered developable. Such a threshold value does not exist for X-rays. Owing to the presence of the threshold value, the grains must first be affected by a minimum amount of light energy before photographic density can be produced. Once this minimum has been reached, small quantities of luminous energy are sufficient to give the necessary chemical stimulus and produce a rapid increase in density. This results in a steep gradation. When the film is exposed to X-rays, no threshold sensitivity occurs. Quite small amounts of energy produce density, which gradually increases as more energy is added. The gradation increases gradually, but the incline, even on its steepest part, is still flatter than that produced by light. Since the latent image on the film is formed mainly by visible light when intensifying screens are used, the gradation of the film-screen combination will be steeper than that of a non-screen film.

### 8.3.3 Detail perceptibility when using intensifying screens

As we have seen, intensifying screens cause an unsharpness in the film image. The degree of this unsharpness is related to the thickness of the fluorescent layer. The thinner the screen, the lower the intensification factor and the lower the unsharpness. Screens that produce the least unsharpness are thus the slowest.

The adverse effect of unsharpness is offset to some extent by the steep gradation of the film-screen combination, for the higher contrasts, in turn, improve the perceptibility of the details. As the scatter of X-rays in the fluorescent layer tends to increase with higher kilovoltages, the unsharpness due to this also increases as a rule. For this reason, it is usual to use thin screens at voltages higher than 100, although the luminous efficiency becomes relatively less, because of the lower absorption of the harder rays. Other luminescent substances with higher absorbing power are also used in this case.

Some manufacturers introduce a light-absorbing pigment, thereby limiting the scattering of the fluorescent light in the sensitive layer and the unsharpness it gives rise to. Naturally, this also involves lowering of the intensification factor.

It is possible, using very thin intensifying screens, to obtain radiographs in which the unsharpness due to the screens is not appreciably greater than that due to the film. However, the intensification factor of such screens is very low (3-5 for example). Their satisfactory sharpness and better contrasts have already caused a great decline in the use of non-screen films. It is already difficult (in some places impossible) to obtain non-screen films.

#### **8.3.4 Exposure for density 1 (one)**

One can determine the radiation dose that strikes the film-intensifying screen combination and is required to produce density 1 after standardised development. For example, density 1 is produced by the use of fast calcium tungstate screens in combination with a fast film with an exposure of  $\frac{1}{4}$  mR (= 250  $\mu$ R) and 100 kV. With the use of screens as mentioned in section 8.3.6, one can even reach this density with an exposure of 0.1 mR (= 100  $\mu$ R) only. The following conclusions can be drawn from these figures:

- (1) The exposure necessary to obtain density 1 for non-screen films is much higher than for film-intensifying screen combinations, especially at higher kilovoltages. Indeed, the intensification factor is in most cases greater with higher, than with lower, kilovoltages.
- (2) The exposure required for a certain density increases with increasing voltages for non-screen films and decreases with increasing voltages for films with intensifying screens.
- (3) The production of density, that is the useful effect of the radiation, varies for different types of screens and at the same time for different kilovoltages.

#### **8.3.5 Comparison between intensifying screens and fluoroscopic screens**

In structure, intensifying screens show much similarity to fluoroscopic screens. Nevertheless, there are several points in which they differ:

- (1) With a fluoroscopic screen it is important that the colour of the luminescent light should be adapted as much as possible to meet the colour sensitivity range of the eye, yellowish-green is the best colour. The colour of light required

from an intensifying screen, on the other hand, is that to which the film emulsion is most sensitive. Since the shortest wavelengths of visible light have the greatest photographic effect, the fluorescent material chosen for intensifying screens is one that emits blue-violet light (figure 8.1).

(2) The intrinsic unsharpness of intensifying screens must be much lower than that of fluoroscopic screens, that is the grains are smaller and the fluorescent layer thinner in the case of an intensifying screen than in a fluoroscopic screen. Sharpness of the image is extremely important in radiography, whereas in fluoroscopy the importance of sharpness is less, in comparison with the importance of brightness and dose limitation.

(3) There should be no, or hardly any, after-glow (phosphorescence) in a fluoroscopic screen, since this would be very disturbing with moving fluoroscopic images. However, there is no objection to slight phosphorescence in an intensifying screen; in fact, it offers the advantage of contributing to the density. In this connection one must be careful that one does not load a cassette, which has been open and exposed to full daylight, immediately with a film. Film fogging could result from phosphorescence of the intensifying screens. Such cases could occur after one has inspected cassettes for specks of dirt or after screens have been cleaned and the cassettes placed in an open position for drying.

The above considerations have led to the choice of different types of fluorescent substances for use in fluoroscopic and intensifying screens, respectively. Zinc sulphide ( $ZnS$ ), or zinc cadmium sulphide ( $ZnCdS$ ), which emits a yellowish-green light, is generally used for fluoroscopic screens, whereas the substance usually chosen for intensifying screens is calcium tungstate ( $CaWO_4$ ), which emits a blue light. For voltages above 100 kV, use is also made of barium lead sulphate ( $BaSO_4$ ,  $PbSO_4$ ), which emits a blue-violet light (see also the following paragraph).

Thus, in summing up, one could say: the eye and film each impose their own demands upon the luminescent material. The fluoroscopic screen should be sufficiently bright and may show a certain amount of unsharpness, whereas, on the other hand, with the intensifying screen, an essential requirement is a high degree of sharpness, even though this means a relatively low intensification factor.

It is clear from the above that, as already mentioned, a fluoroscopic screen is useless as an intensifying screen because of the insufficient sharpness, and that an intensifying screen would be useless for fluoroscopic purposes due to insufficient light emission for the eye.

### 8.3.6 New developments in screen-film combinations

There can be considerable differences between intensifying screens, even if they all have calcium tungstate as the luminescent substance, as a difference in thickness as well as a difference in density of the luminescent layer determine the intensifying factor and the sharpness. There are no more essential improvements expected to calcium tungstate; its properties have been thoroughly examined and are well known. By the application of other luminescent substances it has been made possible to achieve higher intensification. They are, amongst others, gadolinium ( $Z = 64$ ) and lanthanum ( $Z = 57$ ), which belong to the group of rare earths. These elements, in certain compounds, show greater luminescence by X-radiation than calcium tungstate. Therefore they cause a much greater

transformation from X-ray energy to light, by which the intensifying effect is considerably increased. In contrast to calcium tungstate, which emits a continuous spectrum, the new phosphors (the name for luminescent materials) emit a *line spectrum*.

By adaptation of film emulsions to this emission (especially in the short wavelength region), great sensitivities and, therefore, high intensification factors are attainable with preservation and even improvement of detail perceptibility. In combination with the special films described in section 8.2.12, these modern screens can lead to valuable improvements. The saving in dose made possible by the higher intensification deserves our full attention, especially at medium kV ranges.

## 8.4 THE CASSETTE

Radiographs made with intensifying screens necessitate the use of a cassette. The most important function of a cassette is to keep the film and intensifying screens in intimate and uniform contact with each other and to exclude external light.

### 8.4.1 The conventional cassette

A cassette is actually a flat box-like container, consisting of a metal frame and two plates. The front plate (facing the focus) is made of a sturdy material, usually aluminium or a synthetic that can be readily penetrated by X-rays. The back plate, or lid, is made of metal or a synthetic material and is sometimes lined on the inside with lead foil. This lead lining serves the purpose of absorbing the rays transmitted through the film and intensifying screens, thus eliminating back-scatter, which could fog the film. The back plate is further lined with felt in order to hold the screens under uniform pressure and ensure intimate contact between screens and film. Usually, the back plate is hinged on one side and is closed by means of spring-clips. On opening the cassette, the back screen is uppermost and the front screen on the bottom.

If the cassette is suspected of being no longer light-tight, one can load a cassette with a film and expose the closed cassette to intense light for several minutes. If the film shows fogging after development, we know that the cassette is no longer light-tight. The 'leak' is usually local, and shows itself as a black streak at the edge of the film.

Cassettes are often in continuous use and can easily become damaged. Knocks, buckling, or any other form of rough handling will upset the uniformity of pressure between film and screens and so cause cassette unsharpness. Dropping cassettes or knocking them must therefore be carefully avoided. For the same reasons, the spring-clips and hinges should be subjected to regular inspection.

Cassette sizes are specified according to the size of film they are intended to hold. The external dimensions are, therefore, depending on the manufacturer, several cm bigger. Whereas the dimensions are usually in cm, many English-speaking countries still retain (for the time being?) the inch measurements. The most usual dimensions (in cm) are: 9 x 12 cm, 13 x 18 cm, 18 x 24 cm, 24 x 30 cm, 30 x 40 cm, 35 x 35 cm, and 35 x 43 cm. In addition, the sizes 15 x 40 cm and

20 × 40 cm are often used. Still others are used for special purposes; the 30 × 80 cm, for example, is used for radiographs of the complete spinal column. Cassettes that, for example for subdivision of the size, are placed in a particular position (stomach series cassette, etc.), are made with a ridge, etc. They then, more or less, belong to a particular X-ray couch and are used there exclusively.

#### 8.4.2 Cassettes for use with photo-timers

When an X-ray machine is equipped with a device for automatic exposure by means of a photo-timer, then the lid of the cassette must also allow the penetration of X-rays. The intensity left after penetration of the object and film is required to influence the photo-cell and so regulate the exposure. For this reason, the lid must not contain any lead foil or metal strips (such as spring-clips). This method of automatic exposure is being increasingly replaced by the ionisation chamber method (see chapter 14, section 14.6.1), for which no special cassettes are necessary.

#### 8.4.3 Flexible cassettes

It is often difficult (if not impossible) to place the film close enough to the object when using the above-named rigid cassettes as, for example, with certain projections of the neck, shoulder, neck of the femur, etc. For these purposes, there are flexible cassettes with flexible intensifying screens. A satisfactory intimate contact between the screens and the film is assured.

#### 8.4.4 Vacuum cassettes

A special form of cassette is coming into use more and more—the *vacuum cassette*. These are used both with and without intensifying screens. After loading with film, the cassette (actually more like a plastic envelope) is attached to a special instrument (a suction pump), which removes all the air from the cassette and then seals it air-tight. By means of atmospheric pressure, the cassette, film and intensifying screens are pressed together with great force. This force is even greater than that of conventional cassettes. The contact between screens and film attained in this way ensures the optimum sharpness possible for that combination.

#### 8.4.5 Cassettes for roll film

Besides the usual sizes for the 'normal' X-ray films, roll-film, 30 m long and 30 cm wide for example, is also used. This roll is initially contained in a magazine, protected against radiation. From this a certain length is pulled out, clamped between intensifying screens, exposed, and then transported ahead to the receiving magazine. This system is essentially the same as with a roll film in amateur photography: before every further exposure, film advancement takes place. However, as roll film manipulation differs from the usual and is limited to a certain size film, in routine practice it is of limited use, chest radiography, for instance. Particularly since the same size film is required, roll film has, since the beginning of photofluorography, been of optimum importance. It is now possible to cut off

various sizes from a roll film so that, after exposure, they arrive in the receiving magazine and can be handled individually. Some modern X-ray equipment contains this construction as an integral part, the receiving magazine sometimes even opening directly into an automatic processor.

### **8.5 A FEW WORDS ABOUT X-RAY PAPER**

As in ordinary photography, sensitive emulsion for radiological purposes can be applied to paper. In the latter case the base is not transparent, the paper being only single-coated. For application in radiography, the emulsion is fairly thick and is used in combination with one thick intensifying screen, (that is the back screen). The front screen is dispensed with, provided a sheet of cardboard is introduced instead of the front screen to restore the pressure in the cassette and thus avoid cassette unsharpness. Thus, the path of the X-rays through the cassette is: front plate (aluminium)—cardboard—base of X-ray paper—emulsion of X-ray paper—fluorescent layer of the single intensifying screen—base of screen—felt—lead foil—lid of the cassette.

It goes without saying that the contrast is not increased by a double coating in this case, as it is in X-ray films. The gradation of the single-sided emulsion is fairly steep, so that the exposure range is rather narrow. However, if the exposure is precisely chosen, an excellent picture is obtained. The great advantage is its low price. For simple problems such as the determination of the position of bone fragments in the reduction of a fracture, checking the barium residue in the stomach, the extent of a pneumothorax, etc., completely satisfactory results can be obtained. Nevertheless, X-ray paper is being used less and less. The main reason is connected with the complications that arise when the exposure and processing techniques have to be altered from the normal. Moreover, the use of paper is not being stimulated by the film industry.

# 9

## Image Intensification and X-Ray Television

When discussing the fluorescent screen we pointed out that, at the milliamperages normally used in fluoroscopy, the luminosity of the screen is extremely low and that consequently the perceptibility of the details in the image is very poor. The luminosity might be increased by using a thicker screen, but this would increase the intrinsic unsharpness of the screen. Another means of brightening the image would be to increase the milliamperage and/or the kilovoltage, but this would mean an inadmissible larger dose to the patient in both cases. Moreover, a higher kilovoltage would result in an increase in scattered radiation, and so nullify the gain in detail perceptibility.

An increase in brightness is essential, however, in order to decrease, or even eliminate completely, the disadvantages inherent in conventional fluoroscopy. These disadvantages are: the diminished visual power of the human eye at low luminosities, the long time necessary for dark adaptation, the necessity to practice fluoroscopy in complete darkness, and the relatively high exposure rate, resulting in a higher radiation dose to the patient and a higher load on the apparatus.

### 9.1 THE PART PLAYED BY THE EYE IN FLUOROSCOPY

The sensitivity of the eye covers a wide range of brightness\*, namely from  $10^{-5}$  to  $10^5$  Cd/m<sup>2</sup>. The brightness at the upper limits, therefore is ten billion times as large as at the lower limit. Great brightnesses (including the perception of colours) are

\*The unit of light intensity is the candela, (Cd). The brightness is expressed in candela per m<sup>2</sup> (Cd/m<sup>2</sup>). Visual acuity is expressed in the inverse value of the number of arc minutes that can still be seen; therefore, in 1/arc-min. One arc-minute, equals approximately 0.1 mm, seen at a distance of 30 cm.

perceived by the retinal cones, whereas low brightnesses are perceived by the retinal rods. The perception of contrast requires a difference of 4 per cent at great luminosities and of 10 per cent and more at low luminosities. The amount of luminosity that reaches the retina is automatically regulated by the pupil; with a wide pupil diameter the visual perception is less than with a narrow diameter (compare the effect of the diaphragm aperture in a photographic camera upon the depth of field). A visual acuity of 0.1 means that, for good perception, the size of the smallest visible detail should be 10 arc-minutes (or 1 mm at a distance of 30 cm). For such good perception a minimum luminosity of  $100 \text{ Cd/m}^2$  should be available. In conventional fluoroscopy, however, the luminosity is only  $0.001\text{--}0.01 \text{ Cd/m}^2$ , which means that for adequate perception it must be intensified 1000–10 000 times. Apart from this, the eye needs a certain amount of time to build up an image, the so called *integration time*, about 0.1 s, but longer at low luminosities. Table 9.1 below shows the relationship between luminosities, visual acuity and contrast perception.

Table 9.1

Luminance or Brightness ( $\text{Cd/m}^2$ )	Rods and Cones	Adaptation time (min)	Integration time (s)	Pupil diam. (mm)	Visual acuity	Contrast perception (%)
$10^5$	Cones	Blue	?	2	1.2	4
$10^4$	Cones	Green	0.08	2.2	1.6	3 } viewing of
$10^3$	Cones	Yellow	0.1	2.5	1.4	2 } radiographs
$10^2$	Cones	Orange	0.1	2.8	1.0	2 X-ray television
10	Cones	Red	0.15	3.2	0.5	2 image intensification
1	Cones		0.2	4	0.2	conventional fluoroscopy
$10^{-1}$	Rods	50	0.2	5	0.1	
$10^{-2}$	Rods	20	0.25	6	0.07	20 thorax
$10^{-3}$	Rods	15	0.3	7	0.05	45 abdomen
$10^{-4}$	Rods	8	0.3	7.5	—	
$10^{-5}$	Rods	5	?	8	—	threshold value

It is obvious that, if in conventional fluoroscopy of the abdomen, on the one hand, only contrast values above 45 per cent can be perceived and, on the other hand, only details larger than  $1/0.05 = 20$  arc-minutes (20 mm at 30 cm distance) are visible, the examination is justly said to be rather inadequate.

## 9.2 THE ELECTRONIC IMAGE INTENSIFIER

The problem of the poor luminous efficiency of the fluorescent screen has been solved to a great extent by the construction of the *image intensifier* which, with the same radiant energy from the X-ray tube, is able to produce a fluoroscopic image about 1000–10 000 times brighter than can be obtained by the conventional

fluoroscopic screen. There are also intensifiers for visible light and infra-red. The development of image intensifiers sprang from research and technology in the field of electronics, which is closely connected with advances in television.

### 9.2.1 Construction of the image intensifier, intensification factor, conversion factor

Figure 9.1 gives a diagrammatic view of the design of an image intensifier tube. In an evacuated glass envelope (with a high vacuum) a fluorescent screen, which has a spherical curvature, is mounted on a thin aluminium carrier. This is the *primary screen*, also called the *receiving screen* or *input phosphor*. A photocathode is intimately connected to the inside of this fluorescent screen. After penetration of the glass envelope, the X-rays strike the input phosphor and the fluorescent light

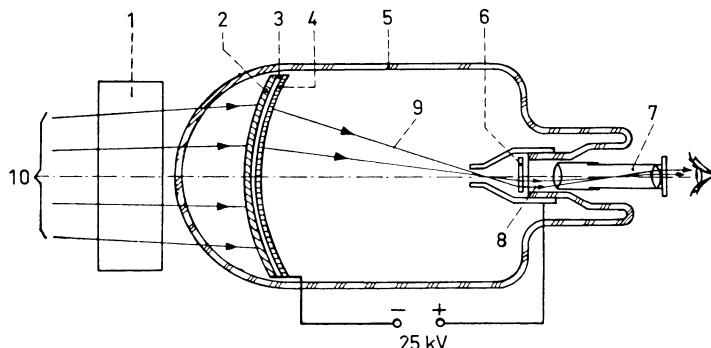


Figure 9.1 Diagrammatic illustration of an X-ray image intensifier. 1. Object; 2. aluminium screen, carrier of the luminescent screen; 3. primary screen, input phosphor or receiving screen; 4. photocathode; 5. glass envelope; 6. secondary screen, output phosphor or viewing screen; 7. optical viewer for the eye; 8. light rays; 9. photo-electrons; 10. X-rays.

produced thereby releases electrons from the photocathode in proportion to its intensity. (The fluorescence which is emitted backwards is reflected by the aluminium carrier and in this way also reaches the photocathode.)

The 'light image' with all its variations in luminosity is thus converted into an 'electron image' with similar variations in density. With the aid of an electric field of suitable size (electrostatic lens), the released electrons are accelerated and converged and focused to the centre of a ring-shaped anode, after which they diverge and strike a second screen—the *secondary screen* or *viewing screen* or *output phosphor*—where they produce the fluoroscopic image (also called anode image), which is reduced in size and reversed in comparison with the image on the primary screen.

Between the photocathode on the primary screen and the anode, there is a potential difference of 25 kV. The brightness of the image on the secondary screen is many times greater than that of the primary screen. The ratio between the luminosity of the output phosphor and that of the input phosphor (expressed in  $\text{Cd}/\text{m}^2$ ) is called the *intensification factor*. The intensification factor of the

present image intensifiers is of the order of 10 000.

A better method of expressing the quality of an image intensifier is to relate the brightness obtained on the output phosphor (in  $\text{Cd}/\text{m}^2$ ) and the exposure rate (in  $\text{mR}/\text{s}$ ) which strike the input phosphor. This relationship is called the *conversion factor*, and has the unit  $(\text{Cd} \times \text{s})/(\text{m}^2 \times \text{mR})$ . As the conversion factor depends upon the quality of the incident radiation, a 'standard radiation' quality is chosen for the definition. For this radiation produced by 80 kV, and filtered by 22 mm aluminium equivalent, is chosen, which results in a radiation quality with an H.V.T. of 7 mm aluminium equivalent. Thus, a conversion factor of 14 (that is  $14 \text{ Cd}/\text{m}^2$  brightness per  $\text{mR}/\text{s}$  exposure rate) is equivalent to an intensification factor of 1000. The conversion factors of present image intensifiers amount to between 50 and 300  $(\text{Cd} \times \text{s})/(\text{m}^2 \times \text{mR})$ . It is understandable that the conversion factor is somewhat dependent on the radiation quality, as harder X-rays produce more light quanta per X-ray photon on the one hand, but, on the other hand, are less absorbed than soft ones. It can not be predicted, therefore, whether the conversion factor will be greater or smaller than when measuring at

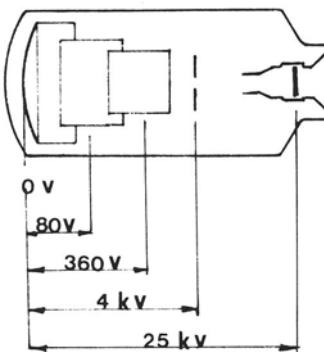
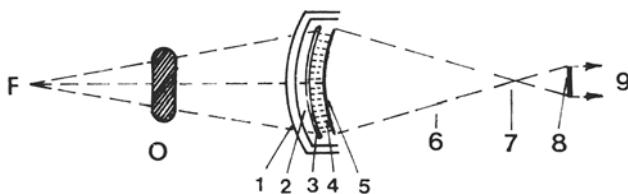


Figure 9.2 Production of the image on the secondary screen.

Above: From X-ray via light ray and electron ray again to light ray. F. Focus; O. object; 1. glass wall of the image intensifier; 2. X-ray image; 3. primary screen (in direct contact with 1); 4. luminescent image; 5. photocathode (in direct contact with 3); 6. electron image sent converging to 7 by means of an electron-optical system; 7. converging point, from here sent to 8 in a divergent manner; 8. secondary screen where 9 is produced; 9. luminescent image (can be perceived visually).

Below: Example of the application of an electron-optical system to send the electron image in the form of a beam from the photocathode to the viewing screen. The secondary screen is 25 kV (positive) with respect to the cathode.

'standard radiation'. The same is true for the intensification factor, as this does not have a constant value either, but is dependent on the radiation quality. In practice, the term intensification factor is used more often than conversion factor, in connection with image intensifiers.

The operation of the image intensifier is again illustrated in figure 9.2 (after Siemens). The X-rays, which originate from the focus F, penetrate the object O and the glass wall of the image intensifier; a relatively small number of X-ray photons are absorbed by the fluorescent (primary) screen, where they liberate a large number of light photons which are absorbed in the photocathode. These, in turn, liberate electrons whereby an 'electron image' is created. By applying a potential difference of +25 kV to the second, much smaller, luminescent (secondary) screen, the electron image is attracted and focused electronically on the way, so that it converges as a corpuscular beam of electrons on the middle point of a ring-shaped anode, from where it diverges and strikes the secondary screen. This luminesces by the conversion of kinetic energy of the electrons into light photons, so that a visible image is created, which can be perceived by the eye by means of some optical device. Thus, one has the following successive stages: behind the object an (invisible) X-ray image, behind the primary screen a light-ray luminescent image (which, however, is not used for viewing, but for the creation of electron emission), behind the photocathode an (invisible) electron image, and finally, behind the secondary screen (viewing screen) a visible luminescent image (light-rays), which is viewed.

### 9.2.2 The production of image intensification

The intensification of the brightness of the luminescent image on the input phosphor (*image intensification*) is not produced directly, but via an electron image, which is created in the photocathode. The contrasts of the luminescent image cause local differences in the density of electrons. This electron image is affected by two factors while the electrons are attracted through the anode:

(1) The acceleration of the electrons in the electric field. A potential difference of about 25 kV is applied between the photocathode and the viewing screen. The acceleration of the electrons by this electric field increases their kinetic energy considerably, so that they give rise to a much greater fluorescence of the secondary screen (for example 40 times greater than in an imaginary case without acceleration).

(2) The electronic reduction of the image. By concentrating the beam of electrons on a screen which is smaller than the photocathode, the amount of energy transferred per unit area onto this screen becomes greater, in fact, inversely proportional to the ratio of the surface areas. If, for example, the diameter of the primary screen is 10 times as great as that of the secondary screen (a reduction factor of 10), this means that the area of the primary screen is  $10^2 = 100$  times larger than that of the viewing screen. The electron energy produced by the primary screen (photocathode) is thus squeezed on to 1/100 of the area, so that the brightness is increased by a factor of about 100.

These two effects combine to give the total image intensification. Using the figures given above, a total image intensification of  $100 \times 40 = 4000$  is produced.

Strangely enough, the increase in brightness caused by the reduction of the image area by the electrostatic lens is not lost when the image on the viewing screen is again enlarged to its original size by means of a viewer or other optical system.

The explanation for this is due to the fact that by optical re-enlargement of the image onto the viewing screen by means of a mirror or lens system, the pupil of the eye lets a greater portion of the light that is radiated by the image pass through, because the pupil can approach the image more closely, as it were. In this way, the cone of light, which has the image point as top and the pupil as base, receives a greater vertical angle and, as this occurs in proportion to the enlargement (apart from a lesser light absorption in the optical system used), no brightness of the image is lost.

This different behaviour on enlargement or reduction by electronic-optical and purely optical methods is a consequence of Abbe's law of optics, which lies outside the scope of this book.

### 9.2.3 Variable image intensification

In a 'simple' image intensifier there is a definite reduction factor which indicates the ratio of the diameters of the primary and secondary image, when these completely occupy the primary and secondary screen, respectively. Both the reduction and brightness intensification are expressed by this. If the primary screen has a diameter of 25 cm and the secondary screen a diameter of 2.5 cm, then the reduction factor is 10 and the electron-optical contribution to the image intensification amounts to  $10^2 = 100$ . In modern image intensifiers, the electron-optical reduction can be adjusted in two or even more steps; the two-step image intensifier has received excellent reception in practice. By altering the electrostatic potential difference on the electrodes, which determines the convergence of the beam of electrons that come from the photocathode, one can arrange, for example, that not the whole of the primary screen, but only its central portion,

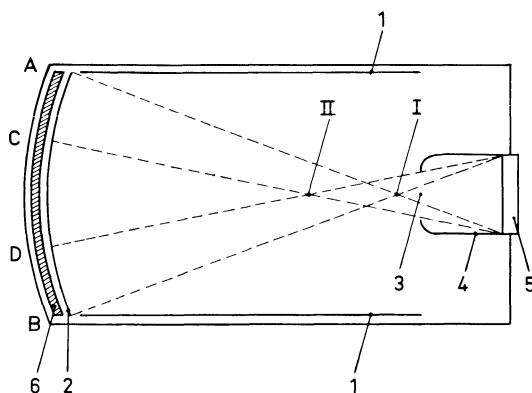


Figure 9.3 Electron-optical enlargement in a variable image intensifier. By altering the electrostatic voltage of the focusing electrodes (1) the convergence of the stream of electrons from the photocathode (2) to the opening (3) in the anode (4) can be changed. By convergence at point I, the entire primary screen (6) is shown from A to B on the secondary screen (5). By convergence at point II from the central portion of (6), from C to D, only this part will be shown on the entire secondary screen (5).

is shown on the secondary screen (figure 9.3).

If, in an image intensifier with a diameter of 25 cm, only the central circular area with a diameter of 12.5 cm is shown, then the reduction factor is decreased to  $12.5:2.5 = 5$ , instead of the original factor of 10. It is clear that the details of this central portion will be viewed in twice the size (linear) as the first. This is called *electron-optical enlargement*. At the same time, however, the brightness is reduced by  $2^2 = 4$  times (as the secondary screen receives only electrons from one-quarter of the original area). To obtain the same brightness as initially, the exposure rate (intensity) will have to be increased fourfold. In general we can say: *With variable image intensifiers, the exposure rate necessary (for equal brightness), or the exposure necessary (for equal illumination), is inversely proportional to the square of the (linear) reduction factors, and directly proportional to the square of the enlargement factors obtained.* Figure 9.3 shows the diagram of a two-step variable intensifier. Usually, an automatic brightness stabiliser is incorporated into the modern variable image intensifiers, so that, in our example, by switching to the electron-optical enlargement 2, the radiation intensity is automatically increased four times. In practice, this electron-optical enlargement is made use of more frequently than radiological enlargement, but they are sometimes combined\*.

Variable image intensifiers are usually named according to the diameters of the fields of the primary screen that can be portrayed. In the above example, the image intensifier with a diameter of 25 cm and an enlargement factor of 2, is therefore a 25/12.5 image intensifier. The 10 inch/6 inch (= image intensifier 25/15) is also common. If one indicates the reduction factors, then these would be 10/5 and 10/6, respectively.

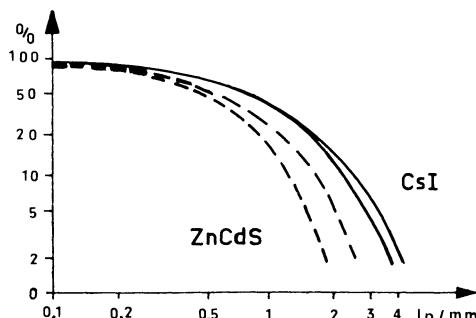


Figure 9.4 Examples of the resolving power of a variable 23/13 cm image intensifier (M.T.F. curves). The contrast is plotted on the ordinate and the frequency (in line pairs per mm) is plotted on the abscissa (logarithmically). The lower solid-line curve represents the M.T.F. for a CsI image intensifier for the entire 23 cm diameter field. The top solid-line curve represents the M.T.F. for the electron-optically enlarged central 13 cm diameter field with somewhat better resolving power (4 line pairs per mm). The dotted-line curves represent the same, for the (now obsolete) ZnCdS image intensifiers.

\*In principle, radiological enlargement still remains in its separate position, as details are enlarged, but not the interfering background; moreover, contrasts are improved. With electron-optical enlargement, on the other hand, both the details and the background are enlarged (as happens when viewing through a loupe), and contrasts are not improved.

The M.T.F. curves which illustrate the great detail perceptibility in modern image intensifiers (with caesium iodide screen, see chapter 8) are shown in figure 9.4 (with continuous lines). Their superiority to the earlier zinc cadmium sulphide screens (dotted lines) is immediately apparent. The lower continuous line represents the M.T.F. of a variable 23/13 image intensifier with its entire 23 cm field performing. The upper curve represents the M.T.F. when the central field with a diameter of 13 cm is electron-optically enlarged. In this latter case, a resolving power of 4 line pairs per mm was even exceeded.

#### **9.2.4 Quality of the intensified image, brightness, definition and contrast**

The greater brightness of the viewing screen makes it unnecessary for the eye to be rigorously adapted to darkness; one can always begin viewing at once. Moreover, one can carry out screening examinations during operations such as surgical operations. However, in order to keep dosages to a minimum, one should be careful not to have the illumination of the room too bright. One can adapt one's eyes by darkening the examination room. The image is then still bright enough to allow the cones in the retina to take part in the viewing process, which improves perception of contrast.

At high brightnesses, unsharpness plays a more important role than at low brightnesses of a normal fluorescent screen, where perception is carried out by the rods and one's vision is not acute; quite coarse unsharpness in the image is then of no importance\*.

The intrinsic unsharpness of the image intensifier is composed of several factors which include the intrinsic unsharpness of the primary and the secondary screen which has already been described in section 8.1). The primary screen cannot be thin as it must absorb X-ray photons; the secondary screen only has to stop particles (electrons) for which a thickness of 50  $\mu\text{m}$  is quite sufficient (resulting in an almost negligible unsharpness,  $U_i$ ). It is true that the geometric unsharpness can be decreased by using a small focus (which is possible, since with image intensification less X-ray intensity is required and a small focus would not have to be overloaded) but, because of the relatively great unsharpness of the viewing system, this improvement of the  $U_g$  does not make a significant difference. Foci of 0.3 and 0.6 mm are quite capable of withstanding loads normally used in fluoroscopy and, moreover, both are used in radiological enlargement technique (see chapter 12).

As far as contrast is concerned, one cannot expect improvement in contrast with the use of image intensifiers; on the contrary, the electron image has less contrast than that presented by the fluorescent image on the primary screen ( $\gamma = 1$ ). Moreover, some losses occur en route to the secondary screen due to scatter, so that the secondary screen is not only bombarded with electrons of the image that is being transferred from the primary screen, but also by scattered

\*A practical demonstration of the great improvement in the observation of detail in fluoroscopy with image intensification may be seen by the fact that people who need spectacles for reading can see the image on a conventional fluorescent screen, with its low brightness, just as well without spectacles. With the image intensifier, the reader immediately notices his defective vision, which he corrects by means of his glasses or by some other optical means.

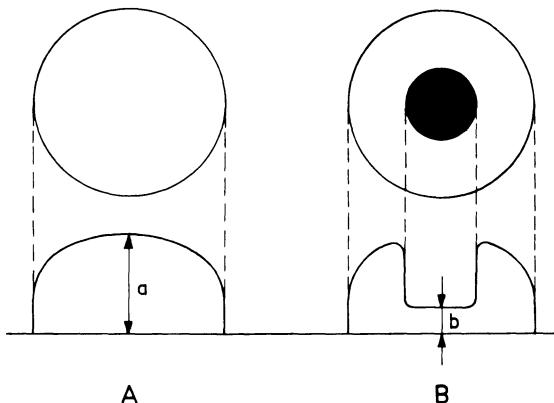


Figure 9.5 Loss of contrast in an X-ray image intensifier.

A. The brightness,  $a$ , of the primary screen without absorbing object.

B. Image of a lead disc which covers 10 per cent of the primary screen surface. The brightness in the shadow of the image is not zero, but still has a value of  $b$  as a result of scattered electrons. This means loss of contrast.

electrons, resulting in loss of contrast. This loss in contrast is illustrated in figure 9.5: the image of the lead disc shows less contrast than would be the case without scatter. Thus, loss of contrast in the image intensifier depends very much on the construction of the tube and especially on the position and action of the auxiliary electrodes inside (electronic lenses), which must form the electron beam and prevent them leaving their prescribed track. However, one can nullify the loss of contrast in the image intensifier and even obtain greater contrasts than that of the radiation image by photographing the image on the output phosphor. As we already know, an increase of contrast is obtained by a gradation ( $\gamma$ ) greater than 1, and this can be made use of by choosing a suitable film. Also, by reproduction via television, one can, within certain limitations, increase the  $\gamma$  and so compensate, or even over-compensate, for the loss in contrast within the image intensifier.

Alas, the detail perceptibility with image intensification is also adversely affected by *noise*. This phenomenon occurs when using low X-ray intensities, which one can afford to use when using an image intensifier.

### 9.2.5 Fundamental limitation of detail perceptibility, photon fluctuation, photon noise

The photons (quanta) in an X-ray beam follow each other in a completely irregular sequence, as one can ascertain when listening to the irregular clicking of a Geiger counter. The number of quanta per unit time varies and fluctuates around an average value. On the viewing screen of the image intensifier these fluctuations are visible as a teeming mass, which, by analogy with radio engineering, is called noise, or more specifically, *photon noise*.

The conveyance of information from the object via the image intensifier to the eye is carried out in consecutive phases by different types of photons, namely X-ray photons, light photons, photo-electrons and again light photons, respect-

ively. The number of quanta in the various phases differs considerably. For instance, one X-ray photon releases several hundred light photons. It is a physical fact that the fluctuation of photons is relatively greater when the number of photons per unit time is small. As this fluctuation contributes to the ultimate noise, it is important to know in which phase the number of quanta conveying the information is at a minimum. By using an image intensifier, the intensity of X-rays and thus the number of photons which come from the patient is low. A portion of these photons is absorbed by the receiving screen, producing light photons, and it is therefore this part that participates in the conveyance of information. It is this phase, the one where the photons of radiation image are absorbed by the receiving screen, that is characterised by the lowest number of photons. It follows that the intensity of the stream of photons in this phase (proportional to the tube current in mA when the kV is constant) determines the magnitude of the noise and thus the minimum level of information on the viewing screen. Greater intensification of brightness (for example by means of greater electron-accelerating voltage or by use of a receiving screen which absorbs the same amount, but luminesces more intensely per absorbed photon) will yield no better detail perceptibility. This situation is similar to that in optical magnification, where the resolving power of a lens system cannot surpass a certain value and where further magnification is 'void', that is does not result in greater perceptibility of detail. This means that there is no point in increasing the brightness amplification without limit in the image intensifier since, with the very low X-ray energy then used, the quantum noise would be so great as to 'drown' the image.

Moreover, one can say, in general, that the contrast has virtually disappeared if the radiation contrast that enters the image intensifier is but weak, and has a photon fluctuation of this magnitude. *Therefore, in practice, contrast in the image intensifier is not visible if it is not at least three times as great as the photon fluctuation.* Brightness intensification of very high values is possible (factors of 12 000 and more). As we've already said, the X-ray intensity must have a certain minimum value, so that the radiation image does not drown in the noise. This minimum intensity would lead to over-radiation of the image with use of film and/or television camera, when using such high brightness intensification (that is such a high intensification factor or, what is the same thing, a very high conversion factor). By weakening the light that is emitted from the viewing screen by, for example, an adjustable optical diaphragm, one can remove so much light so that it is possible to maintain the X-ray intensity on a level where the noise remains acceptable.

There would be no point in throwing away the dearly won brightness amplification in this way, if it were not for the fact that it can be useful for electron-optical enlargement of the intensified image in the variable image intensifier. With these image intensifiers, one can adjust the electrostatic lenses by varying the voltage, so that only the photo-electrons originating from the central part of the input phosphor can be directed onto the whole output screen, enlarging the central portion.

If this central part of the photocathode is, for example, half the total width, then its area is only one quarter of the total, and when this is projected onto the entire secondary screen the brightness of the latter is also reduced to a quarter. If the light diaphragm in the optical system is opened twice as wide, we get the enlarged image of the same brightness as the unmagnified image without increasing the X-ray intensity. Naturally, one should also collimate the X-ray beam by means of the tube diaphragm.

Another advantage of a very high initial intensification factor is that the tube has a longer useful life (ageing diminishes the intensification factor).

It is obvious that it is of great importance that the image intensifier has made possible both improved detail perceptibility and the use of decreased X-ray intensity. The latter means an important saving in patient dosage.

### 9.3 LIGHT INTENSIFICATION

There is another system that increases the brightness of the fluorescent screen which, unlike the X-ray image intensifier, is situated outside the tube itself. The principle of this brightness intensification is as follows: the image obtained on the fluorescent screen is projected in reduced form, by means of an optical system (lenses and/or mirrors), onto the photocathode of a light intensification tube. The construction of a light intensification tube is the same as that of the X-ray intensification tube, except that the photocathode in the light intensification tube receives the image of visible light from outside. The electron image is conducted towards the anode (which is provided with a viewing screen) and there produces a more intensely luminous image; this is entirely similar to the operation in the X-ray image intensifier. The disadvantage of this system is that during the transition from the first image (on the fluorescent screen) to the second image (on the photocathode), losses occur because only a small portion of the fluorescent light is used. This differs from the situation in the X-ray image intensifier, where nearly all the light photons produced in the primary screen influence the photocathode. Therefore, when the first image is reduced, extremely high luminous intensity and a sharp distinctive optical system must be used. For this purpose, the concentric mirror system, developed by Bouwers, is used in the well-known 'Oude Delft' light intensifiers (Cinelix and Delcalix). The light intensity of the optical system used in these intensifiers can be adjusted to  $f/0.68$ . The great advantage in using the light intensifier is that the size of the primary image can be reduced to the size of the photocathode in the light intensifier tube by purely optical methods. Therefore, it is only necessary to construct a light intensifier tube of one size. The diameter of the primary screen in the Cinelix and Delcalix is 32 cm.

In general, the saving of radiation dosage, as well as the progress in image quality with respect to conventional methods without brightness intensifiers, is less with light intensifiers than with X-ray image intensifiers. Also a practical disadvantage of the light intensifier in comparison with the X-ray intensifier, is its great size and weight.

### 9.4 METHODS OF VIEWING THE 'INTENSIFIED' IMAGE

There are several methods of viewing and recording the image on the output phosphor of the image intensifier (or light intensifier). Besides direct viewing, there are the possibilities of television. The recording of the images can be done photographically on small-size film (70 and 100 mm) or by means of cinematography on film (16 and 32 mm), whereas it is also possible to record the television

image onto magnetic tape (video recorder). Direct viewing is possible with the aid of some sort of optical system (in its simplest form, a monocular viewer) which allows one to see the image in its normal size as well as right way up (and no longer reversed).

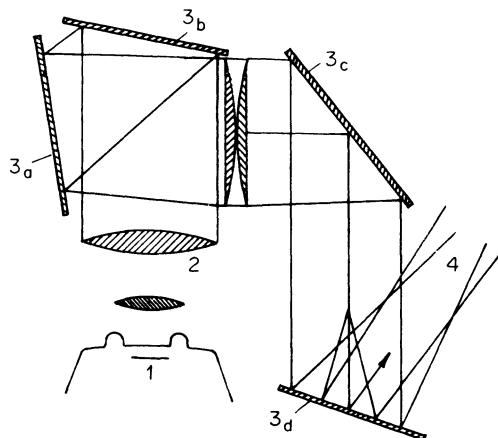


Figure 9.6 Example of an optical viewing system of the secondary image intensifier screen. 1. Secondary screen of the image intensifier; 2. optical system (the emerging rays are parallel); 3a-c. reflecting mirrors; 3d. revolving mirror, reflecting a larger image on one side than on the other; 4. exit pupil, large enough for binocular observation. By folding mirror 3d out of the way the concave mirror enlarges the image, whereby the exit pupil becomes smaller (monocular observation).

A better system of perceiving the image on the viewing screen is by means of a system of lenses and mirrors (figure 9.6). The great advantage of the latter is that one can view the image from a different position and in a different direction (by turning the mirrors to the desired direction), and not only in the long part of the tube, as is the case in the simple viewer optical system. Therefore, the investigator can choose his position more freely in relation to the patient. He can be closer to the patient, which is useful when palpating, etc. Moreover, with such an optical system, another lens or mirror can be added which, by switching it into the path of the rays, allows one to see a more enlarged image of the entire secondary screen. In the latter case, the beam has become narrower, as it were (narrower exit pupil), preventing (at short distances at least) binocular viewing; one must perceive the image monocularly which, generally speaking, is more tiring. Most commonly, *indirect viewing* of the secondary screen is carried out, and then usually by means of television.

## 9.5 TELEVISION CAMERAS IN RADIOLOGY (X-RAY TELEVISION), VIDEO SIGNAL

The X-ray image intensifier made the gaining of sufficient brightness in fluoroscopy possible. In general, it was only used when its combination with television was introduced. The X-ray television consists of a television camera tube, which

is attached to the output phosphor of the image intensifier, a so-called television chain, and one or more television screens, also called *monitors*. In the television camera the various light impulses, which come from the image on the fluorescent screen, are transformed into electrical impulses, which together form the *video signal*. This signal is transferred, amplified and transformed into an image made visible upon the television screen by the television chain.

In X-ray departments, one uses a closed-circuit television chain, that is the video signal is brought to a nearby monitor via a cable. This differs from ordinary television, in which the signal is transmitted via radio waves and received with aerials. The *medical television chain* differs also from ordinary, general television in other ways. The great advantages of indirect viewing by means of television are that

- (1) the observer can choose a position which is independent from that of the patient or the image intensifier,
- (2) several persons can observe simultaneously (possibly by using several monitors in other rooms),
- (3) the images can be recorded (video recording),
- (4) the image can be modified (reversed from negative to positive, or left to right, harmonised, etc.),
- (5) one can follow the action while making cine recordings.

The reproduction of the image depends, among other things, on the strength and quality of the video signal, and in this respect there are differences between the two well-known types of television cameras, the *Vidicon* and the *Plumbicon*.

#### 9.5.1 Image-Orthicon tube

The initial tube, the Image-Orthicon, has fallen pretty well into disuse. This type was very easily damaged, heavy and expensive, and almost too sensitive in combination with the modern image intensifiers. This type of tube is now only used in the Delcalix in an improved form (the *Isocon*).

#### 9.5.2 Cameras with a Vidicon tube

In the *Vidicon tube*, use is made of the photoconductivity of selenium. Under the influence of light and approximately proportional to its intensity, a thin layer of selenium, which has been charged beforehand, is discharged in localised areas. The differences in electric charge thus form a kind of electrostatic image, which is scanned by an electron beam which, in its turn, is modulated according to the individual components of the image and so results in the video signal.

The construction of a Vidicon tube is fairly simple. This type of tube, however, is slow in operation, due to the non-instantaneous reaction of the photoconductivity of the selenium. This may cause persistent overlapping of images of fast-moving organs or instruments (heart catheterisations). An advantage of this persistence is that the quantum noise also overlaps, so that a certain amount of blur enters into the background pattern; this is less disturbing than a background of sharp details. As the Vidicon has a  $\gamma$ -value of 0.6, the contrasts are reduced;

this is a disadvantage on the one hand, but, on the other hand, greater radiation contrast can be picked up, and this is an advantage. In conclusion, the Vidicon is more robust (and cheaper) than the other types of cameras. Its main advantage lies in the excellent image of non- or slow-moving objects achieved at lower tube loads and with lower patient dosage, generally speaking, than can be accomplished with conventional fluoroscopy.

### **9.5.3 Cameras with a Plumbicon tube**

The principle of this tube is the same as that of the Vidicon tube, but with lead instead of selenium. Philips were successful in constructing a tube with low inertia, reacting almost instantaneously, called the *Plumbicon*. The Plumbicon has a somewhat steeper gradation (thus gives images with greater contrast) and has proved to be especially suitable in combination with X-ray image intensifiers for application where extremely fast movements must be perceived via the television (for example angio-cardiograms). The television images of the fluoroscopy are free from afterglow and rich in contrast. As far as the disadvantages are concerned, interfering noise (which here is not blurred out, as was the case in the Vidicon), and because of the higher  $\gamma$ -value (= 1), the sometimes too high contrasts and over-radiation of the image must be mentioned. Moreover, the price is relatively high. The sensitivity of the Plumbicon is not high, so that connection to an image intensifier is essential.

The following summarises the characteristics of the television cameras described:

*Vidicon*: With use in combination with an image intensifier; low exposure rate together with blurring of noise, afterglow.

*Plumbicon*: With use in combination with an image intensifier; high exposure rate together with noise, no afterglow, good contrasts.

### **9.5.4 Image transfer from the secondary screen of the image intensifier to the receiving screen of the television camera**

Image transfer from the output phosphor of the image intensifier or light intensifier to the input phosphor of the camera tube is achieved by:

(1) A lens system, consisting of a so-called base lens (or collimator lens) and a camera lens, which together form a *tandem lens optical system*. The base lens has its focal plane in the output phosphor, so that the rays emitted from there are parallel (figure 9.7). These parallel rays are converged to the focal point of the camera lens, which is situated in the input phosphor of the camera. The advantage of the parallel rays between the two lenses is that by means of a mirror, their direction can be changed. If this mirror is semi-transparent and hinged, then part of the light may go straight on in the original direction, another part being reflected in the desired direction. A disadvantage of the tandem lens optical system is that a certain amount of *vignetting* is apparent, that is the edges are shown with less light intensity than the central portion.

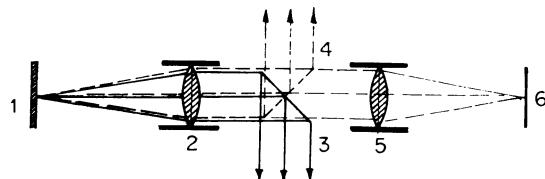


Figure 9.7 Tandem lens optical system. 2. Base lens, attached to the image intensifier and focused onto the output phosphor (1). The parallel rays that are emitted are directed onto the camera lens (5) which is focused onto the input phosphor (6) of the camera. In the section 2–5 the rays can be entirely or partially bent sideways in direction 3 or 4 (dotted lines) by means of a folding mirror.

(2) A *fibre optical system*. Here the coupling is brought about by hair-thin glass rods, which are arranged parallel to each other in a regular pattern. The light that enters one side of these glass rods is reflected against its walls several times and undergoes practically no weakening. Thus, the light that appears on the secondary screen of the image intensifier is transferred to the corresponding area of the input phosphor of the camera tube with only slight losses. In this way, the image is divided amongst the many parallel fibres and is led through them. The image exhibits no vignetting and the light transfer is excellent (figure 9.8). It is obvious that interconnection of mirrors is not possible, as in the tandem lens optical

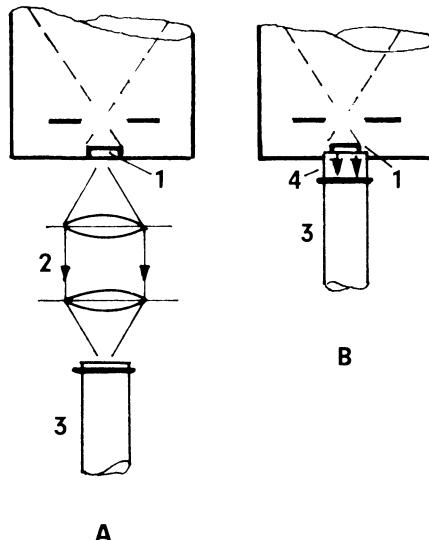


Figure 9.8 Image transfer from the secondary screen of the image intensifier to the television camera.

- A. Image transfer by means of a lens optical system (tandem).
- B. Image transfer by means of a fibre optical system. 1. Output phosphor of the image intensifier; 2. tandem lens optical system; 3. television camera (Vidicon or Plumbicon); 4. fibre optical system.

system, and that this fibre optic system is only suitable for direct coupling of the image intensifier and the television chain. The latter has the advantage, in practice, that its construction is shorter (which can also be seen from figure 9.8).

### 9.5.5 Image distribution

By means of semi-transparent mirrors in the parallel light beam between the lenses of the tandem lens system, several image presentation systems can be connected simultaneously. This is done by means of an *image distributor*, or image divider, which (depending on its possibilities) is called a two- or three-channel image divider. The switching from one channel to the other is also possible with this. Usually, one of the channels is intended for the fluoroscopy and then receives 90 per cent of the incident light; 10 per cent is then allowed to pass through the semi-transparent mirror to the other channel, to which a camera is attached, which does not function during the actual screening. In view of the fact that the exposure rate that is used during fluoroscopy is low, this 10 per cent would be insufficient for the taking of films anyway. By switching the mirror out of the way, the proportion can be reversed, so that 90 per cent is made available for the recording channel and 10 per cent for fluoroscopy. As during the actual taking of films a much higher exposure rate is switched in, 10 per cent of that is quite adequate for the viewing of a fluoroscopic image, which now can be done simultaneously, that is at the same time as the taking of film(s). This fluoroscopic image is of excellent quality because it is produced with a higher exposure rate (and therefore with much less quantum noise).

With a three-channel image divider (figures 9.7 and 9.9) two channels can be used for different recording apparatus (for example a cine camera and a 70 mm camera). It is especially important in cine recording that it is possible to see the images one is recording via fluoroscopy. In practice, one usually sees the two-channel system, where the main channel is used for recording (single, series or cine) and the side channel for the television camera.

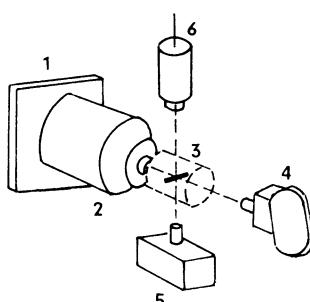


Figure 9.9 Three-channel image divider. In the parallel (light) radiation of the tandem lens optical system a revolving mirror, which allows 90 per cent of the light rays to pass through and reflects 10 per cent can allot 90 or 10 per cent of the available light to both the central and the side channel, according to choice. 1, 2. Image intensifier, attached to the stand; 3. tandem lens optical system with fold-away mirror; 4. cine camera; 5. 90 (100) mm camera; 6. Vidicon (or Plumbicon) television camera.

### 9.5.6 Information transfer by means of the television camera

The image received by the television camera is transformed into an electronic signal, the *video signal*. In the camera, the image which has caused localised variations in charge is scanned by an electron beam which moves with very high speed from left to right and top to bottom across the receiving screen of the camera tube.

#### 9.5.6.1 Information transfer to the television monitor

The video signal is amplified and conducted to a television monitor, where it is again transformed into a fluorescent image.

With a television system of 625 lines per second (here, for convenience sake, the same 625 lines per second have been chosen for this 'closed' circuit television chain as is used for the 'ordinary' television) the image is 'written' as lines from top to bottom, with great speed.

The extreme speed with which the image is 'written', and the inertia of our eye, is the reason that we always see the whole image on the monitor and not a rapidly proceeding line pattern. An adjustable amplification of the video signal enables us, within certain limits, to alter both the brightness of the image and the contrast ( $\gamma$ -values); this is well-known from using ordinary television. Much use is made of both these possibilities, especially contrast improvement. However, contrast improvement does make quantum noise somewhat more interfering.

However, amplification also carries with it *electronic noise*, or *amplification noise*. This is produced in the first stage of the video signal amplifier. With correct adjustment of the television chain, this electronic noise can be limited to a very low level. One can perceive amplification noise when the X-rays are switched off when, of course, the quantum noise disappears. Electronic noise has a finer structure than quantum noise; the latter shows a more coarsely grained aspect. The magnitude of quantum noise (dependent on exposure rate) is completely different, in principle, from the magnitude of electronic noise. The first is a fundamental physical phenomenon, and can be modified with the exposure rate. The latter is related to the electronic design of the video-amplifier and can be limited by the specialised engineer at the time of installation; it is strongly influenced by the position of the contrast regulator.

#### 9.5.6.2 Information transfer to magnetic tape (video recorder)

In addition to sending the video signal to a monitor, it can also be supplied to a recording system (*video recorder*). For the latter, often magnetic tapes or discs are used as recording equipment. The electronic signal produces a magnetic image on the magnetic tape, which in turn can be played back, transformed into an electronic signal, and made visible on a television monitor. It is a well-known fact that many television programmes (for example a football match) do not show happenings that occur at that moment, but are played back from magnetic tapes, which have been recorded beforehand (therefore, during the actual football match). This reproduction is therefore 'play back' and not 'live' (terms which are commonly used in this connection).

Likewise, it is possible to 'pick off' the tape recording from the video signal that goes to the television monitor, by which one can simultaneously view the image directly, and record it for 'play back' later, and so view the image a second time (or more). Progress has made possible that one can derive slow motion images as well as 'stills' (and reverse the direction so that the images run backwards) from the magnetic tape.

#### **9.5.7 Brightness stabilisation in the image intensifier and television image**

When using image intensification, with or without X-ray television, the great difference in brightness that occurs, due to difference in absorption by the object, such as turning the patient, or by changing from the thorax to abdomen (or vice versa), is felt to be interfering. One would continually have to adjust the mA and/or kV manually. This complicates the examination for the person examining, and threatens to distract his concentration from the medical aspects. In view of this, an automatic brightness stabiliser has been developed, so that the brightness of the viewing screen of the image intensifier remains constant. There are two methods of stabilising this brightness. One is based on measurement of the brightness of the output phosphor of the image intensifier by means of a photo-cell. By the other method, the television chain is not only used as intensifier and conveyor of the video signal, but also as a measuring instrument, that is it measures the magnitude of this video signal, which is again directly based on the brightness of the output phosphor.

With both methods, the brightness of the output phosphor is regulated during the examination by continually passing on the beginning of a change to the X-ray generator, where the mA and/or kV are adjusted, so that the brightness becomes the same again. If the brightness of the secondary screen is constant, the exposure rate on the primary screen is also constant. Obviously, the magnitude of the quantum noise is then also the same during the whole examination.

The brightness level of the image (and its associated amount of quantum noise) can be adjusted, and this is related to the X-ray intensity that enters the image intensifier, that is the radiation that leaves the patient. This exposure rate usually has a magnitude of the order of 10-100  $\mu\text{R/sec}$ .

Brightness stabilisation is particularly of great importance in the case of television, because the exposure latitude of a television camera tube is much less than that of the image intensifier. Namely, without stabilisation, a little too much brightness could easily lead to over-illumination of the image, so that details can no longer be seen.

According to choice, one can let the stabilisation eye of the television chain look at either the whole viewing screen (where, for example, also the very bright area outside the patient contributes to the stabilisation level) (*large field stabilisation*), or at a small area (central portion of the viewing screen) (*small field stabilisation*). In this way, a large field stabilisation with the thorax, where the lung fields determine the brightness to a great extent, gives too light an image of the spinal column, whereas the small field stabilisation, where the central portion with the spinal column determines the measurement, procures an excellent image of the spinal column, but the lung fields will be too dark.

When the stabilisation eye looks at a very dark field, whether it be the large

field or the small (for example when there is a great deal of barium in the image), then the X-ray intensity would increase to undesirably high values (to the detriment of both the patient and the X-ray tube). To prevent this, an upper limit setting (for example 2 mA maximum in fluoroscopy) of the electrical value is possible. With regard to the quantities that can be adjusted, formerly, the tube current could only be altered. At present, it is possible to adjust the mA and kV jointly. This creates a much greater area of adjustment and does not require separate manual regulation of the kilovoltage.

### **9.5.8 Automatic exposure control in image intensifier photography**

Besides the ionisation chamber (well-known in ordinary, large film radiography), use is also often made of the photo-cell of the fluoroscopic stabilisation (see section 9.5.7) in image intensifier photography. Adjustment of exposure with practically no inertia is essential for the changing situations that present themselves (such as turning the patient) and both systems can fulfil this requirement. Manual correction and adjustment is here practically excluded. After sufficient illumination, the photocell or ionisation chamber terminates the exposure (we won't go into the technical aspects at present).

With the photocell this is similar to the automatic exposure control in conventional fluoroscopic image photography, where the photocell 'looks' at the illuminated screen. This exposure registration (and termination) can also be achieved ionometrically.

The choice of dominant field portion, or 'dominant', as it is called, is important (with phototiming, the whole field or the central portion only). Also, with the increasing application of image intensifier image photography (for example with the 70 or 100 mm camera), this automatic exposure control is used.

### **9.5.9 Various size image intensifiers**

Problems in construction pose certain limitations to the dimensions of the primary screen in X-ray image intensifier tubes. The primary screen is always round in shape and in the first image intensifier introduced into radiological practice had a diameter of 12.5 cm. This small field, by its very nature, limits its use in practice as one can only gain a total impression of a large object (for example the whole thorax) with difficulty. Since then, larger image intensifiers have been manufactured with diameters of 15, 17.5, 20, 22.5, 25 and even 35 cm. At present, the 15 and 22.5 (25) cm types are the most useful\*.

The choice of a particular size image intensifier depends on the purpose for which it is to be used. For use during surgery (reduction of fractures under fluoroscopy, etc.) the small size has a sufficiently large viewing field (as one views a small area only), and due to its smaller dimensions would be easier to handle (under operating tables, etc.). In cardiology, on the other hand, a larger field is desirable, so that the whole heart can be seen at the same time, if needed,

\*One still hears people speak of 6 and 9 (or 10) inch image intensifiers; this is quite superfluous and undesirable. It would be more logical and better from a mathematical aspect if this tendency were reversed, that is that the English measurements were expressed in metric units.

(while, of course, one will always collimate to as small a field as possible, (for example 9 cm  $\times$  9 cm, during a heart catheterisation); the 22.5 and 25 cm sizes are very well suited for this purpose. The same is true for investigations of the stomach and intestines. However, this limitation to a 25 cm diameter primary screen is still a handicap, especially since, due to the divergence of the beam of radiation, the portrayed object is still smaller than this size. Exposures with the 70 (and 100) mm film (with or without the rapid series technique, see chapter 12) and X-ray cineradiography, the portrayal of larger object parts may be desirable or necessary. This, for example, is the case in simultaneous arteriography of both kidneys, cranial vessels, etc. In these cases, a larger field size should be made available\*. One then usually falls back on the large size films, such as radiography with a rapid sequence cassette (A.O.T. or some such construction, see chapter 12, section 12.9.11).

#### **9.5.10 Influence of image intensifier size on quality**

When the entire primary screen of the image intensifier is used, then the information that the video signal must convey in different size image intensifiers, is approximately proportional to the square of the ratio of their diameters. Therefore, an image intensifier with a 30 cm screen will present four times as much information to the video signal as would an image intensifier with a 15 cm screen.

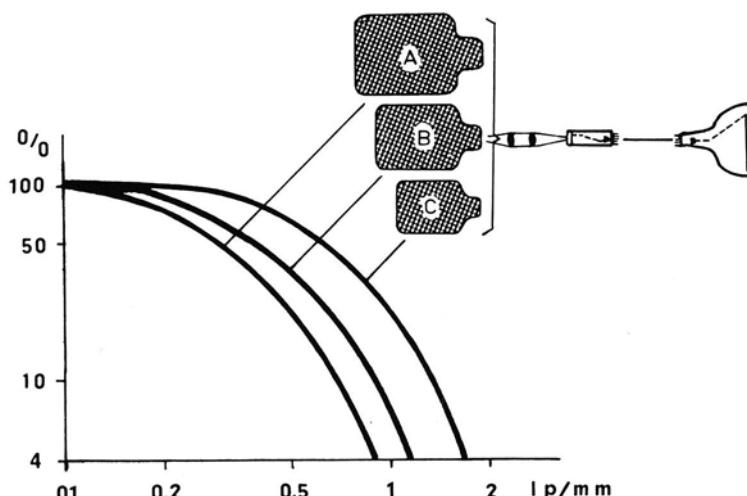


Figure 9.10 Examples of image detail in three image intensifier television chains with input phosphors of different sizes (according to Haendle, Röntgenpraxis), expressed in their M.T.F. The contrast is plotted on the ordinate from 100 per cent to (the just barely perceptible) 4 per cent; the number of periods per mm (frequency) is plotted on the abscissa. The left-hand curve is related to a 30 cm image intensifier (A), the middle curve to a 25 cm image intensifier (B), and the right-hand curve to a 17 cm image intensifier (C). The fact illustrated here continually arises: the smaller the size of the image intensifier (all other factors remaining the same) the better the M.T.F.

\*A new type of 35 cm image intensifier has been shown at the Congress Exhibition, Rio de Janeiro, 1977.

Obviously, in the smaller size the reproduction of detail is better, which is expressed in the M.T.F. (see figure 9.10).

In conclusion, we should remember that the M.T.F. of the whole image intensifier television system results from the multiplication of the individual components of the M.T.F. curves (or by adding their logarithms). This is shown diagrammatically in figure 9.11. From such a representation, one can clearly see in which component of the chain, and for which spatial frequencies, improvement prevails above others. In component 6 there is almost an optimum situation; in component 1 (the image intensifier itself) the limitation lies at about 3.5 line pairs per mm.

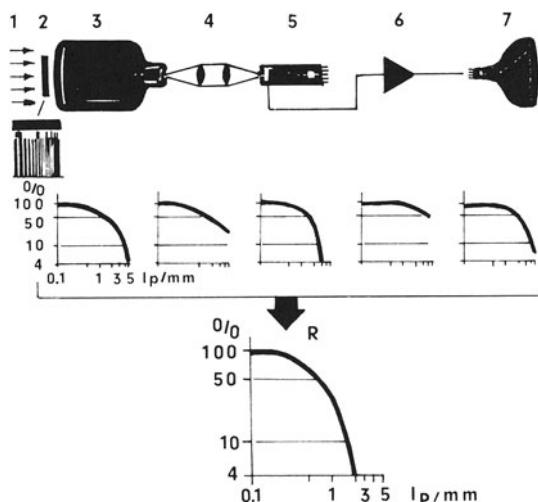


Figure 9.11 Representation of the M.T.F. of an image intensifier chain as a whole and of its component parts (roughly diagrammatic). 1. X-rays; 2. test phantom; 3. image intensifier; 4. tandem lens optical system; 5. Vidicon television camera; 6. television channel; 7. television monitor. The M.T.F. values are given underneath and together these give the M.T.F. for the entire system, represented by the resultant R.

By the introduction of a new component in the chain, such as another primary screen, for example, one can, by comparing its M.T.F. with the M.T.F. of the old component, see immediately whether there is improvement and, if so, in which area. In this way, it has become obvious that for certain spatial frequencies, the M.T.F. of 70 mm films (with modern image intensifiers) can be better than that of a large size film; in other words, that the 70 (and 100) mm camera results can not only equal the resolving power, but exceed that of large radiographs.

The evolution of image intensifier television is still not concluded; on the contrary, there are still great advances to be expected, both in the area of greater resolving power, ways of diminishing dose, and perhaps less interference from quantum noise.

# 10

## Processing Technique

### 10.1 THE PROCESSING ROOM

The part played by the processing room in the X-ray department is extremely important, for it is here that one works with sensitive and costly material and has the responsible task of turning a latent image into a clearly visible image. No matter how well an X-ray department is equipped and how accurately a film has been exposed, a faulty processing technique can completely spoil a result and so nullify the value of the examination. It would not be an exaggeration to say that the processing room leaves its imprint upon the photographic results and thereby either enhances or detracts from the prestige of an X-ray department. Grey, poor in contrast and otherwise unsatisfactory 'bad' films are more often due to incorrect procedure in the processing room than to shortcomings in tubes, equipment or radiographic technique. A thorough study of the essential procedure and above all the strictest adherence to the regulations are the main conditions that must be satisfied if the processing room is to produce optimum results.

It would exceed the scope of this book to describe ideal processing for every type and size of department; for individual needs specialists should be consulted and reference made to the extensive literature that exists on the subject. Now that the modern automatic processing machines have taken over all the procedures of developing, fixing, washing and drying, as it were, a discussion about the 'classic' or 'conventional' processing room might seem superfluous. However, considering the fact that these machines are still in the minority with regard to the conventionally equipped processing rooms, it is still necessary that the radiographer should learn to master the conventional processing technique thoroughly during her training period; first, because she will most likely be concerned with it in practice later on (in small X-ray departments, in the developing countries, etc.), and, secondly, because this knowledge will be an advantage when working with

an automatic processor (the recognition of film faults, etc.). As well as a processor, therefore, a conventional processing room (albeit much smaller) will remain necessary, especially in departments where students are being trained.

## 10.2 IMPORTANT REQUIREMENTS FOR AN EFFICIENT PROCESSING ROOM

### 10.2.1 Location of the processing room

As the processing room works in closest conjunction with the radiographic room(s), the distance between them must be as short as possible. If there are a large number of radiographic rooms, the processing room should be sited as centrally as possible. Modern diagnostic departments are often so large that such a central position cannot be realised. An acceptable solution for cassette transport in such cases can be found in some type of conveyor belt or chain which transports the exposed films to the processing room and sends unexposed cassettes back to the radiographic rooms. In extremely large departments it may prove an advantage to site several separate processing rooms, each surrounded by a number of diagnostic rooms.

It is inadvisable to set up a small 'auxiliary' processing room, near an operating theatre, for example, if this processing room is not used very often. A processing room must always be ready for immediate use, and this is only practicable when it is used regularly (the same goes for processors). If it is not used for long periods of time, then it often happens that the developer or some other essential link in the chain is not right, just when one needs to use this auxiliary processing room. The inconvenience of bringing a cassette from the operating theatre to the processing room is more than compensated by the assurance that everything will be ready and waiting to process it there.

The room where the radiographs are viewed and possibly reported on, by the radiologist, should be located as near as possible to the processing room, so that new radiographs can be evaluated immediately. Wet films could, for example, be conveyed to the viewing room by means of a wet-film transfer cabinet, for example a through-the-wall film wash tank (under-water light-tight sluice). Radiographs should never be viewed in the processing room itself, for this hinders the work of the technicians and interrupts the routine. Under no circumstances should the processing room be situated in a hot or damp basement.

### 10.2.2 Size and appointment of the processing room

The conventional processing room differs from the modern one in this respect.

#### 10.2.2.1

The *conventional processing room* should be large enough to accommodate all the equipment necessary without overcrowding. The equipment comprises the loading bench and the processing tanks, each with its requisite accessories. On the loading bench the exposed films are removed from the cassettes and new ones inserted,

and it is here that the exposed films are marked and mounted in their hangers.

In the processing tanks the films are developed, rinsed, fixed and washed. During, or preferably after fixing they can be transferred to the viewing room, where, after the washing has been completed, they are dried.

It is essential, under all circumstances, that dry and wet work are carried out a safe distance apart; for this reason, it is best that the loading bench and the processing tanks are arranged along opposite sides of the room. Obviously, every processing room should have a sink.

A great deal of work can be efficiently done, even in a small processing room, if the space available is used to full advantage, for instance, by placing storage compartments for cassettes and films under (or in) the loading bench and the racks for film hangers above it, and by having waste paper receptacles for film wrappers, etc., incorporated into the loading bench; these should have a wide inlet on top, and should be easy to empty from the front.

All operations that do not require darkness should be performed outside the processing room. Equipment and films not in regular use should also be kept outside. It is best to use a separate processing room for 'ordinary' photography, for developing photofluorographs, cine films, for making contact prints and copies of X-ray films and other similar work. The preparation of fresh processing solutions should always take place outside the processing room and the chemicals needed for the purpose stored outside also. Only in very small departments should film drying and the development of photofluorographs, etc., be carried out in the processing room, and in that case the space available should be correspondingly larger.

The general rule for the plan of a processing room is that the exposed film should travel along the shortest possible route to the processing room and there be put simply and smoothly through the logical sequence of operations and be made available as quickly as possible in the viewing room.

Figure 10.1 shows a plan of an X-ray department in which the location of the processing room ensures efficient functioning of the department.

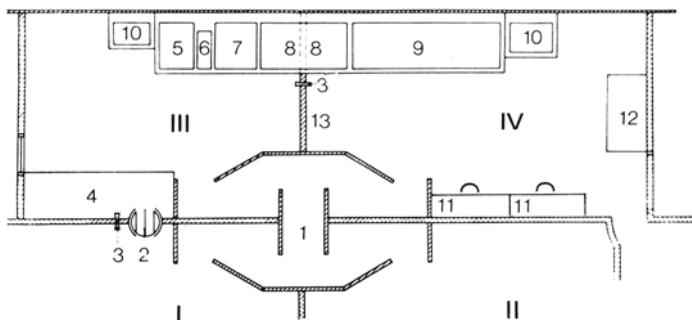


Figure 10.1 Diagram of a processing room with an open labyrinth to two diagnostic rooms. I, II. Diagnostic rooms; III. processing room; IV. viewing area. 1. Example of an open labyrinth or maze; 2. cassette-transfer cabinet (or cassette hatch); 3. speaking tubes; 4. dry bench (loading bench); 5. developing tank; 6. rinsing tank; 7. fixing tank; 8. under-water light-tight sluice; 9. final washing tank; 10. wash basins; 11. illuminator with desk; 12. drying installation; 13. dividing wall.

### 10.2.2.2 A modern processing room

The most important difference from the classic processing room is the absence of the 'wet' side, as the whole developing process up to and including the drying is carried out within the processor. Exposed films are removed from the cassettes, marked or written upon on the 'dry' side (loading bench), just as in the classic processing room; they are then fed into the processor, making film hangers superfluous. Cassettes are again loaded. The dried film is delivered outside the processing room (for example to the viewing room) by the machine. With the most up-to-date automatic processing installations, the loading and unloading of cassettes is also automated or, in some cases, cassettes are no longer handled in the processing room, which limits the procedures carried out in, and the part played by, the processing room even further.

### 10.2.3 Protection against radiation

If the processing room is right next to the radiographic room, it is of prime importance that it is well protected against radiation. The requirements for this are strict, as obviously the films remain in the processing room for uninterrupted, and sometimes quite long periods, before they are used, which could happen with certain size films that are used less often. The following general rules apply for the protection against radiation:

(1) The lead equivalence of the wall adjoining the radiographic rooms should be sufficient to prevent the films from being fogged by radiation from those rooms during the whole time they are in the processing room.

(2) Where there are breaks in the wall (for the cassette transfer box or hatch, for instance) any joins in the protective material (usually lead) must fit flush, or better still, overlap.

(3) When installing the X-ray equipment in the adjoining room, precautions should be taken to ensure that the direct X-ray beam does not strike the wall of the processing room during normal working.

### 10.2.4 Entrances

Smooth communication, both for personnel and cassettes, etc., is a condition for efficient operation.

#### 10.2.4.1 Personnel entrance

The entrance to the processing room should be light-tight. Where entry is by an ordinary door, then this should be kept closed from the inside by means of an 'engaged' lock, while work is in progress. This is not necessary if a two-door system with a waiting space between is used. An interlocking device should be installed to prevent both doors being opened at once. A signal system can also be used for this purpose. A turnstile door may also be used as an entrance to the processing room with the advantage of taking up little space, but with the disadvantage of impossible or difficult passage of bulky objects. These systems are simple in construction and economical in floor space but they are far less handy than the *labyrinth* or *maze* system. The absence of doors in this system has the double advantage of being convenient and providing good ventilation. Its disadvantages

are that it takes up more floor space and makes the bringing of bulky equipment into the processing room difficult. The latter difficulty can be overcome, however, by making the labyrinth of folding partitions that can be folded back against the wall as illustrated in figure 10.2.

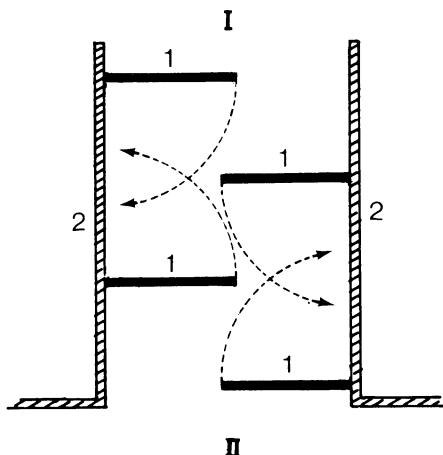


Figure 10.2 Labyrinth with folding partitions. I. Processing room; II. adjoining radiographic room. 1. Folding partitions, which can be folded back against the wall in the direction of the arrows; 2. permanent walls.

It should be realised that such labyrinths do not need to have brick walls; thin wooden partitions are quite sufficient. This labyrinth is light-tight when the white light invading from outside falls upon non-reflecting walls at least three times; it then cannot reach the processing room. The minimum width of the passage can be taken as 60 cm, or even less at bends (55 cm). To assist in finding the way through the labyrinth, phosphorescent strips or arrows can be used. Obviously, these wooden walls will prevent the entrance of light, but not the possible radiation originating from the radiographic room. As far as protection from radiation is concerned, the necessary measures should be taken.

#### *10.2.4.2 Cassette entrance*

The cassettes can best be introduced into the processing room via some sort of cassette-transfer cabinet or hatch, of which several types exist. A simple version is the one where there is a door in the radiographic room and one in the processing room, giving access to two spaces, one for exposed cassettes and one for unexposed cassettes. These two doors are so interlocked that they cannot both be opened at the same time (figure 10.3). The issue of cassettes on a small scale takes place by means of such a hatch.

On a larger scale special constructions should be considered. Several very useful solutions exist for this. For instance, a hatch, subdivided into several sections for the various different sizes of cassette, is very useful. These sections can be emptied from outside; obviously, there must be interlocking doors (figure 10.4).

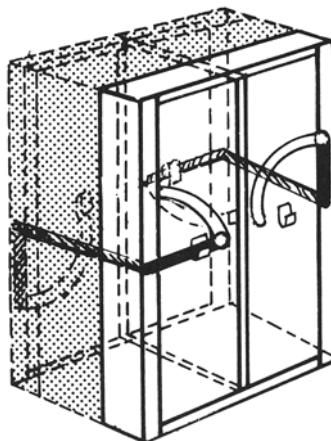


Figure 10.3 Simple double-cassette transfer cabinet. The interlocking system prevents the two doors of a compartment to be opened at the same time, thus blocking light which cannot pass through. In the illustration, the door on the right-hand side on the front and the door on the left-hand side on the back can be opened; both other doors are locked.

It is also possible to have a conveyor belt for transporting the cassettes to and from the dry side of the processing room; such systems are sometimes found in big, modern radiographic departments. There must be contact between all radiographic rooms and the processing room and vice versa. An intercom system connecting all these rooms cannot be recommended strongly enough. Apart from this intercom system, a speaking tube should also be fitted beside the hatch; this speaking tube should have a bend in it, so that no light can pass through.

#### 10.2.5 The electric wiring

The conventional processing room is a place where electric shock can be a very serious danger because of the presence of electric wiring in close proximity to aqueous solutions, water pipes, taps, damp walls and moist fingers. For this reason, it is essential to earth all instruments, switches, the casing of electric timers, the viewing box, indicating instruments, etc. These safeguards are probably laid down in the local electrical safety regulations (as, for example, for bathrooms), but in any case, the radiologist and radiographers should be certain themselves that the earthing has been carried out, since in damp areas one cannot always rely on the insulation. All electric cables entering the processing room should be controlled by a main switch outside the processing room, with a warning lamp to show directly whether or not the light is on in the processing room and to prevent lights burning needlessly. The instruments for keeping the developer at constant temperature and for the silver-recovery unit, which should be kept working continuously, should not be connected to this switch, since the processing solutions must always be ready for use, and the silver-recovery unit requires complete 24-h periods to remove the silver from the fixer. In the modern processing room with automatic processing machine(s) the requirements for earthing all instruments still all apply.

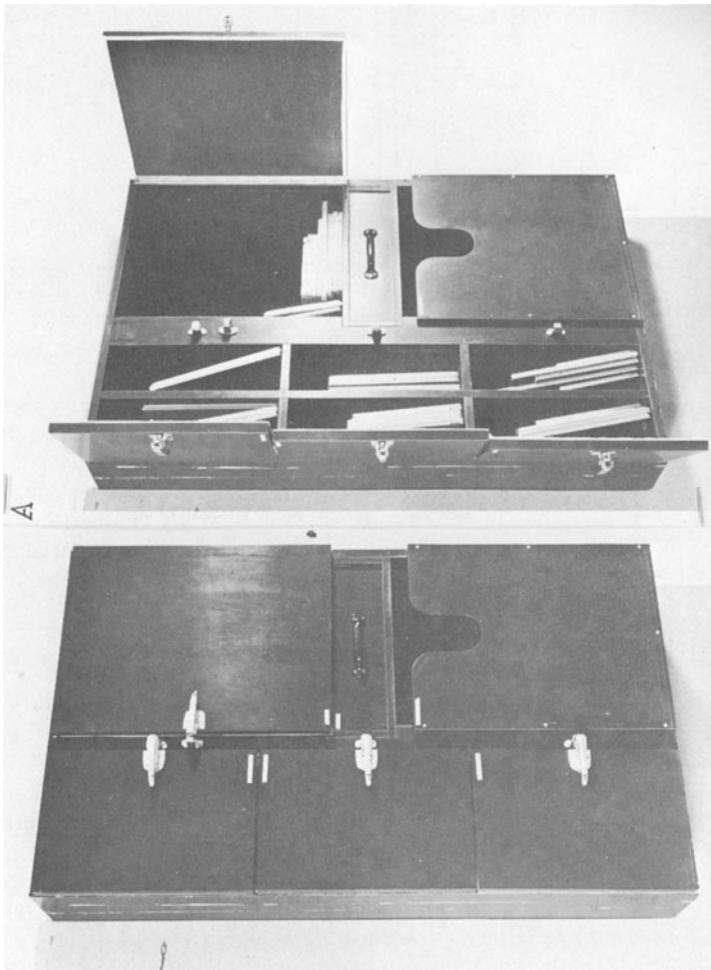




Figure 10.4 Large cassette-transfer cabinet.

A. Photographs of the outside of the cabinet, completely closed and entirely open. The exposed cassette is placed horizontally through the slit and slides onto an angled surface, underneath a light-excluding flap, on the cassette-receiving table in the processing room.

B. Photographs of the processing-room side (also entirely closed and completely open) of this multiple sluice with various sections for the different cassette sizes and a transferring drawer. The cassette sliding in, underneath the flap, is clearly visible.

#### **10.2.6 Ventilation**

A good processing room should be well ventilated. If it is not included in the air-conditioning system of the whole radiological department, special measures should be taken. Obviously, the atmosphere can quickly become contaminated with unpleasant fumes as well as very humid. An open maze affords excellent ventilation and is very useful. Ventilation during working hours should be sufficient to change the air completely six to ten times an hour. If an electric fan is used, the air should be blown into the processing room through a dust filter. A slightly positive air pressure is created in the processing room, which prevents dust being drawn in through the cracks of doors and other openings. Windows, which can be opened during breaks, are highly recommended. (Excellent light-tight roller blinds are on the market for blacking-out windows.) It is best to maintain a temperature of approximately 22°C and a relative humidity of 60 per cent. Under no circumstances should the moist air from a film drying installation be allowed to pass into the processing room. For processing rooms that do not have access to fresh air from out of doors and are totally dependent on air conditioning, an open maze and an extra ventilator are strongly recommended.

#### **10.2.7 Floor and wall covering**

High demands are made on the floor covering in a processing room. The floor should be durable and strong, resistant to chemicals and be pleasant to stand on. Above all it must be easy to clean. Tiles, or an acid-resistant rubber floor are probably best, better than porphyry tiles, for example. Colovinyl is also unsuitable. Linoleum is not suitable as a floor covering in the processing room. Developer and fixer solutions stain it badly and soften its texture, and in any case it needs a great deal of maintenance.

As far as the wall covering is concerned, it is now generally known that the walls of the processing room do not have to be dull black, as used to be the case. A light, cheerful colour is technically justifiable and psychologically desirable. It is important that the walls reflect the safelight as much as possible (thus giving a diffuse lighting, as it were), and this is the case when the colour of the walls more or less correspond with that of the emitted light. The walls themselves should be made of corrosion-resistant materials (although the corrosive power of the chemicals used in the processing room is by no means great), or painted with an oil-based paint. In order to prevent reflection of light that originates outside the processing room, the open maze should be painted on all sides with a dull colour paint (possibly black) with a matt finish.

#### **10.2.8 Illumination of the processing room**

Working under red light, as was formerly the rule, is unpleasant and, moreover, unnecessary. Nowadays, the illumination of an X-ray processing room can depend on the spectral sensitivity of the X-ray film and be yellowish-green (or, with some films, an amber colour). If other films such as photofluorographs or cine films are also developed in the processing room, then one must take into consideration that these have a different spectral sensitivity and, therefore, must be processed under another light colour (red, for example), or perhaps even in complete darkness.

Since, with reflected light, no other wavelengths are reflected than those of the incident light, the walls may quite safely be made bright and reflecting. This diffuse distribution of light causes almost no fog and makes working conditions

considerably more agreeable. The use of lacquered lamps should be avoided as the lacquered coating on the bulb can easily crack or be damaged, and thus allow undesirable light into the room. Fixtures with flat filters or coloured glass lamps are the best. The light fixtures should be mounted in such a way that the light does not shine directly into the eyes, but on to the hands. If, moreover, the ceiling is provided with indirect safelight illumination, then the entire processing room will be practically and pleasantly lit. The filter fitted in the lamp-holder should be carefully chosen and be regularly checked. It should be borne in mind that no lamp and no filter is 'safe' under all circumstances. The 'safeness' of the light depends upon:

- (1) the distance of the film from the light (inverse square law),
- (2) the wattage of the lamp used,
- (3) the spectral sensitivity of the film with respect to the light,
- (4) the length of time the film is exposed to this light.

Even if all the conditions laid down for the use of the filter (wattage of the lamp, distance, etc.) are satisfied, one should not take it for granted that the lighting is safe, but always make a test first to ensure that the films are not fogged under normal working conditions. This test is carried out in the following way: Switch on all the lamps that are normally used. Then take a film (13 x 18 cm size, for example) wrapped in black paper and pull the film in stages out of the wrapping (at the same place in which films are ordinarily unloaded from the cassettes). Expose the first strip for 80 s, then pull it a little further from the black paper and expose, together with the first strip, for a further 40 s, then together with the third strip for a further 20 s, with a fourth strip a further 10 s, and with the fifth strip another 10 s, leaving the sixth strip unexposed. The film is then developed in the normal way. It now has six different exposures, that is strips of 0, 10, 20, 40, 80 and 160 s exposure. After development, the film may show six stages of blackening caused by exposure to the illumination of the processing room. If it is found that the 40 s strip shows no sign of fogging, the illumination can be regarded as sufficiently safe, as with normal handling (removal of film from the cassette, marking, clipping it into a hanger, placing it into the developer and loading a new film in a cassette) it should take no longer than 40 s to perform when one is working efficiently. If the 10 s strip shows definite blackening then the lighting in the processing room is at fault, and the level of lighting should be lowered, by increasing the distance of the lamps from the working areas, for example, or by installing lamps of lower wattage (15 W instead of 25 W, for example). The fog test should then be repeated. If, even the 0 s strip shows fogging after development in complete darkness, then this cannot be the fault of the safelights. The fog may have a variety of causes, among which, for example, are too old a film, too warm a developer, exposure to ionising radiation, etc. (see chapter 8, section 8.2.4).

Every processing room should also have ordinary white light at its disposal, in order to be able to inspect intensifying screens for example. White light is also necessary for cleaning, which is best performed by daylight with the windows open.

Each lamp in the processing room should have its own switch. Fluorescent

lighting does not often come into consideration; incandescent lamps are better and more economical in this case, as they have to be switched on and off so often.

As we've said before, the entire electricity supply of the processing room (except the thermostatically controlled heating of the processing solutions and the silver-recovery unit) should run outside the processing room and be controlled by a main switch; a warning light should be connected to indicate that the processing room is being used. Although the films do not have to be clipped into hangers in a processing room with an automatic processor, this does not mean that exposure to the lighting of the processing room is of shorter duration, as delays can occur when films are being fed into the machine. Therefore, lighting conditions mentioned also apply here.

#### 10.2.9 The dry side

The primary component of the dry side of a processing room is the loading bench. The cassette hatch, cassette compartments, film hopper, storage brackets for film hangers and waste-paper receptacle are in close proximity (figure 10.5). The load-

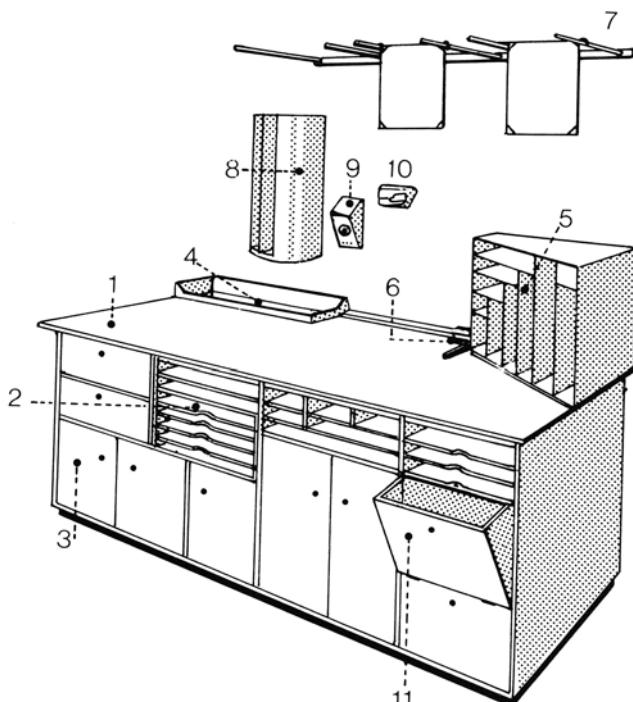


Figure 10.5 Dry side of the processing room (example of a loading bench). 1. Loading bench; 2. compartments for storing cassettes; 3. storage cupboards; 4. waste-paper slot; 5. storage compartment for film cartons in use; 6. film identification printer; 7. brackets for film hangers; 8. cassette-transfer cabinet ('tourniquet' type in this case); 9. intercom installation; 10. processing-room lamp; 11. film hopper (hinges at the bottom).

ing bench should be at least large enough to accommodate three of the largest size cassettes easily side by side, on the working surface. For film 'marking' (with name, date etc.) an X-ray film identification printer can be set into the bench top. This consists of a small pane of glass behind which there is an incandescent bulb. Several of such devices are on the market (some use X-rays instead of white light). The bench top is best covered with a synthetic material (possible formica) which is non-static and of such a colour that objects used on the bench can be easily distinguished under safelight illumination. A slot may be cut at the rear of the bench top through which waste paper can be dropped into a receptacle under the bench. Separate compartments, made to measure, for storing every size of cassette are useful. As for films, there should be a separate compartment for each size film carton. Storing films in their own cardboard boxes is only suitable in small X-ray departments. As the constant opening and closing of boxes in a busy processing room takes up far too much time, here films are stored in a special hopper, hinged on the bottom and fitted with an automatic safety(light) switch. Formerly, films were always individually wrapped in paper (which of course had to be removed), but it is becoming increasingly more usual to have unwrapped films delivered, which are placed in the film hopper. Film hangers are best kept on brackets above the loading bench, each size of hanger having a separate pair of brackets. Naturally, care should be taken that a hanger cannot fall down and so possibly damage intensifying screens or films.

#### 10.2.10 The wet side

This consists of the tanks for developing, rinsing, fixing and washing, a sink and several accessories necessary for heating, silver-recovery, etc., and a timer. As the wet side does not always receive the attention it deserves, in order to give optimum results it would be well to summarise the most frequent omissions and shortcomings:

- (1) no anti-splash panelling in front of the tanks, hence splashing and messy work; (the splash-board should project at least 15 cm above the front rim of the tanks);
- (2) a developer tank and fixer tank, in which the film hangers have to be introduced parallel to the rear wall. This makes it impossible to view the film away from the light (by incident light);
- (3) inspection light for checking development mounted too high, so that the film has to be lifted right out of the developer for inspection (an additional disadvantage of this is that developer can run down one's sleeves);
- (4) the absence of a timer or non-use of a timer;
- (5) no thermometer or the non-use of one;
- (6) the absence of a thermostatically controlled heating system for the developer or not even an immersion heater;
- (7) no running water in the rinsing tank;
- (8) the fixer tank too small, so that the films become crowded together or leave the tank too soon;
- (9) the absence of lids for the developer and fixing tanks or, which is just as

bad, the lids provided can inadvertently be interchanged;

(10) too small a washing tank, again involving the risk of overcrowding and the risk of damaged films.

Nowadays it is usual to combine the whole wet side (even when not automated) into one functional unit. A design of this type is illustrated diagrammatically in figure 10.6. It contains several compartments, one for the developing tank(s), one for rinsing, one for fixing and a large one for washing (preferably constructed in such a way that part of it is an under-water sluice that leads to the viewing room). It is advisable to make the front wall 15 cm higher than the rims of the compartments for the various tanks, to avoid splashing and dripping. The compartments themselves are about 60 cm deep; their width depends upon the demands to be made on the capacity of the installation.

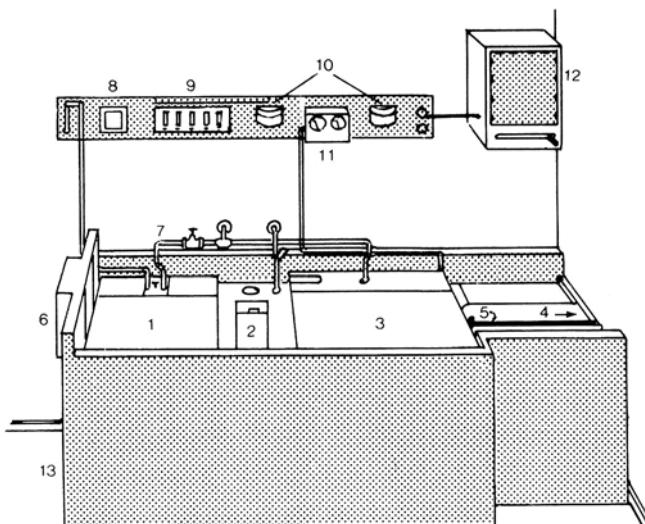


Figure 10.6 Wet side of the processing room. 1. Developing tank with lid closed, hinged at the back; 2. rinsing tank; 3. fixing bath with lid closed, hinged at the back; 4. interlocking device for under-water sluice; 5. under-water sluice (or through-the-wall washing tank); 6. laterally placed safelight for viewing the film by transmitted and reflected light; 7. water supply pipe; 8. thermostat; 9. processing-room timer; 10. processing-room lights (safelights); 11. supply unit for silver-extraction installation; 12. illuminator; 13. anti-splash protective panel, 15 cm higher than the level of 1, 2, 3 and 5.

The developing tank proper is surrounded by water at the sides and underneath, the water being heated electrically to a constant temperature with the aid of thermostatic controls (figure 10.7). The water-bath surrounding something that has to be kept at a particular temperature is called a 'bain-marie' or water-jacket. It is not a good idea to heat the developer directly by means of an immersion heater, for example, as was often done in the past, as local over-heating can lead to decomposition of the chemicals. The temperature must be checked by means of a thermometer giving a clear reading, between 15 and 25°C, and provided with

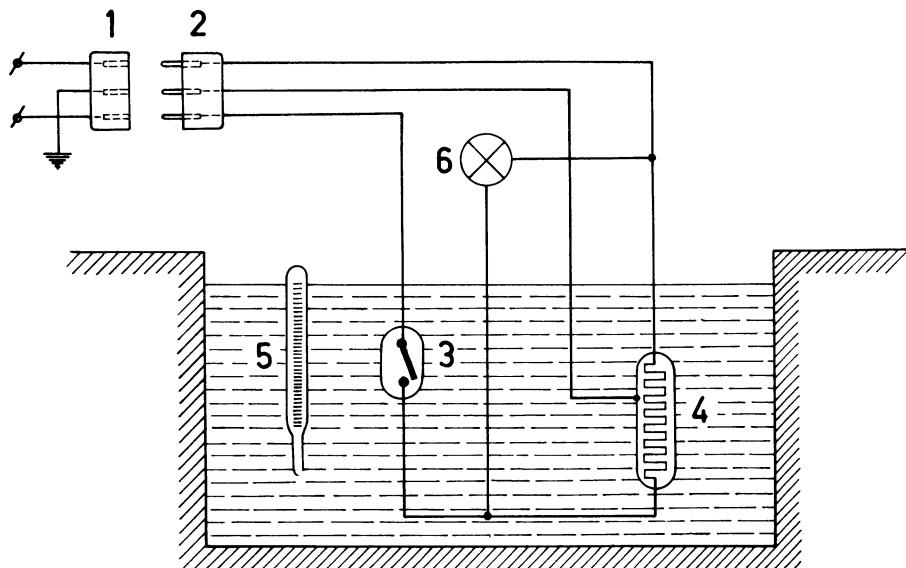


Figure 10.7 Thermostat and immersion heating element. 1. Mains supply connection (earthing); 2. plug; 3. thermostat; 4. immersion element; 5. thermometer; 6. pilot lamp (or meter) indicating that the immersion element is in operation (circuit closed by contact switch in 3) and when element is not in operation (contact switch open).

a mark at 20°C. *It should be regarded as a serious fault not to have, or not to use, a thermometer in a radiographical processing room.* The fixer compartment need not be installed in a water-jacket, since the fixing process is not as dependent upon temperature as the developing process.

It is advisable to mount the electrodes of the fixer silver-recovery unit at right-angles to the position of the film hangers (figure 10.8). A darkroom lamp which can be switched on and off separately, built into the wall adjoining the developer compartment just above the top of the tanks, is useful for checking the progress of the development (both by incident and transmitted light) (figure 10.6). If the construction is such that the film hangers are parallel to the wall, it will be impossible to inspect the film by incident light.

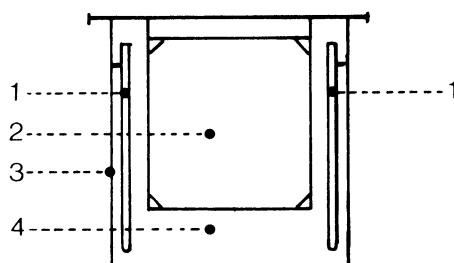


Figure 10.8 Section of fixing tank. 1. Electrodes for silver recovery; 2. film in hanger; 3. fixing tank; 4. fixing bath.

It is very important that the processing room should have an electric timer, which permits a check on the development times of several films processed together.

In order to be able to use the 'big light' or white light, the developing and fixing tanks should be provided with light-tight lids.

A viewing box with variable light intensity is built above the wash tank.

In large installations, washing should preferably be done outside the processing room. The films are conveyed to the viewing room by means of an under-water sluice, as shown in figure 10.6. This method also avoids disturbing the work in the processing room by persons entering to view wet films. The transportation of films through the under-water sluice can be done manually or mechanically. Obviously, an interlocking device must be fitted to prevent both covers of the tanks, the one in the processing room and the other in the viewing room, from being opened at the same time. The rear wall behind and above the wash tank can be painted matt white. Indirect lighting on these walls, provided by fluorescent fittings with hooks underneath, allows the wet films to be conveniently viewed while they are suspended in their hangers from these hooks, and to drip into the wash tank.

### 10.3 THE DEVELOPMENT

The purpose of development is to reduce the exposed silver bromide molecules present in the latent image to metallic silver by the action of the developing solution and thus make the image visible.

#### 10.3.1 The developer

As a general rule, it is best to use, for a particular film, the developer recommended by the makers of that film. Obviously, it is in the film manufacturers' own interests that the radiographic results be as good as possible and therefore they have done a good deal of research in their own laboratories to find the best formula. It is not a good idea to make one's own developer, as is still done here and there, since one then takes little or no advantage of the research work which is continually being carried out in the laboratories of the film factories. In this case, 'penny wise is pound foolish'.

When preparing the developer, one should follow the maker's instructions carefully. The developer is supplied either in liquid form or as chemicals which must be dissolved. The dissolving or mixing is best done in scrupulously clean plastic or stainless-steel buckets. Enamelled buckets are not suitable as, after damage, iron is liberated. Developer is an alkaline solution. Under no circumstances should one use a bucket or tank that has been used for fixer, for the developer too, since even slight traces of fixer can completely spoil the developer. (Fixer, on the other hand, is not so sensitive to traces of developer.)

For those who wish to prepare the developer themselves, (due to the chemical reactions which are not particularly odourless, this should be done outside the processing room) the following formulae can be recommended. These materials should be dissolved in the order listed, in warm water (not warmer than 40 °C), stirring constantly. One will obtain an alkaline developer with a pH of about 10.5. Here are three formulae (to make 1 litre of developer).

	1	2	3
distilled water	900 ml	900 ml	900 ml
metol	3.5 g	—	—
anhydrous sodium sulphite	60 g	60 g	60 g
Leave to cool to 30°C and then add the following, stirring continuously:			
hydroquinone	9 g	11 g	24 g
phenidone	—	0.275 g	0.75 g
sodium carbonate, anhydrous soda	20 g	40 g	—
potassium carbonate (anhydrous)	26 g	—	—
sodium hydroxide	—	4 g	19 g
sodium metacarbonate	—	—	33 g
potassium bromide	4 g	4 g	10 g
nitrobenzimidazol	—	—	0.5 g
benzotriazol	—	0.1 g	—
trilon B	—	2 g	3.5 g
sodium hexametaphosphate	3 g	—	—
polyethylene glycol 200	—	—	0.2 ml
hardener (dialdehyde, for example)	—	—	17 g

With distilled water make up to 1000 ml, filter and decant.

The solutions should be light yellow in colour. Brown discolouration indicates oxidation due to the use of poor-quality chemicals (impure sodium sulphite, for example). Solution 1 is a metol-hydroquinone developer for manual processing. Solution 2 is a phenidone-hydroquinone developer for manual processing. Solution 3 is a phenidone-hydroquinone developer for use in automatic processors.

The most frequently used developing chemicals are the following:

*Metol*: This is a developing agent, with rapid but superficial action; it produces marked nuances in the image but no great contrast.

*Sodium sulphite*: This checks the rate of oxidation of the other chemicals and therefore acts as a preservative. The quantity used is extremely critical as too little sodium sulphite results in grey fogging and too much gives a dichroic fog (the latter is also known as 'colour fog', as the film looks like the surface of water with oil floating on it).

*Hydroquinone*: Developing agent with slow but deep action, hence producing good contrast.

*Sodium carbonate and potassium carbonate*: These have the effect of accelerating the action of the developing agents. Moreover, they bind the bromine released from the film and soften the emulsion layer.

*Potassium bromide*: This acts as a brake on the action of the developer, thus it is a restrainer. Provided it is not used in excess, it promotes contrasts and prevents fogging. The organic materials *benzotriazol* and *nitrobenzimidazol* are also anti-fogging agents.

In recent years, instead of metol, alongside hydroquinone, a new, strong developing agent called *phenidon* has appeared on the scene. This replaces metol and in combination with hydroquinone becomes a developer which produces more contrast and has a longer life.

*Sodium metaborate*: This substance is used as an alkaline material in developers. It is also known by its trade-name 'Kodalak'.

*Trilon B (EDTA, ethylenediaminetetra-acetic acid)*: This substance, like sodium

hexametaphosphate, is used to prevent the deposition of lime in the developer, by removing the lime-containing components of the mains water supply (water softener).

### 10.3.2 Temperature of the developer and developing time

In general, the temperature at which development takes place lies between 18° and 24°C. Each film has a certain optimum development time at a given temperature. If one has to develop at a temperature other than the optimum, one should make use of a correction table, which gives the optimum time at that temperature. At higher temperatures this time is naturally shorter (and hence more critical) and the fog increases sharply; at lower temperatures, the 'optimum' developing time is longer and the fog is less pronounced. Temperatures below 17°C and above 24°C must be considered useless in the conventional developing technique.

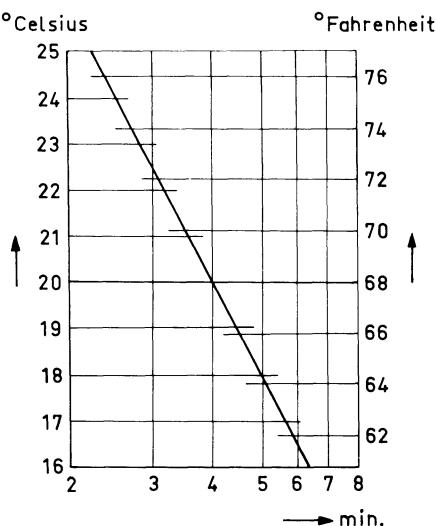


Figure 10.9 Correction graph. Example of a correction graph from which one can read the optimum development time for developer temperatures which deviate from the normal. 20°C is assumed to be the normal temperature in this case; at this temperature the optimum developing time is 4 min.

Figure 10.9 is an example of a correction graph. Graphs of this type, possibly in table form, are included in the directions for use of each developer. As only a constant temperature of the developer can produce constant results, a thermostatically controlled water-jacket (bain-marie) surrounding the developing tank is the best solution. If this is not present and the heating is to be done with an immersion heater, then this must also be used as a stirring rod until the required temperature is reached. Repeated cooling and heating is detrimental to the developer; therefore, one should endeavour to obtain thermostatically controlled heating.

In tropical countries, it is more often a question of lowering the temperatures. For this there are thermostatically controlled refrigeration installations available, so that the required optimum temperature can still be obtained. If the developer temperature is kept constant, one important condition for a standardised processing technique is already fulfilled.

### 10.3.3 Developer replenisher

The rate of use of the developer is important. Every square centimeter of film draws 'developing power' from the developer, which becomes weaker and exhausted. Furthermore, the bromine content increases sharply, owing to the release of bromide ions from the film emulsion into the developer solution. Also, the level of the liquid falls since each film carries a certain quantity of fluid away with it as it leaves the tank. Therefore, the solution must be replenished regularly, and in such a way that its developing power changes as little as possible. The replenisher must be so constituted that the undesirable changes which have taken place in the developer, that is the increase in the bromide content, are corrected. Water and developer (new or old) are not suitable for this purpose. In general, film manufacturers supply a replenisher suitable for their films, in addition to their developer. It is also recommended that the preparations commercially available, which are designed for a particular developer, be used, and the directions for use carefully followed.

A formula for the preparation of a replenisher (*regeneration replenisher*) is as follows (for 1 litre):

In 900 ml distilled warm water (which should not be warmer than 40 °C) dissolve, while stirring constantly:

anhydrous sodium sulphite	60 g
metol	2.5 g

Allow to cool to 30 °C, after which dissolve, while stirring,

hydroquinone	15 g
anhydrous sodium carbonate	100 g

Finally, add cold distilled water to make 1 litre. Filter or decant.

Replenisher does not contain any sodium bromide. In order to prevent oxidation as far as possible, each bottle must be completely full and tightly closed.

Each square metre of film placed dry into the developer and removed wet, without draining, removes about 300 ml of developer. After the development of about 3 m<sup>2</sup> of film (that is 30 000 cm<sup>2</sup> of film area has been developed) 1 litre of replenisher should be added. In practice, one maintains the developer in the developing tank at a constant level, by replenishing it regularly with replenisher. This process cannot be continued indefinitely, however, as the developer will eventually become too old and of too poor a quality. When the tank volume has been replenished five times, new developer should be prepared.

During periods when the developer is not in use it should be kept covered to

exclude air. A lid is sufficient for this purpose. Where development is carried out at irregular intervals, it is best to cover the solution with a rectangular piece of paraffin or place a synthetic float on the surface to prevent oxidation.

#### **10.3.4 Fogging**

The film should not be repeatedly taken out of the developer during processing; it serves no useful purpose and merely increases the risk of fogging. It is sufficient to inspect the film after at least one and a half minutes, just to see whether the film is 'coming up' by looking at the upper edge for a moment against or away from the safelight. If it is satisfactory, the film should be left undisturbed in the tank until its development time is completed. If this check shows abnormally high or low density, then a new check will be unavoidable, and perhaps it will be necessary to deviate from the normal period of development. Any abnormalities should be reported immediately, so that the next exposure can be corrected. Most irregularities of this kind are due either to over-exposure or under-exposure. Corrections by longer or shorter development produces at most a serviceable, but never an optimum, result.

Density checks during development should be carried out rapidly. If the film is removed from the developer for too long a period, there is considerable risk of fogging due to:

- (1) exposure to the processing room light (light fog);
- (2) exposure to the air, which locally oxidises the developer adhering to the film (oxidation fog).

It is advisable to hold the hangers at right-angles and not parallel to the back wall, so that one can view both sides of the film, both against and away from the light (by transmitted and incident light). It is especially valuable to view dental and non-screen films by incident light. If the light by which the density check is carried out is mounted not behind the tank but on the side, then the film only need be partly removed from the developer. The safelight on the side is therefore to be recommended. With the present, quite bright processing room illumination it is much easier to judge the exact degree of development (by reflected and transmitted light) than with the previous, weak red lights.

Once the film has been developed, it should be removed from the developer, *not too quickly*, so that most of the adhering developing liquid flows back into the tank.

#### **10.4 INTERMEDIATE RINSING, STOP-BATH**

After development the film is suspended in the rinsing bath, where the water must be kept running. The (alkaline) developer must be removed as much as possible, otherwise contamination by the developer would soon deprive the (acid) fixer of its effectiveness and give rise to dichroic fog. The film should remain in the rinsing bath for about 20 s; it takes some time to remove the developer and that time cannot be appreciably shortened by hurriedly and nervously shaking the film frame.

An insufficiently rinsed film is a permanently spoiled film.

Another method (which is quite efficient) of stopping the developing process, is to immerse the developed film into a solution of acetic acid (1-3 per cent): a *stop-bath* (Instead of the unpleasant odour of the acetic acid, the use of citric acid is often preferred.) This neutralises the action of the developer, so that development stops immediately. This intermediate bath should be renewed regularly, as its acid is soon neutralised by the alkaline developer residues. Blue litmus paper placed in the solution should turn red immediately, otherwise the stop-bath should be considered inactive.

The film should be removed from the intermediate rinse or stop-bath slowly. If this is done, the layer of liquid on the film remains in contact with the surface layer of the liquid in the tank, and this layer is then, as it were, pulled off the film by the cohesive forces. This not only prevents splashing, but also ensures that not too much liquid is removed from the rinsing bath, diluting the fixer unnecessarily and spoiling it prematurely.

## 10.5 FIXING

After rinsing, the film must be fixed. The purpose of this process is to 'fix' the silver that is laid down, that is to make the image permanent, and to remove the remaining, unexposed, silver bromide. The latter constitutes about 2/3 of the silver that is present in an X-ray film. The fixer tank should have a capacity of at least twice that of the developing tank. Whereas the level of the developer gradually falls, it remains fairly constant in the fixing tank, for of course, the films are wet when they enter and when they leave it. The quality of the fixer does decline, due to the exhaustion of the chemicals.

### 10.5.1 The fixer

General use is made of acid *rapid fixer*, which is commercially available under various trade-names. The exact chemical composition of fixer is less critical than that of developer, so that any good make is generally suitable for any film. Every firm supplies a particular fixer for its own film, and here again it is better, in general, to regard the films and chemicals as belonging together, and to order them together.

One can, if one so wishes, prepare a litre of rapid fixer in the following manner:

In 800 ml of water at a temperature of about 50°C dissolve in succession, while stirring,

sodium thiosulphate ( <i>hypo</i> )	200 g
ammonium chloride	38 g
potassium metabisulphite	25 g

Add water immediately, making up to 1 litre. Filter and decant.

The action of these chemicals is as follows. The *sodium thiosulphate (*hypo*)* dissolves the non-reduced silver bromide and makes the film transparent at these

places. The *ammonium chloride* accelerates the process and the *potassium metabisulphite* prevents the residual developer from causing oxidation, which would turn the fixer and the film brown. The potassium metabisulphite takes up this oxidation, as it were.

### **10.5.2 Silver recovery**

Owing to the continuous increase of the silver salts, the fixer solution quickly becomes exhausted. The quantity of silver lost per film in the fixer tank is quite considerable, amounting to some  $100 \text{ mg/m}^2$  of film. Economically, therefore, it would be an irresponsible act to throw away old fixer, especially since, due to the enormous amounts of silver used throughout the whole world, the (limited) supplies of silver are shrinking quickly and a serious shortage threatens. Up to the present time, no effective silver-recovery method has been found for photography.

In order to remove the surplus silver from the fixing bath continually, it is recommended that one has an electrolytic silver-extraction unit installed.

For this purpose, two electrodes are fixed permanently inside the fixer tank; they are supplied with 20–40 mV from a rectifying unit with ammeter and voltmeter. The current amounts to 20–30 mA. The electrolytically dissociated silver ions then move uninterruptedly to the negative pole (as metal ions are cations), where they form a metallic silver deposit. After some time (two months, for example), the cathode should be desilvered to prevent too great a build-up of silver. The advantage of a silver-extraction unit is not only the recovery of the silver itself, but also the continuous withdrawal of surplus silver from the fixer, which is thereby given a longer useful life and need not be renewed so frequently.

Another way of extracting the silver is to pour the used fixer into a large vessel, add some old zinc, and stir from time to time. The zinc releases the silver from its compounds and a muddy sediment is formed which contains the silver. Test for silver precipitation by occasionally immersing a piece of red copper (a penny, for example) into the fluid; if after some time, it no longer turns grey, then sufficient silver has been deposited and the liquid may be poured off. After desilvering several quantities of used fixer in this way, the accumulated sediment (a sort of black mud) can be dried and sent to a metal-purifying establishment. This method of precipitation, although it enables the silver to be recovered, does not improve the quality of the fixer solution.

### **10.5.3 Quality and extent of use of the fixer**

If the fixer bath is of good quality, the film should be ‘clean’, that is completely transparent at the unblackened places, in at most 3 min. The film should not be exposed to white light (however weak) during the fixing, as residual patches of silver bromide may thereby be impressed in the film emulsion and ruin it permanently. If the fixer is weak or old, then the after-effect of traces of developer can lead to dichroic fog, which is enhanced by exposing the film to light too soon. If the film is ‘clean’, then there is no harm in looking at it for a moment in front of a viewing box, but the fixing process is by no means yet completed. After a film is clean, the film should remain in the fixer for at least as long again before the film can be regarded as properly fixed. The total fixing process thus takes

10-15 min. Exhaustion of the fixer expresses itself as an increase in the time needed for film to become clean.

Because of the chemical action of the rapid fixer on the surroundings (edge of the tank, etc.), and the loss of solution, it is advisable to remove the film from the fixer slowly, as from the developer and the intermediate rinse. Before the film is viewed, it should be immersed in the wash tank; the drops of solution that fall off after that are no longer chemically active.

A simple experiment can be used to tell whether or not the fixer is exhausted. A little fixer is put in a test-tube and a few drops of 10 per cent potassium iodide solution added. This gives rise to a milky turbulence, which disappears on shaking if the fixer is not yet exhausted.

When a radiology department is of such a size that one particular radiographer (or some other member of the staff with experience in film processing work) does all the work in the processing room, then he (or she) should keep a constant check on the whereabouts of the various films, so that he (she) does not have to look through all of them when asked for a particular one. When the film is completely fixed, the radiologist is informed, who then evaluates the radiograph in the viewing room to ascertain if the investigation can be regarded as completed, or if it should be continued further.

## 10.6 FINAL WASHING

The purpose of the final washing is to remove the residual chemicals to safeguard the film from their further action.

The films should be washed in running water. It is important to have a fresh flow of water in all parts of the washing compartment, and to keep it circulating between the films. For larger departments, a cascade washing system is recom-

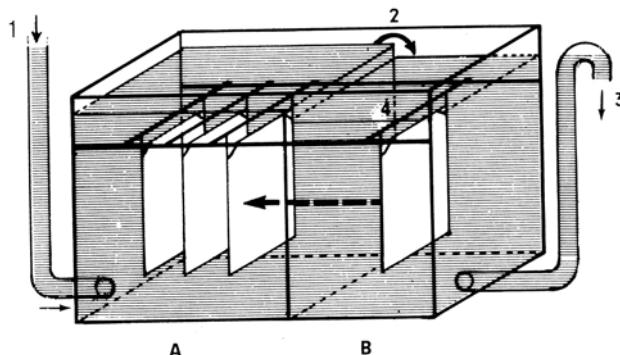


Figure 10.10 Final washing following the counter-current principle. The wash tank is divided into two compartments (A and B). The water flows in via 1, at the bottom of tank A, overflows at 2 to the other side into tank B and flows to the other side of B along the bottom to 3. The film to be washed (4) is first hung in tank B, then transferred to tank A; there it is moved in the direction of the large arrow.

mended, where the films are arranged in accordance with the counter-current principle; that is they are moved from the outlet to the inlet end, which prevents the films that have been in the wash water for some time from being contaminated by the fixer around the newly introduced films. Figure 10.10 shows such a counter-current washing arrangement.

With efficient water circulation, washing should take about half an hour at room temperature. If the wash water is 30°C, 15 min is sufficient, and above 30°C, 10 min (take care, however, not to melt the emulsion). It is quite unnecessary and indeed undesirable to wash the films for hours on end; this can soften the emulsion too much, so that it 'runs' during the drying process. If no running water is available, one can renew the water in the wash tank three times in half an hour, but it is not certain that this will be effective enough.

## 10.7 DRYING

The common practice of removing films from their hangers and hanging them on a line to dry is time consuming, inconvenient and may easily lead to damaged radiographs. Every X-ray department should have a hot-air drying cabinet. The hot air is blown along the surface of the films and ducted outside (not into the processing room). A drying cabinet should be thermostatically controlled and an automatic cut-out of the heating elements incorporated, in the event of fan failure. It is recommended that the film hangers are arranged at right-angles to the front wall to enable one to view the arranged films and facilitate the removal of films required for inspection. The fan should work as noiselessly as possible. The drying time naturally depends on the construction of the drying cabinet and varies from 15 to 30 min. After the films have been dried and taken out of the hangers, the hangers must be carefully cleaned to remove all traces of fixer (especially in the clips), which would otherwise contaminate the developer when next used, and spoil it. The frames should be washed in a separate sink with a brush, soap and water and then dried, after which they are returned to the processing room. The films go to the administrative section of the department for further operations such as sorting.

There are a number of very quick-drying cabinets on the market, which can dry a film in one minute or less. Their use pre-supposes the use of a hardening fixer (see section 10.5.1). The film is then removed from its hanger and inserted into the drying machine, where rollers squeeze it dry, as it were, and circulating warm air does the rest. Such a drying installation saves a great deal of time and can be recommended for every conventional processing room. In the automatic processor, the drying time is shortened to the utmost in this manner.

## 10.8 PROCESSING-ROOM PROCEDURE

When dealing with the lay-out of the processing room, we mentioned several measures for promoting the efficiency of work in the processing room. Obviously, these measures are no guarantee of good results unless the radiographer or special processing-room staff work skilfully, responsibly and accurately. Above all, one should follow a definite system. An important part of the work is the loading and unloading of cassettes, and the care of intensifying screens and films.

### 10.8.1 Working with cassettes

When mounting new intensifying screens, the cassette is placed on the loading bench with the lid facing upwards, and opened in such a way that the lid opens out towards the left. The intensifying screens are carefully placed inside. By means of the adhesive strips provided on the backs of the intensifying screens, they are mounted in the cassette. When they are combination screens (one screen thicker than the other), then the thick screen (back screen) should be mounted inside the lid.

To load a cassette, a film is taken from the appropriate compartment and placed on the loading bench, after which the film box or film is closed. The left hand lifts the lid of the cassette slightly and, with a simple manoeuvre with the right hand, the film is placed into the cassette. With the right hand one checks whether the film is lying flat and within the groove, after which the cassette is closed. One is strongly advised against completely opening the cassette, as this could lead to soiling and damage. Not until just before insertion of the film (that is when it has already been removed from the film hopper) is the lid of the cassette opened. When the exposed film comes back to the processing room, an appropriate hanger is placed in readiness.

The cassette is placed on the loading bench; with the left hand the lid is opened towards the left; the film is taken hold of by the upper right-hand corner and carefully removed from the cassette, while the left hand closes the cassette (but not the catch). The film is now quickly marked or labelled, clipped into its hanger, and quickly hung in the developing tank and moved to and fro a few times to remove any air bubbles which may be on it. (The ends of the suspension arms of the hangers are sometimes fitted with rubber tips to prevent slipping.) The developer timer is started and the lid of the developing tank is closed. While development is taking place, the cassette can be re-loaded as described above.

### 10.8.2 Film marking

Every film should be marked or labelled. Previously, a pencilled scribble on a corner of the film was made, and later, after the film had dried, it was transcribed with white ink. Simpler methods are to be recommended, which are accurate, efficient and save time.

Use can be made of X-rays, which, by means of a small metal plate (with the patient's particulars) in a special marking unit, expose a corner of the film; in this way, the patient's particulars are 'X-rayed' onto the film (radiographic marker). A small lead strip, mounted on the cassette, masks a small part of the film, so that it can't be blackened during the radiographic exposure.

Another method (the most often used by far) utilises light. Somewhat transparent strips of paper are printed with the name of the ward, etc. The particulars of the patient, date, examination, etc., are typed on this strip of paper, carbon paper having first been placed underneath with the carbon side up. These details can now be easily viewed by transmitted light. The strip of paper is now placed over a small window (built into the loading bench) under which there is a low wattage lamp (figure 10.11).

On the upper right-hand corner on both intensifying screens (the cassette hinge is taken to be on the left side) are fixed black strips of paper of the same size as the little glass window. In this area, therefore, the film shows practically no blackening, since the intensifying screens are out of action, and only X-rays can act on the film. This corner of the film is now laid upon the printed strip of paper on the small glass panel, pressure is applied evenly with a felt-covered block and the film

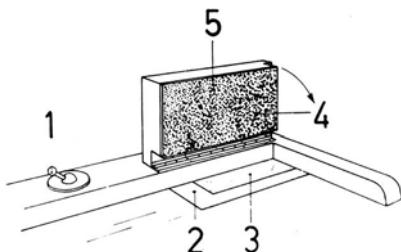


Figure 10.11 Film marking. A small frame covered with a small pane of glass is located in the loading bench; a low wattage bulb is attached under this and is controlled by a push-button or switch. A hinged lid with felt covering is used for applying even pressure on the film which is placed on the printed name strip on the glass panel. 1. Switch; 2. window; 3. glass pane; 4. hinged lid; 5. felt covering.

is exposed to the lamp for a few seconds. The data on the printed strip thus becomes a latent image on the film and, after processing, appears as a neat black section with clear data in transparent letters on the finished radiograph. These particulars have now become an inseparable part of the film.

If the lid of the cassette is provided with a label, and the cassette is always placed so that when one looks at the lid this label is always on top (when the cassette is used lengthwise, the label is proximal to the patient's head and when the cassette is used crosswise, the label is on the left of the patient), then the photographic marking is always on the proximal side of the film, and it ensures that the radiographs are not placed upside down in the hangers, or written upon upside down.

The direction of the beam during the radiographic exposure and the method of viewing determine whether the strip should be placed on the panel of glass the normal way up so as to be directly readable, or whether it should be the other way around (mirror image). It is placed the *normal* way up for p-a (postero-anterior) radiographs (chest, skull p-a, gall bladder, stomach, etc.), and most radiographs taken during fluoroscopy. These films are viewed against the direction of the beam. It is placed *the other way round* for a-p (antero-posterior) radiographs; that is, for all films that are viewed from the focus, as it were, in the direction of the X-ray beam.

For this method of marking, the cassette can also be provided with a strip of lead over the corner where the data are to be printed, to prevent any 'free' radiation reaching that part (for example outside the skull during a skull X-ray). If one uses the method of black paper strips on the intensifying screens above, it is advisable to put a strip of lead foil on the cassette as an extra safeguard against exposure, where the corner of the film in question is exposed to the full power of the primary beam, for example in skull radiography.

When non-screens are used, a separate lead strip of the size of the name-plate, can be placed on the corner in question to keep off the radiation from there. It is advisable to fill in the marking strips beforehand and to have them ready in a convenient place in the processing room. In particular, when several radiographs have to be taken of the same patient, but radiographs of other patients have to be developed in between, this is very important and saves a lot of time looking around for the strips, and prevents mistakes. For this purpose one can simply use a hanger with compartments for the various strips (made, for example, from an unexposed, fixed film or a 'cleaned' film), which is hung under the safelight

above the loading bench, so that all the strips can be seen at a glance.

With many film marking units that are on the market, marking takes place along one of the four edges of the film in the form of a long narrow strip. Also in this case, the strip can serve as a means of indicating the direction of the beam.

### 10.8.3 Further processing-room procedures

Before the dry radiographs are passed on for further administration, etc., their four corners, which are usually somewhat damaged by the hangers, are cut off with a special device to prevent scratches, etc., on other films. This is unnecessary with automatic processing.

All equipment in the processing room should be cleaned regularly, and this applies especially to the developing and fixing tanks before new solutions are put in. This is best done by scrubbing with warm water. If this seems inadequate (as, for example, with fur or scale caked on), one can use dilute acetic acid (50 ml/litre of water). Rinse well.

The intensifying screens too, must be well looked after. However, if the procedure described above is followed (for example cassettes never fully opened), the risk of soiling is very slight, and they should need checking only once a month. When screens are lying open it should always be borne in mind that the merest drop of moisture (even from the lips when speaking) is enough to cause the film to stick to the screen. This means that when the film is removed, a piece of the sensitive layer will be torn from the screen, thereby damaging it irreparably, and result in a white patch on all subsequent radiographs. This causes great inconvenience and financial loss. Therefore, one should never leave cassettes with intensifying screens lying open. The cleaning and sponging of intensifying screens should be done according to the manufacturer's instructions and with utmost care. Usually, cotton wool swabs soaked in water or spirits, are used.

In the above, we have described by way of example, and in detail, the procedure in a conventional processing room, which, if used sensibly, scarcely leaves room for mistakes. This makes the processing room not a variable, unreliable part of the radiology department, but a constant and reliable one. This allows the exposure technique to produce optimum results, which is never possible when one has to keep on chopping and changing the exposure to suit the processing room.

Such a reliable processing room has not only the right, but also the duty to modify the exposure technique if this is necessary to obtain optimum results.

The duties of the processing-room assistant can be regarded as some of the most important in the whole department. If the assistant is up to this task, then the processing room is always neat and tidy; while behind the scene, as it were, he (she) follows actively all that is going on in the whole diagnostic department. The processing room assistant arranges radiographs that belong together into groups in the wash tank and drying cabinet; he takes care that the films are moved in groups at the right time from fixing tank to wash tank and from there to the drying cabinet. In short, he (she) is the hub of the whole department. If she is not up to the job, the processing room will soon become very inefficient: the fixing tank is too full, films show dichroic fog, are too dark or too light, the wash tank is over-crowded, whereas the drying cabinet is empty, etc. A thorough understanding of the importance of a faultless processing room technique is therefore of prime importance.

Nevertheless, in this book we should not omit to point out some of the possible faults. The following faults are the most common in connection with development:

(1) Wrong temperature. The development time must be adapted to deviations in temperature in accordance with the rules.

(2) Over-exposure, shown by the fact that the density 'comes up' too quickly. One should attempt to compensate for this fault by under-developing the film (shorter time) 'by sight', and dipping the film into the rinse water now and then in order to retard development.

(3) Under-exposure, shown by the fact that the density comes up too slowly. Conversely, here an attempt should be made to over-develop the film (for a longer time) by sight. Obviously, the film should be placed in the least used developer, if developers in different stages of exhaustion are in use.

Over-exposure and under-exposure can scarcely be regarded as faults in the case of radiographs which, for one reason or another, fall outside the scope of normal radiographic technique, as for example, radiographs taken through plaster or radiographs in an operating theatre, etc. In these cases it is essential to develop 'by sight', since adhering too rigidly to the standard regulations could lead to useless results.

### **10.9 AUTOMATION OF FILM PROCESSING, PROCESSING MACHINES**

Particularly in large institutions, there is a growing tendency to automate the processing of films, and there is already a large number of processing machines on the market. The aim here is to attain a fast, constant method of processing, to produce a dry film quickly, and to replace manpower by machines. There are various ways by which these aims can be realised to a greater or lesser extent.

If one analyses the operations through which the film must pass before it is dry, one finds that the washing and drying are the most time-consuming. If we take, for example, developing 5 min, fixing 10, washing 30, and drying 30 min, then we see that time could be saved in the last two operations in particular.

A considerable amount of time can be saved in conventional processing by forcing the washing so that it only takes a few minutes, and immediately after that, forcing the drying (in, for example, 60 s). The advantage of this is that the ordinary chemicals can be used at the normal temperature and that nothing except the washing and drying is accelerated; thus, for example, graininess (film noise) remains low.

Against this semi-conventional processing room, stand the completely automatic processing machines. In these, every phase is shortened as much as possible, enabling one to obtain the film completely ready, after processing times varying from 10 min to 45 s. This is accomplished by the use of a special developer of high concentration and at a relatively high temperature, fixed in a similar manner, greatly forced washing and drying. Moreover, as the developer is agitated continuously, fresh solution always acts on the film, thereby achieving a considerable shortening of the developing process as well.

Table 10.1 shows an example of how the speed of film processing is achieved by raising the temperature amongst other things. In addition to the influence of temperature, the different composition of the developer (see section 10.3.1.) and the forced penetration of the solutions into the emulsion also play a large part.

Table 10.1

	<i>Conventional processing</i>		<i>Machine processing</i>		<i>Machine processing</i>	
	Time	Temp. (°C)	Time	Temp. (°C)	Time	Temp. (°C)
Developing	4 min	20	65 s	27	25 s	33
Rinsing	10 s	15	—	—	—	—
Fixing	10 min	20	48 s	28	20 s	33
Washing	15 min	15	36 s	28	17 s	33
Drying	30 min	40	65 s	45	26 s	50
Total	60 min		3.5 min		90 s	

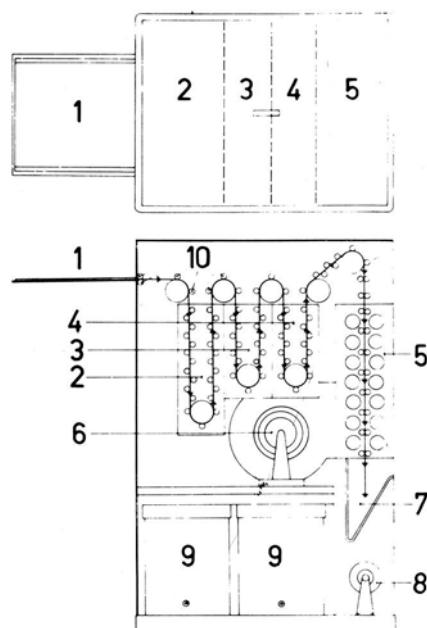


Figure 10.12 Diagrammatic representation of a completely automatic processor with the roller system.

Top: (view from above). 1. Film loading slot in which the films are slid without hangers; 2. developer compartment; 3. fixer compartment; 4. washing; 5. drying.

Bottom: (section through the centre). 1. Film loading slot; 2. developer tank; 3. fixer tank; 4. washing; 5. drying; 6. hot air blowing in; 7. receiving tray for dry film; 8. electrical supply of the machine; 9. tanks with reserve developer and reserve fixer; 10. roller which transports the still dry film to the developer compartment.

There are small and large types of processing machines, in which 120 films an hour can be processed. The solutions are pumped round, automatically replenished and have to be replaced after relatively short periods. Figure 10.12 shows a completely automatic processing machine diagrammatically. On feeding the film into the machine it is immediately seized by the transport system (for example by a roller system) and conveyed at a certain speed through the developer tank, fixer tank, wash tank and drying area, and presented dry into a receiving tray. The solutions are to a large extent pressed out of the films by the 'squeegee' action of the rollers and the warm air takes care of the final drying.

In general, with these machines, it is not possible to intervene in order to correct an over- or under-exposure. When automatic density control is used, incorrect exposures hardly ever occur, but even with non-automatic exposure it has been found, in practice, that the radiographers expose more accurately, as the machine delivers an immediately visible criticism of their work, as it were. This brings us to the advantages and disadvantages of this fully automatic processing. Although such a machine cannot be said to level out the results as much as similar machines used for amateur photography, where totally different exposures give practically the same density, there is a certain levelling nevertheless. As a result, the quality of the radiographs obtained reaches a fairly constant, *quite high level*, so that in the end the average quality rises with few or no exceptions (much better or much worse). As a consequence, this also implies that the number of exceptionally brilliant radiographs falls, but after a few weeks, when one has got used to the mechanical results, this is hardly noticed any more. Spoiled radiographs (due to over- or under-exposure) can result with non-automatic exposures, when the exposure has been much too long or too short; this can happen when radiographs are taken in the operating theatres especially. However, routine automatic processing cannot be used for special techniques where other films such as non-screen films, special mammography films, etc., are used.

The many processing machines available do not differ (or hardly differ) in principle from each other, except in form and performance. Through the years, they have become smaller and more convenient; some even offer the possibility of varying the duration of the process according to choice and, for example, can be switched from 90 s to 5 min duration (in this latter case, the developing process is more tolerant and less critical than with the shortest times).

The processing machine, as a highly specialised piece of equipment, requires careful cleaning and expert maintenance; the latter should be undertaken by a special service. Nevertheless, a broken-down machine (no exception) can paralyse a department, and it is therefore essential to have an alternative method of processing in addition to the processor. This can be a conventional processing room (albeit limited) kept in readiness, which, moreover, is very useful in certain cases such as correction of dubious exposures (operating theatre, etc.), or when there is not point in switching on the whole machine (for an emergency case at night, for example), or when one really wants to obtain a first-class result. In a large X-ray department, it is advisable that at least two automatic processors be acquired, so that the function of one machine (in case of failure, etc.) can be taken over by the other, temporarily.

For each type of machine a particular film is recommended, and indeed, not every film is suitable for every machine. Of course, the film manufacturers are

trying to break these priorities and with that the embarrassing situation of the radiologist, caused by the acquisition of a processor. Great progress has already been made in this direction, and the films offered can be processed in more machines and vice versa. The manufacturers of the processors are also making their machines in such a way that they are less particular in the type of film processed. The machine does not bring with it great economic advantages. Often the opposite is the case. Although there is a saving in some processing-room staff, servicing the machines is costly and, what is more, larger amounts of chemicals and water are used in comparison with the conventional processing room. The manufacturers are also working on this problem, and so, for example, washing with warm water has already been replaced by washing with unheated mains water.

By far the greatest advantage of automatic processing is the speed with which the completely processed film is made available, which alters the whole routine in the diagnostic X-ray department radically, in a favourable way.

A modern X-ray department without one or more automatic processors is unthinkable nowadays. The enormous progress in the composition of emulsions, together with specially formulated developers and fixers and their resistance to higher temperatures has led to the fact that results of good quality are obtained. The much increased use of automatic exposure contributes to this good quality and also to the uniformity of radiographs especially.

## 10.10 SPECIAL PROCESSING PROCEDURES

In various cases it is necessary to modify, to a greater or lesser extent, the standard methods described above.

### 10.10.1 Hardening of the emulsion

If the temperature of the solution is 25°C or more in one or more of the phases in the developing process, then a special hardening of the emulsion is necessary. The purpose of this is that the emulsion becomes more resistant to damage and the influences of temperature, especially in connection with fast drying. The dosage of hardener is especially important in the case of automatic processors as, on the one hand, too great an absorption of chemicals (harmful swelling of the emulsion) should be avoided, and, on the other hand, adequate absorption of water might be prevented, making efficient fixing and/or washing impossible.

Method of preparing 1 litre of hardening fixer: Three solutions (A, B and C); are made:

Solution A: 50 ml distilled water  
5 g chrome alum

Solution B: 350 ml distilled water  
25 g potassium metabisulphite

Solution C: 600 ml distilled water  
200 g sodium thiosulphate (hypo)

First, solutions A and B are mixed together, after which C is added. Finally filter or decant.

When using hardening fixer, the film should be rinsed for at least one minute after development and should be agitated in the fixer for the first minute. In some processing machines, where the films are transported by means of rollers, the rinsing process can be omitted; due to the squeegee action of the rollers, sufficient developer solution is pressed out of the film. The temperature of the fixer is less critical than that of the developer; nevertheless, the fixing process is quicker at 21°C than at 18°C. The fixing temperature should therefore be at least 19°C.

### **10.10.2 Rapid developing**

It is sometimes necessary to develop films rapidly even if it means risking non-optimum quality, as could be the case in radiographs taken in the operating theatre. The surgeon must know the result as soon as possible, especially if the patient is under anaesthesia. Therefore, one over-exposes on purpose so that the developing time in the processing room can be reduced below its normal value. The result can then be viewed after 2–3 min. It also is possible, as may be seen from figure 10.9 to reduce the developing time by increasing the temperature (but one should take care that the emulsion does not soften and run).

Another, better method of obtaining very quick results which, however, photographically speaking, is just as imperfect, is the use of a rapid developer and rapid fixer. For this one can use:

Solution A: 1000 ml distilled water  
               100 g sodium sulphite (anhydrous)  
 or:     200 g sodium sulphite (crystalline)  
       100 g pyrocatechine

Solution B: 1000 ml distilled water  
               60 g sodium hydroxide  
               100 g sodium bromide

The solutions, which individually will keep, but not together, are mixed in the proportion 1:1 immediately before use. With normal exposure, about 1 min is needed for development at a temperature of 18°C. The film can be made suitable for inspection after immersion for about 30 s in a highly concentrated fixer, containing 35 per cent hypo, immediately after development. The radiographs must later be thoroughly fixed. Pyrocatechine developer has a severely corrosive action on both skin and fabric, so that great care should be exercised when handling it. It is recommended that rubber gloves and a plastic apron be worn.

A simpler formulation which gives better results and does not require over-exposure is as follows:

#### *Rapid developer*

15 g metol  
 15 g hydroquinone  
 100 g sodium sulphite (crystalline)  
 20 g sodium hydroxide  
 1 g potassium bromide  
 water to make up to 1 litre.

Developing time 15 s at 20°C with constant agitation.

*Stop-bath*

3 per cent acetic acid for 5 s.

*Rapid fixer*

300 g      sodium thiosulphate (hypo)  
35 g      sodium metabisulphite  
50 g      ammonium chloride  
water to make up to 1 litre.

Fixing time: 30 s.

After rinsing in a water-tank, the film can be viewed in normal light. The procedure in the processing room has taken no more than 1 min. Afterwards, the radiographs are fixed in the normal manner, washed and dried and they then do keep normally. The quality is satisfactory.

Unused developer can be kept in full, tightly corked brown bottles for about 3 months. After use, the developer is poured back into the bottle. In order to prevent oxidation of the developer by the oxygen in the air, a few drops of ether are poured on top of the solution, after which the bottle is stoppered with a well fitting cork. In this way, used developer can be kept for about two weeks. The stop-bath is not kept. The rapid fixer keeps well for a long time and is only renewed when the action become noticeably slower.

### 10.10.3 Photographic reduction

If, due to over-development, a film has become too dark so that it cannot be viewed in the normal manner, reduction can give a usable result. The reducing agent most often used is *Farmer's reducer*; it consists of two solutions, which are kept separate until required for use:

Solution A: 1000 ml distilled water  
              100 g crystallised sodium thiosulphate

Solution B: 100 ml distilled water  
              10 g potassium ferricyanide

Before use, 9 parts of solution A are mixed with 1 part of solution B. After the film has been in the wash tank for one hour, reduction is carried out in subdued light until the required density has been reached. The film is then submerged in a 10 per cent solution of sodium sulphite for 5 min after which it is thoroughly washed. Obviously, reduced films can never give optimum results. Reduction attacks the low densities in particular, so that in the low density area, contrast and therefore much of the detail is lost before the excessive densities are reduced to the desired levels.

### 10.10.4 Photographic intensification

It is not very often that use is made of photographic intensification. If a radiograph has been so under-exposed or under-developed that its density is quite inadequate, it should be re-taken. Only when this is not possible should the complicated intensification procedure be considered. The procedure is described here

for the sake of completeness. The intensification solution, which is highly poisonous, consists of:

1000 ml	distilled water
20 g	sublimate
20 g	potassium bromide

After fixing, and thorough washing, the film is laid in this solution and left until the entire layer has turned white. After a brief rinsing, the film is blackened again in the developer or in a 10 per cent solution of crystalline sodium sulphite under bright light. In this way, the unsatisfactory silver precipitation is replaced by a more strongly blackening mercury precipitation.

#### **10.10.5 Rapid drying**

The rapid drying of films also belongs in the category of special procedures. When one does not have a rapid drying machine, one can use the following solution:

1000 ml	methyl alcohol (poisonous)
400 ml	distilled water
50 ml	formalin (40 per cent)

The film is dipped in this solution for 3 min, after which it can be dried in a couple of minutes by waving it to and fro, or with the help of a warm stream of air. One disadvantage of this method is that the emulsion from which water is extracted in a forced manner can shrink non-uniformly, giving a corrugated or grainy surface.

### **10.11 UNSATISFACTORY PHOTOGRAPHIC RESULTS**

The purpose of the following summary is to enable one to find the cause of possible film faults, and, if possible, to correct them. If one knows the causes of faults that can occur during processing, one will have a better understanding of the reasons for systematic and accurate work in the processing room.

#### **10.11.1 Fogged films**

##### **(1) Age fog**

Cause:

Film too old. A fog density of more than 0.25 should be regarded as inadmissible. Note the date on which a film's useful life expires: always use the oldest film first. Damp and heat accelerate the ageing process. Modern films are able to withstand higher temperatures and keep longer (especially important in the tropics).

##### **(2) Light fog**

Causes:

- (a) Unsuitable safelight (wrong colour of light, for example); light too strong (due to faded filter, cracked lacquer on lamp, etc.).
- (b) Film exposed too long to safelight.
- (c) Film inspected too often and for too long during development.

(3) *Radiation fog*

Causes:

- (a) Film exposed to radiation either in the radiographic room, going to it or coming from it.
- (b) Inadequate protective measures against radiation in the processing room.
- (c) Inadequate protection against radiation in store (for example against radiation from radioactive substances).
- (d) Influence by cosmic radiation.

(4) *Oxidation fog*

Cause:

The emulsion is oxidised by the air, by inspecting the film too frequently and for too long during development.

(5) *Chemical fog*

Causes:

- (a) Film left too long in the developer.
- (b) Temperature of the developer too high.
- (c) Faulty composition of the developer.
- (d) Contamination of developer with other chemicals.

(6) *Back-scatter fog*

Cause:

Scattered radiation through the underlayer when using non-screen films (always use lead as underlayer).

(7) *Dichroic (colour) fog*

Cause:

Interaction of developer and fixer, due to insufficient rinsing and/or old fixer.

### 10.11.2 Streakiness

Causes:

- (1) Failure to agitate the film during development, causing the liberated (heavy) bromide to run down and locally slow down development.
- (2) Inspection of the film during development. (The developer then runs in streaks down the film, resulting in uneven reduction of the emulsion.)
- (3) Interaction of developer and fixer, due to inadequate rinsing. (Therefore always use running water or an acid rinse bath.)
- (4) Dried-in residues of fixer. (Avoid this by keeping the film hangers scrupulously clean.)

### 10.11.3 Yellow patches

Causes:

- (1) Too long a period of development in old, oxidised developer.
- (2) Film not properly rinsed.
- (3) Use of exhausted fixer solution.
- (4) Use of developer that has been exposed to air too long. (There may sometimes be a thin layer of micro-organisms floating on the surface; this attaches

itself firmly to the film emulsion and cannot be removed. It gives the film a brownish-yellow, cloudy appearance.)

#### **10.11.4 Reticulation (spidery markings)**

Cause:

Sudden changes of temperature during processing. (Keep all processing liquids, including the rinse and wash water, at about the same temperature.)

#### **10.11.5 Frilling (loosening of film emulsion from its base)**

Causes:

(1) Use of warm or exhausted fixer, without hardener.

(2) Developer too warm.

(3) Film washed for too long at excessive temperature. (One sort of water may cause frilling quicker than another.)

(4) Drying at too high a temperature.

(N.B.: Modern films are less sensitive to high temperatures during the developing process and drying. It should be pointed out that some cleaning agents (biological action) contain enzymes which dissolve albumins and also act on gelatin. A film can be seriously damaged by this. Use of these cleaning agents for cleaning tanks without adequate rinsing could lead to this phenomenon.)

#### **10.11.6 Flash marks (black)**

Cause:

Static electricity on the film, due to friction, as, for instance, when unloading a cassette too quickly, or removing the film from its paper wrapper too quickly. It is more likely to occur in a warm, dry atmosphere.

#### **10.11.7 Light patches (on these spots the film is under-exposed or not exposed)**

Causes:

(1) Kinks (half-moons), stains or other flaws in the intensifying screens.

(2) Dirt, dust, bits of paper between film and screens.

(3) Drops of fixer or acid-rinse fluid on the film before development.

(4) Dried-in spots of fixer or developer.

(5) Air bubbles on the film during development.

(6) Kinks in the film before exposure.

#### **10.11.8 Dark patches**

Causes:

(1) Drops of developer or water on the film before development.

(2) Kinks in the film caused when unloading the cassette (black half-circles).

**10.11.9 Fingerprints**

- (1) Dark: caused by touching the film with fingers soiled by developer or metallic particles.  
(2) Light: caused by touching the film with fingers soiled by fixer, grease, etc.

**10.11.10 Writing or printing**

- (1) Dark or light printing: the film was on a reflecting, printed surface (for example a film carton) under unsuitable lighting.  
(2) Light writing: caused by a previous film having been marked while still lying on an intensifying screen, so that the letters have remained imprinted in the screen. Such a screen is ruined irreparably, because the writing will be reproduced with every exposure. If light writing is visible on a non-screen film, then that film was used as an underlay when writing.

**10.11.11 Blackening**

Excessive or inadequate:

This is usually due to over-exposure or under-exposure. Usable results can often be achieved, however, by suitably correcting the period of development, either shorter or longer than normal.

Other possible causes:

- (1) development time: too long or too short;  
(2) developer temperature: too high or too low;  
(3) developer: too concentrated, too diluted or exhausted.

**10.11.12 Mysterious images on the film**

The cassette has been open in strong light before loading. This can, for instance, cause the pattern of a window blind to be portrayed on the film, due to the after-glow of the intensifying screens.

**IT IS A GOOD IDEA TO KEEP FILMS SHOWING ONE OR MORE OF THESE FAULTS, FOR TRAINING PURPOSES.**

**10.12 OTHER PHOTOGRAPHIC WORK**

The X-ray department, especially in small hospitals and institutes, often has ordinary photographic work to do. Here, we shall mention only work which is directly concerned with medical X-ray procedures and leave out ordinary photography of patients, etc. We shall deal with the following in the order listed:

- (1) The reproduction of radiographs ('prints');
- (2) The handling of photofluorographs;
- (3) The handling of cine films;
- (4) The making of subtraction photos.

### 10.12.1 Reproductions, LogEtronic

Prints of an X-ray film can be made with a camera or with reduction apparatus especially designed for the purpose. Various automatic reduction units are available, by means of which the various sizes of radiographs can be reduced to the required size of print, for example, to 13 × 18 cm, or 9 × 12 cm, or the modern 10 × 10 cm size. In the absence of such equipment, an ordinary camera can be used; this must be accurately focused on the film to be reproduced.

These reductions can be made on paper, the most common being bromide paper, or they can be made on special reproduction film. Slides or transparencies, etc., can also be made in this way, but this is one of the more complicated processes and will not be dealt with in this book.

Whereas normal reproductions reverse the image, so that a dark spot on the radiograph corresponds to a light spot on the (negative) copy, special 'positive' photographic material also exists, which thus gives a black spot on the copy where there is a black spot on the original. Such a copy is known as a positive copy. This positive reproduction material is made so that it works in the solarisation range of the characteristic curve, where *more* exposure gives *less* density. This positive reproduction material is specially suitable for making contact prints of a radiograph. As long as the exposure and following operations are done correctly, this method gives such a good copy that it can only be distinguished from the original by the fact that the latter has emulsion on both sides and the reproduction on one side only. However, this positive reproduction material requires accurate exposure and careful processing.

It may be necessary, when certain areas of the film are too light, to shield them for some of the exposure time in order to avoid patches of excessive density. This can best be done by moving a screen to and fro to soften the contrast on the reduced print.

A much better, but more complicated method, which is used in reproductions for making prints intended for publication, is the *contrast levelling* method. This can be done photographically (by means of an intermediate phase) or electronically. With the photographic method, a print is made on a separate film or special paper (thus, negative in respect to the radiograph), and this print is used as a mask for superimposition on the radiograph; in this way a new print is obtained (also negative with respect to the radiograph, but separated from it by a sheet of glass). This is placed in between so that the contrast transition will not be too strongly marked. Thus, on the second print all the contrasts are levelled as required.

There are three grades of material, hard, standard and soft, to which special developer and specific rules apply of course. With poor contrast radiographs it is necessary to use hard grade material (steep gradation) in order to obtain serviceable contrasts in the prints. Soft grade material (flatter gradation) is used when reproducing contrasty radiographs.

It is also possible to level contrasts electronically, giving a more harmonised image on the copy. Here one speaks of *harmonisation* or *contrast compensation*. Here a ray of light, which passed a certain detail of the radiograph, is without any delay electronically intensified or weakened, according to whether it involves a dark or bright part of the radiograph. The radiograph to be reproduced is scanned by the very fast moving ray of light, and locally intensified or weakened

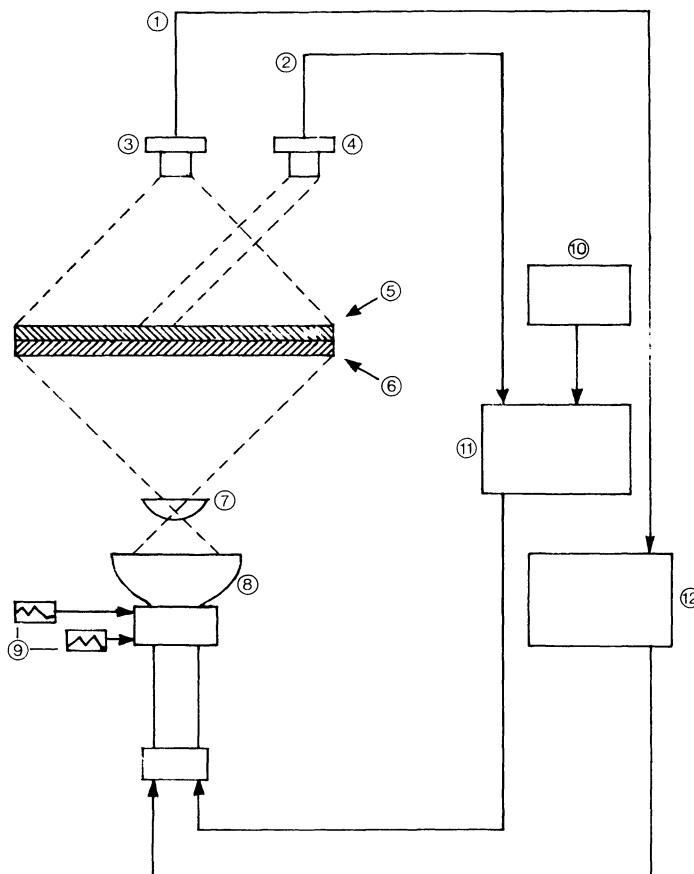


Figure 10.13 Principle of the LogEtronic. The photograph to be reproduced (6) in contact with the film which is to be exposed (5) is scanned by means of a beam of light from the cathode-ray tube (8) concentrated by the lens (7). The movement of the beam is effected by the deflectors (9). The photo-electric cell (3) reacts to the changing intensity of the light signal (inversely proportional to the density traversed) via connecting cable (1) with attenuation or amplification (with greater or smaller intensity as the case may be) in the modulator (12). This results in immediate (that is without inertia) adjustment to differences in density and harmonisation. The photo-electric cell (4) is integrated and terminates the exposure via (2) and (11) according to an adjusted index on (10).

(figure 10.13). In the special piece of apparatus, the LogEtronic, this principle has been realised in practice. It was originally expected that this contrast harmonisation would allow the original radiographs to be made less contrasty, thus with a higher kilovoltage and so with a lower dose to the patient. It is hardly surprising that this expectation has not been fulfilled; no process can extract good information from too low contrasts. This electronic levelling (or increasing) of contrasts has therefore not found its way into general practice in order to limit X-ray dosage, but it has been further developed for the making of harmonised copies for illustrations in books, for slides and for documentation and archive work.

Reductions (reduced reproductions or copies) are often required as documents, in case histories, in countries where radiographs remain the property of the radiologist or radiology department. Care must be taken that the details one is really interested in show up particularly well on the copy. (Hair-line fractures, for example) In order to obtain good results, one should preferably reserve a separate processing room, or at least a separate part of the processing room, for this purpose, since, among other things, the normal radiological developer is not capable of giving optimum photographic results with these prints.

It is advisable to print these reduced copies on glossy paper and to give them an extra gloss ('high gloss'), as this gives a better impression of definition. The modern LogEtronic apparatus also makes reductions possible with excellent reproduction of detail. Possibilities for installing an archive of reduced reproductions instead of large-size radiographs, in relation to the great space problem, are certainly here. One should, however, weigh the cost factor that comes with the extra photographic procedures against the cost of building a large radiological archive (or film store).

#### **10.12.2 Photofluorography**

There are very few departments that are specially equipped for processing photofluorographs besides their normal work. The processing of photofluorographs can be done in either the radiographical processing room or in a special processing room where other photographic procedures are also carried out.

The development of photofluorographs can be done in the same manner as the development of roll film in normal photography (for example in developing boxes). There are also types of photofluorographic films and cine films that can be processed by means of the (X-ray) film automatic processors. Special accessories are available for great lengths of film. The manufacturers usually provide a complete set with their apparatus, for the processing of the 70 mm and 100 mm (film widths) in the processing room. Usually, with the 70 × 70 mm and especially with the 100 × 100 mm sizes, each picture or small series of pictures is processed separately; special accessories are available for this purpose.

With the processing of large series, but also with single pictures, individual correction is not possible, due to the requirement of complete darkness during development. This is not a serious disadvantage, as the modern photofluorographic machines are provided with automatic exposure control, by means of which a constant density is obtained on the radiograph which can be regulated according to choice; individual density differences are extremely small and are practically negligible.

Photofluorography of the secondary screen of the image intensifier (viewing screen) hardly differs from normal photofluorography as far as the processing of the film is concerned. Here, one is also concerned with the 70 × 70 mm and the 100 × 100 mm sizes, both as single films or as rapid series. For this last application, the film should not be too sensitive, since then both the quantum noise and grain size produce interference; a fine-grain, less-sensitive film does not give as much trouble in this respect. For this same reason, a special 'fine-grain' developer is sometimes used.

### 10.12.3 X-ray cine films

Cineradiography is nowadays used exclusively in combination with an image intensifier by filming the images of the viewing screen of the image intensifier. This is also called 'film of the anode image'. In practice, 35 mm and 16 mm film widths are usually used as negatives (by way of exception 70 mm is sometimes used).

One should know beforehand whether the film itself is to be viewed (in which case it will soon deteriorate due to damage), or whether it is to be used for making copies for reproduction (demonstration or instruction) purposes. In the first case, one should try to get a contrasty film by strong development (which gives large grains); in the second case, one will use a gentle developer to give a more harmonised, fine-grained film, more suited to reproduction purposes. It is easily possible to process film lengths of 30 m and more, oneself, in a simple manner by means of available processing installations. However, only in specially equipped departments can one make reproductions of these films in the same size or smaller (for example 35 mm reduced to 16 mm) for demonstration and instructional purposes; this can be considered to be in the domain of the professional cine film makers. Automatic processing and copy equipment, specially made for X-ray cine films, are available for large institutes. Positive film is now also used in cineradiography, the first in the 16 mm size (a heart filled with an iodine contrast medium shows up black in the image). The processing of such films is still a professional matter; one sends them to special processing laboratories, just like amateur cine films.

### 10.12.4 Subtraction photos

The subtraction method was described by Ziedes des Plantes as long ago as 1934. Although practically no applications were found for it in radiography for a long time, modern vascular investigations with contrast media have opened up a useful field for this method.

#### 10.12.4.1 Photographic subtraction

As the name implies, with this method one subtracts one photograph from another. One takes a first radiograph. As soon as a change has taken place, after the administration of a contrast medium, one takes a second radiograph. If the first radiograph is now subtracted from the second, all that is left is the change. This is demonstrated very clearly by the original illustrations of Ziedes des Plantes, in which, after subtraction, only the change (the number 2) that had been added to the original photo, is left (figure 10.14).

In practice, subtraction is carried out as follows. A copy of the first radiograph is made on film, a *diapositive*. If this copy is placed upon the first film and viewed by transmitted light, then one would see nothing. Everything is then equally grey, since everything that was transparent in the original film is no longer in the positive copy, and vice versa. If, however, this copy is placed on the second photo, then everything that is the same in the two photos is invisible; only the differences are now immediately apparent. Naturally, one does not aim at complete invisibility, but to give an idea of the position of the changes, at a not too high a density on the copy film. In order to obtain a good end result this density is somewhat

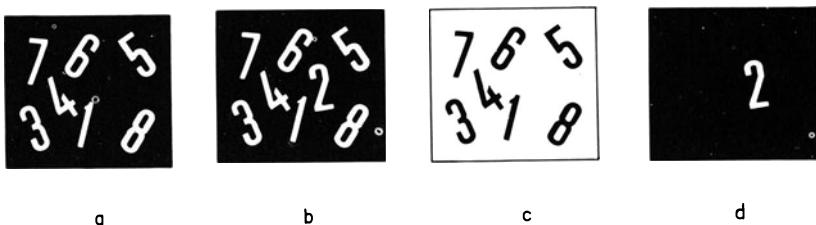


Figure 10.14 Subtraction (illustration according to Ziedes des Plantes).

- a. Radiograph of metal numbers.
- b. Radiograph after the addition of the number 2.
- c. Positive copy of a.
- d. Result when b and c are superimposed.

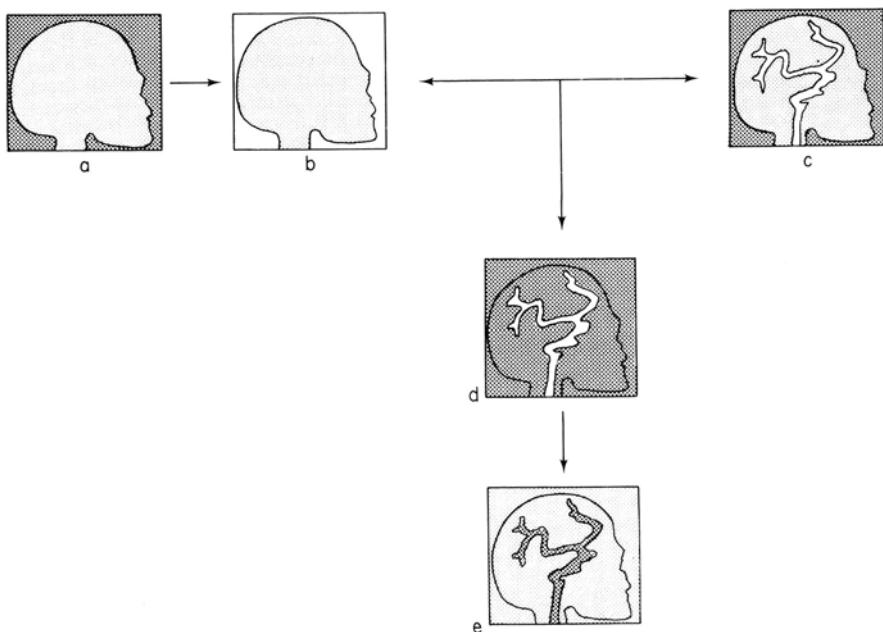


Figure 10.15 Photographic subtraction in cerebral angiography.

- a. An 'empty' radiograph, made before the injection (the negative).
- b. A (transparent) print of a on film (the positive).
- c. A radiograph taken during the injection, a negative therefore, upon which the contrast medium is visible. By superimposing b and c one obtains d, in which the contrast medium alone is seen as a clear image on a dark background. By making a print of d one obtains the ultimate subtraction photo e in which the angiogram (in black) is visible on a clear background.

critical, in practice. The already classic example of the advantages of subtraction in angiography is provided by a cerebral angiogram. The positive copy of the radiograph of the skull, the 'empty' radiograph (that is before injection), is superimposed on the second radiograph with the contrast medium. Now one sees only the cerebral angiogram, unhindered by the difficult to interpret structural shadows

of the skull as can occur with the orbits (angiography of the ophthalmic artery, figure 10.15).

It goes without saying that the conditions required to produce satisfactory subtraction are a completely motionless object (apart from the changes one is interested in), a copy of suitable quality, and the possibility of exact superimposition of the copy of the first radiograph with the second radiograph. This superimposed image can be viewed in front of the film illuminator or one can make a copy of it giving one the subtraction photo.

#### 10.12.4.2 Electronic subtraction

In addition to photographic subtraction, electronic subtraction has become highly developed, making use of the great possibilities offered by the television system in the areas of addition, subtraction and 'remembering' or storing of images. Also the reversal of images (turning black into white and vice versa) is no great problem here.

The principle of a television set-up for this subtraction technique is shown in figure 10.16. In this case the two original radiographs (negatives) (the 'empty' photo '1' and angiogram '2') are placed on a light box. Arranged above each radiograph is a television vidicon camera; from one camera (via 3) a positive, and from the other camera a negative, signal is sent to the television system and combined there, with the result that the similarities in the two radiographs cancel each other out and become virtually invisible. What remains are the points of difference between the two radiographs (in this case the vessels filled with the contrast medium) and these are displayed on a television monitor (figure 10.16).

The subtraction image obtained in this manner can be 'held' as it were, and photographed with the aid of a polaroid camera. If artifacts are to be excluded

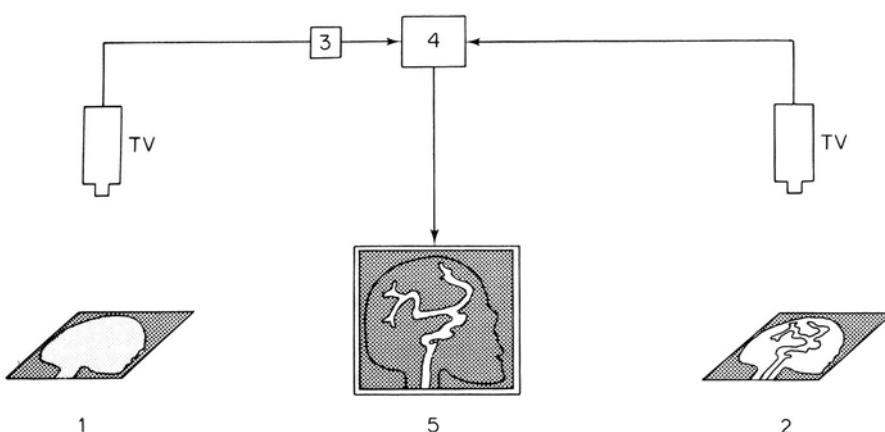


Figure 10.16 Electronic subtraction by using two television cameras. The 'empty' radiograph is shown on the left (1) and the radiograph with contrast medium on the right (2). The original films (both 1 and 2) are negatives. The television camera above 1 converts the image in 3 into a positive image, which, along with the non-converted image of 2 by the television camera above 2, are combined in the subtractor (4) and presented as a combination image on the monitor (5): the ultimate subtraction image. This can be viewed as a positive (black vessels) or a negative (transparent vessels) by conversion.

as far as possible, then the two television cameras must be identical in order to prevent the sending of quality differences to the subtractor. If a memory device is used (for example a video recorder) one camera will suffice.

Also, one can successfully (spectacularly) make use of a colour television system, where one records three phases of the investigation (0 = 'empty', A = arterial, V = venous phase) in three different colours (such as green, red and

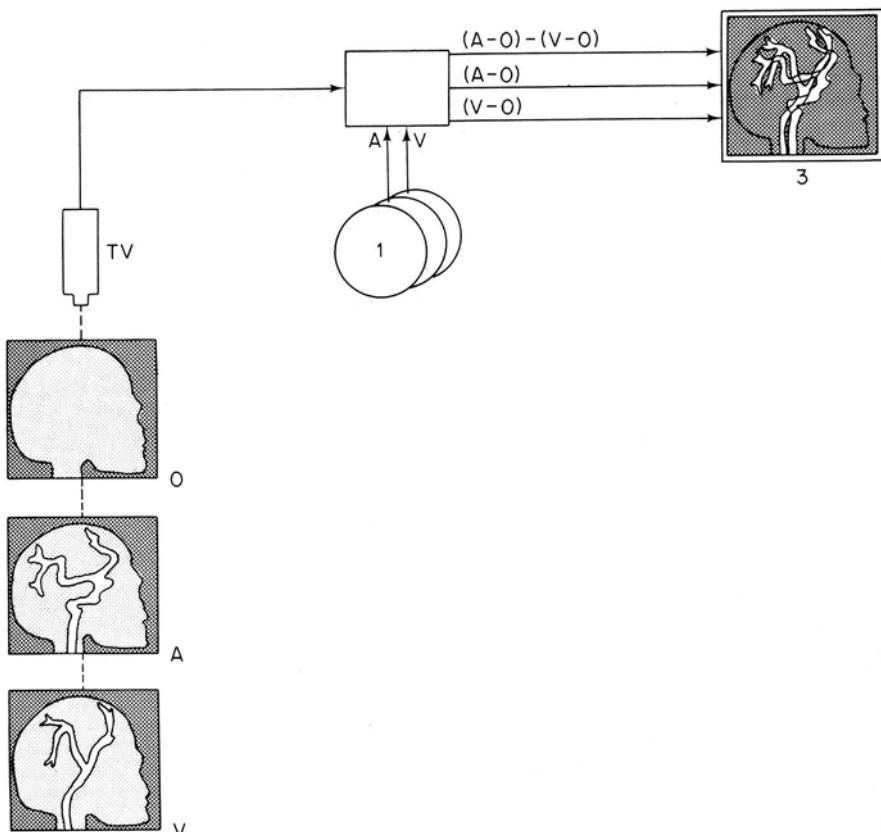


Figure 10.17 Subtraction with the three-colour system. A radiograph 0 is taken before the injection, radiograph A during the arterial phase and radiograph V during the venous phase. These are viewed by the television camera and transmitted as a green, red and blue signal, respectively. The red signal (A) and the blue signal (V) are each fed to a double memory and stored there. By combining these with image 0 (singly or combined) in subtractor (2), the coloured angiogram can be seen on the monitor (3).

blue, respectively) and store A and B in a double memory. One can then combine according to choice (figure 10.17). In this way, one can either view the arterial phase by itself (in red), or the venous phase by itself (in blue), or both phases at the same time (red and blue) demonstrated against a white background. Here also, the monitor image can be recorded in colour by means of a polaroid camera.

Radiographers who will be concerned with the making of reproductions, photo-fluorography, subtraction photography, and possibly with cinematography (and this goes for every radiographer, if not now then certainly in the future) and they would be well advised to obtain a thorough grounding in normal photographic methods by following special courses. Most countries in the Western world offer ample opportunities in this direction.

### 10.13 SOME REFLECTIONS

The still increasing tendency to bring further automation into practice has found a grateful area in the processing-room technique. Due to this, by far the greater part of the contents of this chapter will not, or hardly, play an important part in the radiographer's routine technique. Developing and fixing solutions are delivered ready to use and the automatic processors deliver radiographs dry and ready for viewing, extremely quickly, which in manual processing would be unattainable. Because of staff shortage and/or because of the high wages, it is understandable that the human element will increasingly disappear from the processing room and be replaced by automatic machines. Already, one step in that direction is the automatic loading and unloading of cassettes without manual intervention. The use of vacuum cassettes goes even further, as these can be automatically loaded from a film magazine in the X-ray couch and after exposure are automatically conveyed to an automatic processor and are unloaded there, after which the film

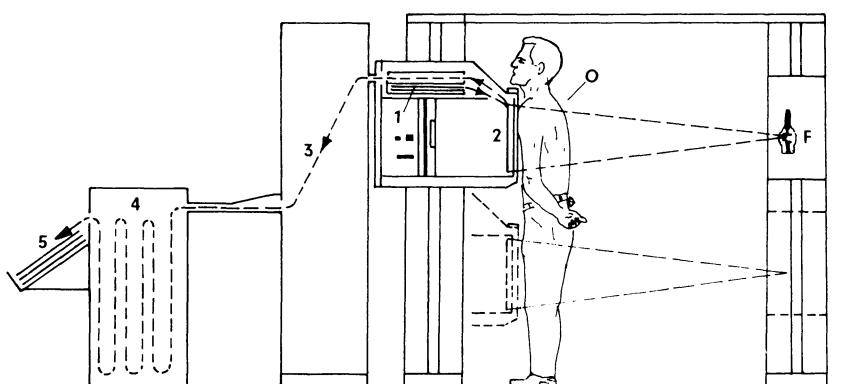


Figure 10.18 Film magazine technique without cassettes in automatic chest radiography. The radiation emitted from X-ray tube F penetrates object O and exposes the film-screen combination 2. After this the film is taken into the processor 4 by means of the transport mechanism 3 and delivered dry and ready for viewing in compartment 5. In the meantime an unexposed film from the magazine 1 is ready for the next exposure in 2. (N.B.: The height can be adjusted to the height of the patient.)

is automatically processed and the dry radiograph is available within a few minutes. With this 'magazine technique' the processing room has virtually become unnecessary and the processor can be placed *in* the particular X-ray room. We shall not

discuss the advantages and disadvantages of such a system (whether with metal or vacuum cassettes, or with the processor in the X-ray room or still in the processing room). The system is not yet widely applied, but it is very promising. Figure 10.18 gives an impression of the possibilities.

In countries which are technically less perfected, the installation and use of the 'classic' processing room is not only preferable, but the work therein can mean an interesting and fulfilling vocation for many.

# 11

## Fluoroscopy and Radiographic Technique in General

Both fluoroscopy and radiography are methods of investigation that have gained a permanent place in radiology.

### 11.1 PURPOSE OF FLUOROSCOPY

In comparison with radiography, fluoroscopy is a rapid and inexpensive method of investigation. As opposed to ordinary radiography, which only procures a stationary image, fluoroscopy makes it possible to observe an object continuously over a longer time and it thus also provides an insight into the function of moving organs. The nature of the examination and the condition of the patient determine in which position the examination will take place. Most fluoroscopic examinations are carried out in a vertical position, that is with the patient erect and the X-ray beam horizontal. Examinations with the patient lying in a horizontal position and the X-ray beam in a vertical direction are also made. However, as other positions are also necessary for many investigations where, with the aid of gravity, for example, the contrast medium that has been introduced can be directed to the area to be examined, all angles between the vertical upright and the horizontal (thus, from  $90^\circ$  to  $0^\circ$ ) are used, as well as still greater angles by which the patient comes to lie with his head lower than his legs. Such a position is called the *Trendelenburg position* and is expressed in degrees. A  $15^\circ$  Trendelenburg means an angle of  $15^\circ$  below the horizontal, and a  $90^\circ$  Trendelenburg indicates that the patient is in a completely upside-down position (securely fastened to the table obviously). We shall deal with this further, as well as how the examiner can continue to view the fluoroscopic image, in the chapter on stands (chapter 16).

During fluoroscopy, one tries to find a favourable position by continually

moving and turning the object. Here 'standard' positions are of much less use than when taking radiographs; they usually only serve as a starting point from which the patient is moved or turned in one direction or another. However, it should be pointed out that a very great advantage of fluoroscopy (although also of radiography) with a *horizontal beam* is that in a cavity where both fluid and gas (air) are present, a fluid level can be seen, which remains horizontal even when tilted sideways. Therefore, free pus in a mandibular cavity, for example, or free fluid in a pneumothorax, etc., can only be demonstrated with complete certainty in this manner, that is with a horizontal X-ray beam.

The perceptibility of detail in the fluoroscopic image is low, however. The fluoroscopic method, therefore, often gives no more than an indication, and in most cases does not make a definite diagnosis possible. Moreover, the patient is exposed to a relatively high dose of radiation. Lastly, fluoroscopy does not furnish a permanent record. Nevertheless, fluoroscopy represents an important method of investigation, which is used for the following purposes:

- (1) the adjustment to the exact position of the patient for particular radiographs, usually radiographs of a certain detail;
- (2) the study of the function of an organ, for example the passage through the oesophagus and gastro-intestinal tract, peristalsis of the stomach, the movements of the diaphragm, etc.;
- (3) the demonstration of fluid in the body (for example pleural exudate) and the transposition of organs (the stomach, for instance);
- (4) the tracing of gross abnormalities, especially in the lungs, the heart, the gastro-intestinal tract and the skeletal system; the detection of metal foreign bodies (the more detailed diagnosis is usually made with the aid of radiographs);
- (5) spatial localisation of these abnormalities and foreign bodies (by turning the patient during the examination);
- (6) as a control during surgical operations, such as with the setting of a fracture, the introduction of a probe or catheter into the bronchi, blood vessels or the heart, and by the introduction of contrast media (bronchography, hysterosalpingography, retrograde pyelography, and the passage of contrast media into the colon, etc.).

## 11.2 METHODS OF FLUOROSCOPY

Several methods of fluoroscopy are used (see also section 8.1.2).

### 11.2.1 Conventional fluoroscopy

For a satisfactory fluoroscopic examination the following are necessary:

- (1) proper adaptation,
- (2) good radiation contrast,
- (3) sufficient X-ray intensity,
- (4) a fluoroscopic screen with satisfactory fluorescence and as little phosphorescence as possible, as has already been discussed in chapter 8, section 8.1.2. More-

over, one should always keep in mind that the dose used should be as low as possible; this can be accomplished by rapid examination and strict beam limitation (the latter also improves contrast, for that matter).

### **11.2.2 Fluoroscopy with the image intensifier**

The image intensifier has completely changed the method of fluoroscopy. Since its application, the diagnosis can, in many cases, already be made during fluoroscopy, and the taking of one or more radiographs is only done to record the examination. Moreover, the radiation intensity is considerably less during screening than would be the case with conventional fluoroscopy (provided that the limitation of radiation, which is made possible by the image intensifier, is actually applied.) This limitation of radiation is especially important in examinations during heart catheterisation, for example, where fluoroscopy may have to take several minutes.

Another use of the image intensifier is in the visual adjustment of the patient for the taking of certain radiographs, of the skull, for example; that is special projections such as those of Rhese, Schüller, Stenvers, Chaussée and others. The details that serve as landmarks for adjusting positions are only visible because of the great brightness made possible by the image intensifier; they are often insufficiently visible in conventional fluoroscopy to serve as guides for the positioning. The great brightness, moreover, makes rapid positioning possible.

### **11.2.3 Fluoroscopy with image intensifier and television: X-ray television**

As already mentioned in section 9.5, the image intensifier is now linked to a television chain. The X-ray television, in its turn, has introduced a new phase into X-ray fluoroscopy. This has even caused fluoroscopy with image intensification without television, which in itself was such a great step forward, to be pushed into the background to some extent, even before it had time to unfurl its merits fully. The method of fluoroscopy has been completely altered with television. The examiner no longer looks at the fluoroscopic screen, but at the television monitor. This can be set up near the patient, so that the direct contact between examiner and patient can be maintained. The examiner is then capable of certain manipulations (palpation, compression, injection, etc.), and is able to place the monitor where it is best visible during the examination. Often, two monitors are used, one being best visible during examinations with the table in an upright position, and the other during examinations with the table in the horizontal position. It is especially recommended that a monitor be placed in the control area or cubicle, if this is separated from the examination area in such a way that the radiographer cannot actually follow the progress of the examination. A television monitor (a small one) in the control area compensates for this disadvantage, and makes efficient cooperation possible.

Especially important with television fluoroscopy and an important advantage with regard to image intensification fluoroscopy, is the possibility of being able to increase both the brightness and the contrast (within certain limitations, of course). This can lead to improved diagnosis as well as a saving in radiation dose

(for patient, radiologist and staff), as one can see so much better and more quickly what one is looking for. Because of this, often shorter screening times can be managed, which is especially important with heart and vessel catheterisations. *It should be pointed out with great emphasis that with these investigations one should strive not for a beautiful clear image by an increase in mA and/or kV, but, after optimum adjustment of the television chain, to reduce the radiation intensity (the mA especially) in such a way that one can see just enough.* Only after satisfying these conditions, has one the certainty that one is working with the lowest possible dose, and is not sacrificing dose limitation for 'beautiful' images.

The great brightness of the television monitor no longer necessitates fluoroscopy in darkness. This has many advantages: the patient feels more at ease, and the examiner has a better view of possible instruments. The cardiologist, for instance, also has his eye on the electrocardiogram, the pressure curve, etc., during a heart catheterisation.

A more-or-less portable or mobile unit (figure 16.2, page 414) has already proved its great use in the plaster room and in the operating theatre; the surgeon can, while looking at the image on the monitor, manipulate easily, and reduce and 'pin' fractures, remove foreign bodies, etc.

Although the bright television image allows for the possibility of doing away with every black-out measure and enables one to work in full daylight, it should be pointed out with great emphasis that not only the perceptibility of detail is less with bright illumination of the room, but also that by darkening the room a considerable saving in radiation dose, especially, can be made. It is true that one does not have to adapt rigorously to the dark, as was formerly the case, before starting the investigation; on the contrary, one can begin immediately, but, if one adjusts the room lighting properly (for example by means of an adjustable transformer), the eye will be better able to perceive the image on the monitor. An environmental brightness that is approximately equal to the brightness of the monitor's image gives the best results, and leads less quickly to fatigue of the eyes. *Our object must always be: dose limitation, and not, cost what it may, unnecessary convenience and/or a beautiful image.* It may be taken as a rule of thumb that a good image intensifier television chain should be capable of producing a good fluoroscopic image of a stomach investigation on an adult of normal size and build at 90 kV and 0.2 mA; 70 kV and 0.2 mA should be enough for monitoring accident surgery.

The fact that the television image can be seen by several persons at once, is a great advantage as well, especially when assistance (surgical assistant, radiographer, etc.) is essential to the investigation. One can then see immediately what is to be done. This television method is also very well suited for demonstration purposes, as it is also possible to set up a monitor in another room, a lecture-hall, for example.

As far as the quality of the television image is concerned, we have already pointed out the possibility of varying the contrast and the brightness by increasing it, for instance. As to the definition, there is nothing to be gained; on the contrary, in comparison with the image on the intensifier, there is even some loss to be found, inherent to the method by which an image is conveyed via the television (see section 9.5.6.7).

The definition of the fluoroscopic image of the image intensifier is limited by the input phosphor; on the television monitor, the definition or sharpness of the

image is limited by the width of the electron beams in the camera tube and monitor, and it is because of this that the definition is not as good. Thus, for example, a bony structure is less well perceived with television fluoroscopy *per se*, than with direct image intensifier fluoroscopy. Because of the possible improvement in contrast in the television chain, television fluoroscopy can still gain over image intensifier fluoroscopy in some cases, when one is concerned with showing details that are not too small, such as gall stones in cholecystography.

#### **11.2.4 Improvement of the fluoroscopic image by means of image intensification and image intensifier television**

Whereas with conventional fluoroscopy an improvement in the fluoroscopic image is only possible by altering the kV and/or mA, and this is seldom done during an examination, the situation is completely different when using image intensifier and television fluoroscopy with the much greater brightness.

##### **11.2.4.1 Change in brightness, brightness stabilisation**

The varying radiation intensities, due to turning the patient, for example, which strike the input phosphor of the image intensifier, create large (and usually interfering) differences in brightness when screening. It causes even more interference when one is concerned with image intensifier television fluoroscopy, as obviously the higher gamma values of the television (contrast intensification) often lead to 'over-radiation' and to 'blotting-out' of the image.

By applying brightness stabilisation (in which the quanta of energy that strike the primary screen remain the same), as described in chapter 9, a uniform brightness level is attained during the entire examination, which greatly improves the perceptibility. This brightness level can be adjusted to the desired degree. If one does not strive towards a perfect image, but towards an image which is sufficiently medically diagnostic, as recommended in the paragraph above, one would adjust the brightness stabilisation to a sufficient level for this purpose and not too high, by which, in many cases, there would be a noticeable saving in dose in comparison to a 'free' adjustment.

For the various stabilisation methods see chapter 9.

##### **11.2.4.2 Improvement of the image by noise limitation**

Noise has already been mentioned as an interference factor in good perception. In the image intensifier, with its low gamma value, the noise is less interfering than on the television screen, where the higher gamma value also increases the contrast of the noise. Only by absorption of more X-ray quanta in the input phosphor can this noise be decreased which, however, also means a greater exposure to the patient (higher dose). When the intensity of the X-rays is considerably increased, as is the case in cinematography, then the noise will decrease noticeably or even disappear completely. Now, if in a two- or three-channel optical system, 10 per cent of the available light is used for direct viewing or for a television camera (the 90 per cent goes to the film camera), then one will see an image more-or-less (or entirely) free from quantum noise (see section 9.5.5).

If one increases the contrast in the television chain too much, then the fluoro-

scopy will be adversely influenced by the (characteristic) television amplifier noise. This should be limited to an acceptable maximum level when the equipment is put into use. The comment should be made that, by the use of direct (radiological) enlargement, one can overcome the disturbance of the 'wriggling' images (caused by noise) for the perception of small details. As we have said before, here the enlarged detail that is shown against the unchanged background becomes visible, or at least more clearly visible.

### **11.2.5 Magnetic recording of the fluoroscopic X-ray images**

(See also section 9.5.6.)

Despite the fact that the brightness of the image intensifier's output phosphor is poor in comparison with the light intensities that act upon the television camera of the ordinary television, they have succeeded in using the video signal created by image intensifier television fluoroscopy for magnetic tape recording (video recording). This, and the production of images on the television monitor, can be done simultaneously. In this manner, the whole fluoroscopic examination can be recorded onto tape (or selected parts thereof). Therefore, one can at any moment view the whole or a part of the examination again, without any X-rays being involved. Naturally, this is very important for instruction and demonstration, but such reconstruction of the investigation is also extremely useful for final results (decision) in routine practice. One can erase the magnetic images after they have served their purpose, and one can use the tape again, as with the ordinary sound magnetic tapes. This method is being perfected. Besides being able to look at good-quality moving images, it is also required that 'stills' or stationary images can be viewed and, furthermore, that the recorded images can be viewed in 'slow motion'. Without a doubt, this magnetic recording has a great future, even for day-to-day practice.

Although it seemed at first as if magnetic tape recording would supersede X-ray cinematography entirely, the latter nevertheless offers so many advantages (especially greater definition) that it has still kept its rightful place.

## **11.3 RADIOGRAPHS**

In general, radiographs give more detailed information than fluoroscopy and, moreover, form a permanent document. In the following, some of the factors that are important in producing good-quality radiographs will be discussed.

### **11.3.1 The placing of the object near the film**

In the previous chapters, the behaviour of the X-ray beam (divergence, inverse square law), the influence of the focus (load, geometric unsharpness  $U_g$ ), exposure time (movement unsharpness  $U_m$ ), unsharpness due to screens, cassettes, etc. ( $U_i$ ), contrast (grids, etc.) etc., which determine the quality of the (invisible) radiation image that reaches the film, have already been fully discussed. Sufficient exposure, satisfactory contrast and good definition (by means of acceptable  $U_g$ ,  $U_m$  and  $U_i$ ) are conditions for a good radiation image, which, transformed into an (invisible) latent image on the film, is offered to the processing room.

In general, the object to be radiographed should be placed as near the film as possible. Thus, radiographs of the gall bladder (situated towards the front of the abdomen) should be made with the beam directed from the back in a forward direction (dorso-ventral), and kidney radiographs with a beam directed from the front towards the back (ventro-dorsal). In this manner the  $U_g$  is reduced as much as possible. If one wishes to show the right petrous bone, the right side of the skull should lie nearest the film.

It is obvious that the best radiographic positions have been thoroughly studied and described, and that these fall outside the intention of this book. However, it does seem desirable to mention some medical terms, and to give a number of general rules, as well as making recommendations which, if consistently applied, will improve the accuracy and speed of radiography, and in particular save materials and radiation dose.

### 11.3.2 Anatomical terms and radiographic projections

The plane that divides the body into a left half and a right half is the *median plane* (portrayed as the *median line*) (figure 11.1). Away from the median plane is the *lateral* direction, and towards it is the *medial* direction. Towards the head is *cranial* or *proximal*, towards the feet is *caudal* or *distal* (the hand is distal to the elbow, and the clavicle runs from the lateral to the medial from the scapula towards the sternum). *Dorsal* or *posterior* refers to the back, and *ventral* or *anterior* refers to the front. Towards the right (looking from within the body) is *dexter*, and towards the left, *sinister*.

The direction *anterior* ↔ *posterior* is the *sagittal* direction. The direction *caudal* ↔ *cranial* is the *vertical* direction. The direction *dexter* ↔ *sinister* is the *transverse* or *lateral* direction.

The drawings in figure 11.2 show some examples of radiographic projections and their names, which occur frequently in day-to-day practice. The direction of the beam of radiation is always followed; thus, from the focus to the film. If the rays are directed from above downward, then this is called *cranio-caudal*. The reverse direction (from below upwards) is called *caudo-cranial* (the exact direction is expressed in degrees). Instead of a-p (antero-posterior), the term v-d (*ventro-dorsal*) is often used, especially when referring to the trunk; similarly, instead of p-a (*postero-anterior*), the term d-v (*dorso-ventral*) is often used (see 1 and 2 in figure 11.2). To indicate a possible deviation from the normal direction, one adds to this the angle in degrees. Thus, drawing 3 in figure 11.2 represents a p-a  $\alpha^\circ$  *caudo-cranial*, and drawing 4, a p-a  $\alpha^\circ$  *cranio-caudal* direction.

In the second row of figure 11.2 the transverse (*lateral*) radiographs are indicated according to the direction of the rays and the side closest to the film; thus, drawing 5 is lat d-s (*dextro-sinister*), or left lateral; 6 is lat s-d (*sinistro-dexter*), or right lateral; 7 is lat  $\alpha^\circ$  d-s *cranio-caudal*; and 8 is lat  $\alpha^\circ$  s-d *caudo-cranial*. In the third row, the projections considered are viewed from a point above the head; that is no. 9 p-a; no. 10 lat s-d (right lateral); no. 11 p-a  $\alpha^\circ$  s-d; and no. 12 p-a  $\alpha^\circ$  d-s.

In the fourth row of figure 11.2, no. 13 represents an *axial* radiograph of the shoulder, no. 14 an *axial* projection of the calcaneus, no. 15 a *latero-medial* projection of the wrist. Finally, in no. 16, the four usual projections in mammo-

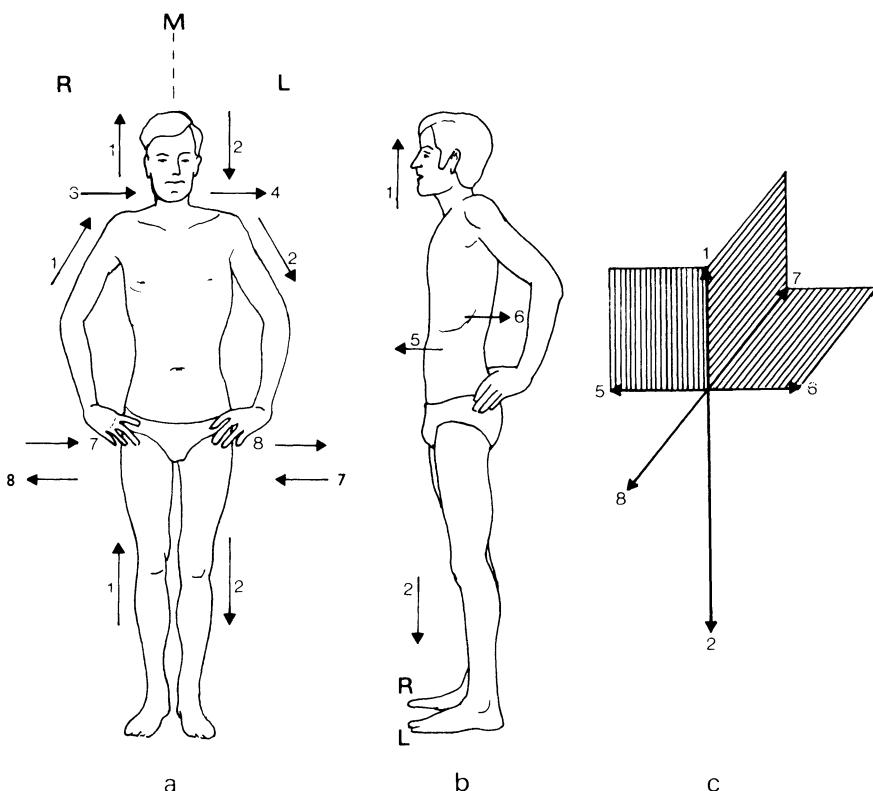


Figure 11.1 Simple representation of the most important landmarks and projection indications (shown by arrows).

a. Seen from the front (the letters R and L are placed cranially and laterally). M is the median plane (or the median line). 1. Cranial (proximal); 2. caudal (distal); 3, 7. medial; 4, 8. lateral.

b. Seen from the side (the letters R and L are placed caudally and ventrally). 1. Cranial (proximal); 2. caudal (distal); 5. anterior (ventral); 6. posterior (dorsal).

c. Representation of three axes at right angles to each other which belong to position b. 1-2. Vertical axis; 5-6. horizontal (sagittal) axis; 7-8. horizontal (transverse) axis. The sagittal plane runs through the vertical and sagittal axes, parallel to the sagittal suture (plane through 1 & 5). The frontal plane runs through the vertical and transverse axes, parallel to the forehead (plane through 1 & 7). The transverse (horizontal) plane runs through the sagittal and transverse axes (plane through 6 & 7).

graphy are shown; namely, 1. *cranio-caudal*, 2. *caudo-craniad*, 3. *medio-lateral*, and 4. *latero-medial*.

In radiographs of the chest, the *dorsso-ventral* direction of the rays is usually used, as the heart is situated towards the front; with very ill patients we are sometimes forced to employ the v-d (thus, a-p) direction, in which the heart is shown to be disproportionately large. If a projection is taken in a direction opposite to the usual one (for example a-p instead of p-a in radiography of the chest), then this should be indicated on the film to avoid incorrect conclusions (for example a heart that is too large).

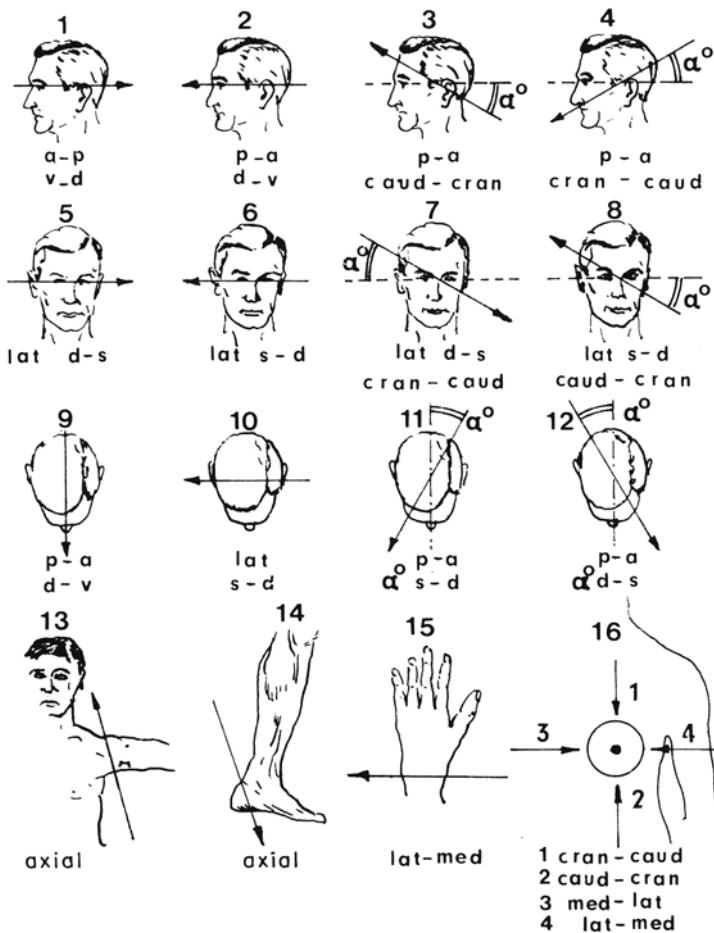


Figure 11.2 Nomenclature and illustration of the most widely used projection directions. The top three rows show the projection directions with the skull as the example. In the bottom row a few projections are shown which are used for radiographs of the shoulder joint, the heel, the wrist and mammography (left breast).

### 11.3.3 Marking of radiographs for identification purposes (placing of the markers, viewing direction, placing the cassette)

It is obvious that every radiograph should be labelled with information which includes the identity of the patient, the date and the projection chosen. By means of photographing the little name plate or identification strip onto a part of the film that has been protected from radiation with a strip of lead, the patient's particulars can be attached permanently to the film in a very satisfactory manner. Several systems exist for this purpose (see chapter 10, section 10.8.2). The indication of projectional directions would perhaps seem superfluous at first, as these can usually be 'read' from the radiograph. This, however, is not the case:

an a-p projection can often not be distinguished from a p-a projection, and if one takes a radiograph of the middle portion of the humerus or femur only, then one would usually be unable to tell which is proximal and which is distal. To establish this, one should thus have to radiograph (unnecessarily) quite a large part of the surrounds (a joint, for instance), which would entail an undesirable increase in dose. In order to overcome these objections, the system described in the following deserves warm recommendation.

#### **11.3.3.1 Placing of letters (right and left markers)**

Every radiograph should show clearly which is the left side and which is the right side of the patient. Without some indication, one could never see this on a radiograph, since turning a radiograph over would merely give the mirror image (thus, for example, a right ankle as a left ankle). For this purpose the lead letters 'R' and 'L' are used.

A marker is not essential on a chest radiograph if the patient has also been screened, as the heart normally indicates the left side. However, if there has been no preliminary fluoroscopic examination (patient too ill, bed-ridden, etc.) the radiograph should always bear the appropriate marker, since the heart is then no certain guide (as in possible transposition of the organs, the heart would lie on the right side: thus, dextro-cardia).

It makes a neat impression if the markers are not just visible anywhere on the film, but are placed neatly and systematically. The letters are used in the following manner, in accordance with further specifications of the examination:

- (1) *The letters are always placed so that the top of the letter indicates the proximal direction, that is not R but R.*
- (2) *The letters are always placed so that they look normal (that is not a mirror image) when seen from the focus looking towards the patient.*
- (3) *With a-p and p-a projections, the letters are always placed proximally (that is towards the head) and laterally (that is away from the median line, which divides the body into a left half and a right half).*
- (4) *For lateral projections and for 45° projections, the letters are always placed distally (away from the head) and ventrally (or towards the abdomen or front of the body).*
- (5) *For lateral exposures (of the skull and trunk, for example) one always chooses the letter corresponding to the side of the patient which is nearest the film.*

If these five rules are consistently applied, we can see at once on any radiograph, no matter how small, what the projection is.

#### **11.3.3.2 Direction of viewing radiographs**

The most usual method of viewing radiographs is in the direction of the X-ray beam; one sees the object as the focus 'has seen' it. Our eye takes the position of the focus, as it were.

Most radiographs, by far, are made with this method of viewing in mind, and one sees the letters in a 'normal' position (not as mirror images). This, for example, is the case for intravenous pyelograms, pelvis projections, spine projections, etc.

However, there are also projections that one usually views against the direction of the beam, such as gall-bladder projections, chest radiographs, p-a skull projections, etc. Here, on viewing, one would see the letters as mirror images; although this is perhaps slightly irritating initially, one quickly becomes used to it. The principle of placing the letter following the rule—the focus sees the letter in a normal position—is certainly justified by the valuable information it gives, that of indicating that one is viewing against the direction of the rays. If, for example, one sees the letter R on a skull radiograph, on the left side of the viewer, then one knows immediately that this radiograph is an a-p projection; the letter Я on the left side of the viewer then indicates that one is viewing a p-a projection *against* the beam, that is in an a-p direction (figure 11.3).

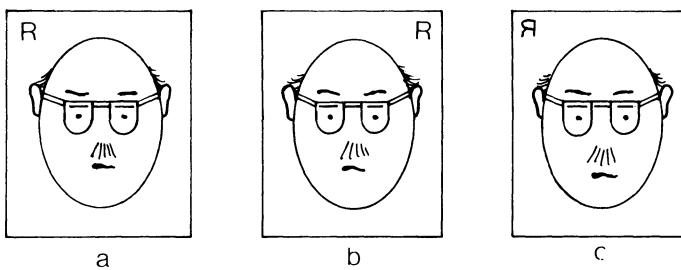


Figure 11.3 The placing of letters in a skull radiograph in a sagittal direction: letter placed on an upper corner.

- a. Focus saw the R in its normal position; thus the radiograph has been made in the a-p direction.
- b. Focus saw the R in its normal position; thus the radiograph was taken in a p-a direction.
- c. The p-a radiograph (b) is reversed and now viewed in the a-p direction. The letters are now mirror images, which immediately indicates that the radiographs are viewed against the direction of the rays.

Because of the information provided by the placing of the letter, it is then entirely unnecessary always to include the adjacent joint along with the rest of the bone in a fracture of an extremity, for example; this is not valid for the first examination, however, where the demonstration of the adjacent joints is always of importance. In general, one can simply take two projections of the fracture site, and the radiograph will show immediately which is the a-p and which is the lateral; also, which are the proximal, distal, lateral, medial, dorsal and ventral sides.

When the body is in the anatomical position, the radial aspect of the forearm (or the thumb-side) is regarded as the lateral aspect. If the arm is suspended in a sling and slightly turned, then as regards the shoulder and upper arm, the side of the biceps is the anterior or ventral aspect and the side of the triceps the posterior or dorsal aspect.

It may perhaps seem excessive to pay so much attention to apparent trivialities, such as the placing of right and left markers. However, experience has shown that this makes for accurate work, as the radiographer learns not to place the cassette and letter any way she pleases, but always realises the anatomy at the site in question and the projection. The additional information provided for viewing also can never be a disadvantage. Moreover, a limited beam for a small-size radiograph (as is described for fracture radiography) means a saving in dose (figure 11.4).

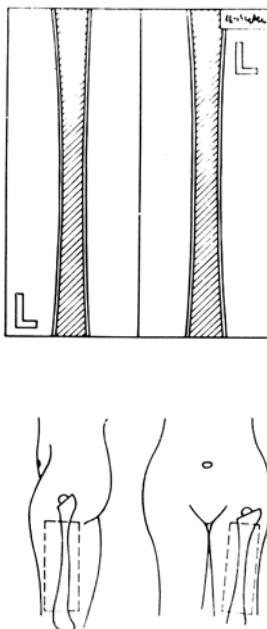


Figure 11.4 Placing of letters enables beam limitation and dose reduction. The left femur has been radiographed in the a-p and in the lateral (medio-lateral) projection; the circled portion only needs to be radiographed in subsequent check radiographs as a'b'. By the placing of the letter L we can immediately see what represents the a-p radiograph and what the lateral radiograph. Moreover, the letter also indicates where the cranial, lateral and ventral directions are. Beam limitation means less dose for the patient.

#### *11.3.3.3 Placing of the cassette*

The way in which a cassette is positioned for an exposure should by no means be a matter of indifference. If this is done indiscriminately, the films are likely to be placed upside down in the hangers in the processing room, which is a great nuisance when they are viewed while wet. For this reason, the lid of the cassette should be provided with a label at the upper right-hand corner (when the hinges are on the left), marked 'top'. This side must always be placed proximal (towards the head) or, when this is impossible (when the cassette is placed crosswise), on the left side, if one looks through the cassette to the focus, as it were. This also ensures that the space for the name plate is always top right (with the cassette in a lengthwise position), or top left (when the cassette is in a crosswise position). With some systems, where the name is shown along the entire top side of the film in a (approximately) 1 cm wide strip, the name will be along the upper side when the cassette is in a lengthwise position and along the right side when the cassette is crosswise, and viewed in the direction of the beam. As it often happens that for certain reasons (limited amount of room for the cassette because of elastic bandages, etc.) one cannot place the cassette exactly lengthwise or crosswise, then one cannot always determine the direction of the beam from the position of the name

plate or identification strip. One should, however, strictly adhere to the correct placing of the R and L markers, as described above.

With the use of an automatic processor, it does not matter how the film is fed into the machine.

#### **11.3.3.4 Additional indicators for the identification of radiographs**

In addition to the left and right markers, small lead figures are used to indicate the serial number of the radiograph (for example in intravenous pyelography), or the depth of the selected layer (in tomography). Time scales, and other means of indicating the time at which a radiograph was taken, are quite often offered by various firms, frequently by way of advertisement. These are nearly always made of plastic and contain lead or barium powder.

#### **11.3.4 Beam limitation**

It is always important to restrict the radiation to the smallest possible area, in order to reduce the radiation hazard to the patient and to improve contrast. Visible contours of the area of exposure should, therefore, not be regarded as an ‘aesthetic’ mistake, but as proof of laudable, economical use of radiation. A localising cone or diaphragm should be used with every tube.

##### **11.3.4.1 Permanent diaphragms, cones, beam limitation**

A diaphragm allows only the desired portion of the beam to pass through, and is used as a matter of course for spot-film exposures; but the use of a diaphragm is also recommended for all other types of exposures, such as on the bucky table, etc. In view of the fact that the X-rays emerge from the tube in straight lines, it matters little where beam limitation by means of the diaphragm takes place, whether it be near the tube or at some distance from it. The only difference is in the different widths of the useless and thus undesirable penumbral region, which form the edges of the beam; this penumbra is nothing other than the geometrical unsharpness  $U_g$  of the edges of the diaphragm in use (figure 11.5).

It is obvious that a narrow penumbra is preferable to a wider one: the penumbra is caused by the radiation which is not used (therefore unnecessary) for the production of the image. This is why beam limitation as far as possible from the focus is preferable, and the more so, the larger the focal size. With the relatively small foci used these days (2 mm with a focus-film distance of 100 cm is already practically considered as useless) the penumbra produced is a problem that practically can be disregarded. With a focus of 1 mm and a diaphragm at a distance of 5 cm, the radiograph would show a ‘frame or border’ of 19 mm width, if it was taken at a distance of 1 m; this is caused by the penumbra ( $U_g = F \times Of/FO = 1 \times 95/5 = 19$  mm).

If several diaphragms are placed in succession in the same beam, then (provided that the beam has not been restricted beforehand) the location of the last (furthest) diaphragm determines the width of the penumbra. The previously commonly used lead-glass or other cones served to limit the beam (field limitation) and facilitated positioning, as one could easily imagine the direction of the beam with this as an aid.

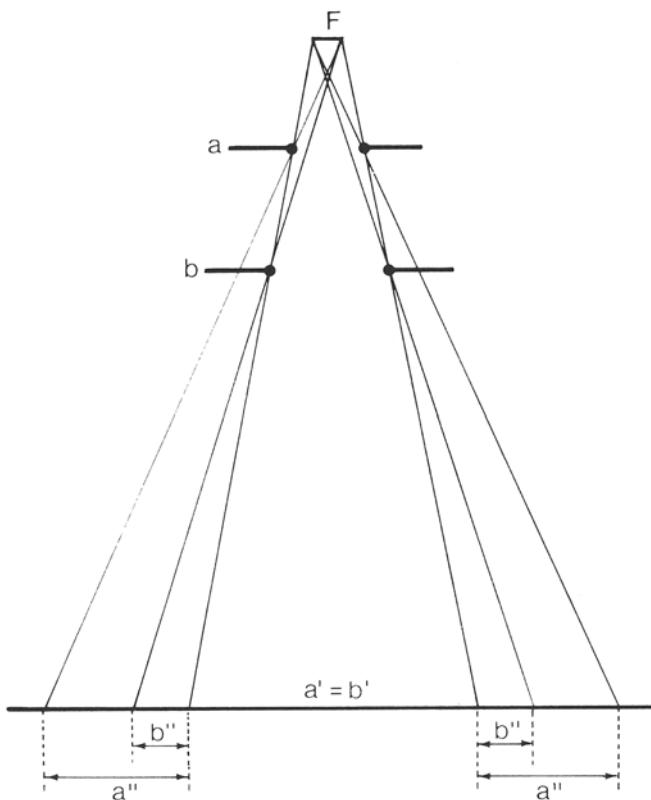


Figure 11.5 Beam limitation by means of a diaphragm at various distances from the focus. By means of diaphragm a beam limitation is effected near the focus F such that the matching, completely illuminated beam width  $a'$  is equal to the completely illuminated beam width projected through diaphragm  $b'$ . The penumbral widths  $a''$  and  $b''$  represent the  $U_g$  of a and b, and differ considerably. In this case the position of diaphragm b is to be preferred.

When using these cones, one should make certain beforehand that the beam emerging from the cone is actually the same size as the aperture of the cone, and that there will be no beam 'cut-off'. Beam cut-off occurs when the mutual relationship between the location of the focus, the size of the diaphragm near the tube (tube diaphragm) and cone aperture is not correct. Figure 11.6 shows several examples of this. An incorrect distance between focus and tube diaphragm as well as incorrect centering of the focus in relation to the tube diaphragm can cause beam cut-off. If the tube diaphragm is relatively large, then the beam will strike the cone wall. If this is sufficiently absorbent (as was the case with lead-glass cones) then this situation is acceptable. If the cone wall allows radiation to pass through, then the cone does not fulfil its purpose of beam limitation and, moreover, one is exposed to radiation while being under the impression that one is safe. In this case, therefore, a decrease of the tube diaphragm to the correct size is urgently necessary.

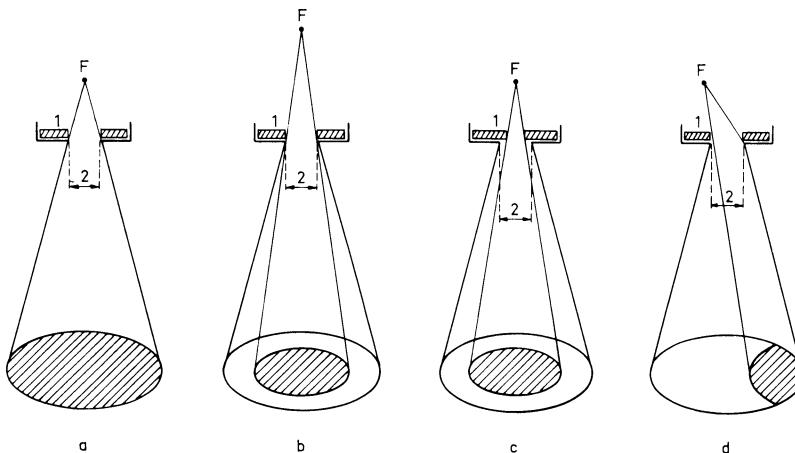


Figure 11.6 Beam cut-off in diagnostic radiographic localisers. F. Focus; 1. lead diaphragm (possibly built in the localiser) near the tube window (tube diaphragm); 2. opening of the (opaque to X-rays) localiser. The illuminated field is indicated by the shaded area.

- a. Correct relationship between F, 1 and 2.
- b. Distance F-1 too great, due to which 2 is relatively too large.
- c. Opening is too small causing 2 to be relatively too large.
- d. Incorrect centering of the tube insert within the tube shield, due to which 1 is not centred with respect to F.

One can easily diagnose a possible beam cut-off by means of an (old) fluoroscopic screen without lead-glass or an intensifying screen: let a beam of radiation strike it, then determine whether the size of the fluorescent area corresponds to the size of the cone aperture. One can also determine the size of the beam exactly by placing a film against the cone aperture and exposing in this position. This cone check is also recommended when tank units (H.T. transformer and tube in the same tube head) are used.

Even more important than the fact that a diaphragm that is placed further away from the focus causes a smaller penumbra, is the avoidance of the influence of *extra-focal radiation* (also called *stem radiation*), which is emitted from the anode stem and from the oil surrounding the X-ray tube. This radiation is allowed to pass through if a diaphragm is mounted near the tube, but is largely eliminated when the diaphragm is placed further away. In this way its unfavourable influence on image formation and radiation safety is virtually entirely avoided.

#### **11.3.4.2 Adjustable diaphragms, light-beam diaphragm**

The modern X-ray tubes have adjustable lead diaphragms fitted to them, which consist of several lead laminae arranged at different distances from the focus. They effect an accurate limitation of the X-ray beam, and a virtually complete absorption of the extra-focal radiation. The positions of the levers that regulate the size of the beam are indicated on the adjustable lead diaphragm for the various cassette sizes (related to the focus-film distance at the same time).

Nowadays, wide use is made of an adjustable lead diaphragm in conjunction with a beam of light: a *light-beam diaphragm*. This device is attached to the tube

window, the purpose of which is to direct an intense beam of light on to a mirror, which then reflects the light in the same direction as the X-ray beam, that is as if the light rays were coming from the focus of the tube. By adjusting the aperture of the lead diaphragm we not only make the beam of light illuminate exactly the area to be radiographed, but define the limits of the X-ray beam at the same time. The correct adjustment of the light-beam diaphragm, whereby the light beam corresponds exactly to the X-ray beam, can be disturbed by rough handling (bumping, etc.). The adjustment can be checked in the same way as described above for checking the correct field size with the use of cones. The illuminated field should essentially correspond with the radiation field. A small difference (which may be ignored) can be perceived by using the large focus of a double focus tube, when the location of the foci differs a little. The light-beam diaphragm does not compensate for this. The position of the levers, which regulate the diaphragm size for the various cassette sizes, is also indicated on the light-beam diaphragm. This is of great practical use, as one obviously cannot see the cassette under the couch top (figure 11.7).

Automatic diaphragms are being used more and more, eliminating manual adjustment. One just selects a certain cassette or film size or a certain X-ray field size, at a certain focus-film distance, and the automatic device does the rest. With the aid of small, built-in motors, the lead diaphragm is then automatically adjusted to the selected beam diameter.

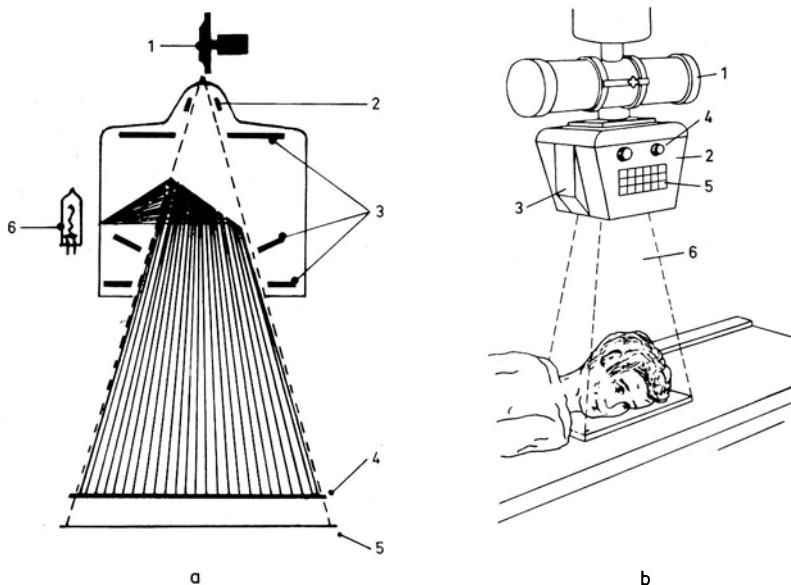


Figure 11.7 Principle (a) and application (b) of the light-beam diaphragm.

a. Principle: 1. Anode of the X-ray tube; 2. lead diaphragm; 3. several lead strips which together make up this lead diaphragm; 4. illuminated field; 5. radiation field; 6. light source. The light emitted by the light source is reflected by a flat mirror in such a manner that it appears as if the light originates from the focus. Thus the X-ray beam corresponds exactly to the field that has been chosen with the aid of the light beam by adjusting the lead diaphragm.

b. Application: 1. X-ray tube; 2. light-beam diaphragm; 3. attachment for bulb; 4. lever for beam limitation; 5. beam sizes in relation to focus-film distance; 6. the beam of light.

By using automatic exposure control (see chapter 14, section 14.6) often the locations of the measuring areas of the automatic exposure device are also projected on to the patient by means of the light-beam diaphragm in the form of small square or round areas. As the choice of the correct measuring field is extremely important for the proper film density in the 'dominant'\* area, this method of making visible the location of the measuring areas is very pleasant and convenient (figure 11.8).

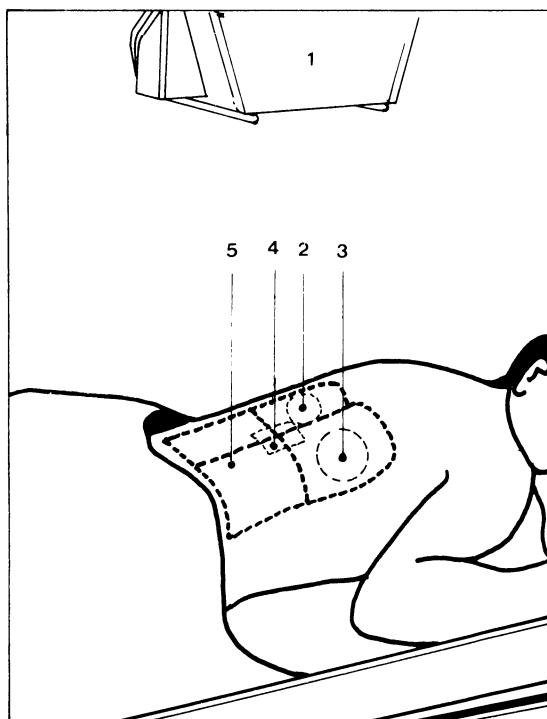


Figure 11.8 Use of the combination light-beam diaphragm with automatic exposure technique. 1. Light-beam diaphragm with marked 'dominant' fields; 2, 3. round, lateral dominant fields; 4. central, rectangular dominant field; 5. the illuminated field with cross-wire marking.

### 11.3.5 Centering

For each exposure, the X-ray beam is directed on to the object; it is highly desirable that this is done as accurately as possible, especially in relation to radiation protection. Therefore, one should endeavour to 'centre' accurately. For this purpose, centering pointers and/or cones, which can be applied to the tube hous-

\*By 'dominant' one understands the part of the object which is chosen to measure the desired density of the radiograph. This part of the object therefore controls (dominates) the quality of the image.

ing or diaphragm, are useful. Hinged, unscrewable and other types of pointers, which usually have distance scales on them, are well known. A common mistake of beginners is that sometimes they take exposures, forgetting to remove the centering device or pointer. A good pointer indicates the direction of the central ray of the beam, that is the ray that passes from the focus through the midpoint of the tube housing window, and—by correct mounting of the tube in the housing and of the diaphragm (or light-beam diaphragm) on to the housing—also passes through the centre of the diaphragm aperture. The central ray does not represent anything special, it is equal in value to every other ray in the beam.

Light-beam diaphragms are being used more and more, also with small X-ray machines. It is true that these are less simple and more subject to breakdown than centering pointers and cones, but, on the other hand, they are excellent for accurate beam limitation and are able to reduce the radiation field size to the necessary minimum.

### 11.3.6 Avoidance of superimposition

Superimposition should always be avoided whenever possible (superimposition is the projection of object details over other object details). Consider, for instance, a lung exposure, normally made at a focus-film distance of 1.50 m, in the p-a projection. If no special care is taken, the film will show the scapulae superimposed upon the lateral sections of the thorax. This interfering effect can be entirely avoided, and the lung fields demonstrated free of the 'shoulder blades', only by placing the patient in a rather forced position (figure 11.9): shoulders brought well forward and downward (not pulled up), elbows and forearms turned inward as much as possible, so that the backs of the hands end up behind the greater trochanters. While in this position, the patient should breathe in deeply and hold his breath during the exposure. It is difficult to avoid superimposition in radiographs of the lower cervical vertebrae and the upper thoracic vertebrae in the lateral projection, and here too, considerable care should be taken with the positioning.

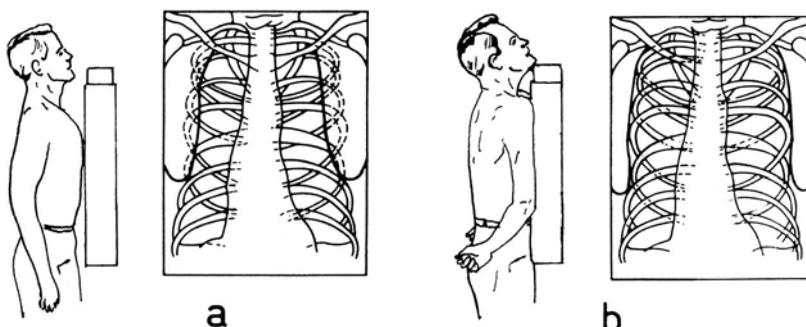


Figure 11.9 Avoidance of superimposition in chest radiography.

- a. Incorrect, the scapulae cover a portion of the lung fields.
- b. Correct, the scapulae are projected beside the chest. The radiograph is taken on deep inspiration.

Superimposition also gives trouble in a-p exposures of the upper cervical vertebrae, this time from the mandible. One simple way of getting round this is to have the patient open and close his mouth quickly during the exposure, the rest of his body remaining stationary. The mandible is then blurred and no longer interferes, or at least much less so. In this way one makes use of the blurring or obliterating of object details by purposely causing gross movement unsharpness. The unmoved part of the object is portrayed sharply. One can apply the same trick when taking lateral radiographs of the thoracic spine, by allowing the patient to breathe quite vigorously during the exposure; the ribs are then considerably blurred and the vertebrae 'leap' more into the foreground, as it were, due to the diminished superimposition. Obviously, in these cases, an exposure time of several seconds should be chosen.

It is self-evident that the part of the body to be radiographed should also be adequately uncovered. Buttons, buckles, ear-rings, hair-clips, dentures and so on should not appear on a radiograph. Even ordinary articles of clothing, such as thin underwear, can hinder diagnosis by showing up as interfering shadows. Owing to the 'end-on' effect, the shadow resulting from the presence of pleats and folds in nylon, for example, can be a particular hindrance.

In photofluorography (mass miniatures) it has become common practice not to have the trunk uncovered, but this is done solely in order to overcome reticence among the public, and thus ensure that a more comprehensive section of the population will be included in the mass survey. Moreover, the influence of clothing on the diagnostic value of the photofluorograph is by no means so severe as to cause any marked deterioration in the quality of the details. Mass photofluorography might be compared to a sieve which is admittedly fine, provided the image quality is good, but certainly not as fine as would be required for a full examination in the X-ray department; therefore, there can be no departure from the rule that the part of the body to be examined should be uncovered. At most it may be covered by a thin sheet or piece of cellular tissue.

### **11.3.7 Compression**

Compression is one means of substantially reducing the proportion of scattered rays that reach the film. By means of a compression band, possibly in conjunction with a rubber air-cushion, it is possible to apply very efficient compression, particularly to corpulent patients, and especially in radiographs of the abdominal region. Not only then is the exposure time shorter, but one gains contrast and the dose to the patient is decreased. Furthermore, it is a means of helping patients suppress their respiratory movements, and thereby lessen the danger of movement unsharpness.

### **11.3.8 Immobilisation**

Great care should be devoted to the immobilisation of the subject. In this respect a relaxed and comfortable position is the first prerequisite, for which purpose ample use should be made of cushions, sandbags, etc. For bucky exposures, the compression band mentioned above can be used to good effect. Immobilisation also requires suppression, as far as possible, of semi-voluntary movements, such as

respiratory ones. The control of breathing should be thoroughly practised, particularly with patients of low intelligence, who will not necessarily understand the instructions 'breathe in' and 'breathe out'. In this case, exaggerated demonstrations, especially of the way to keep still, yield the best results. By spending a little more time and effort on practice with the patient you prevent spoiled or inferior radiographs. Patience is called for here, and only in quite hopeless cases should compression be applied to suppress respiration for a few moments.

As regards children and babies, the problem of fixation is often insoluble. In some cases a satisfactory result can be obtained by suspending the child in a special harness. Several types of harness are on the market. Some of these allow the child to be fixed so that it cannot move, after which the harness with child and all can be placed in the desired position during the investigation. It is advisable to have such harnesses available in all departments, since it is often otherwise impossible to investigate small children optimally without exposing a third person, who has to hold the child still, to an unnecessary dose of radiation. The simplest and most responsible solution in such a situation is to ask the accompanying person (not an X-ray department employee) to hold the child for a few minutes (after putting on a lead apron and possibly lead-rubber gloves). Some person (preferably older) from the waiting room could also be considered for this purpose. *On no account should a radiographer be permitted to hold a child in position during an examination*, for this would often expose the hands to primary radiation and the rest of the body to secondary radiation. In the radiography of babies, and of rapidly moving objects whose movements cannot be suppressed (the heart, for example), it will frequently be necessary to adapt the exposure technique to the circumstances. One can, for example, use fast screens and a relatively short focus-film distance to obtain an extremely short exposure time, thereby decreasing the otherwise overbearing movement unsharpness, albeit at the cost of some screen unsharpness and geometric unsharpness.

### 11.3.9 Bucky radiographs

(See also chapter 6, section 6.3.6.)

Potter-Bucky diaphragms usually employed are provided with flat grids, which are suitable for focus-film distances of between 70 and 150 cm. These grids have a ratio of up to about 7:1. For grids with a higher ratio (for example 15:1), which are mainly used at higher kilovoltages, the exposure distance is more critical, and for a grid focused on 100 cm, for example, the critical distance lies between 90 and 120 cm. To avoid grid cut-off, it is not only necessary to choose the correct focus-film distance, but also to centre the tube focus exactly to the central axis of the grid.

If one uses a bucky, which must be 'cocked' by winding up a spring before the exposure (the spring driving the bucky during the exposure, like a catapult), then a safety circuit should be provided which ensures that no exposure can be made if the bucky is not cocked. The exposure should also be terminated before the bucky stops moving. The exposure time must thus always be shorter than the time during which the bucky is in motion.

If a uniformly moving grid produces lines on certain radiographs owing to the stroboscopic effect, a slight lengthening or shortening of the movement time can

prevent this effect. With modern bucky constructions, which are made to move continuously, electromagnetically, the problems mentioned no longer occur, as the movement time of such grids is automatically adapted to the exposure time. By this, and in the manner by which modern bucky grids move (see chapter 6, section 6.3.6.4), it is highly improbable that any stroboscopic effect will result, provided that the exposure time is not too short. As the length of the exposure time is unknown when using automatic exposure control, the use of a continuously moving (oscillating) bucky grid to avoid grid lines is an absolute necessity. The use of these is becoming more and more widespread.

When taking stereoscopic radiographs, it is important to note that, if the tube is shifted at right-angles to the direction of the lead strips, slight under-exposure will result due to grid cut-off (defocusing). With such a shift, a uniform under-exposure of the whole field will occur if the tube is at the correct focus-film distance; when deviating from the correct distances, non-uniform (one-sided grid cut-off) under-exposure will result.

### 11.3.10 Film sizes

The following are the sizes of X-ray film in common use for medical purposes:  
 $9 \times 12\text{ cm}$ ,  $13 \times 18\text{ cm}$ ,  $15 \times 40\text{ cm}$ ,  $18 \times 24\text{ cm}$ ,  $20 \times 40\text{ cm}$ ,  $24 \times 30\text{ cm}$ ,  
 $30 \times 40\text{ cm}$ ,  $35 \times 35\text{ cm}$ ,  $35 \times 43\text{ cm}$ ,  $40 \times 40\text{ cm}$ .

It is important in radiography that as far as possible use is made of the smaller film sizes. Films are expensive, and much material can be saved by subdivision using lead-rubber strips, etc. When taking a check radiograph of a limb in plaster, for example, it is usually enough to ascertain, possibly by reference to previous films, exactly where the fracture is located, and then to take two different views on one film of, say,  $18 \times 24\text{ cm}$  (figure 11.3). However, when radiographing an injury for the first time, as, for example, a suspected fracture of the tibia, it is important to use a large-size film in order to show up any associated lesions higher up or lower down. Even if the tibia is evidently fractured immediately above the ankle, there may also be a fracture much higher up, at the head of the fibula, which would naturally be missed on a small film.

Due to further development of image intensifier technology, the taking of radiographs on the  $70 \times 70\text{ mm}$  and  $100 \times 100\text{ mm}$  sizes by means of the image intensifier, with a quality almost comparable to the large film sizes, is becoming more common. In view of the generally occurring shortage of space, the change-over to this small size with an eye on the necessary film storage (archive) would be a great advantage, provided that *all* radiographs are taken on this size. For this, however, image intensifiers with larger input phosphors (at least  $40 \times 40\text{ cm}$ ) as well as with excellent resolving power will have to be developed. However, in practice, medically or economically speaking, it does not look as if, in the foreseeable future, all types of radiographs (one thinks of fracture work, out-patient clinics, operating theatre radiography, among others) will be made by means of an image intensifier, causing conventional radiographs to become a thing of the past.

### 11.3.11 Dental radiography

Although it is true that dental radiographs are not often asked for in X-ray departments, as many dentists have both the necessary equipment and experience, it is

recommended, however, that sufficient attention is paid to the radiographic technique of this limited area.

Without going into great detail of the positioning, some basic rules will be discussed here. For intra-oral dental radiographs, that is radiographs in which the film is placed inside the mouth, the central ray must be directed towards the object following the law of Dieck-Cieszynski. This rule states that the central ray should be at right-angles to the plane bisecting the angle made by the film and the long axis of the tooth. The tube should be centred to the apex of the tooth. If these rules are followed, the tooth will be demonstrated in its true size. If the tube is angled too much, the image of the tooth will be foreshortened; if the tube is not angled enough, then the tooth will appear elongated (figure 11.10). Moreover, the central ray should be directed in such a way that it strikes the jaw at right-angles at the point of interest to prevent lateral distortion (ortho-radial positioning) (figure 11.11).

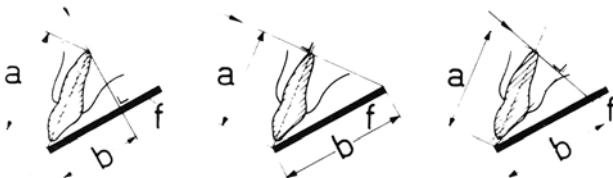


Figure 11.10 Projections of a tooth with different angles of the central ray. a. Length of the tooth; b. image size; f. film.

Left: The central ray is directed perpendicularly to the plane of the film. Result:  $b < a$ .

Centre: The central ray is directed perpendicularly to the longitudinal axis of the tooth. Result:  $b = a$ .

Right: The central ray is (according to the law of Dieck-Cieszynski) directed to the plane that bisects the angle made by the film and the long axis of the tooth. Result:  $b > a$ . In other words, the tooth is demonstrated in its true size.

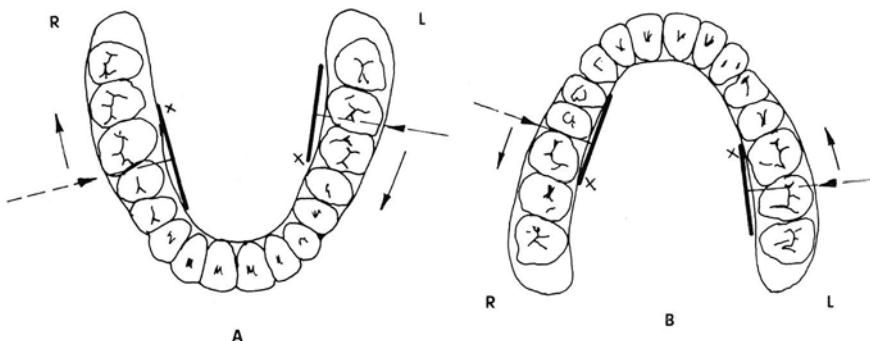


Figure 11.11 Ortho-radial projection. The central ray should strike a plane that is perpendicular to the tangent of the arch of the jaw at the point of interest. The arrow indicates where the embossed 'pip' of the dental film should be located, that is always towards the right.

A. Lower jaw viewed from above; B. upper jaw viewed from below. R. right; L. left.

As often several radiographs of the 3 × 4 cm size are made (especially for requests for a complete set of dental films), special attention should be paid to the identification of each film. Although it is usually obvious which type of tooth is demonstrated (molar, incisor, etc.) and also whether it is situated in the upper or lower jaw, this does not answer the question of whether it is situated on the left or right, and when several teeth are missing then identification is practically impossible. However, as each dental film is provided with a small embossed 'pip', which can both be seen and felt externally, by placing this pip always on the right when positioning the dental film inside the mouth, one will always know the relative positions of the teeth (figure 11.11).

It should be stressed that the radiographer should never hold the film in place herself; this should be done by the patient, after appropriate instruction.

A special form of radiography of the complete set of teeth, in which the focus is placed within the mouth and the film outside it, is called a panoramic view of the teeth (see chapter 12, section 12.1.10). For extra-oral exposures and for special dental views, the reader is referred to the specialised literature. It may be mentioned in this connection that, particularly for the teeth (the head of the mandible, etc.), the use of a very short focus-film distance, as described in chapter 4, section 4.5.3 under contact exposures, can be extremely useful.

#### 11.3.12 The role of the radiographer in dealing with patients

Finally a few tips for the radiographer in the diagnostic department. You should always remember that the patient is in surroundings that you are used to, but he is not. Being pushed into a cubicle to get undressed is by no means the best preparation for what is for him a rather unnerving experience, especially if fragments concerning other patients' examinations can reach him there. Avoid expressions like: 'is the kidney lying on the table?', 'fetch the gall bladder from cubicle no. 6', 'has the chest from room 4 been done yet?', etc.; use other terms. Above all, *no boisterousness*. The patient has the right to expect that the investigation is carried out in a serious manner and with the fitting decorum of medical surroundings. In this connection, it should be mentioned that the patient should never be left alone unnecessarily in the examination room. Exposed parts of the body should be covered up as soon as possible. It goes without saying that you are not expected to carry on a running flow of conversation, but neither should you restrict your conversation to a few words of command. You will have to discover for yourself the attitude appropriate to each individual patient. In any case, even when you are very busy, you should give the patient the feeling that the examination (however minor it may be), which is such an event for him, also occupies an important place in your work.

# 12

## Special Radiographic Techniques

In the previous chapter, the somewhat simpler forms of fluoroscopy and radiography were discussed. As far as fluoroscopy is concerned, there are only three alternatives, namely conventional fluoroscopy, fluoroscopy with image intensification and fluoroscopy with both image intensification and television, and these, in this order, represent the maximum, the realisation of which is above all a financial question and not a matter of principle.

In radiography, that is the taking of radiographs, the situation is different. In addition to the ‘simple’ radiographs taken ‘blind’ as standard projections, or taken after positioning under fluoroscopic control, there are special radiographic techniques based on particular principles and they can often only be carried out with specialised equipment. Some of these methods, which should actually now be regarded as routine procedures, will be described below.

### 12.1 TOMOGRAPHY, THE PROJECTION OF AN IMAGE OF A PARTICULAR LAYER IN THE BODY

A radiograph is made up of superimposed images, and the image of an object detail in a particular plane is generally considerably influenced by the images of other object details that lie within the X-ray beam and are projected on top of it. An old question is, therefore, how can interfering superimpositions be avoided. When the details of special interest are situated near the film (the object-film distance therefore, is short in comparison with that of more distant details) one can sometimes successfully avoid interfering superimposition by making a contact radiograph (making use of the different  $U_g$ ; see chapter 4, section 4.5.3). With this the disadvantage of the extra high skin dose, although not prohibitive, should, however, be kept in mind. Contact radiographs of the head of the mandible, the sternum and the patella, among others, are well known.

### 12.1.1 Principle of tomography

For the radiography of more deeply lying details without interfering superimposition, we must resort to a special radiographic technique, known under the names *stratigraphy* (Vallebona), *planigraphy* (Ziedses des Plantes, Bartelink), *tomography* (Grossman), etc. This method aims at providing an image of a particular layer (stratum), plane (planum), or section (tomas). The term *tomography* is the most widely used internationally, and in daily practice tomographs are often called 'tomas'.

The principle of tomographic technique is to blur all structures above or below the layer under investigation. This is done by means of a correlated movement of two of the three components of the tube, object and film triad: which in ordinary radiography are mutually stationary. In stratigraphy (Vallebona), the object and film are moved in relation to the stationary tube. By far the most usual, however, is the movement of tube + film with respect to a stationary object. This method will now be discussed in detail.

One wishes to show exclusively, as it were, a layer at a particular depth in the object. For this purpose, one couples the tube and the film in such a way (usually by means of a rigid connection) that, by the displacement of the tube in a plane parallel to the film, the rigid connection has its axis of rotation (also called the fulcrum) in the plane that one wishes to show—the '*plane in focus*' or *selected plane*. The film is hereby displaced in an opposite direction, the distance travelled being determined by the proportion between the distances, tube-selected plane and selected plane-film. Three-dimensionally speaking, this means that the three planes are parallel to each other: the plane in which the tube moves, the selected plane and the plane in which the film is moved.

In figure 12.1 these three planes are represented by the lines F, O and f, and it is clear that every time the focus is shifted along line F, a shift should take place in the projection of an object detail present in O along line f. However, as the film in f is rigidly connected to F and the shift is coupled, the projected image does not alter in position. This is true for all object details that lie in the selected plane, but not, however, for details that lie outside. In this way, the selected plane (also called *tomographic section*) alone is sharply projected.

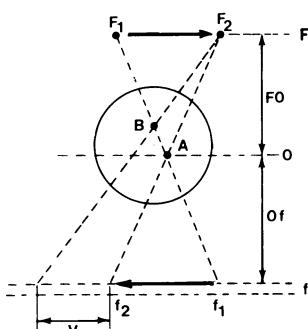


Figure 12.1 Principle of tomography. By shifting the focus of the X-ray tube from  $F_1$  to  $F_2$ , and simultaneously moving the film from  $f_1$  to  $f_2$ , point A will always be projected sharply in the same place on the film. The image of point B, on the other hand, is spread out over a distance  $V$  on the film and is, therefore, blurred and unsharp.

In figure 12.2 this is elaborated further. If by means of coupled movement, with A as the fulcrum, the tube moves from left ( $F_l$ ) to right ( $F_r$ ), the film moves in the opposite direction, from right to left. This movement is equal to the movement of the projections of  $A_l$  to  $A_r$ ; in other words, the projection of object detail A remains unchanged at the same place on film f during the entire movement. The same is true for the object detail C ( $C_lC_r = A_lA_r$ ), which lies in the selected plane. It is not so for object details situated outside the selected plane ( $B_lB_r$  is not equal to  $A_lA_r$ ), and the greater their distance from the selected layer the poorer will be the definition of the projected details.

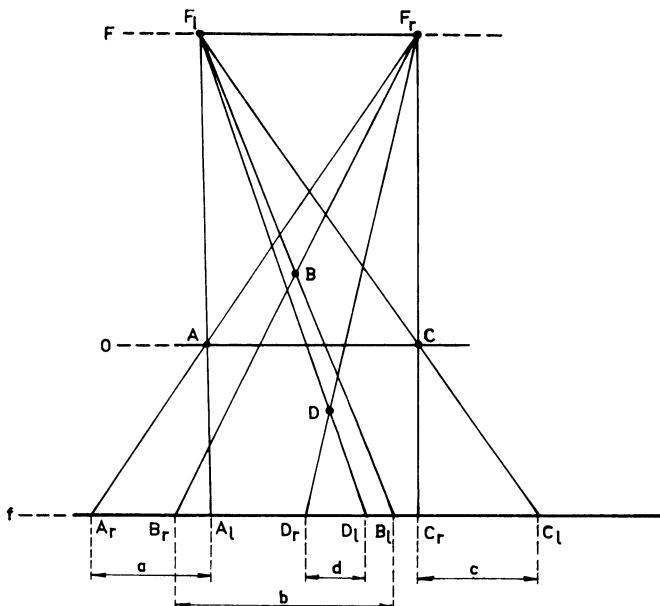


Figure 12.2 Various degrees of blurring. By shifting the focus, the projections of the object details also undergo displacement and the further removed from the plane in focus the greater will be their displacement.  $b > a > d$  and  $c = a$  = displacement of the film f (see text).

From the diagram it follows that the proportion of the film movement in relation to the tube movement at a particular (chosen) position of the selected plane is a constant value. If this tomographic section is taken as the object (O) then one is concerned with the proportion  $FO:OF = F_lF_r : A_lA_r = F_lF_r : C_lC_r =$  focus displacement: film displacement. Therefore, no movement unsharpness takes place here, but there is movement unsharpness outside the selected layer. It is also clear from the illustration that the blurring increases the greater the distance between B and the selected layer; the same is true for other details that lie both above and below the selected plane.

### 12.1.2 Factors that determine the thickness of the 'sharply' projected layer

A simple observation shows us that the greater the tube displacement during the radiographic exposure (and, consequently, the displacement of the film), the greater will be the blurring of the details that lie outside the selected plane

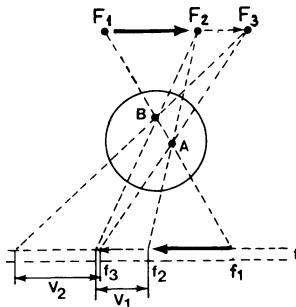


Figure 12.3 Effect of the size of the panning angle on the sharpness. If the focus of the X-ray tube is displaced from  $F_1$  to  $F_2$ , and the film, coupled to the tube, is displaced from  $f_1$  to  $f_2$ , and A is located in the selected plane, then A will be sharply projected, but the blurring of B will equal  $V_1$ . If the panning angle is increased to the position  $F_1$  and  $F_3$ , then this will make no difference to A but B will be blurred to an even greater extent with an unsharpness equal to  $V_2$  (= displacement of the projections of B minus the film displacement  $f_1 - f_3$ ).

(figure 12.3). As the tube movement usually occurs due to a swinging motion of the rigid tube-film connection, one speaks of the angle of swing or *panning angle*. This is the angle formed by the central rays when the tube is in the two extreme positions. In figure 12.3 it can be clearly seen that when the tube moves over the distance  $F_1F_2$ , the blurring of B on the film is equal to  $V_1$ , but that a blurring over a greater distance ( $F_1F_3$ ) causes a greater blurring ( $V_2$ ). This means that with an increase in the panning angle the blurring of details situated outside the selected plane is increased.

The selected plane itself, in theory, is infinitely thin, and is constantly projected sharply. In practice, a required object detail always has a certain thickness, and therefore the selected 'plane' must have a certain thickness also, that is it must be a section in which the object detail is located. Consequently, in practice, we have to accept a certain amount of unsharpness in the section. If we set the limit of this acceptable unsharpness for a tomogram at a certain value, 1 mm for example, then all details with an unsharpness of less than 1 mm will be contained in this slice or section 'in focus', which lies at either side of the selected plane. The thickness of the section depends on the degree of unsharpness we are willing to allow and, hence, to the panning angle (see above) and the geometric unsharpness.

It is obvious that, in practice, extremely large panning angles cannot be considered, as very oblique incident radiation must travel through a longer path and consequently is absorbed to a greater extent, so that the oblique components contribute little to the radiograph, and the greater integral absorbed dose that is administered would not be justified. One therefore, in general, limits oneself to a panning angle of  $35^\circ$ - $50^\circ$ , which can usually be adjusted to any desired value within these limits. The greater the panning angle, the thinner the 'sharp' section that is projected, and the greater the definition of the tomogram. On a tomogram we therefore see a number of relatively sharp details, which are located within and immediately above and below the selected plane. Superimposed on this are the more or less blurred details of the rest of the object. It is essential to realise that in tomography there is no abrupt transition from the (infinitely thin) plane where the details are sharp to a completely blurred background (and foreground), but that

the transition from sharp to blurred is a gradual one. It is equally incorrect to imagine that the desired section is 'sharp' and that everything next to it is completely blurred. On the contrary, the 'sharp' section adjoins one which is slightly less sharp, and so on, and all these sections, including the sharp one, are superimposed to give one unsharp image: the tomogram. The thickness of the 'sharp' section is a matter of arrangement. A 'sharp tomogram' looks very blurred compared to a good, sharp, ordinary radiograph. This lack of definition is an unavoidable characteristic of this method of projection. By striving to obtain 'sharp' tomograms, attempts have been made to improve the radiographic quality by using finer foci. Due to the 'inherent' unsharpness of every tomogram, an unsharpness that can never be completely removed, the improvement by finer foci is not very spectacular. Therefore, in general, for tomography, one is satisfied with the usual foci (1.2 mm, for example), and only for very specialised tomography (investigation of the petrous bone, etc.) does one require very fine foci (0.6 mm and finer).

#### **12.1.3 Blurring with narrow panning angle: zonography**

As well as endeavouring to obtain 'sections that are as thin as possible (for example for detailed projection of the inner and middle ear), the importance of projecting much thicker sections has been advanced by Ziedses des Plantes, and has been introduced as a special method of investigation called *zonography*. If one decreases the panning angle then the thickness of the projected layer increases and, finally, at a panning angle of 0° (stationary tube) the entire thickness of the object is projected (an ordinary radiograph can obviously be regarded as a tomogram with a panning angle of 0°). In zonography (= tomography with a narrow panning angle), one attempts to project a part of the object in its entirety. This method is especially considered for object parts around which interfering superimposition can arise (for example by intestinal gas). In this way, zonography, among other things, is used for the projection of the sternum, petrous bone, the mandible, bile ducts, and kidneys. The thickness of the section in these cases is approximately equal to the thickness of the object itself, and can amount to from one to several centimetres. The panning angle can be adjusted to values between 5 and 8°, for example.

#### **12.1.4 Blurring patterns and exposure in tomography**

If the tube movement takes place in the direction in which the object details extend, one cannot achieve proper blurring, as the connected unsharp projections of these details give a false impression of the situation in the section that is to be projected.

This is especially noticeable with linear or arcuate tube movements, which are the most common tomographic movements by far. If, for example, tomograms are made of the vertebral column, whereby the tube movement is in the direction of the sides of the vertebrae, then these edges will not stop at the intervertebral spaces (as one would expect), but carry on, and continue in the adjoining vertebrae, as it were. These streaks are not only interfering, but also provide a false image. If possible, therefore, the direction of the tube motion should be at right-angles to the borders of the objects that have to be projected. Ribs, for example,

are efficiently blurred by moving the tube crano-distally; however, this movement (as is explained above) is unsatisfactory for projecting the sides of the vertebrae. The same problem occurs with the nasal septum and mandibular rami when taking tomograms of the skull in an a-p or p-a direction. It is always desirable, therefore, that the direction of the object detail is at a certain angle (preferably 90°) to the direction of tube motion\*. For better blurring one should change to movement patterns which greatly deviate from the edges of object details in the body.

A circular motion of the tube is relatively easily realised and, therefore, often used, though there is the possible risk that round details will be insufficiently blurred. There is even a risk, in this case, of producing pseudo-images of round structures that have a great deal of contrast (for example incisors projected into the throat). For this reason, even more complicated motions have been worked out, which give excellent blurring and also allow very thin layers to be projected (for example details of the petrous bone and the inner ear). In this respect, the elliptical and hypocycloidal movements realised in the Polytome of Philips-Massiot are well known.

Excellent blurring is also possible by means of a spiral (helical) movement, which was already recommended by Ziedses des Plantes at the time of his first invention and at present used in the *Stratomatic* (of CGR) among others. The adoption of these complicated blurring patterns in practice has become a condition for entering into the 'university' of tomography, as it were. Obviously, the film must describe the same path as the tube, but in the opposite direction; this is clearly shown in figure 12.4.

With some tomographic equipment it is possible to shift the tube from its central position, at right-angles to the long axis of the table (see section 12.2), in order to obtain a stereotomogram in which one can perceive depth (hence it will appear that the projected section has a certain thickness).

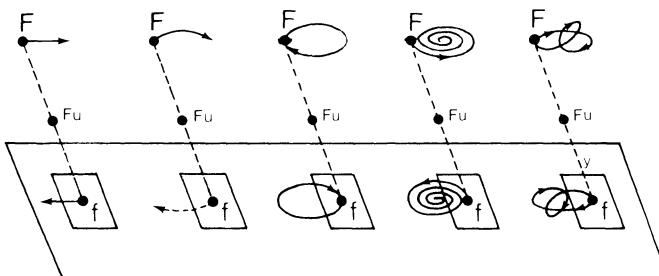


Figure 12.4 Diagrammatic representation of some blurring patterns used in tomography. From left to right: parallel linear movement, arcuate linear movement, circular movement, spiral (helical) movement, hypocycloidal movement. F. Focus; f. film; Fu. fulcrum (turning point on the imaginary fixed connection between the focus and the film). For the sake of clarity, the movements made by the film are illustrated at the same size as the path described by the focus. In reality, the movements of the film are less since the fulcrum is located nearer the film than the focus.

\*In reality, this problem is the same as with a moving grid: a movement in the direction of the lead strips would not blur these on the radiograph; therefore, the movement is always at right-angles to the lead strips (see chapter 6, section 6.3.6.3).

The exposure of a tomogram differs considerably from the ordinary radiographic exposure, where, in general, one attains short to extremely short exposure times. The swing or other movement mechanism entails a certain length of exposure. The exposure switch should in these cases be adjusted to a length of exposure that is shorter than the length of time during which the movement takes place. This time is usually adjustable, and amounts from single tenths of seconds to several seconds. In connection with this necessarily long exposure time, a separate adjustment on the control panel for a (low) mA value is possible for the purposes of tomography.

More attention is now being paid to a special type of exposure during the tube movement. If, for example, the panning angle is 50°, it is obvious that with constant X-ray intensity during the entire movement, the central part of the panning angle delivers the lion's share of the exposure, because of the shorter focus-film distance and less absorption of radiation due to the shorter distances travelled through the tissues. Due to the small (to extremely small) contributions made by the peripheral parts of the panning angle, the 'effective panning angle' is actually smaller (and thus the projected layer thicker) than one would expect. With the aid of adjusted automatic exposure this disadvantage can be anticipated. The radiation intensity (tube current, possible tube kilovoltage) is then adjusted in such a way that, during the entire time of exposure, the rate of exposure that reaches the film remains constant, with the result that the tube load is least in the central part of the movement and greatest in the peripheral parts. The 'effective' panning angle is thus increased, with the welcome result that the section becomes thinner. This automatic *variable load* can therefore be considered as meaningful. Special multiple movements, such as the hypocycloidal and helical movements, require a long time (3–6 s), and these can therefore only be used when the object can be immobilised for a long-enough period.

### **12.1.5 Altering the selected layer**

One usually takes a series of tomograms (for example a range from 6 to 12 cm in  $\frac{1}{2}$ –1 cm steps), that is a number of sections in front of and behind the plane where one suspects the lesion to be located, in order to give a three-dimensional impression of the state of affairs. One transfers the 'selected plane' for every exposure to the next layer by moving the fulcrum or by moving the patient along the direction of the central ray (with the tube in the central position) towards or away from the focus.

In the first case, assuming that the focus-film distance does not change, there will be a small difference in magnification of the projected tomographic sections. The sections that lie further away from the focus (thus nearer the film) will be magnified to a lesser extent than the layers that are located nearer the focus. In the second instance, this is not the case: for every projected layer both the focus-object and the object-film distance (and, therefore, the magnification factor) have remained the same. In practice one would not notice these differences, as a simple calculation of the magnification can show.

The depth of the selected plane can be chosen on the tomograph with the aid of a scale graduated in centimetres. This scale gives the distance from the fulcrum to the table-top on which the patient is lying. If a tomogram is said to have been

taken at 10 cm with the patient in a supine position, this means that the selected plane is 10 cm from the skin of the patient's back. In order to save film it is often useful to choose the best position for the tomogram by screening during the movement of the tube and the screen. By shifting the patient backwards or forwards one can bring the plane in which the details remain at the same place on the screen during its movement to the desired depth. This method, which is known as *tomoscopy*, is directly possible on some modern tomographic equipment, but is only considered when there is a distinct fluoroscopic image (the lungs) and, on the grounds of dose recommendations, is not often used.

Good immobilisation of the patient is an important prerequisite for a satisfactory set of tomograms, in view of the fact that the procedure takes a long time. This is impossible during tomography of the lungs; the patient cannot hold his breath for so long. It is therefore important to instruct the patient to assume the same phase of inspiration for all exposures, otherwise the interpretation of the localisation of the various planes could be incorrect.

A drawback of tomography, in addition to the large number of films used, is the fairly high radiation dose given to the patient. This, however, is appropriately controlled by the determination of the desired section depth beforehand (by means of tomoscopy or on the basis of ordinary fluoroscopy or radiography), and by suitable subdivision of large films, for which there are special cassettes or inlay frames available (for example 6 or 8 exposures on a 30 × 40 cm film). Proper centring (by means of fluoroscopy or test films) avoids the disappointment of taking a whole series of exposures of an undesired area. The most modern tomographic machines have both an automatic subdivision of cassettes and an automatic tomographic cut or section adjustment, by which, after every exposure, without any intervention by the radiographer, the correct section is adjusted and the next portion of film is moved forward.

More serious than the large amount of film used is the already mentioned disadvantage of the large X-radiation dose that the patient receives, due to the large number of exposures (8, for example). This entails both the integral absorbed dose and the skin dose, of which the former is by far the most important. Beam limitation (use of small films) is already a very useful and efficient method of saving dose. Above all, tomography should only be carried out when strongly indicated, particularly as it is often used for lung and kidney disorders, etc. (tuberculosis, silicosis, etc.) for which patients have to undergo many years of X-ray investigations: fluoroscopy, radiographs and tomograms. A radiation lesion could result because of an accumulation of dose.

As far as the applications of tomography are concerned, it is the lungs that have long been investigated, and most often, by means of tomography, particularly for the purpose of making decisions with regard to tuberculous infiltrations and cavities or enlargements of glands or tumours. Tomography is also of use in investigations of the bony structures of the skull and spinal column. Tomography of the petrous bone, particularly using multidirectional tube-film movements, has already been carried to a high degree of perfection (with section thicknesses of only a few millimetres) due to which the projection of the auditory ossicles, etc., is no longer any problem. Tomography of the larynx has also already become a routine method of investigation. Tomography for intravenous pyelography and zonography for an investigation of the bile ducts is often done to eliminate interference by superimposition (skeletal structures and intestinal gas).

The combination of tomography (ordinary and transverse) with a pneumoperitoneum and retropneumoperitoneum should also be mentioned. With this technique, the kidneys, suprarenals and their pathological processes can often be clearly shown. Sometimes information can be obtained concerning one of the organs that is, radiologically speaking, most inaccessible—the pancreas. Also by this means, tumours of the mediastinum can be shown by filling the mediastinum with air (pneumomediastinum).

A few words about terminology. Although local variations in interpretation do occur in practice, the names stratigraphy, planigraphy and tomography are used interchangeably without indicating a particular method, for example vertical or horizontal, or a particular type of apparatus.

#### 12.1.6 Simultaneous multisection tomography

It is possible to take several tomograms or 'cuts' of one patient simultaneously, that is with one exposure. The principle of *simultaneous multisection radiography*, as it is called, is illustrated in figure 12.5. A special thick cassette or *magazine* can incorporate several films (each between two intensifying screens) parallel to each

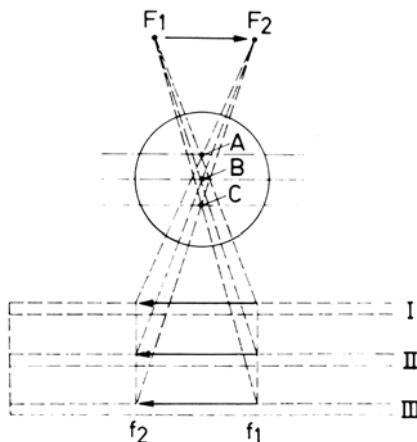


Figure 12.5 Principle of simultaneous multisection tomography. Three films (I, II, III) are located with suitable spacing, one above the other in a special cassette, which is moved from  $f_1$  to  $f_2$ . The tube focus is displaced simultaneously from  $F_1$  to  $F_2$ . On each of the films a different plane is sharply projected. The planes parallel to the film should be thought of as passing through points A, B and C as fulcra, situated on imaginary axes of rotation.

other and suitably spaced. If the fulcrum is set at A, then the details of planes B and C on film I will be blurred. For film II, point B can be taken as the fulcrum, thus on film II plane B will be sharply projected. Similarly, point C acts as fulcrum for the tomogram projected on film III (the planes through A and B are blurred). In practice, 4–6 films are used simultaneously. In selecting the depths to be covered, the fulcrum is placed at the level of the uppermost objective (selected) plane, that is the top film since it is located at the same level as the film in an ordinary cassette when doing single-film tomography. Obviously, the intensity of X-radiation decreases as it passes through the successive films and intensifying screens. Intensifying screens, particularly, absorb a relatively large amount due to

their high atomic number. In order to end up with as uniform a density on all the films as possible, the successive intensifying screen pairs should have increasing intensification factors. The uppermost film receives intensification from only one screen with a low intensification factor, whereas the lowest film, with the aid of two highly intensifying screens must attempt to produce a useful radiograph with the small amount of radiation that is left. The absorption in the films themselves and the reduction in intensity due to the inverse square law also contribute to the attenuating factors (albeit very little). It is clear that this puts simultaneous multisectiion radiography in an unfavourable position, qualitatively speaking. For example, a rather high voltage is needed to produce sufficient intensity to penetrate all the screens, etc., which decreases the poor contrast already inherent in tomography. Partly for this reason, simultaneous multisectiion radiographs are of a much poorer photographic quality than single tomograms, and are therefore not widely used. Against this evident disadvantage, there are two medical advantages; in the first place, simultaneous multisectiion radiography shows the patient in the same state in all radiographs (for example at the same respiratory phase), so that the depth of the layer is fixed beyond any doubt. Secondly, this method only requires about half the dose that would have been needed for the same number of single tomograms, which means that the dose received by the patient can be limited. Moreover, the investigation does not last so long, which must be regarded as an advantage, especially for patients in a weak state.

As in normal tomography, the various depths must be clearly indicated on the films; in the simultaneous multisectiion cassette, with its strict sequence of the various screens, this has been facilitated by marking these screens.

It is, and remains still a challenge for the manufacturers of intensifying screens to re-awaken the much decreased interest in simultaneous multisectiion tomography by drastic improvements of the results.

### **12.1.7 Simultaneous multisectiion tomography using cassettes with adjustable distances between the films**

An interesting new construction, which is apparently leading to a 'come-back' of simultaneous multisectiion tomography, is the replacement of the thick magazine with fixed distances by a thinner cassette with adjustable distances. Its peculiarity is that, by a shift of the intensifying screens during the exposure, part of the focus-screen distance can be cancelled out, therefore enabling the screens to lie close together (construction by Goos according to Landau). This principle is further explained in diagrams of figure 12.6.

At the top left of figure 12.6, the exposure of the first and sixth films is illustrated when these are incorporated in an ordinary multisectiion cassette. These films remain in the same position with respect to each other during the exposure. At the top right, the swing of the same rays from  $F_1$  to  $F_2$  is illustrated, but now, due to the shift of film 6 with respect to film 1, the ray that passes through the lowest fulcrum is curtailed, as it were. The intensifying screens (with films) follow the rays that belong to the desired 'cut' by their movement around their virtual fulcra.

Below, left, in figure 12.6, the central rays for the six exposures in the multisectiion cassette are illustrated, and on the right the central rays that strike the individually shifted screens. In this case, it appears that the screens must shift in

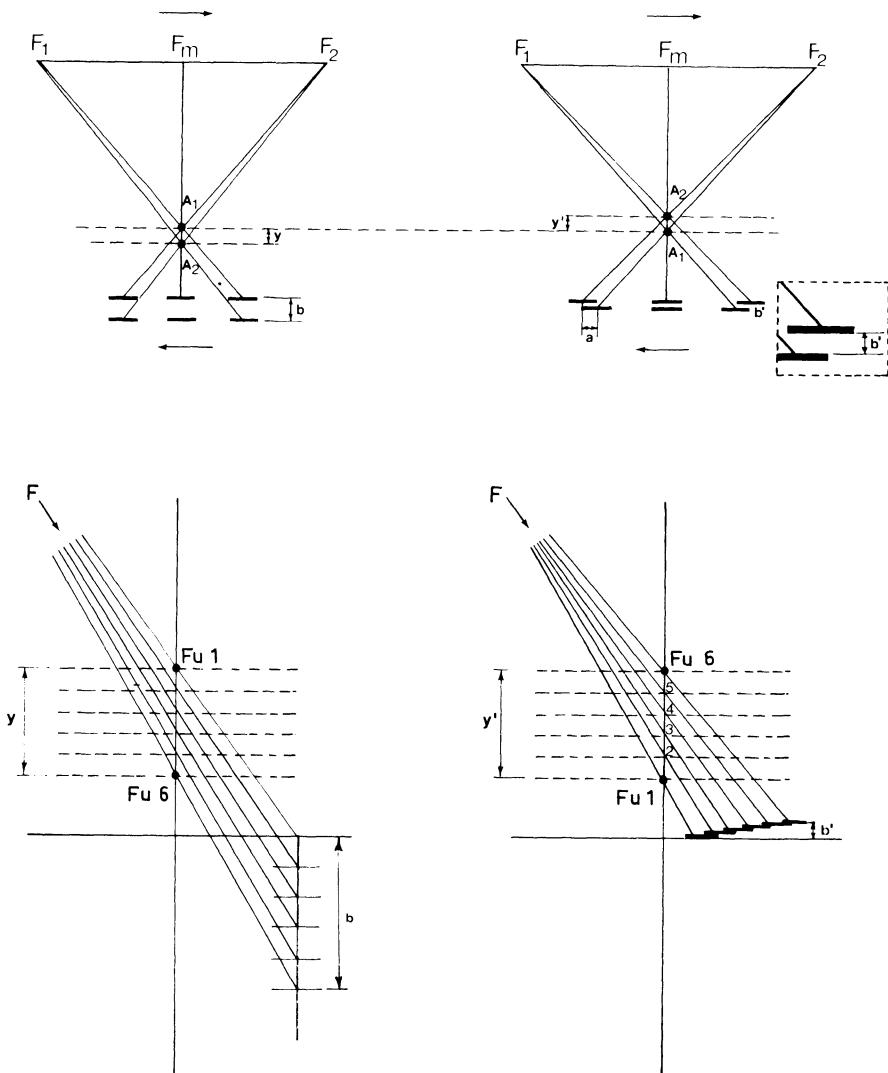


Figure 12.6 Comparison of a conventional multisecton cassette (left) and a Synchroplane cassette (right).  $F_1$ ,  $F_m$  and  $F_2$  are the end and middle positions of the focus during its swing. The arrows indicate the direction of the tube and cassette displacement.  $F_u$ . Fulcrum = axis of rotation.

Above: Cuts 1 and 6 at distances  $y$  (left) and  $y'$  (right). On the left is the movement without shifting of the intensifying screens and on the right with shift (in this case maximum =  $a$ ). On the left the actual mechanical axis of rotation  $A_1$  is above the axis of rotation  $A_2$ , and on the right it is below  $A_2$ .

Below: Detail of the six cuts.  $F_u\ 1$  is the actual (mechanical) fulcrum,  $F_u\ 6$  is the virtual fulcrum for cut 6. On the left, the actual fulcrum  $F_u\ 1$  lies in the top cut and on the right it lies in the bottom cut. On the left the distance between the first and sixth film is  $b$  and on the right this distance is equal to  $b'$ . Due to the great difference between  $b$  and  $b'$  follows the very great difference in thickness between the conventional and the Synchroplane cassette.

relation to each other during travel of the tube and when passing the midpoint must lie exactly on top of one another, so that, after that moment, they shift in an opposite direction in relation to each other.

Due to this system, it has been possible to reduce the total thickness of the multicassette to about 15 mm, so that it can be accommodated in every bucky tray. As the speed of the individual shift is adjustable, the individual distances between the 'cuts' can also be arbitrarily chosen and adjusted (0.5–2 cm); this is not possible in the ordinary cassette. This system has been developed exclusively for linear blurring and at present is still limited to the 24 × 30 cm film size. Briefly, then, in other words, during the swing of the tube the screens follow the central rays which travel through the virtual fulcra (axes of rotation) of the desired planes. The fulcrum of the actual movement is located in the lowest plane that has to be projected in this system; this is different to the ordinary multisection cassette, where the fulcrum is situated in the uppermost layer.

Although the objections to simultaneous projection of several layers have by no means all been met by this cassette, and in particular the requirement of improved uniformity of contrast and definition of the six films still remains, this new construction does mean an undoubtedly widening of the possible range of applications and, therefore, a worthy replacement of the former multisection cassette.

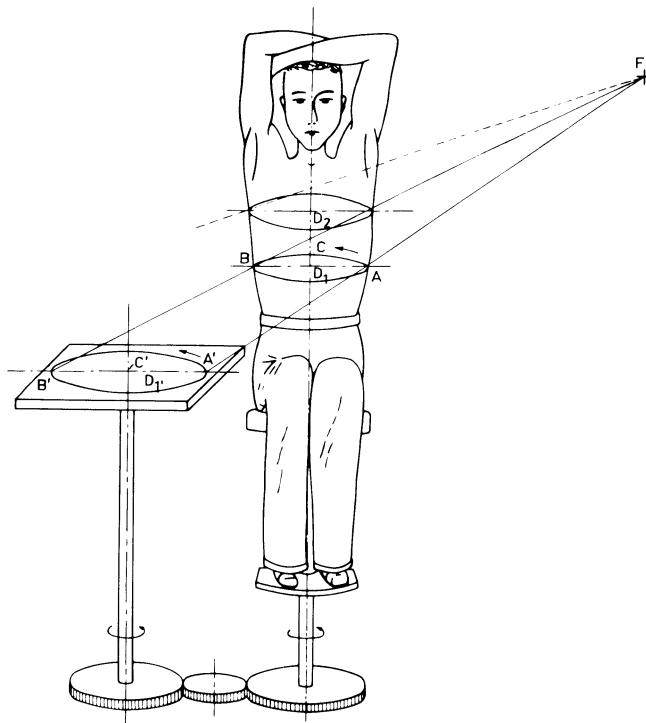
Although the following methods of investigation, transverse tomography, axial tomography and pantomography, certainly do not belong to routine procedures, it is, however, logical to describe these in connection with routine tomography.

#### **12.1.8 Transverse tomography**

Whereas the tomography described above can only demonstrate layers parallel to the long axis of the body, transverse planigraphy enables us to obtain layers at right-angles to the long axis. It is obvious that it is impossible to make a transverse (or horizontal) cross-section of, for example, the thorax by normal tomography; the tube would then have to be placed above the head and the cassette under the seat of the patient, and the resulting absorption would make this method impossible.

In transverse tomography (figure 12.7) the beam of X-rays passes through the body at an angle of about 20° crano-distally to the plane of the section to be made (the selected plane). On emerging from the body, the X-rays strike the film, which is placed perpendicular to the body axis, that is parallel to the plane of the section. By now rotating the object and the film synchronously and in the same direction, one ensures that only the points in the desired plane are always projected onto the same spot on the film, while all details above and below this plane are blurred, the further away they are the more they will be blurred.

Since a rather large object-film distance is necessary, a high degree of magnification is inevitable, even though one uses a large focus-object distance (about 2 m). The radiation energy must therefore be high, and the focus must be very accurately positioned with respect to the axis of rotation and the film, and with respect to the plane of the desired section and the plane of the film. This positioning must be rigidly adhered to during the exposure, since even a slight deviation can ruin the results.



**Figure 12.7** Principle of transverse tomography. During the exposure the patient and the film move in the same direction and at the same speed. The patient is seated on a revolving chair; the film is mounted on a turn-table. The film is located parallel to the transverse section through the patient; the X-ray beam is projected obliquely, at an angle of 20°. The points A, B and C in the plane D<sub>1</sub> of the patient are projected on to the film as A', B' and C', respectively, in a plane D'<sub>1</sub>, resulting in a transverse section radiograph. Plane D<sub>2</sub> will be projected unsharply and partly outside the film. The coupling of patient and film movements in this illustration is represented as mechanical, but it may also be done electrically.

It is inherent in the nature of the method that the lack of definition and the blurring are even more obvious here than in normal tomograms, so that it will only be possible to distinguish relatively coarse details in these transverse planigrams. There is thus, for example, no possibility of seeing structural details of bone. The main applications are the localisation of tumours in the thorax and abdomen. For this latter investigation, air is usually introduced retroperitoneally before the exposure is made (*retropneumoperitoneum*).

This method is unsuitable for very accurate localisation; the possible information obtained is also rather approximate. Transverse tomography is also used for investigations of the neck, where it can give a satisfactory impression of the lumen of the trachea.

Transverse tomography requires the patient to be in a sitting position and carefully immobilised, which naturally limits its range of application. Another disadvantage of the method is the large amount of film used; as only large-size films

can be used, it is not possible to make several exposures on one film (that is subdividing the film). Moreover, it is not possible to make simultaneous multisection exposures. It is possible, however, to take sections at an angle to the axis of the body (oblique sections).

After an enthusiastic beginning, the interest and application of transverse tomography has greatly diminished, and transverse tomographic equipment in most places is not being used. However, during the past few years, some transverse tomographic machines have still been made. At present, the patient is allowed to lie down comfortably; the tube and connected cassette holder are moved around the patient.

### 12.1.9 Computerised axial tomography—CT-scanning or CAT-scanning

A new form of tomography has become possible by the use of computers and electronic memories. This method was at first called computerised (transverse) axial tomography (CAT), but now the term CT-scanning (CT, computerised tomography) is commonly used. The installations are therefore known as CT-scanners. There are two types of scanners (with one detector and with several detectors).

#### 12.1.9.1 CT system with one detector, computertomogram as numbers and as image

We will deal first with the oldest type, namely the CT system with one detector, which was introduced in 1972 by the British firm, E.M.I.\* This scanner is exclusively intended for investigations of the cranium (figure 12.8). Use is made of an

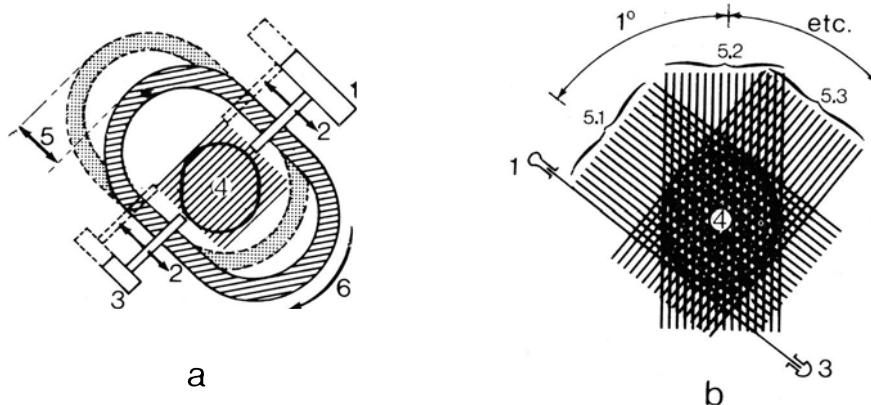


Figure 12.8 Diagrammatic representation of a head scan using one detector.

a: Arrangement of the apparatus. 1. X-ray tube; 2. collimators; 3. detector; 4. object (head); 5. linear movement; 6. rotation (after each linear movement the system rotates through an angle of 1°).

b: Indication of the path of radiation. 5.1, 5.2 and 5.3 are some of the 180 positions in which the linear movements take place.

\*The fact that the development and introduction of this procedure did not originate from the radiological side but from a completely different one, namely, the radar specialists of the Electronic Musical Industry (Hounsfield and co-workers) is extremely surprising.

extremely narrow collimated beam of X-rays; this is achieved by using an ordinary X-ray tube and collimators with narrow apertures. The diameter of the beam is about 1 cm. A beam detector, also fitted with a narrow diaphragm, is mounted on the other side of the object and the beam strikes this precisely. The detector consists of a crystal, which converts the X-ray quanta into light, and a light meter; these features cause this detector to be extremely sensitive. The current that leaves the detector, the signal, is proportional to the incident quantity of X-ray quanta, and both, in their turn, are (with constant X-ray intensity from the source) inversely proportional to the attenuation in the object. This attenuation is the product of the attenuation in the parts of the object, which the narrow beam passes through, at that moment. Now we move the source and the detector in such a way that the beam runs parallel to itself in a flat plane. After this linear movement the beam has passed through a thin slice or section of the object. The electronic signal of the detector reproduces, at every moment, the attenuations that the beam undergoes in the various paths through the section.

Let us suppose that we can distinguish the signal of 240 adjacent positions. This signal is recorded in an electronic memory. Next, the X-ray source and detector rotate around the object in steps of an extremely small angle ( $1^\circ$ , for example) and the procedure is repeated. After 180 rotations, the section is 'looked at' from all sides and  $240 \times 180 = 43200$  measurements are noted. A particular object detail has been irradiated 180 times and, indeed, each time superimposed with other object details. The computer is now able to calculate the attenuation of the individual details from the many stored data, and reproduces this in the form of a grid pattern of, for example,  $160 \times 160 = 25600$  numbers (shown as a  $160 \times 160$  matrix). Every number in a number matrix indicates the radiation absorption in a tiny three-dimensional unit of which the shape and dimensions depend on the type of equipment used and the system (for example, cube- or prism-shaped), with a volume of  $1.5 \times 1.5 \text{ mm} \times$  the slice thickness. This latter amounts to 8 or 13 mm in the older type of scanner; in modern installations the slice thickness is adjustable (for example, 4-17 mm).

With such a number matrix, one cannot work quickly in practice; therefore, the system has been changed to convert this 'number image' electronically into a black and white or colour television image, in which every matrix number is presented as a particular component part (picture matrix point) of the image; the brightness and/or colour of each component is determined by the number. When a coarse matrix is used ( $80 \times 80$ , for example) the components are visible with the naked eye, and appear as tiny squares; when finer matrices are used (at present a matrix with  $256 \times 256$  points or components is most often used) these fuse together, as it were, and can only be seen individually after enlargement.

The superiority of computer tomography lies in the fact that one can perceive and record no fewer than 2000 different absorption values, which far exceeds the discrimination that the density range of an X-ray film is able to offer. At most 30 different grey values (of white to black) can be distinguished on a television screen. However, it is possible to spread out, as it were, a particular small area of the number matrix electronically over the whole range of grey values so that an enormous contrast intensification takes place and very small absorption differences, such as those found in soft tissue for example, become visible.

A computer tomogram is marked in relative absorption values, varying from

zero (which represents the absorption value for water), expressed in promille. The following relative values then occur: air -1000, solid bone +1000, fatty tissue -100, blood +12, clotted blood about +65, water 0. It is true that soft tissues shows small individual differences, but these can still be expressed in the image by the spreading mentioned above. The image is photographed to provide a permanent record (see figure 12.9).

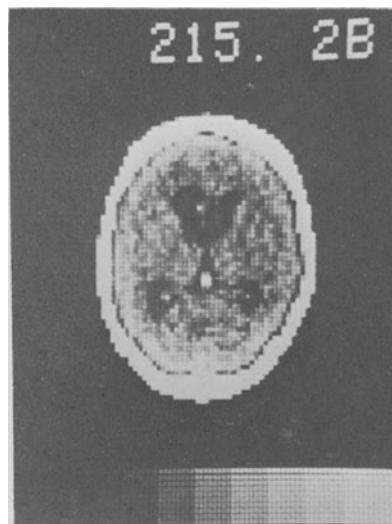


Figure 12.9 Example of a CT scan in the skull of a patient with a brain tumor. The streaky, cube-like appearance of the image (in this case with a matrix of  $160 \times 160$  points) is typical of the method.

The following example demonstrates the fact that the calculations mentioned are quite extensive (see figure 12.10). The absorption for X-rays of the  $4 \times 4$  ( $= 16$ ) areas is indicated in a square by itself. If the beam crosses the square from left to right, then the detector will measure a total absorption of 31, 35, 30 and 35 consecutively\*. After rotating through  $45^\circ$  towards the right the detector will indicate 13, 39, 31, 20 and 9; after  $45^\circ$  rotation towards the left one measures 21, 13, 36, 20 and 21; by a vertical measurement 36, 18, 37 and 40 are indicated.

If we now consider the small internal volume of tissue that causes an absorption of 9 in the diagram, then it is clear that if the absorption amounted to 0 instead of 9, then in the horizontal measurement the number 30 would change to 21; with the left rotation the number 31 would change to 22; with the rotation towards the right number 20 would change to 11; and with the vertical measurement the number 37 would become 28. Hence, the possibility arises that, starting from the numbers measured from the exterior, the internal pattern of the investigated slice can be compiled into a picture puzzle, as it were, which is expressed in the illustration.

\*These figures represent the log values of the X-ray absorptions. The product of the various attenuations is represented by the sum of these log values.

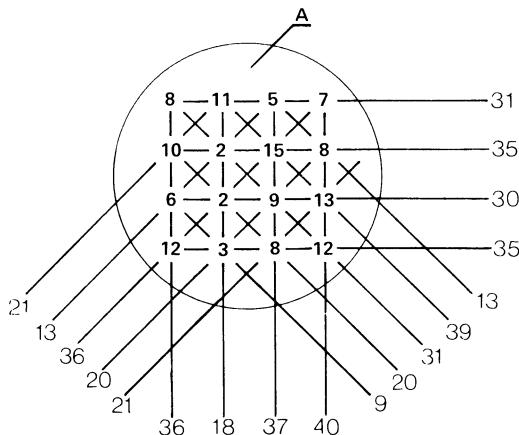


Figure 12.10 Simplified model to show the calculations with CT-scanners. A is the object. The 16 numbers in the centre represent the internal (unknown) local X-ray absorption values, which are calculated from the external measurements by the computer. With a linear movement from left to right one measures a superimposed absorption of 31, 35, 30 and 35 (log values) consecutively. After rotation of 45° from top-left to bottom-right one measures the diagonal 13, 30, 31, 20 and 9, etc. See explanation in text.

In order to gain a clear impression of the principle and of the extensiveness of this procedure, one could solve the following problem by really treating it as a picture puzzle, in which one has to fill in the numbers to the nine volumes so that they agree with the values indicated (the external measurements) (figure 12.11).\*

The narrower the beam, the greater the number of measurements that are

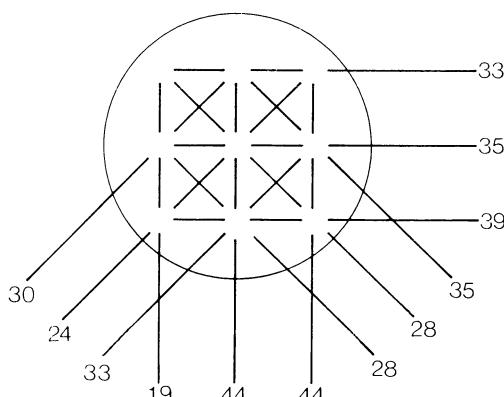


Figure 12.11 Problem. The externally measured absorption values measured by means of scanning in four directions, caused by nine tissue volumes have been given. The absorption in each volume is asked for. To facilitate the problem: the absorption in the central volume is 8. The answer is given in the footnote below.

\*Solution to problem 12.11: Top row: 3, 19, 11 Middle row: 11, 8, 16 Bottom row: 5, 17, 17.

required and the more complicated the puzzle becomes, but also, the more exact the determination of the local absorption. In practice, one measures not in 4 directions rotated in relation to each other, but in 180° and, moreover, by parallel shift. The solving of the enormously large number of essential calculations (many tens of thousands per investigation), which must take place in an acceptably short period of time, has only been made possible with the use of computers.

The procedure described above gives us the X-ray absorption differences in one slice of the object of approximately 1 cm thickness, a slice that is situated perpendicular to the axis of rotation of the X-ray system. Therefore, it is a particular form of *axial tomography* (see figure 12.12).

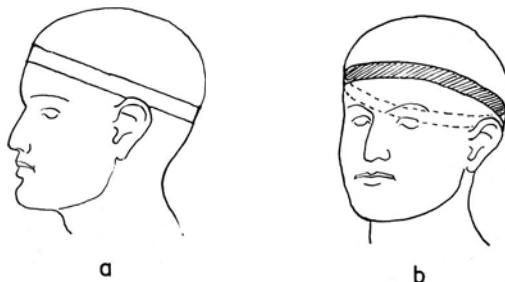


Figure 12.12 Representation of the position of one slice of an axial skull tomogram.

a: Viewed from the side. The slice is angled backwards, parallel to the plane through the orbito-meatal line.

b: Representation of the position of the slice in perspective.

From the above descriptions and illustrations, it appears that only one slice is projected with this CT-scanning, which has no connection with (and therefore also is not disturbed by superimposition of) adjoining slices. This is therefore a very essential difference with regard to the axial tomography described in the previous section (section 12.1.8). This is clearly shown in the following illustrations (figure 12.13) taken from Elke and others in *Röntgenpraxis*, January, 1976. In a, the six slices 1A, 2A, 3A, 1B, 2B and 3B, assumed to be 'standard slices', are shown, whereas in b the CT-scans that belong to these are shown; they have all been taken parallel to the plane that passes through the supra-orbital margins and external auditory meati (orbital-meatal line). Whereas in cut 2B the greatest part of the brain's ventricles is shown, slice 3B is already situated above the uppermost point of the ventricular system. Displacement or changes in shape can be shown to great advantage in such slices (compare figure 12.9).

What now is the advantage of a radiograph taken by this method? By the number of different superimpositions, it is possible to differentiate between very small differences in local X-ray penetrability. One obtains great contrast resolution. Where otherwise small differences in penetrability cannot be found in a radiograph nor in tomograms because of superimposition (particularly in the skull) here one can see very accurately into the interior, as it were. The cerebral ventricles, extravasations of blood and growths, of which the differential absorption of X-rays is not shown on a radiograph due to the fact that these belong to the soft tissues (with the same effective atomic number, and virtually the same density), the computer tomographic scanning does demonstrate the absorption dif-

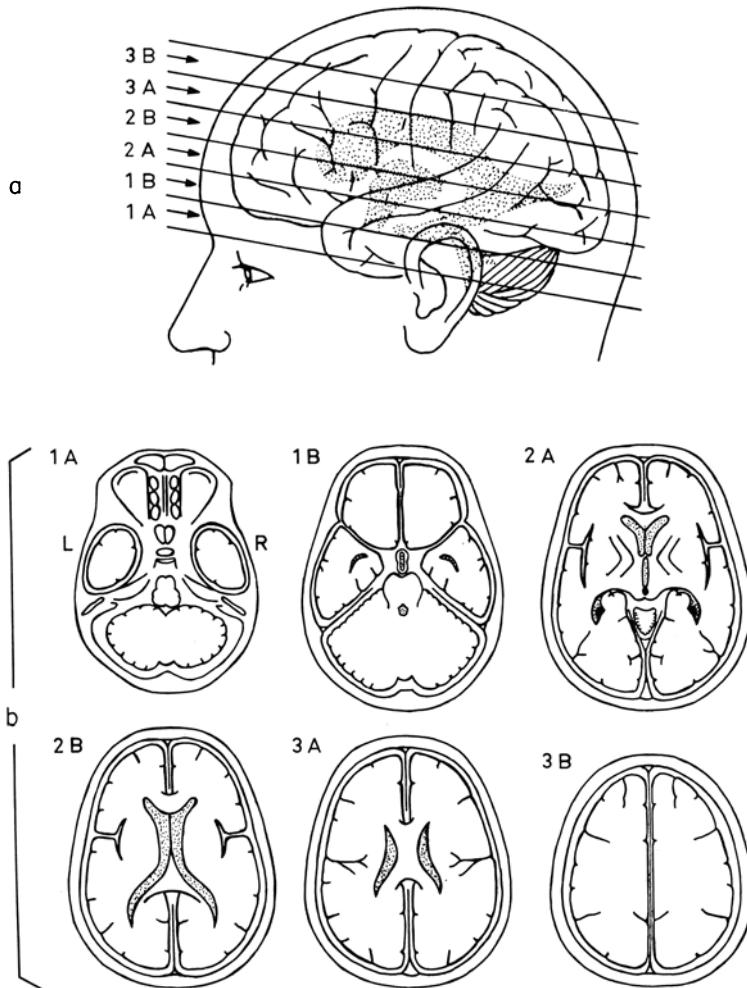


Figure 12.13 Diagrammatic representation of standard cuts with computerised tomography of the skull (*Röntgenpraxis*, January, 1976).

a: Side view of the position of the six cuts, parallel to the orbito-metral plane (bottom line).

b: Diagrams of the anatomical relationships in these cuts. For further explanation see text.

ferences that do exist between them (even though they are small) and which can be discerned without additional administration of contrast media. This also results from the fact that, by the use of a narrow beam and a focused detector, the latter does not receive any scattered radiation. A disadvantage is the rather coarse 'lattice' effect of the image. The three dimensional resolution amounts to about  $3 \times 3 \times$  the diameter of the beam in mm; this forms an image component (or unit or point). Thus, the definition of the image in comparison with the conventional radiograph is much less.



Figure 12.14 Illustration of a brain scanner with patient. The patient lies with his head immobilised securely in a close-fitting rubber cap, while the X-ray tube and detectors rotate around the head. By displacing the couch in a lengthwise direction the various cuts are scanned. The examination only takes about ten minutes, and can be carried out on outpatients.

In addition to the accessibility of the morphological conditions, which hitherto could not be detected in living beings, both the patients and personnel are also affected by the convenience and comfort of CT scanning (figure 12.14). The patient is in a recumbent position, and the radiographer controls the procedure in a sitting position behind a control desk, similar to the set-up for making radiographs behind a protective screen, always at a distance. There are no complicated positions and rotations as is the case in pneumoencephalography, and no introduction of catheters as in cerebral angiography. Occasionally, an injection is indicated in order to show up a blood vessel or tumour somewhat more clearly.

#### 12.1.9.2 Simultaneous scanning with several beams

Soon after scanners were introduced, a construction was chosen whereby two parallel X-ray beams were individually and simultaneously measured by two detectors. In this way, two parallel slices were scanned simultaneously, and this saved time, so that the duration of a scan could be reduced to about 4 min. *The patient must not move during this period.* Careful immobilisation is necessary which, in the case of the skull (to which, in the early stages, computer tomography was applied almost exclusively), appeared to be easily possible. For other applications, however, much shorter scanning times are necessary. By extending

the single detector to a whole row of detectors, and using a fan-shaped X-ray beam (that is arranging many rays, lying in a plane, into narrow diverging beams), it becomes possible to irradiate a large part or even the *whole* selected slice with the X-ray tube in one position and with one exposure. By this method, the simultaneous signals from the detectors are individually recorded in the electronic memory. With this, the 'translation movement' can be decreased, or even done away with completely; in this latter case, one need only carry out the rotation movement with the fan of radiation beams. In this way, the time taken to scan a slice is considerably shortened, and can be limited to ten, or even to only a few seconds (see figure 12.15).

It is obvious that the geometrical relationships of the diverging directions of the rays that cross each other are in this case much more complicated than in the

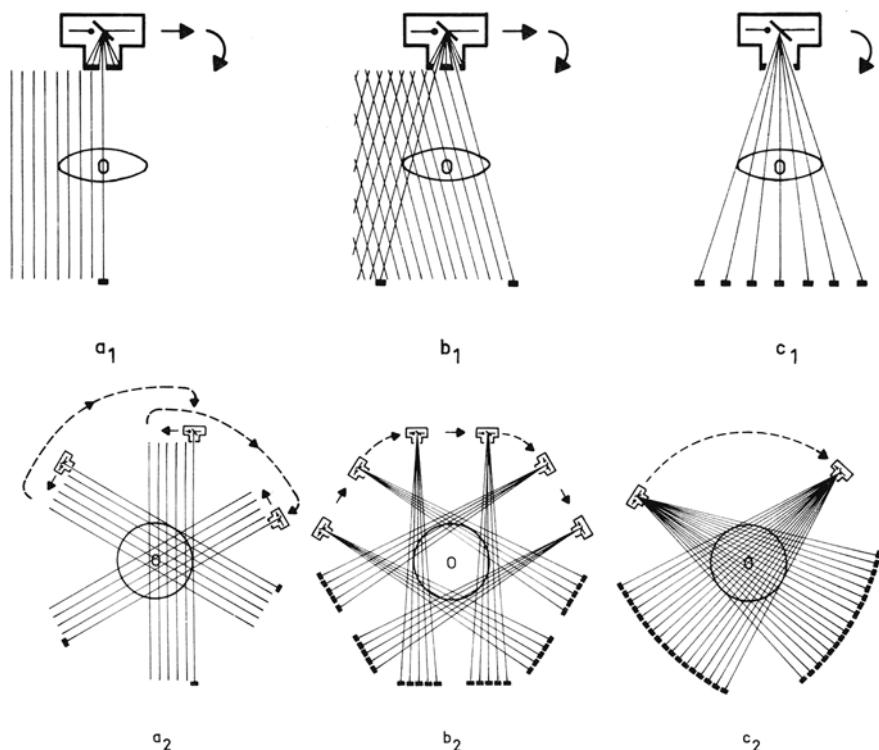


Figure 12.15

a<sub>1</sub> : Scanning with one beam which moves in a sideways direction. The rotation through 180° is not illustrated.

a<sub>2</sub> : The translation and rotation movements of one beam (scanning time about 5 min).

b<sub>1</sub> : Scanning with several beams simultaneously. The 'fan' of detectors does not encircle the entire object so that translation movement is still necessary.

b<sub>2</sub> : Scanning with beams in the shape of a fan, which move sideways as well as rotate (scan time 3½ min to 20 s).

c<sub>1</sub> : Scanning with widely diverging beams that encircle the entire object. The translation movement is no longer necessary.

c<sub>2</sub> : The fan of beams rotates around the object (at least 180°, and a maximum of 360°).

parallel beams with linear movement, described in the previous paragraph. It is true that the demands made on the computer as well as on the reconstruction of the image are much greater here, but the results achieved completely justify the attempts to fulfill these requirements.

With the newest scanning machines it is possible to extend the scanning angle to more than  $180^\circ$  ( $220^\circ$  and  $360^\circ$ ); this complicates the installation, but can benefit the investigation. Due to the short scanning times (10 s and less) movement of many internal organs can be avoided, which otherwise could irrevocably lead to incorrect conclusions because of artefacts on the tomograms. Movements in the thorax and/or abdomen result in useless or only roughly useful orientations because of the shift of the volumes that are measured. Technical shortcomings are being overcome continually and in an improved manner; thus, it is becoming increasingly possible to produce valuable computer tomograms of body parts other than the skull. Because of the great contrast resolution already discussed above, organs are being made visible by CT-scanning that previously remained hidden as far as radiological examinations were concerned.

Scanning of the abdomen has already led to an enormous contribution to investigations into the spleen, liver, pancreas and kidneys without the need for the introductions of contrast media, and progress is still in full swing. The radiation source and detectors rotate around the body in this case; the cuts are axial, that is, perpendicular or slightly angled with respect to the longitudinal axis of the body (see chapter 16, section 16.3.3).

In the following illustrations (figure 12.15) the various methods of CT-scanning are shown diagrammatically (according to Linke, *Röntgenpraxis*, 1977). A disadvantage of the use of fan-shaped diverging beams compared with parallel beams is that the total volume producing scattered radiation is much greater, which necessitates extra collimation by the detectors, in order to avoid a decrease in contrast. However, on the other hand, the great advantage is that the X-radiation produced in the tube is used much more extensively, resulting in much shorter scanning times; this is shown in figure 12.15.

#### **12.1.9.3 CT-scanning compared with photographic radiography, definition, dose**

CT-scanning differs from the other tomographic methods, which have already been discussed, in the following important respects:

(1) The investigated slice is not overshadowed, as it were, by the adjacent slices, which is unavoidable in the case of 'ordinary' tomography (even if these adjacent slices are not sharply projected).

(2) The investigated slice is not reproduced *primarily* as a photograph, but as a number pattern of local attenuations, expressed by means of electronic signals via detection. This pattern can be presented *secondarily* as an image on a monitor or as a photograph, so that the electronic signals that have been obtained can be interpreted (and this is what is usually done).

The usual criteria applied to photographic reproduction with regard to the resolving power, such as definition, contrast, etc., cannot be used for this image, and also the discernment by modulation transfer function is not taken into account. Thus, one will not see any M.T.F. curves with CT-scanning. The contrast depends

upon the adjustment, etc. A sharpness of the order of tenths of millimetres, as is the case in ordinary radiographs, is never attained. One has to be satisfied with a three-dimensional resolving power, which is determined by the apparatus and system, as well as by the type of matrix used. Therefore, for example, with a matrix of  $256 \times 256$  image points with a field size of 25 cm diameter, the 'separating ability' could amount to  $1 \times 1$  mm\*. With a larger field diameter this separating ability becomes inversely proportionally less when the same matrix is used, and will consequently amount to  $2 \times 2$  for a 50 cm field diameter. A diagnosis of fine and extremely fine details with CT-scanning as opposed to X-ray photography, is also out of the question, therefore, particularly when this is used in conjunction with the radiological enlargement technique as is described in section 12.3.

Also of great importance is the question of radiation dose with regard to scanning. This type of installation with which the investigation is carried out, that is always from a distance, guarantees complete safety for radiological staff and other personnel. As far as the patient's dose is concerned, it appears that this is the same as for photographic radiography. The skin dose for a skull X-ray, for example, amounts to 1-2 R; the exposure in the projected slice is of the order of 2-3 R. However, lower values are now also being indicated. In relation to the dose, the use of high kilovoltage with very small ripples (six-pulse or twelve-pulse generator) is to be recommended. Kilovoltages of 50-150 kV are considered.

CT-scanning, without a doubt, represents a complete novelty in the development of radiology; it has already brought results that hitherto were unattainable. The system has deeply affected radiology of the skull. The brain, of course, in particular, is in many respects 'terra incognita', unknown territory, both in its normal anatomy and in pathology. However, the methods of investigation that have prevailed up to the present, such as pneumoencephalography, cerebral arteriography, isotope scanography, etc., have by no means suddenly become redundant. Although their indications have changed, that is have become much less (this is especially true for pneumoencephalography or A.E.G.), one would be well-advised not to over-estimate CT-scanning, but to consider it as a very valuable addition or alternative method, at least for the time being. As it is a simple procedure as far as the radiographer's duties are concerned, it poses few or no problems for her; for the neuroradiologist the interpretation signifies a whole new area; for the budget of the X-ray department it entails an enormous load (an investment of some hundreds of thousands of pounds). For the present, CT-scanning is only used in the larger centres, but the technique will no doubt continue its advance, and will be applied on a much larger scale than is the case at present. This will most certainly be promoted by further refinements in contrast resolution, and by extension of the image pattern. Much can yet be anticipated in the field of detection (improved and more rapid detection, for example).

In conclusion, it should be mentioned that data obtained by CT-scanning can be recorded on magnetic tape, film, magnetic discs, etc. (just like the images produced by X-ray fluoroscopy, for example). They can be recalled or projected from the 'memory'.

The X-ray quanta are not only capable of producing luminescence in the detector, but can also ionise gas. By constructing the detector in the form of an ionisation chamber that contains gas under high pressure (thus filling it with many gas mole-

\*Newer apparatus has matrices of up to  $512 \times 512$  image points.

cules), one can increase the number of ionisations considerably. In this way, one increases the number of absorbed X-ray quanta and, thus, increases the sensitivity of the system. With rapid detection (only a few seconds or even fractions of seconds), a much shorter immobilisation time is required, and would enable the inclusion of moving organs (stomach, etc.) in the investigation. Already considerable progress has been made in this field.

### 12.1.10 Pantomography

Both in ordinary and in transverse tomography, described in the previous paragraphs, only projection of a flat plane (selected plane) on to another plane (the film) was discussed. However, it is also possible to project a curved selected plane, while blurring the surrounding structures. Paatero used a method for this, which is called *pantomography*. In this case a coupled movement of object and film takes place with a stationary tube focus. The object is rotated and the film moved

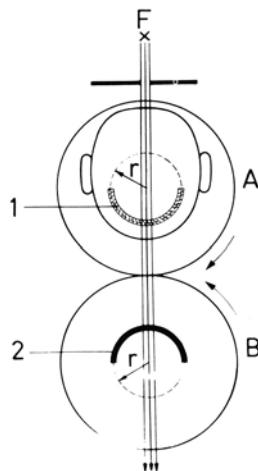


Figure 12.16 Principle of pantomography with rotating object and rotating film. Since disc A is in contact with disc B it causes disc B to rotate also but in an opposite direction. Both discs have the same dimensions. Through the fulcrum of each disc passes an extremely narrow beam of X-rays. All points on the surface of the discs pass the X-ray beam at some moment. The speed with which each point passes the beam is greater the further it is removed from the fulcrum of the disc. Points that lie at the same distance from their fulcrum pass the beam with the same speed, whereas the points that are not equidistant from the axis of rotation pass the beam with different speeds. If one describes on each disc A and B a circle of equal size (with ray  $r$ ) around the fulcrum as the centre, then all points in the vicinity of the circle on disc A will pass the beam with the same speed as the points on the circumference of the circle on disc B. The points that lie on the side of the circle away from the tube on disc A and those that lie on the side of the circle B towards the tube not only pass the beam of radiation at the same speed, but also in the same direction. If we now place an object on disc A, and on disc B a film, which stands upright and is bent in such a way that it takes on the exact shape of the circumference outlined on the disc, then, when the discs are rotated a section of the object 1, which is situated at right-angles on the disc, will be projected sharply onto the film in such a way that the image is reversed on the surface of the film, indicated by 2. All other points of the object are more or less unsharply projected onto the film, because they pass the beam with a different speed or against the direction of rotation.

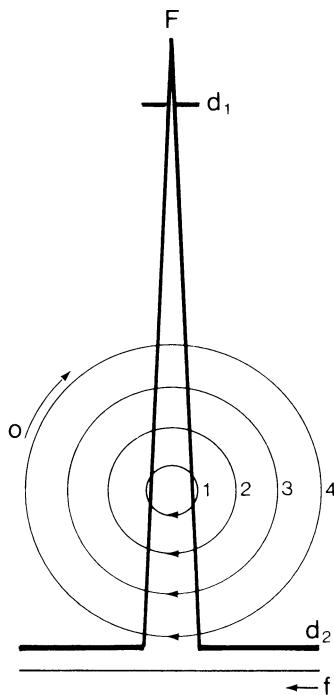


Figure 12.17 Principle of pantomography (or panoramic radiography) with rotating object and moving flat film. F is the non-moving focus with a very narrow X-ray beam collimated by means of  $d_1$ . O is the object on which, with the axis of rotation as the centre, four concentric circles are drawn. By rotation (in the direction indicated) these circles have the same angular speed but a different linear speed. Film f, which is affected by the narrow (limited, at the same time, by the lead diaphragm  $d_2$ ) beam, moves in the same direction as the object. Only the circle in the object that has the same linear speed as the film movement is projected sharply.

(shifted or rotated), while only a very narrow X-ray beam is used. By this method, the rotating object is not projected onto the film at once, in its entirety, but in continuous, joined, exposed strips and, thus, compiled into the total image.

When the method with rotating film is used, the condition must be satisfied that the object detail is lined up as part of a circle with respect to the axis of rotation, whereby the film is placed likewise with respect to the second axis of rotation, but in a mirror image position. Only the plane in which the object detail is located will then be sharply projected, as all the points therein travel with the same speed and are affected by the X-ray beam from the same direction as the plane of the film. One obtains, therefore, a contact print of the object detail in the selected plane on the film. All object details that lie outside this plane are passed through the beam either at a faster or a slower rate, or in another direction, and are therefore blurred accordingly.

Instead of bending the film, and allowing it to rotate, one can also use a flat film (in a cassette). While the object rotates, the film is shifted, and as there is only one circle circumference present in the object, which has the same (linear) speed as the film, only the object details, which are located on that circle, will be sharply projected, and the others will be blurred. It is obvious that object details

that lie inside this circle have less speed, and object details that lie outside have greater speed than the film and thus are blurred.

By altering the speed of the film shift, one can project the whole object, as it were, onto different, consecutively exposed radiographs. With rotating object and stationary film, pantomography will only reproduce the area of the axis of rotation. The faster the film shift, the more peripheral the location of the projected cylindrical area.

The principle of both types of pantomography are illustrated in figures 12.16 and 12.17.

It is obvious that the conditions required for a good pantomogram in the human body are never entirely fulfilled: no part of the body is of a sufficiently mathematical shape. Its application is, therefore, mainly limited to the skull, especially for a pantomographic projection of the teeth. Owing to the fact that the whole dental region does have a more or less cylindrically arched shape, the dental structures can be projected as a relatively 'sharp' pantomogram with blurring of the surrounding areas.

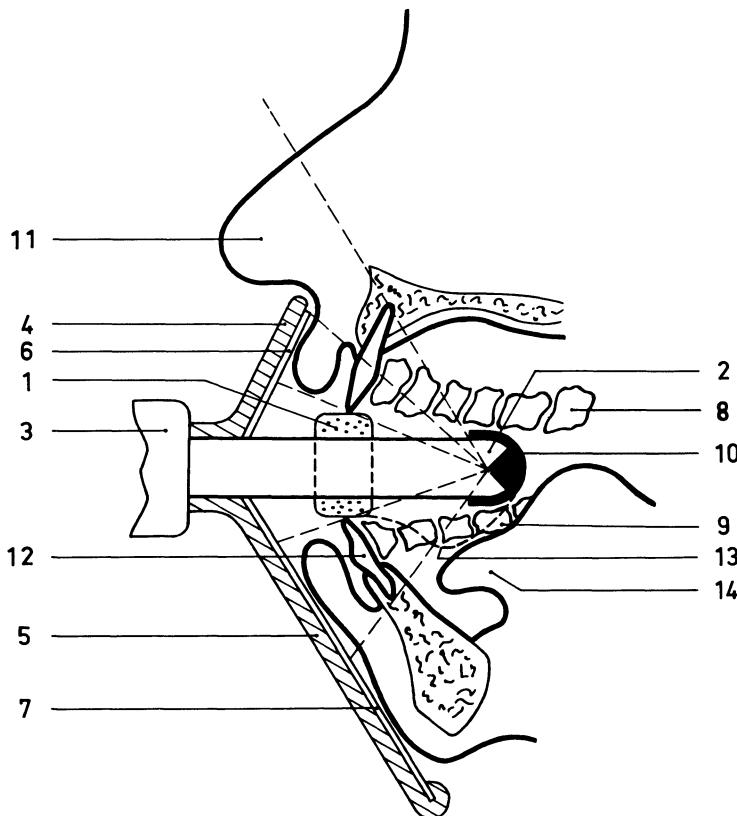


Figure 12.18 Diagrammatic representation of a panoramic radiograph. 1. Cork which is placed between the teeth (the X-ray tube can pass through its centre); 2. X-ray tube; 3. tube holder; 4, 5. clamp pressing the film (6 and 7) against the upper and lower jaws; 8. upper teeth; 9. lower teeth; 10. lead cap, shielding from unwanted radiation; 11. nose; 12. lower incisors; 13. plastic accessory with which the tongue is held at a safe distance from the tube; 14. tongue.

### 12.1.11 Panoramic radiography, panoramic exposures

As X-rays spread out in all directions from the anodal focus, one would obtain a larger beam than that from a normal tube, where the beam is limited by the relatively small window. Such a wide beam is found in a special tube with a very fine focus of about 0.1 mm which can produce panoramic exposures (see chapter 6, section 6.14). It is used for dental purposes, and produces a complete picture of the whole upper or lower jaw in one exposure. For this purpose, the tube is placed inside the mouth, with the focus roughly at the centre of the dental arch. The film in the form of a strip is arched round the outside of the mouth and held in place. Adequate screening against undesired radiation can be achieved, and the doses administered can be called acceptable. This method would seem to be quick and efficient for periodic checks and dental surveys (for example in schools), although the definition of these radiographs is inferior in comparison to normal dental films (figures 12.18 and 12.19).



Figure 12.19 The taking of a panoramic view of the lower jaw. The tube is placed within the mouth. The film, which is bent around the lower jaw, is pressed in place by means of a lead-rubber strip, protecting the hands from radiation at the same time. The use of a Philips apparatus is illustrated.

## 12.2 STEREOSCOPY IN RADIOLOGY

Perception by means of vision is virtually completely based on the use of both eyes: *binocular vision*. This enables us to see three-dimensionally (thus, also depth) contrary to perception with one eye (*monocular vision*). A single photograph taken with one lens actually produces a two-dimensional (that is, flat) image; pei

ception of depth is suggested on such a photograph on the grounds of experience (but is not actually perceived). Thus, if one object partially covers another on a photograph, one knows that the latter must lie behind the first. This criteria fails us completely in the case of radiographs: the entire projected image is transparent, as it were. Therefore, on a sagittal radiograph of a knee one cannot tell whether the patella was on the tube side (a-p) or on the film side (p-a radiograph) during the exposure. Thus, it is impossible to determine the depth of an object detail that is visible on a radiograph; for this a second exposure, taken from another direction (possibly perpendicular to the first direction), is necessary. From the combination of both findings depth is inferred, not seen.

In normal photography, instead of a flat image, taken with a single lens, one can obtain a *stereoscopic image* (with depth) by making use of a camera with two lenses (stereo camera), or by taking two photographs with a camera with a single lens, moving the lens for the second photograph. The resulting photographs (which differ slightly from each other) are presented to the left eye (left exposure) and the right eye (right exposure), and the images projected onto the retina in this manner are merged together in the brain into a three-dimensional image by which depth is *seen*.

### 12.2.1 Stereoscopic radiography by means of tube shift

X-ray stereographs can be produced in a similar manner to normal photographic stereographs. For this purpose, two exposures must be made, moving the focus of the X-ray tube after the first exposure. The object is, as it were, seen by two 'X-ray eyes' (the focus of the tube in its two different positions), and we then view the photographs with our two eyes in the same two positions that the focus occupied during the exposure. Thus, one position of the tube focus serves as the 'left X-ray eye' and the other position as the 'right X-ray eye'. When our left eye views the 'left' image, and our right eye views the 'right' image, the two images are merged together in the brain into one image, which we perceive as an image with depth.

It is also possible to use two tubes with their foci a certain distance apart in X-ray stereoscopy, similar to the use of a stereo camera in normal photography, but, unlike the stereo camera, these two foci cannot both be used at the same time, as the radiographs would then be superimposed on top of one another. Therefore, the tubes must be used one after the other, the exposed film being replaced by an unexposed one during the interval.

When object details A, B and C of an object (figure 12.20) are projected by the focus in the left position ( $F_L$ ) on to a first film ( $f_L$ ) as  $A_L B_L C_L$  and in the right position ( $F_R$ ) on to the second film ( $f_R$ ) as  $A_R B_R C_R$ , the distances  $A_L A_R$ ,  $B_L B_R$  and  $C_L C_R$  are named the *parallactic shift* of the projection (see chapter 4, section 4.4.2). This is at its greatest when object details are at greater distances from the film. When viewing, our perception of different parallactic shifts is interpreted as different depths. This means that a parallactic shift in the projected object details is an essential condition for stereoscopic perception. *If this parallactic shift is absent (both photos then are completely the same), then there will be no depth perception. If a shift is present, then one must have the certainty that this was achieved only and exclusively by the other tube position and not by other effects.* The interval between the two exposures, for instance, may not permit movement of the object.

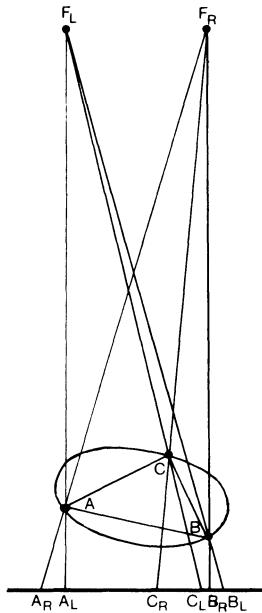


Figure 12.20 Principle of stereoscopy by means of tube shift. The object is 'seen' by the focus of the tube from two points ( $F_L$  and  $F_R$ ). The projection of the object details A, B and C takes place at  $A_L$ ,  $B_L$  and  $C_L$  with the focus located at  $F_L$ , and at  $A_R$ ,  $B_R$  and  $C_R$  with the focus at the right-hand position  $F_R$ .  $A_L A_R$  is the parallactic shift of the projection of A. The shift is greatest for detail C, which lies at the greatest distance from the film.  $F_L F_R$  is the base distance with these projections.

Although very ingenious installations are available, which should result in as short an interval as possible, the problem of the desired *simultaneous* exposures has still not been solved to complete satisfaction. Therefore, one can obtain X-ray stereographs only in cases in which there is no movement of the object between the two exposures. Stereoscopic radiographs of moving organs (oesophagus, stomach, vascular system, etc.) always have the danger of interim motion giving an incorrect stereoscopic impression as, obviously, every shift of the projection is interpreted as depth. The greatest area of application of stereoscopy is the skeleton, for which sufficient immobilisation is no problem. The technique is usually carried out with one tube. After taking the first radiograph with the tube at a certain position, the film is quickly changed, and the tube shifted in a given direction by a certain fixed distance, after which the second exposure is made. The images obtained in this way will differ, and only the parts of the object in direct contact with the film will remain in the same position in both photographs. All other parts of the object will be more or less shifted with respect to these parts and with respect to one another by which they can be seen three-dimensionally (in space), stereoscopically. The distance over which the tube is moved between the two exposures is called the *base*. This distance need not be precisely equal to the distance between the pupils, nor need it be precisely known as long as one does not wish to *measure* the exact depth, but only to *see* depth. A *base focus-film distance ratio of 1:10 gives a good impression of depth*. A smaller ratio (for

example 1:20) gives a diminished impression, and a larger ratio (1:6) gives a greater impression of depth. In the latter case we speak of *hyper-stereoscopy*. There are limits to hyper-stereoscopy, since with too large a base not enough details are projected on both radiographs. As the base becomes relatively smaller, the impression of depth decreases, to vanish completely when the base is 0. Both radiographs are then identical, and, when viewed with binocular vision, give a completely flat impression.

In practice, a stereoscopic pair of radiographs is best made as follows. Starting from the normal position of the tube for a given projection (for example, a p-a projection of the skull on the bucky table with a focus-film distance of 100 cm), one moves the tube half the base length ( $0.5 \times 0.1 \times 100 = 5$  cm) to the right (at right-angles to the long axis of the object, for the first exposure). After the exposure has been made and the film changed, the tube is moved the full base length to the left (10 cm), and the second exposure is made. It is also possible to choose the standard position (thus, with the tube centred to the middle of the film) for the first exposure, and then move the tube 10 cm to the left or the right for the second exposure. This method has the advantage that the two radiographs do not then both show an 'eccentric' projection and one of them can also be used as a standard projection. A disadvantage is that the defocusing sideways requires a somewhat longer exposure (see chapter 6, section 6.3.6.6).

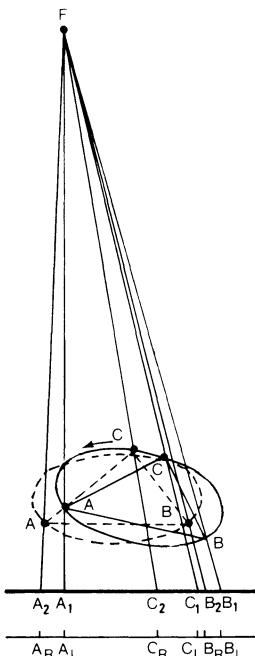


Figure 12.21 Principle of stereoscopic radiography by means of rotating the object. The triangle ABC is rotated slightly (slightly turned) in the direction of the arrow. The parallactic shifts produced in this manner,  $A_1 A_2$ ,  $B_1 B_2$ , and  $C_1 C_2$ , are virtually the same as those achieved by tube shift as shown in figure 12.20. These are shown beneath for comparison ( $A_2 A_1 = A_R A_L$ ,  $B_1 B_2 = B_R B_L$  and  $C_1 C_2 = C_R C_L$ ).

### 12.2.2 Stereoscopic radiography by rotating the object

The same result can also be obtained by rotating the object slightly (about 6°) instead of shifting the tube. If the image is turned to the left (as seen from the tube) for the second exposure, then this has the same effect as if the tube had been shifted to the right (figure 12.21). It is then possible to make useful stereoradiographs even if the tube remains fixed. This method gives excellent results in combination with the spot-film technique, and can be used for exposures of optical foramina according to Rhese, of the petrous bone according to Stenvers, of the mastoid according to Schüller, of the accessory nasal sinuses according to Liliënfeld, etc. Since, with the tube shift method of stereoscopy, when using grids with high ratios, the decentering in a sideways direction can result in considerable loss of radiation due to the useful rays striking the lead strips, the rotation method (about 6° turning of the object) can be advantageous, as then the focus remains fixed in relation to the grid.

### 12.2.3 Taking stereoradiographs in practice

The production of stereoradiographs always necessitates taking two exposures and, in general, also two films. Certain stereoscopic radiographic projections can be taken on one film. In the latter case, one half of the film must alternately be shielded. This can be done most simply by means of a *cassette tunnel*, in which one half of a film is exposed in the first position of the tube (after shifting the cassette along). It is particularly important to ensure that the tube is shifted in exactly the same direction as the cassette, and not obliquely to it. If their directions of movement are not parallel, the images will not lie properly side by side, but will be vertically displaced to some extent, making true stereoscopic perception impossible. At the present time, use is normally made of the possibilities which modern equipment offers for subdivision of the cassette, either in the spot-film changer, or with a sliding subdividing leaf in the bucky tray. When it is not a question of measuring depths, but merely of getting a stereoscopic impression, the tube displacement need not be exactly known; a displacement of about 1/10 of the focus-film distance gives excellent results.

The application of stereography on the bucky couch is greatly facilitated by the use of a *stereo plank*. This is made in such a way that a space is left in the lead equal to half the width of the cassette (figure 12.22) and the bucky tray then functions as a cassette tunnel.

The stereo plank so simplifies the procedure that with its aid stereography can easily be applied as a routine method for certain examinations, such as for obtaining stereoscopic a-p views of the spine on one 30 × 40 cm film.

When taking radiographs of thick objects (skull, vertebrae, etc.) it may happen that the image on both films will be projected somewhat eccentrically. In such cases, the remedy is to place the film, or the part of the film to be exposed, in a slightly eccentric position with respect to the middle line and in the opposite direction to the tube shift.

Extreme care should be taken to ensure proper immobilisation of the object both during and between the two exposures, because otherwise parallax (due to movement) could occur, and result in a false stereoscopic image. For example,

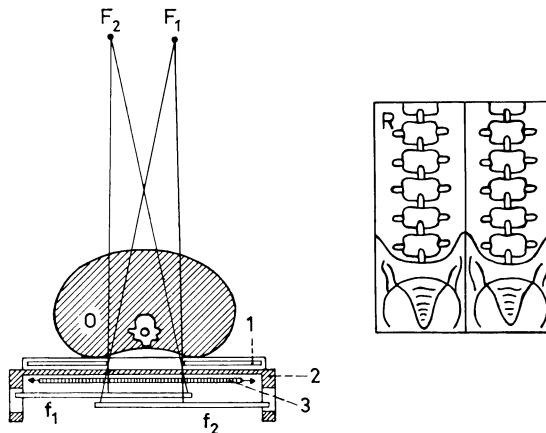


Figure 12.22 Stereoplank.

Left: Both sides of the stereoplank are lead-lined (1), whilst the central portion (half the width of a cassette) is radiolucent. First exposure: focus at position  $F_1$ , film at position  $f_1$ . Second exposure: focus at position  $F_2$ , film at position  $f_2$ . Thus, the tube and film are placed so that they move in the opposite direction. 2. Table top; 3. grid; O. object.

Right: Stereoscopic pair of exposures showing the lumbar vertebrae. The letter R indicates the right side of the patient, as well as which film should be viewed with the right eye. This double indication with one letter is only possible when two stereo radiographs are taken on one film.

on a pair of stereograms taken at different respiratory phases, a cavity may appear to lie outside the thorax.

When using a grid with a high ratio (for example 16:1) the tube should preferably be shifted symmetrically with respect to the middle position. If the first exposure were to be made, for example, as the standard exposure in the middle position, and then the tube shifted over the whole distance, the second radiograph would almost certainly be under-exposed. It is preferable in this case to produce stereoscopic films without tube shift, and rotate the object 5–10° instead. Here too, one can, if desired, start from a standardised middle position.

If stereo projections are made on one film, then the placing of one letter (R or L) according to the directions given in chapter 11 (section 11.3.3) is sufficient to indicate the side of the body as well as with which eye the projection provided with the letter should be viewed (figure 12.22). If, however, both projections are separate then double letter placing is essential. It is recommended that the first letter always indicates the most important information, namely, the side of the body. This letter then is the same on both exposures. The second letter should indicate:

- (1) that the particular radiograph belongs to a stereoscopic pair,
- (2) with which eye that projection should be viewed in order to view the radiograph in the same position as the focus has 'seen' the object.

If, for example, a radiograph of a knee is marked with RL in an upper corner, then this indicates the fact that it is an a-p projection of the right knee; moreover, that it is part of a stereoscopic pair to which belongs another projection (RR). The

RL projection should be presented to the left eye, and the RR projection to the right eye.

If no tube shift was used, but rotation of the object instead, one needs not be too exact here either, if no measurement of depth has to be made (and this is seldom the case), and a slight rotation is sufficient for a satisfactory stereoscopic impression. *Summing up: On each stereoradiograph one should place two letters, the first to indicate the side of the body (R or L), and the second the eye for which it is intended (R or L).*

#### **12.2.4 Stereographs: viewing details, pseudoscopy**

There is a noteworthy and essential difference between the viewing of normal stereophotographs and stereoradiographs. When a normal stereophotograph is made of a knee in an a-p projection, one will see the front of the knee and not a single detail beneath the skin, and, obviously, nothing of the back of the knee (the popliteal fossa). This is completely different in the case of radiographs, as the radiograph is influenced by *all* details (both of the front, the deeper layers and the back). Thus, on an a-p steroradiograph of the knee one not only sees the patella, but behind it the femoral condyles and possibly also the fabella, a sesamoid bone, situated at the very back. One looks, as it were, through a transparent knee from the front through to the back. An a-p stereoradiograph of the skull is particularly fine: one sees the orbits in front, the sella turcica deeper within, and still further back the petrous bones and the occipital foramen. If one, for example, looks at the object in the same direction as the radiation (with the eyes instead of the focus) one speaks of *orthoscopic perception*. If, moreover, one sees the object as it really is (that is not a mirror image), then one speaks of a *direct* image. Viewing a mirror image is called an *indirect* image. The peculiarity is that, if one reverses both radiographs, but leaving them in the same position in relation to each other (so that one doesn't see RR but ЯЯ), one also reverses the viewing direction and, thus, will not perceive an a-p direction but a p-a direction. This perception against the actual projection direction is called *pseudoscopy*; *this represents, as it were, a privilege of stereoscopic radiography.*

#### **12.2.5 Viewing stereoscopic radiographs**

Instruments used for viewing stereoradiographs include the *mirror stereoscope* and the *binocular stereoscope*. The mirror stereoscope, which also allows accurate depth measurements (this method was brought to a high level of perfection by the anatomist Hasselwander), is not used much any more; the binocular stereoscope is much more common. It should be stressed, however, that nearly everybody can learn to see depth in stereophotographs (also in stereoradiographs) with a little practice under expert guidance—without instruments. The acquisition of this ability to see stereoscopically without a stereoscope may cause some difficulty to begin with, but after that it becomes an inalienable possession of great value.

For this purpose, the convergence of the eyes (by the external ocular muscles) and the accommodation (= focusing by the internal ocular muscles), which are constantly coupled in normal vision but are basically independent, must be uncoupled, as it were, and used independently. When we look normally at an object,

for example 50 cm away from us, our eyes converge on this object, and our eye lenses *automatically* focus at this distance (without us being able to do anything about it). The two images formed on the right and left retinas differ slightly from one another, and are perceived by us as one image with depth. Thus, normally convergence and accommodation (focusing) are always coupled together. If, now, a pair of stereophotographs is made of this object, and then the left-hand and right-hand photographs are held at a viewing distance of 30 cm for instance, then not only do the eyes focus at this distance, but also the convergence, and it will not be possible to view the left-hand image with the left eye and the right-hand image with the right eye, and this is an essential condition for stereoscopic perception. Our *lines of sight* converge on the plane in which the photos are located. Convergence and accommodation can be separated by practice, however. Figure 12.23a illustrates the result of viewing two stereophotographs of small size (similar

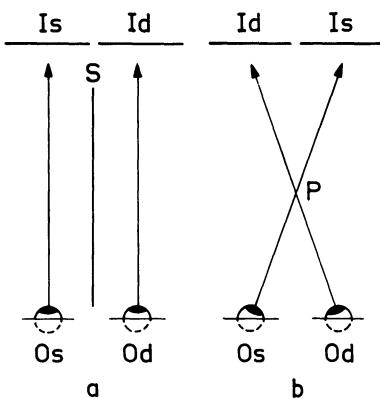


Figure 12.23 Stereoscopic vision without instruments. Od. Right eye; Os. left eye; Is. left image; Id. right image; S. partition.

- a: With parallel lines of sight. Convergence on infinity, accommodation on plane I.
- b: With crossed lines of sight. Convergence on point P, accommodation on plane I.

details on both photographs should be no further apart than 63 mm). The eyes Os and Od stare into the distance to infinity (parallel lines of sight). At first, one will see Is and Id as unsharp images because the accommodation facility, due to habit, also adjusts to infinity; but since the eyes, as it were, do not wish to receive unsharp or blurred images, the accommodation focuses sharply onto the plane of the photographs (at 30 cm distance) in spite of viewing into the distance (parallel lines of sight). One feels the eyes 'pull' a little, and suddenly the impression of depth will appear, at first for brief moments, but later easily and for as long as one wishes.

This method of viewing with *parallel lines of sight* (or slightly converging) can only be used when the corresponding details are separated by at most a distance equal to the distance between the eyes (pupils)—63 mm. By the use of a partition such as a piece of cardboard one can prevent the right eye from looking at the left-hand image and vice versa. Most radiographs are too large for this (at most radiographs of the 9 × 12 cm size or dental radiographs). As our eyes have never learnt to diverge, larger images cannot be viewed in this way. Stereophotos of any

size can be viewed by *crossing the lines of sight* (figure 12.23b). For this purpose, the right-hand photo is placed on the left and the left-hand photo on the right, and the lines of sight converge to a point in front of the photos and so placed that the right eye still sees the right-hand photo and the left eye the left-hand one. In this case the lens of the eye must focus sharply on the plane in which the photos are located, which now lies behind the point of convergence. As has been mentioned above, the main thing is to keep the direction of convergence fixed; the accommodation will then automatically take care of the rest.

(N.B. Stereoscopic viewing both with parallel and crossed lines of sight can well be practised, by which both orthoscopic and pseudoscopic, as well as direct images and mirror images, can be seen. May we once again urge readers to try these simple but fruitful exercises.)

An example from practical radiography may clarify these four possibilities still further. Let us suppose we have two stereoscopic films of a right knee, taken in the a-p projection. On viewing the films we may consider the following possibilities:

(I) If the right eye sees the right image, and the left eye the left image, in the direction of exposure, then the stereo-image will be exactly as it was with respect to the tube, that is the right knee is seen in the a-p position, with the patella to the fore (right eye sees RR, left eye sees RL). This image, seen in this way and in the direction of exposure, is called *orthoscopic*, and, as it shows the correct side, it is referred to as the 'direct' image.

(II) If we turn both films over we also turn over the image; thus we see the right knee from back to front. This image, seen counter to the direction of exposure, is called *pseudoscopic*. It is still, however, a direct image (the right eye sees JR, and the left eye sees YR).

(III) If starting from I, we interchange the films so that the right image is seen by the left eye and the left image by the right, we have a pseudoscopic 'mirror image'; that is we are looking at a left knee from back to front, whereas in reality the right knee was radiographed from front to back (the right eye sees RL, the left eye sees RR).

(IV) If, starting from I, we both turn the films over and interchange them, then one will see an orthoscopic mirror image, that is a left knee from front to back (the right eye sees JR, the left eye sees YR). With the aid of photos one has taken oneself, the above facts can be easily and satisfactorily established. This practical exercise is also highly recommended.

It should be kept in mind that the fundamental condition for a stereoscopic examination or depth perception is the taking of two radiographs from two different directions. A stereoscopic impression obtained by viewing a single picture with a lens, for example, is a false one: a single radiograph can never represent three-dimensional details. Nevertheless, if one imagines depth in it, this is no more than an artificial interpretation, a mentally built-up image, that is artificially displaced image points due to refraction by means of the lens. This is true both for normal photographs and radiographs.

The viewing of stereophotographs with parallel lines of sight (this is only possible with radiographs if they are reproduced in a reduced size) is usually done

with the aid of a simple manual stereoscope. The anaglyphic method is more usual; it makes use of the complementary colours (red and green). Both images are reproduced in one colour and viewed with a pair of red-green spectacles. If the green glass is in front of the right eye then one will see the red right-hand image but nothing of the green left-hand image. Likewise, the left eye will only see the green left-hand image when it views through the red glass. Both impressions are united in the brain into a three-dimensional image. The condition, 'right views the right side, and left sees the left side' has been satisfied. One sometimes comes across these 'stereo' glasses in certain books and other printed matter.

#### 12.2.6 Stereoscopic fluoroscopy

If one is successful in screening an object by means of two foci, which are situated some distance apart, and in viewing these images in rapid succession with the right and left eye, respectively, so that the right eye perceives only the images produced by the one focus and the left eye the images produced by the other, then one has *stereoscopic fluoroscopy*. The screen must be free from after-glow, for the left image must already have vanished when a few hundredths of a second later the right image appears. The frequency of image alteration should be at least 16 per second. The alteration of the picture produced by the right-hand and left-hand foci can be achieved by connecting the tubes in antiphase. If an alternating current of 50 Hz is used, one tube will operate during the 50 'positive' half periods per second, and the other tube will operate during the 50 'negative' half periods (which are, however, still positive for the tube, that is still cause an electron current to flow from the cathode to the anode). Or, one can produce the desired number of images per second by using continuously operating tubes, and interrupting the beams by means of a rotating lead shutter. In both cases, the right and left eyes should be alternately shielded by a shutter mechanism in a viewer. The eye is not capable of perceiving a large number of images per second separately, but integrates them to give a stereoscopic image in this case. As in the viewing of stereoradiographs, one can present the left-hand picture to the right eye and the right-hand picture to the left, thus giving a pseudoscopic mirror image.

Stereoscopic radiographic equipment is available for stereofluoroscopy either with two tubes or one tube (provided with two foci placed about 63 mm apart, that is the distance between the pupils). Normal stereoscopic radiography is in most cases carried out with one tube only. Whereas stereoscopic fluoroscopy with ordinary fluoroscopic screens is rather unsatisfactory, as seeing depth at low screen brightnesses (rod vision) is scarcely possible, electronic image intensification has improved this situation. In this case, the image is viewed via an image intensifier, whereby the image is transmitted to the left and right eye alternatively by means of an optical system, synchronised with the alternate switching of the foci (50 times per second).

The eye (since the cones come into operation) is better able to perceive details because of the great brightnesses produced by the image intensifier, and the method has already come to be used in practice. Stereofluoroscopy gives important information when carrying out selective angiography, since one can easily see stereoscopically both the direction in which the catheter curves, and the position of the tip of the catheter in relation to the last turning. This method has already

proved successful during catheterisation of the coronary arteries. A non-stereoscopic fluoroscopic examination cannot furnish this three-dimensional information to this extent. If one does not have access to such (expensive) apparatus which, moreover, has the added disadvantage that one has to view the image intensifier by means of an optical system during the catheterisation, which is extremely inconvenient, one can make do by either rotating the patient (for example on a revolving table-top) or the combination X-ray tube (image intensifier/television) (for example on a C-arch) a little around the long axis of the patient. In this way, one also gains an impression of the three-dimensional situation.

#### **12.2.7 Stereoscopic X-ray cinematography**

Stereoscopic X-ray cinematography can also be carried out in a similar way to stereoscopic fluoroscopy, namely by the alternate functioning of two foci connected in antiphases by some electronic means. The simplest to understand is the system used to show stereoscopic films in the cinema, namely the recording of all right-hand images on one film, and all the left-hand images on another film. The anaglyphic method can also be applied when projecting these films, the viewer wearing a pair of red-green spectacles.

Another method consists of projecting one film through vertical, and the other film through horizontal, polarised light (onto a special screen), and the viewer wears spectacles with lenses that are polarised at right-angles to each other. This method is restful, but gives rise to difficulties in gaining sufficient light intensity.

The third method requires the use of a pair of synchronising spectacles, whereby the right eye is covered when the left image appears on the film, and the left eye is covered when a right-hand image is projected. The eyes do not notice these rapid interruptions, and see a continuous image. Thus, here also the condition, right—right-hand side and left—left-hand side, is satisfied and adequate stereoscopic perception is possible. Pseudoscopic X-ray cinematography is most often applied in angiocardiology, where three-dimensional vision of the vessels can add much to the diagnostic value of the investigation.

### **12.3 MACRORADIOGRAPHY (RADIOLOGICAL ENLARGEMENT TECHNIQUE OR RADIOLOGICAL ENLARGEMENT)**

Even less than stereography, can macroradiography be considered a routine procedure. The method came to the fore after the introduction of X-ray tubes with very fine foci (0.3 mm). This made it possible to augment the magnification normally present in every radiograph by increasing the distance between the object and the film.

#### **12.3.1 The effect upon definition and contrast**

Macroradiography offers the following advantages:

- (1) It is possible to improve *definition*, because details which in normal radiographs are smaller than the 'grains' of the intensifying screens and which, because of screen unsharpness (intrinsic unsharpness,  $U_i$ ) are not visible, can be made

visible by magnifying them two or more times. Their images are then larger than the 'grains' of the screens, and therefore become visible (figure 12.24).

(2) An improvement in *contrast* is possible due to the greater object-film distance. This improvement has two causes. First, the object volume that emits scattered radiation towards the film is smaller than for non-magnified radiographs

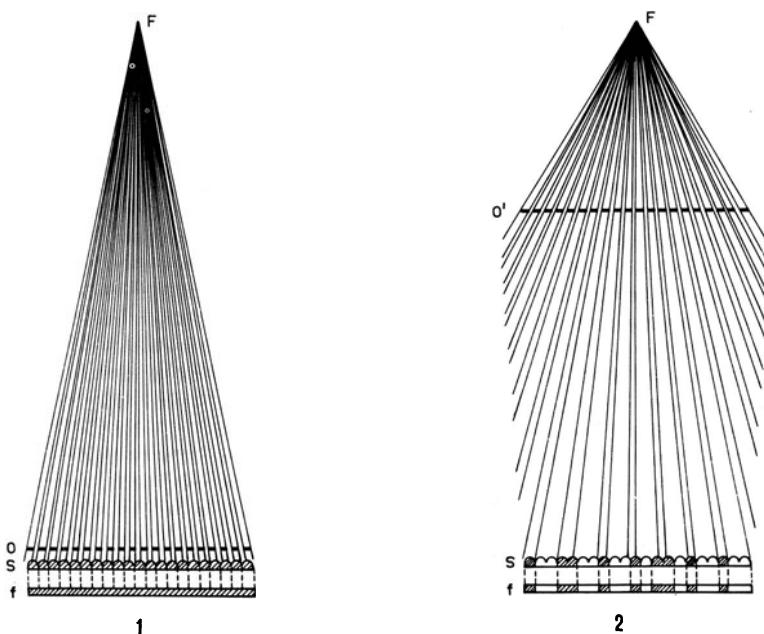


Figure 12.24 Improvement of detail perceptibility by means of radiological enlargement (macroradiography). F. Focus; f. film; S. intensifying screen; O. object.

1. The rays that have been allowed to pass through the small openings in object O lie so close together that all the grains of screen S are affected, and therefore film f shows over-all blackening and no details. The object details are *infraliminary*.

2. The object is now placed in position O'. The radiation that is allowed to pass through now diverges to a greater extent and misses some of the grains on S. This results in alternate blackening (and non-blackening in certain areas), a projection of the object, therefore. Due to the enlargement the object details have become *supraliminary*.

(when the exposed area of the film is equal). Secondly, the proportion of primary to scattered radiation alters in favour of primary radiation due to the inverse square law. The primary radiation, which produces the image in both cases ('normal' and 'enlarged' radiograph) is the same; no extra absorption occurs. However, the scattered radiation, as far as its effect on the film is concerned, is produced much further away from the film and, therefore, is much weaker due to the inverse square law. It is therefore said that a part of the scattered radiation 'is scattered sideways' before it reaches the film. This improvement in contrast is illustrated diagrammatically in figure 12.25.

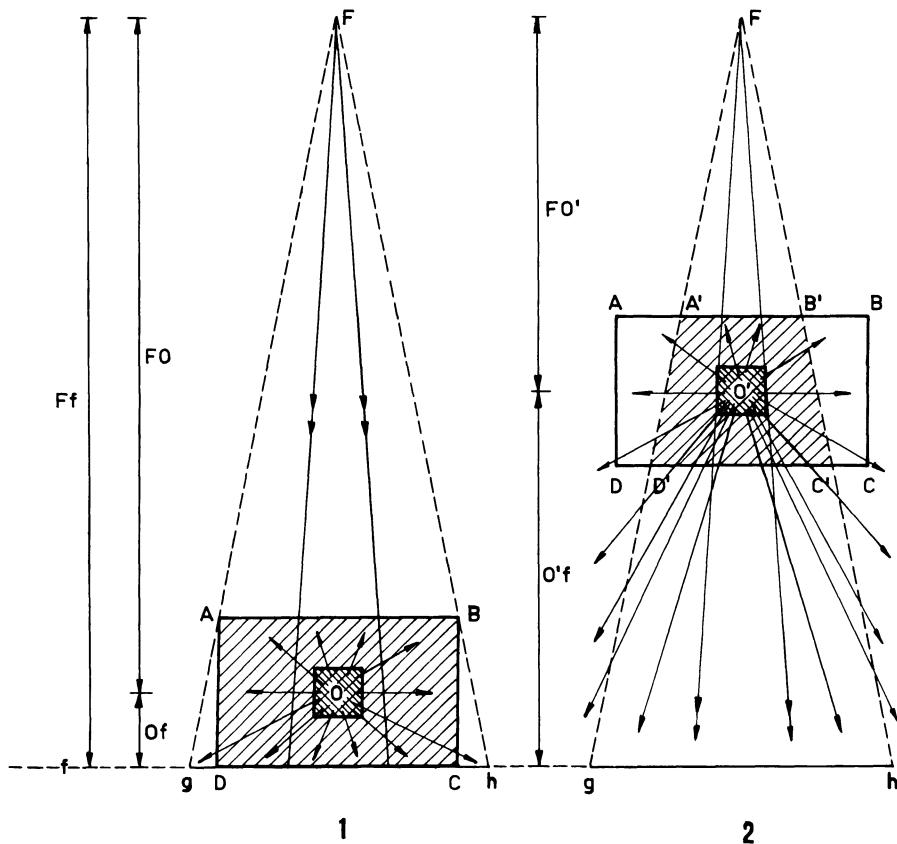


Figure 12.25 Improvement in contrast with macroradiography. F. Focus; f. film; O. object; Ff. focus-film distance; FO. focus-object distance; Of. object-film distance.

1. *Normal* radiographic technique. The object detail O in the projected body ABCD on film gh is of interest to us. The scattered radiation (arrows) emitted by this body affects the contrast on the film adversely.

2. Macroradiography. Now only A'B'C'D' of the body ABCD is located in the radiation, because of which, therefore, less scattered radiation is emitted. Moreover, a large part of the scatter (namely, the portion outside lines D'g and C'h) does not reach film gh. The primary radiation that strikes gh virtually follows the same path as in 1, but the scatter, which still reaches gh, has travelled a much greater distance and is, therefore, much weakened. The radiation image that affects gh in this case is, therefore, 'poor' in scattered radiation and thus rich in contrast.

Also, due to this improvement in contrast, an invisible (infraliminary) detail can be made visible (supraliminary). This usually makes it possible to dispense with the use of a scatter grid. From the practical point of view, however, what is more important than the visualisation of infraliminary details is the fact that macro-radiography can make details that are already visible by means of the normal radiographic technique, much more distinct and, hence, easier to perceive and recognise.

### 12.3.2 Admissible degree of magnification

If we consider an unsharpness of 0.3 mm as still sufficiently sharp then, with a focus of 0.3 mm, a magnification factor of 2 can be considered as the optimum. With a magnification of  $2\times$ , the geometrical unsharpness is always equal to the size of the focus, in this case 0.3 mm (see chapter 5, section 5.1.3). Further magnification above  $2\times$  gives rise to troublesome geometric unsharpness.

It should be realised that this macroradiography (also called radiological magnification or direct enlargement) is basically different from optical enlargement, achieved by enlarging the photograph itself, or viewing it through a loupe (magnifying glass). With optical enlargement the total unsharpness (of object + screen gain + film grain) is also magnified and, thus, only the fact that one sees 'larger' might be an advantage. With macroradiography the object is projected as an enlarged image on a background with non-enlarged unsharpness. Screen unsharpness becomes relatively less in relation to the unsharpness of the image (the unsharpness due to the film grains is negligible in practice) and thus a real gain is made.

However, the practical advantage of macroradiography with foci of 0.3–0.6 mm is not so much the perception of details which, because of their small size, would not be visible on the normal radiograph (whether viewed with or without a loupe), but especially the fact that fine structures and differences in tissue composition can be perceived more easily and in an improved manner. The improvement in contrast particularly can play an important part in this. The technique of radiological enlargement, which was introduced into radiography by the author, finds one of its most important applications in the investigation of callus formation (for example in fractures of the neck of the femur) for the study of incipient osteolytic and osteoplastic processes, the projection of details of the petrous bone, the orbits, the sella turcica, etc. Macroradiography can also clarify the situation in doubtful cases of fracture (for example the scaphoid bone).

The technique also been used with success in investigations of silicosis, as well as for the projection of fine-vessel branching in angiography of organs such as the kidneys. However, the low rating of the very fine focus is a disadvantage here, as it increases the risk of movement unsharpness. If a broader focus is used, one should bear in mind that the degree of magnification one can apply before reaching the limit of acceptable unsharpness decreases (for example at an acceptable unsharpness of 0.3 mm, a magnification of no more than  $1\frac{1}{2}$  times when using a focus of 0.6 mm). The necessity of using higher kilovoltages than is usual in ordinary radiography will be fully discussed in chapter 14, section 14.3.

Macroradiography has been further developed by the Japanese investigators, especially after 0.1 mm and even 0.05 mm foci had been made available to them. Besides the above advantages regarding more rapid and more accurate diagnosis of details, which could easily be overlooked in ordinary radiography, they succeeded particularly in rendering infraliminary details visible and thus making these accessible to diagnosis. Magnification factors of 2, 4, 6, 8 and even 20 were investigated for this purpose. It is obvious that the greatest magnification certainly cannot always give the best results as, of course, the long exposure times that would be necessary when extremely fine foci are used (due to their low rating) could cause interfering movement unsharpness (at least with moving objects). The possible movement, the thickness of the object (scattered radiation) and the focus at one's

disposal (tube rating) determine the optimum magnification. Thus, with a non-moving object, with the presence of scattered radiation, the best results are produced by an enlargement of 6-8 times with a 0.05 mm focus, an enlargement of 3-4 times with a 0.1 mm focus, and an enlargement of 2 times with a 0.3 mm focus.

In the curve shown in figure 12.26 (derived from Takahashii) the influence of the size of the focus is illustrated, and at the same time the M.T.F. curve for a

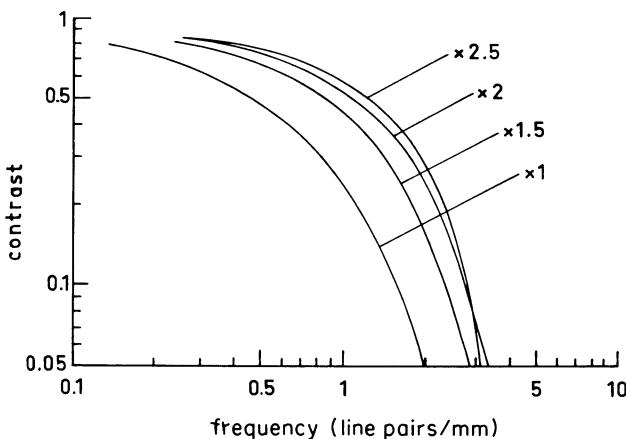


Figure 12.26 M.T.F. curves for enlargements of 1.5 $\times$ , 2 $\times$  and 2.5 $\times$  in comparison with the curve for unenlarged radiograph with a 0.3 mm focus and scatter of 15 cm water equivalent. The unenlarged radiograph is indicated as being 1 $\times$ . An enlargement of 2 $\times$  can be considered as optimum.

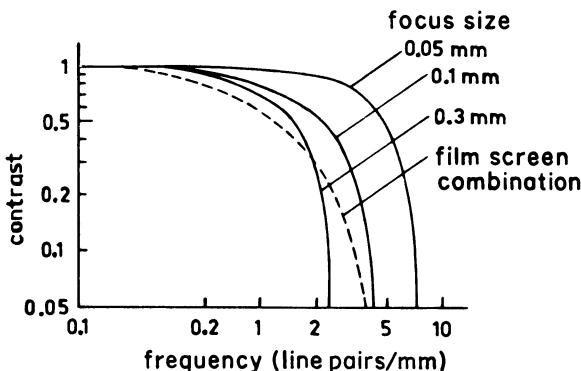


Figure 12.27 M.T.F. curves of 0.05, 0.1 and 0.3 mm foci. In this illustration the M.T.F. of a film-screen combination (dotted line) is shown at the same time (normal type). Thus, without scatter, movement, etc., a fine focus is better.

film-screen combination is shown. Here, there is no influence by scatter, movement or other factors, and it is obvious that the following is then valid: the finer the focus the greater the resolving power. However, when movement, scatter and/or other detrimental factors play a part, the situation could change noticeably,

and to strive towards a high degree of magnification could be a mistake. The 0.1 mm and particularly the 0.3 mm foci are thus the most often used. In figure 12.27 scatter is assumed through a body of 15 cm thickness (water equivalent), no movement and a focus of 0.3 mm for magnifications of  $1.5\times$ ,  $2\times$  and  $2.5\times$ .

From the comparison with the contact (unenlarged) radiograph ( $1\times$ ) the advantage of the enlargement is obvious. However, at the same time, it is evident from these M.T.F. curves that an enlargement of more than  $2\times$  is no advantage under these circumstances.

### 12.3.3 Macroradiographic technique

One can use direct radiological enlargement either with the help of fluoroscopy or with 'blind' positioning. In the first case, the desired position of the object is adjusted in the normal way with the image intensifier. Then, while adjusting (narrowing) the tube diaphragm opening, the object-(fluoroscopic)screen distance is increased until the desired amount of enlargement is obtained, the object is centred (if necessary), rapidly corrected and after this is done the macroradiograph is taken immediately.

As a routine procedure with 'blind' positioning, macroradiography can also be applied, for instance, by introducing the object (wrist, ankle, etc.) midway between focus and film; this results in a magnification factor of 2. For these objects it is sufficient to place a radiolucent elevating device on the radiographic table. One can also take fine enlargement radiographs of the cervical spine, larynx, sella turcica, etc., with the patient either in a standing or sitting position. For heavier objects (skull, spine, etc.) the special bucky table with a movable bucky, which can be placed low down, away from the table-top, and higher up in its normal position (and preferably with a transparent table-top), is best used.

With the use of an image intensifier with a variable reduction factor (see section 9.2), electron-optical enlargement can be applied and combined with the direct radiological enlargement technique. A detail (for example, the sella turcica) directly enlarged, can be projected on to the primary screen of the image intensifier, but only taking up its central portion. By simply moving a switch the reduction factor of the image intensifier can be altered (for example, from 9 to 5), so that the central portion of the image on the primary screen can be electronically enlarged to such an extent that this fills the entire secondary screen. In this way, a further improvement in detail perceptibility is attained. The best result is obtained when the degree of radiological enlargement is chosen so that the geometric unsharpness is equal to the intrinsic unsharpness of the image intensifier-television combination. It is not possible to quote a numerical example for this due to the enormous progress in image intensifier technique, as a result of which the intrinsic unsharpness of image intensifiers is becoming less and less. The special stands for universal application of 'high magnification radiography' as are being used in Japan are very impressive (see figure 16.3).

### 12.3.4 Dose problems in macroradiography

It is obvious that by using macroradiography the surface exposure of the side facing the focus is considerably increased, namely, in inverse proportion to the square of the focus-object distance. This means that, roughly expressed, the skin

dose is four times as great, with  $2\times$  magnification, than with ordinary contact radiography. This apparently serious fact proves to be less serious when one considers the exposure values used which, thanks to the high sensitivity of the materials employed (obviously, by using image intensification) are at an acceptable level (of the order of 1 R). Here, one thinks, for example, also of the much higher (compared with ordinary radiography), but justified skin dose, which is used in tomography and mammography (due to the use of very low kilovoltages which require high exposures). Therefore, this is no real reason for rejecting macroradiography.

In this connection it is important that, due to the great object-film distance, scattered radiation has little effect on image quality. Therefore, one can in many cases put the scatter grid aside. Since the grid always intercepts an important part of the primary beam, the removal of the grid gives rise to a significant gain in dose (more than twice) and benefits the film. It has an even greater effect on the integral absorbed dose (I.D.) which, in the biological sense, is actually more important than the skin dose (see section 3.8), and in practice is expressed in  $R \times \text{cm}^2$  or kgrad. If one starts from a certain area of film that one wishes to expose entirely (for example  $18 \times 24 \text{ cm}$ ), then it is obvious that with an enlarge-

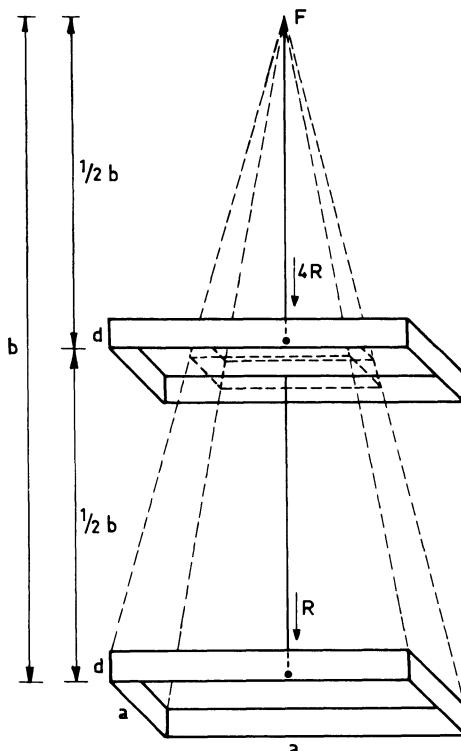


Figure 12.28 Skin exposure (skin dose) and integral absorbed dose (I.D.) with macroradiography. Given: an object  $a \times a \times d$  (which one views from below), a focus-film distance  $b$  and  $\frac{1}{2}b$ , and exposure of 1 R and 4 R (exposed film surface  $a \times a \text{ cm}$ ). By adjusting the beam size to the field size of  $a \times a \text{ cm}$ , the I.D. on the film remains the same, that is  $a^2 \text{ rd}$ . For further explanation see text.

ment of  $2\times$  at half the distance, an area  $1/4$  of the original size (that is  $9 \times 12\text{ cm}$ ), need only to be exposed. At this half distance, however, the exposure rate is four times as great. The product of exposure and surface area, therefore, remains the same for the enlargement distance as it was for the normal distance; in other words, the integral absorbed dose (I.D.) remains unchanged (as we already know, the constant value of the product of the diameter of the beam with the exposure at every point in the beam forms the basis of the measurement ( $R \times \text{cm}^2$ ) for the I.D.).

The above is illustrated in figure 12.28. A square body with side  $a$  and thickness  $d$  (volume therefore  $a^2 d$ ), is located at a distance  $b$  from the focus, and when radiographed it is affected by an exposure of 1 R. This means that the skin dose in that surface area amounts to 1 rad. The integral absorbed dose in the whole body, therefore, is proportional to  $a^2$  kgrad. With an enlargement of  $2\times$  (the body is placed at half the distance  $\frac{1}{2}b$ ) and the same size beam, an area of  $\frac{1}{2}a \times \frac{1}{2}a = \frac{1}{4}a^2$  is now affected; the exposure there amounts to 4 R and the skin dose to about 4 rad. The affected volume amounts to  $\frac{1}{4}a^2 d$ . The integral absorbed dose remains unchanged, namely proportional to  $\frac{1}{4}a^2 \times 4 \text{ rad} = a^2$  kgrad. In figure 12.29, the skin dose and integral absorbed dose for various enlargements are indicated for a body of  $10 \times 10 \times 15\text{ cm}$  (water equivalent).

It appears from the curves that the skin exposure (skin dose) is nearly proportional to the square of the magnification factor, whereas the I.D. remains virtually constant. However, one should realise that this not only means that the whole absorbed dose changes, but that with the macroradiograph the dose in the smaller

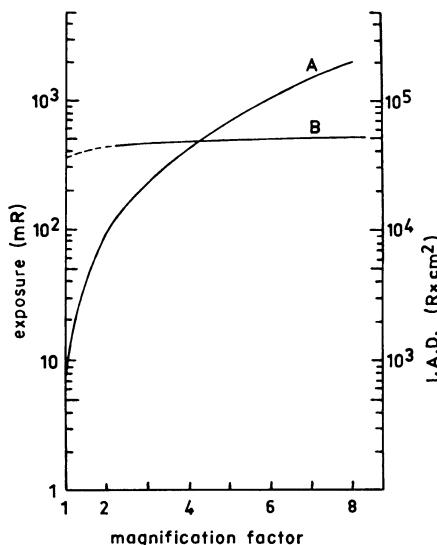


Figure 12.29 Skin dose and integral absorbed dose with macroradiography. The magnification factor is indicated on the abscissa, the exposure (in mR) is indicated on the left ordinate and the integral absorbed dose on the right ordinate. The ordinate values are not absolute but relative. Curve A (surface exposure) runs virtually proportional to the square of the magnification factor. Curve B (integral absorbed dose) is practically a straight line (constant value), unless a beam is used that affects a film area of equal size, in both cases.

volume, *per unit volume*, (or per gram of tissue), is substantially increased, similar to the skin dose. However, it would be incorrect to conclude from these facts that with macroradiography the integral absorbed dose is always virtually equal to the I.D. with normal radiography. The similarity is only valid if in both cases the exposed area of film is equal. However, in practice, this is usually not the case. With a non-enlarged radiograph (of, for example, the sella turcica) one would obviously not expose the whole  $18 \times 24$  cm film size, but use beam limitation, to  $9 \times 12$  cm, for instance. If one now wishes to enlarge, so that at half the distance the  $18 \times 24$  cm film size is entirely exposed, then in this case there would be a substantial increase in the integral dose with enlargement.

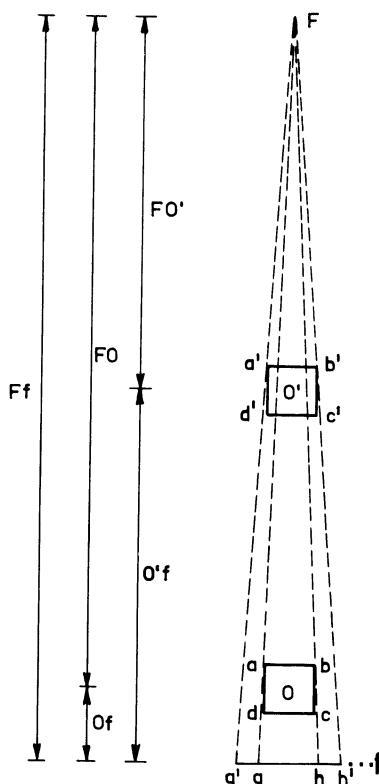


Figure 12.30 Increase in integral absorbed dose (I.D.) in macroradiography and limitation of the beam to the object detail. For the conventional exposure, object detail O is projected by the 'coned down' beam Fag-Fbh. The gh portion of the film is exposed. For the enlarged exposure (O is at position O') the larger beam Fa'g'-Fb'h' is required ( $a'b' = ab$ ). With this adjustment in beam size with macroradiography the I.D. of O' = I.D. of O multiplied by the magnification factor. With the enlargement, part g'h' of the film is exposed.

This is obvious from the diagram in figure 12.30. Here it is assumed that with the normal radiograph of the object detail O (compare also figure 12.25 parts 1 and 2) the area is coned down considerably, so that the beam is limited by the lines Fag and Fbh. The density produced by this beam arises due to primary rays

and (relatively many) scattered rays, the latter being controlled by measures which increase the exposure (grid). The I.D. has a certain value. If one now places the object detail at the position O' for macroradiography (for example  $2x$ ), then the beam must be widened when  $F_a'g'$  and  $F_b'h'$  are the limiting lines, due to which the exposed film area also increases from  $gh$  to  $g'h'$ .

As opposed to the previous example in figure 12.28, there is now no question of a decrease in surface area for the incident beam, but the area has remained the same ( $ab = a'b'$ ). It follows, therefore, that here there is an increase in the I.D. which amounts to about the square of the magnification factor. With enlargement, very little and, moreover, very much weakened, scattered radiation reaches the film.

It is obvious that such strict beam adjustment as described in this example, would hardly ever occur in practice, and that the truth regarding the increase of the I.D. with enlargement lies between the factors 1 and the enlargement factor 2, as it were. One would be well advised to remember that the integral absorbed dose increases to a higher value of  $\frac{1}{2} - \frac{3}{4}$  times the square of the enlargement factor.

*Summing up:* With a magnification factor of  $V$ , the skin dose increases by a factor of  $V^2$  and the I.D. by a factor of  $\frac{1}{2} - \frac{3}{4} V^2$ . It is also true here that this increase in dose does not necessarily have to be prohibitive in macroradiography, but that this procedure, as far as the danger of dose is concerned, should be put on a level with other procedures which require higher exposures, such as tomography, mammography, cinematography, etc. The skin exposure values of the different types of radiographs vary from a few tenths to several R. Depending on the predominant tendencies, which may vary between complete nonchalance with respect to radiation danger, and a complete radiation phobia, macroradiography will have many, few or no supporters.

## 12.4 PHOTOFLUOROGRAPHY

In chapter 4, section 4.2.3, the principles of both the 'classic' and the image intensifier photofluorography have already been mentioned.

### 12.4.1 Photography of the conventional fluoroscopic screen

With this form of photofluorography, a photograph is made of the image on the X-ray screen with the aid of a camera. As opposed to the ordinary camera, here no shutter is used; the film exposure is determined by the duration of X-ray exposure itself as timed by the X-ray apparatus. This is made possible by the light-tight hood between the fluorescent screen and the camera. The photographs obtained can in various cases be used instead of ordinary large radiographs.

The size of the image depends on the type of camera employed. The former, much used  $24 \times 36$  mm size (the so-called Leica format) on a film 35 mm wide is being replaced increasingly by the very popular 70 mm size, and at present the 100 mm size is becoming more common. These sizes indicate the film width and not the actual image size (this is approximately 6–10 mm less). A 70 mm film, therefore, contains an image of about  $60 \times 60$  mm. The photofluorographs (as a roll or individual pictures) are photographically processed in the normal way, and

then are viewed with either a strong magnifying glass or by means of projection.

The quality of the photofluorograph is mainly dependent upon the following factors:

(1) The quality of the fluorescent screen. As the absorbing power of the screen must be sufficient to allow it to emit enough light, it may not be made too thinly; it is, therefore, more coarsely grained (has a greater intrinsic unsharpness) than, for example, an intensifying screen. It is normally made of zinc cadmium sulphide.

(2) The quality of the optical system. It should produce images that are as free from distortion as possible, and are of uniform definition, even with the relatively large camera aperture (that is necessary). Frequently (and also in this case), the quality of the optical system represents a compromise between the required definition and the maximum light intensity, because with a relatively large lens aperture (= diameter of the optical system: focal distance) definition is at risk. All modern photofluorographic cameras have very rapid optical systems.

There are two types of camera in use. The first is the classic type with a lens optical system, the second type of camera has a mirror system. The latter, particularly because of the special corrections which Bouwers introduced, has acquired world fame as the Odelca camera (Oude Delft camera). These cameras have a particularly large relative aperture (1:0.75), outstanding definition, excellent light distribution over the entire surface and little or no vignetting.\*

Figure 12.31 shows the light path in a photofluorographic lens camera and in a photofluorographic mirror camera. Although in the latter case, the film transport system intercepts a portion of the light, a very high light intensity is nevertheless achieved (even to 1:0.6).

(3) Film quality. A fine-grained film is essential to ensure clarity of detail as the film has to be viewed in a magnified form (with magnifying glass or by means of a projector) and no interfering grain outline should be visible. Since a fine-

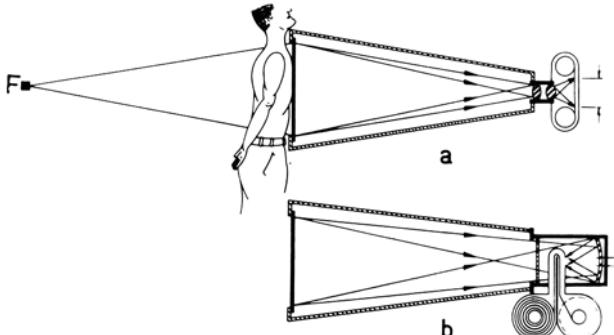


Figure 12.31 Principle of photofluorography. a. Camera with lens optical system. b. Camera with mirror optical system.

\*One speaks of *vignetting* or the *vignetting effect* when the margins of an image are different from the central portions with respect to exposure and/or definition.

grained film in itself is relatively insensitive, high demands are made on the rapidity of the optical system for that reason and, moreover, an X-ray exposure is required which is many times (10–25 times) as large as is needed for an ordinary radiograph made with modern highly sensitive screens and film. This latter fact is a disadvantage of photofluorography, but it is not an adequate reason for not using this method, as long as it is not used frequently with any given patient.

It is important that a film is used of which the spectral sensitivity matches the colour of the light emitted by the screen. With a certain combination, the shortest exposure times and thus the smallest exposures are obtained. In photofluorographic equipment, the exposure time is automatically controlled by a phototimer. This phototimer is built into the hood, and terminates the exposure at the moment when enough radiation has been received for a particular projection. It actually reacts to the luminescent light emitted by the screen.

In contrast to normal X-ray photography, where the film is directly influenced by the radiation contrast, which varies greatly, in photofluorography the film is influenced exclusively by the visible light on the screen, and the film can never reproduce more than what the screen makes visible from the radiation contrasts. By a correct choice of the gradation of film-developer combination, low contrasts on the screen can nevertheless be well shown on the film. However, the exposure of the photofluorograph is more critical than that of the ordinary radiograph.

The hood of the photofluorographic machine has a grid built in, which usually need not be a moving grid. The grid lines are, in general, either completely invisible or not interfering. The grid makes possible the use of higher kilovoltages, by which the exposure times can be shortened. A correct exposure of all the photofluorographs is essential, as they are usually developed en masse by means of automatic processing, and individual correction of an exposure as far as the density is concerned by adjusting the time of development is not possible.

Photofluorography is still most widely used for the purpose of mass chest survey

Photofluorography is still most widely used for the purpose of mass chest surveys, the tracking down of heart abnormalities and lung cancer. This investigation has the advantage of an objective evaluation, and the provision of a record. The suspect cases, selected during projection by a number of specialists, are subjected to closer examination by normal radiographic methods. Also in sanatoria and hospitals, photofluorography is still being used and can be regarded as a perfectly adequate means of carrying out check examinations, especially with the 100 mm film size. The use of this small film size can represent a great saving of film costs. Besides, compared with mass fluoroscopy, photofluorography requires a lower X-ray dose and also provides a permanent record. Care should be taken that no radiation phobia hampers the application of periodic photofluorography of the lungs (mass surveys, surveys in firms, etc.), as this method is extremely important for the health of us all. Frequent checks on patients ought not to be carried out by means of photofluorography because of the much greater exposure.

#### **12.4.2 Photography of the secondary screen of the image intensifier**

Image intensifier photofluorography is becoming increasingly important. Here the anode image of the image intensifier is reproduced in an enlarged form on to 70 × 70 mm or 100 × 100 mm film. Due to the enormous (and not yet concluded)

improvement of the phosphors (see chapter 9, section 9.2.3) the photographs thus obtained can compete with the normal full-size radiographs and are replacing these more and more. The advantages are that, per radiograph: the dose is about 1/5–1/10 in comparison to the normal large size radiographs; the film store takes up less space; and it is easier to do rapid series. The disadvantages are: high cost of acquisition; the necessity (for the time being?) of the maintenance of large film sizes; and the limitation of the field to at most the size of the primary screen of the image intensifier (too small for the projection of both kidneys, thorax, survey of the entire abdomen, etc.). The last disadvantage is the most serious as, for example, with a lung or colon investigation only parts can be projected and not a body part or organ as a whole. However, there are already image intensifier photographic installations being developed with the aid of which both good definition and large image size can be achieved using low, acceptable doses. At the moment attempts are being made at developing larger input phosphors (to 40 × 40 cm).

#### **12.4.3 Photography of the television monitor screen**

The images produced on the screen of the television monitor can also be photographed, and this thus represents the third type of fluoroscopic screen photography. There are, however, certain conditions for this type of photofluorography, imposed by the way in which television images are produced. This image is drawn in a line pattern by the electron beam, governed by the video signal from the television camera, in 1/50 s travelling from the upper left-hand corner to the lower right hand corner writing the lines 1, 3, 5...625 (assuming a 625 line system is used). The electron beam then sweeps back to the upper left-hand corner and writes in the next 1/50 s the lines 2, 4, 6...624. The complete image is thus written in these 2 × 1/50 s and for a photofluorographic image (photograph) taken from the monitor screen, an exposure time of 1/25 s, or a multiple of it, is required. Moreover, it is desirable that the writing of the image by the electron beam and the film exposure start at exactly the same moment, in other words, that the camera shutter and the writing of the image (caused by the video signal) must be synchronised, at least for exposure times of 1/25 s. At exposure times shorter than 1/50 s one half of the number of required lines is not yet finished and the image is thus incomplete. At 1/50 s the whole image has been written, but only with half the number of lines, so that the resolving power is naturally much worse than when also the second half of the number of lines join in, as is the case at 1/25 s. At a 3/50 s exposure, one half of the picture would be double-exposed with respect to the other half (for example the set of lines with the uneven numbers), which would also unfavourably influence the reproduction of detail.

At longer exposure times, exact shutter-video signal synchronisation is not necessary, since an additional, incomplete exposure shorter than 1/25 s does not influence the picture noticeably. An advantage of long exposure times covering several periods of 1/25 s (for example 1/5 s), is that the influence of noise on the image is then reduced considerably or is even invisible, because its pattern is not constant, but changes from each building up of the image in 1/25 s to the other, and is more or less wiped out, resulting in a homogeneous blur, which is less interfering. At a sufficiently high exposure rate, both the quantum noise and the

intensifier noise can be reduced to such an extent that reasonable images can be produced on the monitor and on the film. At a high exposure rate the photographic result is then better (due to suppression of noise).

## 12.5 GEOMETRIC PROCEDURES

Among the special radiographic techniques are certain geometric procedures, whose purpose is the furnishing of exact data.

### 12.5.1 Measurements

There are several methods of determining measurements of the interior of the body, as has already been described in chapter 4, sections 4.5.1 and 4.5.2, with the measurement of heart size. The principle of all these methods is founded on the construction or calculation of plane and/or three-dimensional figures where from some known data one can calculate the unknown. These data, for instance, could be a certain displacement of the focus, a certain focus-film distance, a measured parallel shift of the projection of the object detail; the location of this can then either be measured and/or calculated. In this way, by means of accurate stereoradiographs, it is possible to carry out measurement. For this purpose the tube shift and the focus-film distance must be accurately known and be reproducible during the measurement. This method, perfected by Hasselwander, is now seldom used in daily practice.

A measurement for the determination of the dimensions of the pelvis for obstetric purposes by means of radiographs, *pelvimetry*, used to be made more often than is now the case. Accurate determination of the pelvic dimensions is important with this examination, particularly of the pelvic inlet and outlet. The most important measurement here is the 'true conjugate' (*conjugata vera*). This is the distance between the sacral promontory and the upper inner border of the symphysis pubis; it is usually about 11.5 cm. The oblique and transverse dimensions of the pelvic inlet are about 12 and 13 cm, respectively. A widely used position in pelvimetry is the axial projection, in which the patient is seated and reclining at an angle of 35°, thereby bringing the plane of the pelvic brim in a horizontal position, parallel to the film. By centering the X-ray tube vertically above the centre point between the anterior iliac spines, and taking account of the focus-object and focus-film distances, the actual dimensions of the pelvic inlet can easily be calculated from the magnified image thus obtained (the upper border of the symphysis is taken as the object plane). The adoption of a large focus-film distance naturally reduces the chance of error. This is also true for the profile projection, that is the lateral radiograph of the pelvis, which can supplement the axial projection but not replace it.

The use of image intensifier fluoroscopy could be an interesting development, if one is successful in using the orthodiagnostic method of fluoroscopy (fixed screen and moving tube with marking of central ray) and viewing both the promontory and the symphysis in a lateral position, marking them and measuring the distance between them directly, as was formerly possible for ascertaining the size

of the heart (heart orthodiaphy, see section 4.5.1). One should not imagine, however, that the fluoroscopic image can supply further information on, say, the relationship of the pelvic brim to the foetal head, etc., for even with maximum adaptation the view afforded by image intensification in pregnancy cases is very indistinct. In connection with the powerful biological effect of X-rays on the foetus, pelvimetry (whether by means of radiographs or fluoroscopy) should never be carried out unless absolutely necessary.

### **12.5.2 Localisation**

There are several geometrical procedures that make accurate localisation of metal foreign bodies (metal splinters, etc.) in the body possible. With the *boloscope*, a Dutch invention, it is possible to determine accurately the site of the foreign body during a surgical operation, saving the surgeon the work of searching for it. By means of two positions of the X-ray tube the location of the foreign body is determined fluoroscopically, after which two *beams of light*, which converge upon the foreign body, take over from the X-ray beam, as it were. The boloscope, which is fitted with a cryptoscope or an image intensifier in such a way that it can be used in the brightly lit operating theatre during the operation, represents not only a valuable time-saver but also a means of ensuring complete accuracy of localisation. Due to the introduction of television, however, the search for foreign bodies has been made easier in other ways for the surgeon, and the boloscope is rarely used nowadays.

Another solution for the localisation of foreign bodies is stereoscopic fluoroscopy by means of the image intensifier, as has already been described in section 12.2.6.

The localisation of foreign bodies in the eye forms a special and important problem. A method of localisation described by *Comberg* makes use of a glass disc bearing several lead dots, which is placed directly on the eye before radiographs are taken. There are, however, also other methods which, like the Comberg method, can give excellent results in skilled hands.

## **12.6 RADIOGRAPHY DURING HIP-PINNING**

Although not an everyday procedure, the radiographs that are taken during the operation on a fractured neck of the femur (the so-called *hip-pinning*) are called for periodically in the X-ray department of every hospital. Broadly speaking, hip-pinning consists of: first, driving one or more guide wires into the major trochanter (which may or may not be exposed for this purpose) after reduction of the fracture and after stretching the patient out on the extension table. The radiographs are needed to show the surgeon which of the wires is properly aligned. Two radiographic views at right-angles or almost at right-angles to each other should be obtained. The taking of a radiograph in only one direction must be regarded as an error of technique, for the alignment of the guide wires in three-dimensions can never be ascertained from one single view.

One small X-ray machine is sufficient for the views required, though it is better to use two, one for taking the antero-posterior view from vertically above the hip,

and the other for taking the lateral (axial) view with the beam passing laterally between the patient's outspread legs.

Having ascertained one of the wires to be in good alignment, the surgeon removes the others and uses the remaining wire as a guide to drive in the hip-pin proper, which is made of stainless steel (vitallium, consisting of Fe, Co, Cr and Mo) and is hollow.

Many devices have been introduced for the purpose of ensuring the immediate correct alignment of the guide wire, preventing the drilling in of wires at random. A sheet of wire-gauze used for the a-p radiograph and the application of certain indicators for the lateral projection, which demonstrate the amount of magnification and the location of the wire, make it possible, without the need of calculation, to determine the correct direction and method to be adopted by a simple reading. The surgeon need only concern himself with the reduction of the fracture; the correct direction for the wire is found entirely by means of the alignment device.

The use of an image intensifier with television, which makes at least some of the radiographs unnecessary, naturally offers great advantages here too. By means of the special image intensifier television stands, constructed for surgical purposes, which are mobile and revolving with C-arch (see chapter 16), fluoroscopy is becoming increasingly an essential aid in the operating theatre. This is especially true for checking the position of fractures before and after reduction, but it is also being increasingly used during hip-pinning. The direction in which the guide wire is drilled, its position, introduction of the pin, and a check on its position take place almost entirely with the aid of fluoroscopy; radiographs then only provide permanent records. We must, however, warn against disregard of radiation protection. The radiation dose used, as far as the patient is concerned, is of virtually no importance (fractured hips are usually only seen in patients who are, genetically speaking, not at a dangerous age), but it is of importance for the surgeon and surrounding personnel, the more so due to the cumulative effect of individually applied doses. The great brightness in the operating theatre induces or tempts one to obtain a bright television image, which can only be achieved by a relatively too brightly adjusted monitor, whereby the image quality becomes poor. One is then inclined to increase the rate of exposure, which still does not lead to the desired result, but does mean a very high radiation dose for all persons in the operating theatre. The radiologist responsible (or his deputy) should for these X-ray procedures strictly ensure that:

- (1) rapid on and off switching occurs, and not allow the image to be viewed 'at ease',
- (2) an exposure rate as low as possible is used and a brilliant image is not strived after,
- (3) the brightness of the lights in the operating theatre is reduced to an acceptable minimum.

The initial, usually somewhat unhelpful attitude with respect to this rule in the plaster room and/or operating theatre will, after the spelling out of the serious motives, certainly change to an understanding cooperation. The use of 'image memories' which, after brief screening hold the image on the television monitor and make longer viewing possible without extra danger from radiation, deserves recommendation in these cases.

### **12.7 PROFILE RADIOGRAPHS INCLUDING SOFT TISSUES**

The main point of practically every radiograph made for diagnostic purposes concerns possible changes in the skeletal system, the appearance and distribution of contrast media that have been introduced, changes in the air-containing lungs, and, except for mammography, seldom concerns the state of soft tissues and virtually never the external form and the skin. It is true that on practically every radiograph the exterior outline and the soft tissues covering the bones, which are heavily over-exposed, can be seen to some extent by means of bright illumination (strong 'spot-light'), but this is, being unimportant, almost never done.

The relationship of the exterior surface and the skeletal system does play an important part, however, in orthodontics with respect to dental regularities. Frequently, the more or less serious malformation of the upper and lower jaw can be the result of congenital abnormalities (for example, the protruding Habsburger mandible comes to mind), but even more often the influence of factors that occur during the growing period of which thumb sucking is especially notorious. The upper jaw (especially the incisor area) is pressed forward and becomes narrowed resulting in protruding upper teeth and an upper jaw that protrudes over the lower jaw. By means of timely recognition and treatment (dental regulation) the orthodontist (a dentist specialised in this area) can prevent or correct malformations by means of braces, etc., and guide development along the correct paths.

In these cases, profile radiographs can be very useful. The pure lateral skull is the most usual view and is taken with the patient in a sitting position. One film (for example 24 x 30 cm) is placed between the intensifying screens of a cassette and a second film is attached to the outside of the front screen. The result is a normal skull X-ray and a grossly under-exposed radiograph upon which the contour of the head (nose, lips, chin, etc.) can practically only be seen. After making a contact print of the skull X-ray (a 'positive' copy upon which the bony parts are black), one places this on top of the (under-exposed) second radiograph and one can then see exactly the skeletal structures and the teeth in their relationship to the exterior surface. By taking these exposures as teleradiographs (a focus-film distance of 120 cm is satisfactory for this purpose) one can, if desired, also take sufficiently accurate measurements. Since one is not concerned with tenths of millimetres, the demands on radiographic quality are not high; one can work with very fast screens and without a grid, so that dental X-ray equipment can be used for this investigation. In this way the result of treatment can periodically be evaluated objectively (for example once every 3-6 months).

### **12.8 TOTAL BODY RADIOGRAPHY, USE OF LARGE FILM SIZES, ATTENUATION COMPENSATION**

We should mention a special but seldomly used method of radiography, namely, the making of *total body radiographs*. This consists of making a photograph on one large film (for example 60 x 200 cm size) with only one exposure. With the aid of a high kilovoltage (to 200 kV) and tubes that can withstand heavy loads, it is still possible to achieve relatively short exposure times at a distance of 3-8 m (Denis Mulder, Janker).

These total body radiographs for diffuse skeletal changes (rickets, multiple cartilagenous exostoses, etc.) are spectacular but their practical value (apart from their difficulty and expense) is not very great. For various examinations (complete spine radiographs, angiography of the abdomen, pelvis and lower extremities) it is becoming more usual to use larger film sizes. For this purpose, special cassettes and grids 80 cm or more in length are already available. For these kinds of radiographs it is sometimes difficult to obtain good images of body parts of high and low absorption. It is difficult, for example, to project the spinal column below and above the diaphragm with uniform density. Because of this, use is frequently made of wedge-shaped aluminium filters (compensatory filters, see chapter 6, section 6.3.4) which increase the attenuation of the radiation at the position of the body parts of low absorption.

Another method of obtaining uniform density on the entire film of a large object with great differences of absorption is the use of the 'graduated' intensifying screens. These screens provide gradually increasing intensification over the length of the screen. These graduated screens are suitable for arteriography of the whole leg, lateral views of the spine, etc.

## 12.9 RADIOGRAPHY WITH RAPID-IMAGE SEQUENCE

*Rapid-sequence technique* and *cinematography* should also be mentioned as special methods of examination.

### 12.9.1 Rapid-sequence technique

This technique is often used in radiology. Its purpose is to record sequential phases and thereby gain an insight not only into the anatomical condition, but also into the function of movements such as swallowing, movements in the oesophagus, peristaltic movements of the stomach and intestines, contraction of the bladder while urinating, contractions of the heart, propulsion of blood (made visible by means of contrast media), etc. Depending on the rapidity of the movement one has to take serial radiographs with longer or shorter intervals. Therefore, a slow stomach peristalsis does not demand a rapid series but the jerk-like emptying of the pyloric cap does. The possibility of choice as to the number of exposures per second is therefore a condition for a useful rapid-sequence device (see chapter 14). At the same time one can vary the intervals according to choice by means of a *program selector*. It is obvious that after every radiograph the radiation is interrupted (by switching off the tube or by interrupting the radiation with a lead filter) and an unexposed film takes the place of the exposed one. This makes great demands on the mechanical construction, the realisation of which is more difficult the larger the film size used. Therefore, in practice, large-size radiographs and small radiographs are poles apart, that is are in different categories.

#### 12.9.1.1 Use of large-size X-ray films in rapid sequence

(1) *Roll film* Here, one allows a film of 30 cm width, for instance, and several metres (for example 25 m) long to unroll rapidly while it passes in a jerk-like manner between two intensifying screens, which are firmly pressed against the film as it pauses momentarily, whereupon the exposure takes place. Immediately

thereafter the pressure is released, the film is moved on over a certain distance, and is again compressed by screens, etc. Instead of such specialised roll film (which in its turn requires special processing-room adaptation), individual films are also used, which in an ingenious manner are brought between the intensifying screens and, after compression, exposure and decompression are again replaced by the next film (cut-film changer).

(2) *Cut film* With the use of cut film one seldom achieves more than eight exposures per second, unless one dares risk serious breakdown. This method requires complicated, highly specialised equipment (among which the rapid changer A.O.T. has become well-known all over the world) and it uses a great amount of film. The medical results are excellent and are considered by many to be the best available. The reproduction of tiny details, especially in angiocardio-graphy and in arteriography (of the brain, abdomen and kidneys), is indeed excellent and is achieved by means of an acceptable dose of radiation. Nevertheless, practical disadvantages (technical and economic) are causing the use of smaller size films more and more.

#### **12.9.1.2 Use of small-size films in rapid sequence**

The rapid-sequence technique has naturally also been applied to conventional photofluorography. With the smaller film size the film transport problem is much simpler (as no intensifying screens are required), the film costs are less, the processing procedure is simpler and breakdowns are much less common than with a large-film size rapid series. A disadvantage of the small films is the necessity of enlargement to a size that can be easily viewed, preferably without the need for a projector. These are the so-called 70 mm and 100 mm sizes (film widths, the images are several mm smaller), which have proved to be acceptable for this purpose. Because of the requirement of as great a definition as possible and high light intensity (concave mirror optical system), spherical pressure is applied when the 70 mm size roll film is used. The 100 mm size is not in rolls but is used as individual 10 x 10 cm films with all the concomitant disadvantages. The (latest) 105 mm size can be obtained as rolls and this, as well as the 100 mm size, can be viewed satisfactorily with the naked eye.

With use of the 70 mm as well as the 100 and 105 mm sizes the maximum number of exposures is limited to 12/s. In practice (especially for the investigation of the digestive tract) one usually limits oneself to 4-6/s. Since with conventional photofluorography the required dose per radiograph is many times greater than for a normal full-size radiograph, this method is very unattractive and, therefore, has virtually been abandoned.

In its place has come photography of the secondary screen of the image intensifier (diameter about 2.5 cm); this small image is enlarged onto the 70, 100 or 105 mm film size in rapid sequence. There are several fundamental disadvantages connected with this system:

- (1) A new possibility of loss in contrast and definition is introduced,
- (2) The size of the body part to be projected can be no larger than the size of the input phosphor of the image intensifier.

The first disadvantage is not as serious as one would expect, since the intrinsic unsharpness of the image intensifier's secondary screen can practically be ignored, and one can compensate for the loss in contrast by using film with steeper film gradation. The second disadvantage is inherent to the system, for which the available size remains limited to a circle with a diameter of 25 cm. However, larger image intensifiers are being developed. The great advantage of the electronic image intensifier connected to a very rapid optical system is that with projection onto the 70, 100 and 105 mm film sizes, the exposure is 1/12–1/3 with respect to the projection onto large film sizes. One can assume an average saving of dose of 5–10 times for the 70 mm size.

The sequence and the number of these rapid series films may be chosen arbitrarily, and possibly programmed by means of a program selector. It is obvious that, especially in this case, automatic exposure control is practically indispensable. The improvement in the quality of the image (therefore also of the recorded screen image) is so great and the saving in dose so considerable that there is an increasing tendency to use this method of investigation.

In conventional stomach investigation, with as photographic result several large-size radiographs of which one or more are subdivided with detail projections (spotfilms), increasing use is being made of image intensifier photofluorography with rapid-sequence technique, with which there is a greater chance of finding an exposure of a particular important condition that shows, for example, pyloric cap contraction with ulceration, among the series.

Much less used (due to the greater lack of definition which arises) is the rapid-sequence technique by photographing the screen of the television monitor. In section 12.4.3 the problems that thereby occur were fully discussed. With the rapid-sequence technique in particular, when one is always concerned with short exposure times (1/50 s is the shortest possible exposure time), of the order of 1/25 s, for example, one should ensure that the camera shutter and video signal are properly synchronised. When longer exposures are used (provided that this is possible in connection with little or no movement unsharpness) this synchronisation is not necessary.

### **12.9.2 Cineradiography (or X-ray cinematography)**

Cineradiography is the pre-eminent method for recording movement. Theoretically it is possible by taking radiographs in rapid sequence (at least 16/s). The method is practically not considered for full-size radiographs because of mechanical (and economic) reasons, and one has, therefore, been forced to resort to the indirect method: photographing the image that is produced on a fluoroscopic screen. The perfecting of photofluorography has gone hand in hand with this cinefluorography. The high radiation dose that must be used in order to obtain a diagnostic film is, and remains, a great disadvantage of the system. If one considers that, for example, after 2 min of cineradiography at 24 frames/s,  $120 \times 24 = 2880$  exposures have been taken and that (as is the case in conventional photofluorography) for each exposure at least 15 times as much radiation is necessary than for a normal large film, then this means that, in this particular example, the patient is exposed to the same dose of radiation as would be the case if more than 40 000 normal radiographs were taken.

Although photofluorographs were made in the thirties (among others, of the runner Nurmi, the 'flying Finn') by Gottheiner and later by Janker and others (experiments on animals, larynx, bronchi, etc.) even combined with phonographic recordings, and electrocardiography and dose measurements, have proved its great value, the problem of dose remained prohibitive and prevented introduction of the method into practice. Image intensification has changed this totally. The required radiation dose has become many tens of times smaller. It is understandable, therefore, that image intensifier cinematography has superceded all other methods.

There are various methods of photographing or reproducing in rapid sequence onto a cine film the image that is produced on the secondary screen of the image intensifier. These methods have been described in chapter 8. In this respect, there is no fundamental difference between the fitting of a photographic camera (for example a 70 mm camera) or a cine camera to one of the channels of the optical system. Even more so than with single-image or rapid-sequence photography, one needs to view the image *while* taking the series in order to be able to switch on and off at precisely the correct moments.

#### **12.9.2.1 Open and closed sector. Frames per second and exposure time**

With every cine exposure the film advances in fits and starts, as it were: when stationary, the exposure takes place, then the exposure is interrupted and the film is transported on over the length of one frame and is again stopped, etc. In ordinary cinematography, the incoming light is blocked by a rotating shutter by which alternately an open and closed sector is achieved. If these are of the same size then one speaks of an open (and closed) sector of 180°. An open sector of 240° means that the closed sector is only 120°, so that one therefore has twice as much time available for the exposure than is necessary for the transport of the film. This extremely favourable condition seldom occurs; the usual maximum open sector is 180°. When the entire open sector time is used for the exposure, then this means that there is a direct relationship between the chosen frame speed and the exposure time. With, for example, 25 frames/s, 1/25 s is available for every frame that is 1/50 s for the exposure and 1/50 s for transport. With a frame speed of 50 it follows that the exposure time is 1/100 s.

In ordinary cinematography, the light source continues to emit light during the closed phase. This is also the case in X-ray cinematography when, as above, one interrupts the light beam by means of a rotating shutter with an open and closed sector. Then also the chosen frame speed determines the exposure time per frame and one would, in order to achieve very short exposure times of several milliseconds, have to use extremely high frame speeds (for an exposure of 4 ms, a frame speed of 125 frames/s). This would entail an unjustifiably high load on the tube and the use of a great deal of film (with 16 mm size film, almost 1 m/s) and, therefore, would be impossible in practice. Even more serious is the fact that during the closed phase of the shutter, X-radiation continues, exposing the patient but not the film. This type of X-ray cinematography (although an improvement with respect to older methods) is now not considered permissible for reasons of radiation dose.

### 12.9.2.2 Open sector and exposure time; pulse technique

It has been made possible to make the choice of exposure time independent from the open sector time. At 25 frames/s one has, for example, an open sector time of 1/50 s, therefore of 20 ms. It is now possible to have the tube switched on and off during the open sector time and to repeat this (pulse technique) continually.

During the closed sector time the radiation remains switched off and waits for the next pulse. Within the limits of the open sector time one can arbitrarily choose the exposure time; for example, with an open sector time of 20 ms an exposure of 6 ms which one can place at will, either at the beginning, in the middle or toward the end of the 20 ms. Also, in this way, one can adapt the exposure per frame to the purpose of the examination and, for example, choose a lower kilovoltage and a longer time (greater contrasts), or a higher kilovoltage and a shorter time. The realisation of the pulse technique can be effected by different methods. One can bring about the interruption *outside* the tube (Philips) or within the tube (Siemens). Both systems are reliable. The interruption of the current within the tube itself occurs by means of a grid, which is charged negatively with respect to the cathode, and prevents the travel of electrons to the anode. This negative voltage across the grid is connected in such a way that it is synchronised with the closed sector of the film camera.

### 12.9.2.3 Filming time and tube load

It is obvious that X-ray cinematography makes great demands on the tube. It follows from the tube nomograms (rating charts) that tube loads of short duration may be of higher values than those of long duration. Whereas a cold tube can dissipate a great deal of heat during the first few moments, this decreases to the condition in which only the amount of heat can be accepted that can simultaneously be given off; the *continuous load*.

In order to obtain uniform exposure on the cine film the load of the tube per frame must be adapted to the circumstances at that moment (considerable or little absorption, etc.). This can be achieved by means of automatic exposure control. If one knows beforehand exactly for how long the filming will take place (for example 12 s) then the maximum permissible load may be determined and adjusted for that length of film time. The tube can be protected against overloading (overload control). When the filming is of shorter duration than the proposed filming time, the tube will not reach its full load capacity as a consequence. This non-intentional underloading will, however, seldom manifest itself as loss in definition and/or contrast.

Whereas the patient benefits from the pulse technique, this is not the case with the anode. The alternate cold and hot spots on the focal track will more quickly lead to cracks and roughening of the tungsten than with a continuous load. The fractional application of an equal number of kilowatt-seconds (= kJ) in the same space of time is, as a result, more harmful to the tube than a continuous load. These difficulties are being met to an increasing extent by modern tube constructions (tungsten, molybdenum, rhenium, graphite) (see chapter 1, section 1.6.2). Naturally, high definition is also very desirable for X-ray cine film, and an extremely fast rotating anode with a relatively fine focus (for example Super-Rotalix 0.6 mm) is the tube par excellence for this purpose. In section 12.2.7 X-ray stereocinematography has already been mentioned.

#### 12.9.2.4 Cinescopy, the filming of the monitor image (see also section 12.4.3)

It is also possible to take a cine film of the image on the television monitor. This appears at first to be an attractive proposition because of the great brightness that can be achieved on the monitor at relatively low exposure rates: a film made in this way would need about a 1/10 of the dose of an ordinary X-ray cine film. However, at the usual 625 lines per total image, only half this number of lines (312) can provide for the build-up of the image, since, during the other half film transport must take place. The resolving power is thus considerably decreased and, moreover, one is tied to a frame speed of 25 frames/s each with an exposure time of 1/50 s and another 1/50 s for film transport time.

One can also choose a frame speed of  $12\frac{1}{2}$  frames/s, each with an exposure of 1/25 s, whereby every other total image (625 lines) of the television screen is recorded. The cine camera and image frequency of the television will have to be exactly synchronised, otherwise the filming will not succeed (shifting bands in the image, etc.). This method, introduced by Chérigié as *cinescopy*, has not found many followers; this must be attributed especially to the poor resolving power (in this case, mainly determined by the television chain).

#### 12.9.2.5 Film sizes used in X-ray cinematography

The resolving power of X-ray cine film is dependent mainly on the ordinary photographic factors, such as (correct) exposure, grain size (intrinsic unsharpness) and also the  $U_m$  and  $U_g$ , the processing technique, etc. Also of importance is the effect of size, which is always indicated as total film width including the perforations. The dimensions of the effective image area are several mm smaller. In cinematography the film sizes 70 mm, 35 mm, 16 mm and 8 mm are well known. It is also true here: the smaller the size, the greater the demands on the intrinsic unsharpness of the film material.

In X-ray cinematography, the 8 mm size, in spite of the enormous progress in film technique, has not (yet) been considered. The 70 mm size, which one only occasionally sees in the cinema with very special films (excellent because of its high definition), is only used experimentally in radiology (Janker), but is not considered in practice. The 35 mm and 16 mm sizes are used. The 16 mm film has perforations on one side only, for the purpose of transport, and the 35 mm size has perforations on both sides. The area available for the image on a 16 mm film is  $7.5 \times 10.3$  mm, on the 35 mm film  $18 \times 24$  mm; thus they are both rectangular. Since the image produced is circular, there are several possibilities of more or less filling the rectangular area. This can be achieved by different constructions and adjustment of the camera lens, which can effect various reductions. In figure 12.32 six different possibilities are represented, from *underframing* to *overframing*. From these it is evident that a is unfavourable, since the entire width is not utilised and detail reproduction would be worse; b is better in this respect, but usually moderate overframing as shown in d is practised. Here, the part of the image area that is left out is equal to the unused part of the film area.

The choice between 16 and 35 mm film is a very personal one. The 16 mm size has the advantage that it has been introduced in amateur photography on a large scale, so that many necessary and handy accessories for coping with this film and for viewing it, etc., are relatively easily and cheaply available. The 35 mm size is much more professional; the cameras have to answer to greater demands, and

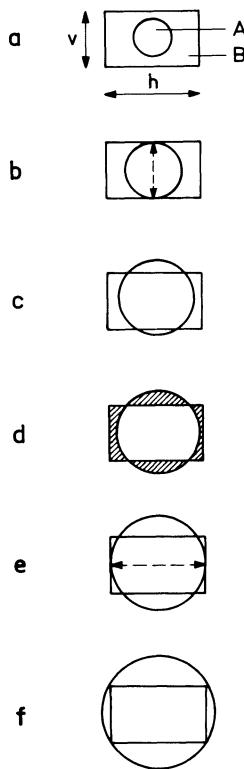


Figure 12.32 Various possibilities of adjusting the size of the image to the size of the film.

A. Image; B. film area frame size ( $v \times h$ ).

- a. Total underframing: diameter of A smaller than vertical frame dimension v.
- b. Equal vertical framing: diameter of A equal to the vertical frame dimension v.
- c. Vertical overframing: diameter of A larger than the vertical frame dimension v, but smaller than h.
- d. Equal area framing: diameter of A chosen so that the overframed surface is equal to the unused frame portion.
- e. Equal horizontal framing: diameter of A greater than v but equal to h.
- f. Total overframing: diameter of A larger than v and greater than h, but equal to the diagonal of the rectangle.

compared to the 16 mm ones are much more expensive. For the reproduction of by far the greater number of details, the 16 mm size can be considered to be adequate. However, especially for application in angiography of the brain and angiocardiography, the 35 mm size is still the choice of many, on the grounds of greater resolving power. Some choose, in addition, a 15 cm image intensifier instead of the 25 cm one because of its greater resolving power.

#### **12.9.2.6 Types of X-ray cine films**

For the photography of the anode image of the image intensifier it is desirable to adapt the film sensitivity to the colour of the light that is emitted by the secondary screen. Moreover (and connected with this), a favourable gradation should be

chosen in order to intensify the contrasts. Since gradation, sensitivity and grain size are closely related (see chapter 8, section 8.2.8), and as these are also determined by the development process, etc., one can, with the same exposure values, obtain films of totally different character.

Steep gradation is necessary if one wishes to use the original film (the negative film on which the stomach is white and the lungs black) to make the diagnosis. Alas, this film is rather insensitive and becomes quite coarse-grained due to the contrasty method of development, which results in a high intrinsic unsharpness ( $U_i$ ).

In order to achieve better photographic and diagnostic results a moderately sensitive fine-grained film with relatively flat gradation is used, which requires a little more exposure, but due to the low quantum noise and smaller  $U_i$  it can provide better information. For this purpose this negative film is copied on to an extremely fine-grained reproduction film, whereby an optimum exposure and an optimum gradation can be achieved. The resultant positive film (stomach black, lungs white) then represents the optimum result that can be achieved. The beautiful, well-known demonstration films are prepared in this way. The original 'mother film' (negative) then remains available undamaged for possible further copying.

#### *12.9.2.7 Viewing of X-ray cine films*

In X-ray cinematography the viewing of individual images is not the prime object, whereas photographs made with the 70 or the 100 mm camera, either in series or singly, with or without rapid changers, are often viewed as individuals. Whereas

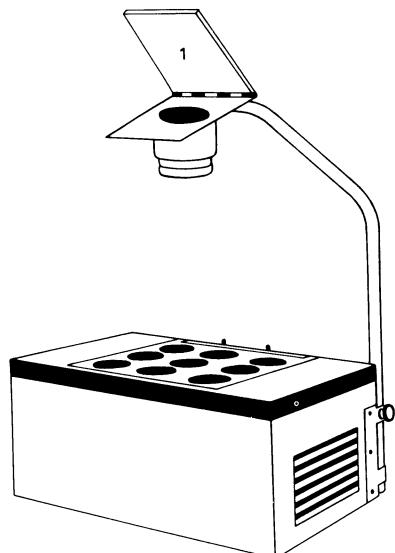


Figure 12.33 Overhead projection of radiographic films. Overhead projector, both for viewing conventional radiographs and for several (up to nine) 70 mm films at the same time. A mirror (1) projects the image onto the screen. The speaker can point out the details during a lecture without turning his back on the audience.

relatively little magnification is necessary for the 70 and 100 mm sizes and for this purpose a specially constructed magnifying glass or simple projector will suffice (figure 12.33), for the viewing of cine films grateful use is made of the already wide experience of ordinary cinematography, which has led to a great deal of equipment for the purpose.

X-ray cinematography requires the following possibilities in particular:

- (1) The ability to hold any arbitrary image for further study.
- (2) Variable speeds so that both slow motion (such as 2 frames/s) and accelerated projection is possible.
- (3) The ability of reversing the direction of the film easily, in order to be able to study a particular phase of movement repeatedly (whereby the viewing of a phase in reverse could also be important).

The modern projectors fulfill these demands, and in addition are usually equipped with the possibility of reproducing optical or acoustic signals (which were recorded simultaneously with the X-ray images). Of special importance is the slow motion and accelerated projection. When a film has been taken at a frame speed of 50 frames/s and it is projected at a speed of 25 frames/s, then one views the movement in slow motion, that is at one-half the original speed. In the modern X-ray cinematographic examination methods of the heart especially, when frame speeds of 100, 150 and even 200 frames/s are used, slowing the motion to 4, 6 and 8 times provides valuable information with regard to movements of the arteries, the valves, reflux of contrast media, etc., to a hitherto unknown extent.

On the other hand, a slow movement can also be accelerated on projection. An extreme example is given by, for instance, 72 frames of an appendix (1 frame/min) which with a projection speed of 24 frames/s (thus viewed in 3 s) can give a good idea of its mobility. Similarly, the movements of the gall bladder, ureters, etc., can be studied.

X-ray cinematography has without a doubt contributed a great deal towards a better understanding of the physiology and pathology of moving organs and has gained a permanent place among radiological procedures.

### **12.9.3 Investigations with the aid of video tape recording**

In chapter 9, section 9.5.6.2, it has already been explained how the video signal, which originates in the television camera, can be partially drawn off, as it were, and sent to a video recorder for recording on to a magnetic tape. The manufacturers have succeeded in making this system so sensitive that even the fluoroscopic image, which is obtained by the image intensifier, can be recorded on the tape without increasing the exposure rate. Simultaneous recording and viewing is possible, and the whole investigation, or parts thereof, can be magnetically recorded for viewing later on as desired. For subsequent viewing with the aid of a television monitor, no additional radiation is required, and one can fully profit from the possibilities of repeated viewing, accelerated or slow-motion projection, and even 'stills', as the most modern machines have made possible (possibilities which are now very well-known in ordinary television, especially from the reports of sporting events with 'stills' and 'slow motion'). It is obvious that this image

recording means an enormous increase in the value of fluoroscopy. If and when the images are no longer of use (similar to dictaphones with magnetic tapes) they can be erased. If radiographs are taken (a single, series, whether rapid sequence or not, or cine recording), then the signal is too strong for the magnetic tape and the 'quiet' fluoroscopic image is interrupted by a sudden over-radiation. This, for example, is the case with a stomach examination in which the fluoroscopy is every now and then interrupted by radiographic exposures.

Due to the simplicity of recording and reproduction, it looked at first as if this magnetic tape recording would sweep cinefluorography right off the field. This is evidently not the case, for the following reasons: cinematography is more flexible as far as the frame speed is concerned, since one can vary this from very slow to extremely fast (200 frames/s). The storage of an X-ray cine film as a record is no great and costly problem, but if a magnetic tape is no longer used this means a costly loss. The greatest disadvantage of the magnetic tape, however, is the rather poor reproduction of detail in comparison with X-ray cine film, due to which it can be considered useless as far as angiographic purposes are concerned. Without a doubt, however, this method of investigation will increasingly gain ground and in addition to its merits of complementing fluoroscopy, it will supersede X-ray cinematography in some areas.

## 12.10 KYMOGRAPHY

Kymography (literally, the depiction of waves) is a very interesting but little used method which allows the movement of organs to be shown on an X-ray film.

### 12.10.1 Portrayal by means of radiographs

When one makes a normal radiograph of the heart, this shows only one phase of the motion of this organ. If instead of exposing the whole film one were only to expose through a number of horizontal slits 0.5 mm wide, situated at intervals of, for example, 12 mm in a grid of lead strips, then during the exposure time (for example 0.02 s) only a number of exposed strips would be produced on the film (figure 12.34). If the slits are moved so that one slit reaches the position initially occupied by the next one in, for example, 3 s, then the projection will be made by means of 'walking' strips, as it were. It is clear that the moving organ will have a different shape at, say, 0.1 s after the start, so that the contour of the organ shown through the slits after 0.1 s will differ from that at the beginning. The radiograph thus shows the heart with a serrated edge, unlike the regular contour shown in a normal radiograph, the varying width of the photo corresponding to the different states of expansion and contraction of the heart (figure 12.35).

Study of the nature and magnitude of these serrations can give valuable diagnostic information. For example, at the moment that the left ventricle contracts the aorta is filled and the kymogram will thus show a reduction in the size of the ventricle and an increase in the size of the aorta.

In pathological conditions the kymogram may differ from the normal shape. For example, a heart infarction may manifest itself in the kymogram as a place where the wall of the heart does not move as much as normal. Kymography is



Figure 12.34 Principle of kymography. Diagrammatic representation of a radiograph of the heart with the aid of a kymographic grid without movement of grid or film during the exposure. The result is a number of thick (heavy) black lines, separated by white strips, which demonstrate the contours of the heart.

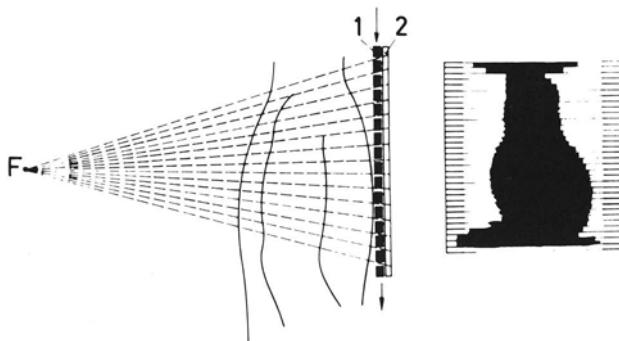


Figure 12.35 Principle of kymography.

Right: Diagrammatic representation (printed as a positive) of a continuous kymogram of the heart taken during the movement of the grid over a distance equal to the spacing between two adjacent slits. The contour of the heart appears as a number of serrations, showing details of the movement.

Left: Projection of the beam in kymography with moving grid (1) and stationary film (2).

also used for other organs besides the heart; for example the stomach, in which the reduction or shift in peristalsis at a site of severe wall infiltration (such as the site of a tumour) can clearly be observed. In practice, kymography can be realised either by keeping the grid still and moving the film or by keeping the film still and moving the grid. In the first case we see a kymograph of certain strips of the heart in the different phases of their motion, which are thus portrayed over 12 mm. The parts of the heart that are covered by the grid are not seen at all. The entire picture of the heart then has a somewhat step-shaped form. In the second, more usual, method, on the other hand, all points of the heart contour are shown, since the

grid moves continuously past the heart shadow. Each point of the contour will be shown at a different phase of its motion, however. The over-all picture of the heart is then different, and one speaks in this case of a *continuous kymogram*. If the heart were stationary, a stationary grid would give a jagged contour on the kymogram, while a moving grid would give a smooth contour, just like an ordinary radiograph of the heart.

When the distance between the slits is not too large, these methods can be regarded as practically equivalent. The displacement of the slits should not exceed the distance between them, as otherwise overlapping would be produced. It is also important that the slits should be as far as possible in the direction of the motion one wishes to portray. For kymography of the heart the slits should thus be horizontal, and vertical for kymography of the diaphragm.

Kymographs are not so much used in order to view movements as a whole (kymoscopy), but rather for the purpose of measuring the serrations of the movements in detail. One should remember, however, that only movements are perceived that are located near the edge and that, for example, a part of the heart that moves less or not at all due to an infarct is not visible unless it happens to be located in the heart margin that is visible on the photograph.

In the field of radiological investigations of the heart, kymography has practically been replaced by the modern angiocardiology with the use of X-ray cinematography and rapid-sequence technique.

#### **12.10.2 Projection by means of a photocell; electrokymography**

When one places a tiny photocell on a projected heart margin on a fluoroscopic screen, then the amount of light received by the cell will be greater during the systolic phase than during the diastolic phase since, of course, the heart margin recedes during the systolic phase. By amplification of the current that is produced a kymographic recording can be made simultaneously with electrocardiography and, for example, the recording of heart sounds. This electrokymographical recording can take place with several cells at different locations on the heart contour. With this method, therefore, curves are obtained and not images. This procedure is also being applied less and less.

#### **12.11 XERORADIOGRAPHY**

With this method of image recording, the invisible radiation image is not photographically converted into a visible image but into an electrostatic pattern that by means of a powder can be made visible. No liquids are used; it is a dry procedure (*xeros* = dry).

A thin semi-conductive layer (30–160  $\mu\text{m}$ ), which consists of amorphous selenium, is applied on an aluminium plate. By exposing this to a coronal discharge (brush discharge) the layer of selenium on one side becomes charged with a uniformly distributed positive charge (600–1200 V), which is retained as long as it remains in the dark due to the great resistance of the layer. When the layer is exposed to X-rays (or light), the selenium becomes locally conductive and there transfers its electrostatic charge to the underlying aluminium layer. In this way,

an image arises with localised electrostatic contrasts, which correspond to the localised contrasts of the incident radiation image.

When this plate is placed in a box, which contains an aerosol of (usually blue) powder whose tiny particles are negatively charged, the powder is attracted to the residually charged spots to an extent depending on the magnitude of the charge, and form a contrast to the uncharged areas, which are black. This 'powder picture' is impressed ('baked') on to paper. Without any chemical processing (wet or otherwise) a picture is produced on the plate immediately; after the picture has been used, the powder can be brushed off and the plate recharged and used again (figure 12.36).

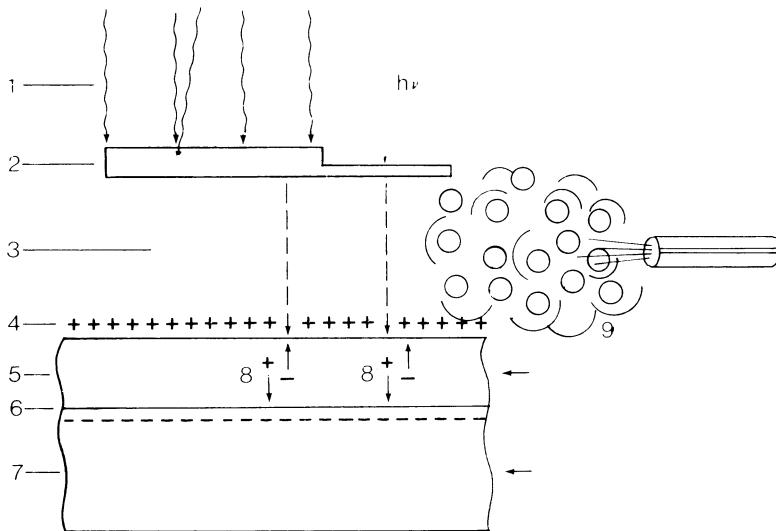


Figure 12.36 Principle of Xeroradiography. 1. Primary X-rays; 2. object; 3. rays that form the radiation image; 4. one-sided positive charge; 5. non-conducting selenium plate; 6. negative charge of 7 held by 4; 7. aluminium plate; 8. conveyance of charge (positive and negative) under the influence of 3; 9. negatively charged powder, which is blown over the positively charged image 4.

Xeroradiography has not become a very significant procedure, especially because of several disadvantages inherent to the method. First of all, the exposure required is more than thirty times greater than that needed for a radiograph taken with intensifying screens and, moreover, its resolving power hitherto has not been very great (at most equal to exposure with high resolution intensifying screens) and is certainly inferior to photographic methods. The resolving power depends on the size of the powder particles and also on the thickness of the selenium layer. Nevertheless, great improvements have already been made in this respect.

The image formation manifests characteristic faults by portraying object details both too intensely and too weakly, which is expressed especially in an exaggerated *edge effect*. In the regions where the electrostatic field strengths are greatest (especially the margins of details) the greatest amount of powder is also deposited. This is expressed in an exaggerated outlining of bony structure and the margins of

organs especially. Sometimes this edge effect fixes attention on a contrast which photographically would not or would scarcely have been noticed; this favours certain applications of xeroradiography, such as mammography (micro-calcifications).

The great advantage of the method in comparison with X-ray film, namely, the almost immediate availability of the image, scarcely plays a part at present, when a modern automatic processor is used by which the film is available in a few minutes, completely finished. Certainly, this method will be of use in situations when serious scarcity or destruction of sensitive material has occurred, which, in case of war (and especially in an atomic war whereby nuclear radiation would appear on a large scale) is, alas, by no means just an imaginary possibility.

### **12.12 POLAROID RADIOGRAPHY**

In ordinary photography, the polaroid method has made it possible to have a photograph (positive) available for viewing after a very short period of time (1 min). Negative and positive material are packed together with chemicals (in the form of a paste) in a light-tight wrapper; after exposure the paste is squeezed between the negative and positive paper. During the development process, which now follows, the bromide is removed from the exposed silver bromide and the silver is deposited on the negative, and the unexposed silver bromide dissolves and diffuses into the positive paper. Here it is combined with sulphides by which the black silver sulphide is deposited and held by the fixing process. The result is one positive; the negative is useless. With the polaroid method in radiography, a negative paper is packed in a special cassette (which is light-tight) together with positive paper (or impression paper) and the chemicals in the form of a paste. After exposure the negative paper in contact with the impression paper is pulled between two rollers, whereby a paste-containing capsule, which is attached to the film, is spread out uniformly between the negative and impression paper. This paste, which combines the function of developer and fixer, removes the unexposed silver bromide from the emulsion and allows this to diffuse into the sulphide-containing impression paper, so that it is deposited as black silver sulphide; a positive image is thus created. This image is ready for viewing as soon as it has been pulled out of the 'box'. The image is of moderate quality and the film material is relatively expensive.

Naturally, this method can be of advantage during certain operations, etc., when the physician can obtain a radiograph any moment he wishes. An advantage is the low exposure: one-quarter to one-half the exposure that would be required for film intensifying screens. A disadvantage is the poor resolving power. The rapid automatic processor for ordinary X-ray films makes the use of this method superfluous at the present time.

This method can also be used in a form more closely resembling that used in normal photography, by fitting a polaroid camera with a flat film holder to the image intensifier, so that the image on the viewing screen can be photographed.

### **12.13 SCANNOGRAPHY**

In section 12.1.9 we have already become acquainted with the scanning of an object with the aid of very narrow beams of X-rays—the CT method. *Scannography* is the photographic method of determining the distribution of a radioactive sub-

stance in the body. The condition under which this method should be used is that the radioactive substance should emit sufficiently hard gamma-rays and that it should accumulate in the body at sufficiently high concentrations so that it can produce an effect outside the body. The standard example is the accumulation of  $^{131}\text{I}$  in thyroid tissue, that is in the thyroid gland and possibly elsewhere (metastases). The radiation emitted is measured and recorded by means of apparatus which, among other things, contains a *scintillation counter* ('spark counter'). The light flashes, converted from the photon energy, can act upon the photographic emulsion. In order to obtain a good picture of the distribution in the organ in question and, hence, the functioning of that organ, one must scan the field point by point. This is done with the aid of localisers with thick lead walls and a narrow channel through which passes only a very narrow beam of radiation on to the measuring equipment. Such a localiser, or *collimator\**, does not concentrate the radiation, but only passes a very narrow beam. The final picture then consists of black spots, more or less separate or running into each other, thus giving a good impression of the form, position and function of the organ. Often a radiograph is made and not developed, and then placed with exactly the same centering in the scannograph. The double-exposed film obtained in this way provides a very elegant representation of the desired information regarding localisation, etc.

The disadvantage of this scanning is the fairly long time that it takes for one picture (tens of minutes). Nevertheless, this scanning method has made enormous progress, especially because of discoveries of further new radioactive isotopes, which are extremely well-suited for the determination of the function and/or anatomical condition of an organ. For many organs, the making of a scintigram, for example, of the liver, kidneys and thyroid gland, has already become a routine method, which, though rightly so, takes place more or less outside the radiological department in the laboratory for nuclear medicine. Further development depends to a great extent on the discovery of improved and suitable materials similar to the introduction of contrast media in radiology in the past, which have a great affinity for a certain organ and, in particular, have little or no unpleasant toxic side-effects.

Great progress has been made in this respect for the investigation of the brain especially, and the pros and cons of an intended neurosurgical operation often depend upon the result of the scannography alone. At the present time, the collimated beam in the gamma scanner is led to a sensitive crystal and the intensity is measured and intensified and then reproduced in print. The modern *gamma camera* works much faster than the conventional scanning apparatus; here the radioactive rays are focused onto a large *scintillation crystal* and are converted into a visible image on a monitor by means of complicated electronic apparatus. This image can also be recorded by means of a (polaroid) photographic camera. By connecting the apparatus to a computer, complicated analysis of the distribution of the radioactive substance in the body can be calculated in a very short period of time.

It is important that the radiographer understands the scanning procedure and scintigraphy because, although she may have only a small or no part to play in the actual procedure, nevertheless she will most likely often be indirectly involved.

\*The word collimator is being used more and more instead of diaphragm; also in the case of beam limitation of X-rays emitted by an X-ray tube.

### 12.14 AUTORADIOGRAPHY

This chapter would not be complete without the mention of autoradiography. Just as, for example, a piece of uranium ore produces an image of itself on a photographic plate (which led Becquerel to discover *radioactivity* in 1896), cells, tissues or organs impregnated with radioactive substances are capable of producing an X-ray image of themselves, as it were. This process, known as autoradiography, has yielded interesting results of microscopic as well as macroscopic details through the use of radioactive isotopes. Naturally, autoradiography only gives a relatively sharp image when it is possible to apply the photographic emulsion very close to the radioactive cells. In all other cases, one sees only a diffuse patch of greater or lesser density.

By applying this process in microscopy, it has been possible to ascertain in which parts of a cell certain elements are contained. Experimentally, one can differentiate between microscopic details that are  $1.5\text{ }\mu\text{m}$  apart. Expressed in modulation transfer function one can perceive 500 line pairs per mm on special films. Macroscopically, the process can be used for example, to trace an abnormal expansion of the thyroid tissue, which can absorb a great deal of radioactive iodine.

### 12.15 MICRORADIOGRAPHY

This method is not generally used in the radiology department; it is more of a laboratory procedure. By using an extremely fine focus (to  $0.5\text{ }\mu\text{m}$ ) and a tube with a beryllium window, it has been found that it is possible to obtain much higher magnifications than are considered in practice. It is thus possible with very soft radiation (for example produced by 3–5 kV) to give highly magnified pictures of thin sections of tissue, which has led to a new area of application, *microradiography*. Direct radiological enlargement to, for example, 5 $\times$  and additional optical enlargement to 200 $\times$  (total 1000 $\times$ ) is possible with this method.

As opposed to ordinary microphotography, whereby sections are more or less denatured by dyeing methods (even if very beautiful and instructive) and produce an unnatural image, microradiography produces a natural image of the section, since it is governed only by the atomic absorption properties of the cells and tissues and not their behaviour with respect to a particular dye. It is of course exceptionally instructive to compare images of the sections obtained by the conventional dye method with those produced by microradiography. This new technique is already used with success in histological, anatomical and pathological laboratories. The film for these radiographs has a very fine-grain, very slow emulsion.

### 12.16 X-RAY MICROSCOPY

Although it is impossible to change the direction of X-rays by normal means as is done with light, it has proved possible in recent years to focus X-ray beams by reflection from concave crystal surfaces, thus making it possible to construct an X-ray microscope working on much the same basic principle as a normal optical microscope, which operates with light rays. Naturally, this should not be confused with the electron microscope, which, of course, works with electrons and not with X-rays. This method does not play any part in medical radiology.

## 13

# Radiographic Examinations using Contrast Media

The great increase in the number of X-ray examinations and the associated ever-increasing part played by the X-ray examination as a method of determining the final diagnosis should largely be attributed to the enormous growth in the number of examinations using contrast media. In addition to the well-known methods, which are still continually being improved, new ones have come into existence, which have made a valuable contribution, and their development is still in full swing. In section 6.6, it was explained that one can use positive and negative contrast and their combination, double contrast, to show up soft tissues which would otherwise not be seen due to their uniform absorption of the radiation. One condition that must be satisfied by all contrast media is that they should be completely excreted, or if this is not the case, they should be entirely harmless to the body. In general, these contrast media can be prepared or made ready for use simply by following the manufacturer's instructions carefully. It goes without saying that injections should be made under sterile conditions, and that the normal antiseptic and aseptic measures must be taken; it falls beyond the scope of this book to give further details of this.

The examinations can be subdivided by the way in which the contrast medium is introduced into the body.

### 13.1 ADMINISTRATION VIA A BODY CAVITY WHICH IS IN COMMUNICATION WITH THE EXTERNAL ATMOSPHERE

#### 13.1.1 Demonstration of the gastro-intestinal tract

The contrast medium most commonly employed for this is *barium sulphate*. It is not toxic and is entirely excreted by the body. It can be readily mixed into a fine suspension, and easily kept in suspension by the possible addition of certain sub-

stances. A variety of preparations are on the market (under many different trade names) which all have the purpose of preventing the barium from flocculating (that is from depositing sediment) and allowing it to adhere to the mucous membrane. Sometimes another ingredient is added to these preparations in order to improve the taste, as pure barium sulphate tastes rather chalky. Here, the contrast is provided by the barium, which has a high atomic number (this is the essential thing) of 56. It is mixed to a thin porridge-like consistency and is then administered by mouth (orally) to the patient prior to the examination. For the examination of the oesophagus (ordinary 'stomach' barium passes too quickly through this) a much thicker barium is often used ('barium paste') which passes more slowly through the oesophagus and demonstrates the mucosal folds much better and for a longer period.

In the stomach, in which an air bubble is always present, one is actually dealing with double contrast: positive by means of the barium, negative by means of the air. For deliberate double-contrast examination one allows the patient to swallow not only barium, but also a gas-forming preparation at the same time (soda-water, effervescent tablets, etc.) due to which the stomach becomes more or less inflated.

In the investigation of the rest of the intestine, where barium is administered by mouth, the positive contrast by itself, as well as the double contrast that appears here and there (for example gas bubbles above horizontal fluid levels in the small intestine with ileus), play an important part in diagnostic radiology.

A suspension of barium sulphate is also used for a retrograde intestinal investigation, that is a barium enema, where the barium is introduced via the rectum. Here also, the combination of barium suspension and air is always present. Here, the double-contrast method has developed into a special method of investigation, usually known as *double-contrast enema*.

Direct administration of barium by injection via a tube, through which, at the same time, peristalsis can be influenced locally by means of drugs, etc., is being used more and more. This, is used in *duodenography*, and when completely filling the jejunum and ileum as introduced in diagnostic radiology (Sellink).

### 13.1.2 Respiratory system

As there cannot be complete and proper excretion in this case, barium is not considered as a contrast medium, but *iodine* (atomic number 53) in one form or another is used. Different concentrations of 10, 20, 40 per cent, etc. are available in the trade, also under various names.

*Lipiodol\** is very well known; in this preparation the iodine is incorporated in an oil that is almost non-irritating and to which the body reacts more or less indifferently. It is (after superficial anaesthesia of the throat and larynx) inspired or introduced via a tube. The larynx can be made clearly visible (glottis, etc., as well as the trachea and the bifurcation). By introducing a bronchial catheter into a particular bronchus under fluoroscopic control, and then filling this with Lipiodol, one can carry out *selective bronchography*, or fill larger sections of the

\*Actually, Lipiodol is a name patented by a firm, Guerbet (Paris), but this preparation has taken hold to such an extent that the expression Lipiodol has become a 'type name' as it were, for every iodized oil (compare 'Odelca' for every fluoroscopic screen camera!).

bronchial structure (the complete right lung, for example) so that all the branches of the bronchial tree become beautifully visible. In favourable cases, the oil can later be completely coughed up; it can, however, often be forced into the spaces between the alveoli by the coughing, and remain there. These interstitial iodine deposits can make proper radiography of the chest impossible for years and, moreover, appear to cause an unfavourable tissue reaction eventually (fibrosis). The Lipiodol in the alveoli and the bronchi is not re-absorbed, but is coughed up during the hours and days that follow the examination, and is also conveyed to the exterior by means of the cilia.

In addition to these oily iodine preparations, there are the water-soluble iodine compounds, which are also available in different concentrations and under various patent names. In general, they are less well-tolerated by the body, but, on the other hand, they are easily absorbed and are promptly excreted by the body.

### 13.1.3 Urogenital system

By injecting a contrast medium (containing iodine) into the bladder via the urethra by means of a catheter, the bladder can be demonstrated. A 10–20 per cent aqueous solution of sodium iodide is suitable for this purpose, as well as one of many iodine preparations available in the trade. Sometimes, this *cystography* is combined with an investigation into the condition and function of the urethra by taking one or several radiographs (or cine film): *urethrogram* and *micturating cystography*. If the (fine) catheter is introduced from the bladder up the ureter to the renal pelvis and the contrast medium injected into this, then this is a *retrograde\** (or *ascending*) *pyelogram*, on which the renal calices and at the same time the ureter and bladder can be visible. The introduction of the ureteral catheters takes place with the aid of *cystoscopy* (viewing the interior of the bladder) and is carried out by the urologist.

In gynaecology, investigation of the patency of the uterine tubes is also a retrograde procedure. Here, the iodine preparation is injected into the uterus via the cervical canal and from there passes through the tubes (if they are patent) into the abdominal cavity. This demonstration of the uterus and tubes (uterine tubes or Fallopian tubes) is called *hysterosalpingography*. When an aqueous contrast medium is used this disappears after some hours; with an oil-containing contrast medium, a check is still possible after 14 h and one can see the small spill of contrast medium low down in the peritoneum (if the tubes are patent).

### 13.1.4 Other cavities that can be filled from the outside

One is able to demonstrate the excretory ducts of glands by retrograde administration of contrast media. In this way, one can inject into the accessory nasal sinuses, into the tear ducts, and so show the tear glands (*dacryocystography*), into the lactiferous ducts of the mammary gland (*galactography*), and, finally, into fistulae (*fistulography*) for which a barium-containing paste is sometimes used.

\*Retrograde = running in a backward direction, that is against the direction of excretion.

## 13.2 THE INTRODUCTION OF CONTRAST MEDIA INTO THE EXCRETORY ORGANS VIA THE CIRCULATORY SYSTEM

When the contrast medium\* is required to render excretory organs and/or their excretory ducts visible by way of the blood stream, generally a high concentration of contrast medium in the excreted fluid (bile, urine, etc.) is necessary. This involves either making the concentration in the blood sufficiently high via the digestive system by ingestion of the contrast medium (*per-oral examination*), or injecting the contrast medium directly into the blood stream in order to achieve a sufficiently high concentration (*intravenous investigation*).

### 13.2.1 Gall bladder

For the examination of the *gall bladder* it has proved possible to ingest iodine-containing materials which, after absorption in the intestine, are taken up in the blood stream, and are excreted by the liver in the bile in such concentrations that the bile (when concentrated in the gall bladder) gives sufficient contrast. The concentration of the contrast medium is not great enough in the liver to render it visible on a radiograph. This method of demonstrating the gall bladder is called (*oral cholecystography*). At present, one has access to excellent oral preparations, which have such high iodine concentrations that with contraction of the gall bladder the bile duct often also becomes visible up to where it joins the duodenum (sphincter of Oddi). Because of these excellent oral preparations, the previous, much more often used *intravenous cholecystography* (where the contrast medium is injected into an arm vein) has consequently, to a large extent, fallen into disuse, and is now only used for the demonstration of the bile ducts (*intravenous cholangiography*), especially in patients who no longer have a gall bladder. The modern contrast media have fortunately lost much of their toxicity and/or side-effects, but the necessity of caution with injection still remains, and the directions for use should be carefully followed.

### 13.2.2 Kidneys

No contrast medium has yet been found that can be administered orally to show up the *kidneys*. Therefore, one is dependent upon the intravenous injection of iodine-containing preparations of 30–80 per cent. As well as manual injection, often the contrast media is administered by means of an infusion. Immediately, the kidneys begin to filter the medium from the blood, are themselves permeated by it, and are often (contrary to the liver) visible as distinct kidney shadows. The areas of higher concentration, that is the calyces and pelves, are clearly visible. This method of showing the urinary system is called *intravenous or descending pyelography*. This takes place entirely in the X-ray department, without cystoscopy. This examination includes images of the ureters and bladder at the same time.

\*As a contrast providing element, only iodine ( $Z = 53$ ) is considered. The former, much used thorium ( $Z = 90$ ) which absorbs radiation to a still greater degree is no longer used, as it is radioactive and has resulted in very serious, even lethal tissue damage.

### 13.3 EXAMINATION OF CAVITIES THAT HAVE NO COMMUNICATION WITH THE EXTERNAL ATMOSPHERE

It often happens that cavities or lumina inside the body, whether anatomically present or having developed due to pathology, have to be investigated by means of a contrast medium.

#### 13.3.1 Joints

By the injection of air, oxygen or another gas into a joint cavity, the joint capsule is inflated and the articular surfaces, etc., can be studied in more detail (*arthrography*). This is used especially in the knee joint, when examining for a possible meniscus lesion. The injection of air is usually combined with the injection of an iodine preparation and then represents a double-contrast investigation.

#### 13.3.2 Bile ducts

Sometimes, a contrast medium is introduced directly into the bile ducts during or after a gall bladder operation (called *intra-operative* or *post-operative cholangiography*). Although these bile ducts do not normally communicate with the outside atmosphere, they do so in this case, as long as the (usually T-shaped) drain remains in the hepatic duct or bile duct. The contrast medium is then injected via this drainage tube.

#### 13.3.3 Vertebral canal

For the investigation of the vertebral canal, negative contrast (*air myelography*) is seldom used, but usually positive contrast (aqueous or oil-containing iodine preparations are introduced by means of a lumbar puncture). In this way, abnormalities in the spinal canal and spinal cord can become visible. The injection for myelography consists of 2 ml of a 40 per cent solution, for example. The aqueous preparations have the danger of causing acute and serious symptoms of irritation; the oily preparations are better tolerated, but can in time give rise to unpleasant chronic symptoms of irritation due to their fixation to the spinal meninges.

#### 13.3.4 Cerebral ventricles

To render the cavities (ventricles) in the brain and their communications visible, a negative contrast medium is used almost exclusively, that is air: *pneumoencephalography* or *air encephalography* (A.E.G.). The air is introduced by means of a lumbar puncture or sub-occipital (cysternal) puncture (*lumbar* or *sub-occipital A.E.G.*) and rises towards the uppermost part of the cavity which can be reached and thus be directed to the desired location. Very occasionally, positive contrast is used. One can also (much less usual), after drilling burr holes in the skull, directly puncture the ventricular space by means of a needle directed through the brain and so introduce the air: *direct ventriculography*.

#### 13.3.5 Abdominal cavity (peritoneal cavity)

When air is introduced inside the peritoneum (rarely done), this gives rise to a *pneumoperitoneum*. If the stomach is surrounded by air and the stomach itself is

filled with air (or CO<sub>2</sub>), then the partition in between, the stomach wall, will become visible and can be radiographed: *parietography*.

### **13.3.6 Retroperitoneal space**

By introducing air (pre-sacral injection) into the retroperitoneal space, the important organs situated in this space (kidneys, suprarenals, pancreas, etc.) can be surrounded by the gas and so by means of its contrast with respect to the soft tissues be made to show up clearly. This method, retroperitoneal air insufflation, is used to obtain a *pneumoretroperitoneum*. The air can rise through the openings in the diaphragm to the mediastinum.

### **13.3.7 Mediastinum**

It is also possible to show the organs that are situated in the mediastinum in this way: *pneumomediastinography*. For this, direct puncture with air insufflation of the mediastinum can also be carried out.

### **13.3.8 Other closed cavities, such as cysts, abscesses, etc.**

It often occurs that a solid shadow on a radiograph must be investigated further by means of a puncture. A puncture of a suspected pleural exudate already means a contrast investigation, when, at the time of the puncture, a little air enters the pleural cavity and the formation of fluid levels becomes visible. Especially solid, round shadows (cysts, abscesses, echinococcus cysts, etc.) are sometimes considered for puncture and followed by a contrast examination (negative and/or positive) when strongly indicated and with strict precautionary measures. If an iodine-containing contrast medium is used, then one cannot expect a therapeutic effect (for example disinfection) from the iodine, as in these preparations the iodine is organically combined and is not liberated.

## **13.4 EXAMINATION OF BLOOD VESSELS, VASOGRAPHY OR (MORE USUALLY) ANGIOGRAPHY**

The fact that the arm veins become visible after injection with a contrast medium when doing an I.V.P. examination was at first observed to be a side-phenomenon only, but later, investigation of vessels in particular has developed into one of the most important branches of diagnostic radiology. The heart and vessel study is included in the field of *angiocardiology*. Both the blood vessels and lymph vessels can be demonstrated.

### **13.4.1 The veins, venography or (more usually) phlebography**

Because of the low blood pressure in the veins and the low speed of the blood stream therein, the puncture, followed by injection of the (iodine-containing) contrast medium is in general not a difficult problem if the vessels are not deep-seated and are not of too small a size. In the latter case (venous sinuses within the skull, vena cava, etc.) then one does not perform a direct puncture; but only blood from the more peripheral areas in which the concentration of the contrast medium is already greatly decreased can reach these places, which does not benefit the radiography (*cavography*). The portal vein is demonstrated by a special method,

namely, by direct injection into the spleen, by which this organ, as well as the liver, is permeated with contrast medium and both show up radiographically (*splenopentohepatography*). Phlebography is most often used in the legs, especially with varicose veins (varices) in order to investigate the function of the venous valves and the communications between the superficial and the deep veins.

After the injection of a contrast medium into an artery, the state of the veins can, a little later, also be determined to some extent. This indirect method of showing veins is important, especially when dealing with the cranial veins.

#### 13.4.2 Demonstration of the arteries of the heart: arteriography, cardiography

With every injection of contrast liquid into an artery, whether by means of direct puncture or by means of injecting through a catheter, the contrast medium immediately mixes with (and is diluted by) the blood that flows through the artery and, moreover, is conveyed onwards with great speed. A sufficient concentration for radiography is only possible when a sufficiently large amount (several tens of millilitres) is injected with such speed that a compact column of contrast medium flows in the artery (at least during the first few moments), which then soon becomes increasingly diluted. For rapid injections through a relatively narrow-gauge needle, great power is necessary. Manual injection is only considered in a few cases, and has virtually everywhere been replaced by adjustable mechanical injection under great pressure (several atmospheres).

Arteriography may be used for:

(1) *Showing the whole region supplied by an artery by direct puncture* (this can be done by means of a manual injection). This, for example, occurs when injecting the carotid artery to show the cerebral vessels: *carotid angiography* or *cerebral angiography*. After the so-called *arterial phase*, the diffuse filling of the capillaries follows (the *capillary phase*), in which the entire area supplied by the injected artery is infiltrated with contrast material and, therefore, shows a greater absorption of X-rays. Finally, shortly after that, the *venous phase* follows, during which the contrast medium, which has in the meantime been greatly distributed and diluted, portrays the cerebral veins more or less clearly. Another application is *translumbar aortography*. Here, also, a rapid (often manual) injection of a fairly large amount of contrast medium, which is immediately distributed throughout the branches of the abdominal aorta, is necessary. The capillary and venous phases are useless for radiography due to the great dilution with blood not containing contrast. By far the greatest number of arteriographical examinations occur by injecting via a catheter according to the technique introduced by Seldinger. Because of the great length and narrow diameters of the vessels through which the contrast medium must travel in great quantities in a very short space of time, an injection under high pressure is absolutely essential. There are many pressure injectors on the market. The principal purpose is:

(2) The demonstration of the branches of several arteries or of a single artery, *semi-selective* and *selective arteriography*. In the first case, the injection takes place when the tip of the catheter is located near the origin of several arteries (for example near both renal arteries); in the second case, the catheter is directed just

into a particular artery (for example into one renal artery), when only the region supplied by that artery alone is portrayed 'selectively'. It is this Seldinger method (with several variations) that has made possible the radiographic demonstrations of most arteries selectively, by which diagnostic possibilities have been enormously enriched. Regularly, catheterisations are carried out (usually by means of the femoral artery) for the purpose of renal arteriography, vertebral angiography, etc. A very particular place is taken by:

(3) Demonstration of the heart, *cardiography*, which is usually carried out along the venous system by means of a catheter injection. In this case, the catheter tip may be introduced into the right atrium and right ventricle or through the septum, into the left atrium, to deposit, in a moment, a large volume of contrast medium which then, carried along by the blood stream, enables the normal or pathological, anatomical and physiological state to be visualised, for example, narrowing, occlusions, abnormal shunts, etc. Angiocardiography has developed into an indispensable part of cardiac diagnosis, and has enriched the knowledge of cardiac anatomy, physiology and pathology enormously; often it indicates the way to surgery of the heart. Selective angiography of the coronary arteries has also made great progress with diagnostic and therapeutic consequences in cases of angina pectoris, etc. (*coronary angiography*).

(4) *Demonstration of the lymph vessels, lymphangiography or (more usually) lymphography.* As the spaces between the tissues represent a swamp or marsh out of which eventually a tiny brook arises, which is a minute lymph vessel, which has an extremely thin wall, it has taken a long time before a suitable method of injecting these vessels has been developed. After the injection of a dye into the tissues between the toes, one will see, after a certain period of time, the course of the lymph vessel that drains that area and which can then be punctured and injected. We shall not deal with this in any further detail.

The lymphatic stream flow is extremely slow, and if the pressure is increased even a little, the lymph vessel will soon burst. The injection, therefore, should take place at an exasperatingly slow rate (1 ml/5 min for 1-1½ h). Special injection apparatus has been constructed for this purpose. For this also, an oil or aqueous contrast medium with a particular iodine concentration is used. The lymph stream passes the glands of the affected area and drains into the left subclavian vein. The lymphogram shows the lymph vessels that are filled, the glands and connections, etc. Oily contrast material (for example Lipiodol fluid) remains in the system much longer, whereas aqueous contrast media are excreted completely in a few hours. The advantage of Lipiodol is that, for example, the next day radiographs can be taken of the filled lymph glands (*lymphadenogram*). The disadvantage is that the tiny drops of oil eventually enter the blood stream and via the right side of the heart can cause hundreds of micro-embolisms in the lungs. Fortunately, it causes very few symptoms, so that this is no real argument against Lipiodol lymphangiography. Lymphangiography and lymphadenography play an important part particularly in the diagnosis of tumours, as well as determining whether a therapy radiation treatment result is positive or negative.

What has been said about films, intensifying screens, image intensifier phosphors and television phosphors (see chapter 9) is also valid for contrast media: continuous further improvement in efficiency. The former regular side-effects observed with or after injections are becoming increasingly rare.

## 14

# Exposure, Exposure Tables, Automatic Density Control

In order to obtain a radiograph a certain quantity of energy is necessary which, after penetrating the object, is still able to act upon the emulsion when it reaches the film. This amount of energy is determined by, among other things, the intensity of the radiation (exposure rate) and the exposure time (as has been previously mentioned, exposure equals the exposure rate  $\times$  time). The exposure rate is highly dependent on the voltage (kV) applied across the tube and is proportional to the current value in the tube (in mA). Since the exposure time is also proportional to the exposure, the current value and the time are combined to form a product, the *milliampere-second product* (abbreviated to mAs), and is proportional to the exposure. Since a charge of 1 millicoulomb (1 mC) flows per second with a current of 1 mA, then 1 mAs represents a charge of 0.001 C which is carried by the tube current. *kV and mAs are the most important electrical factors that determine the exposure of a film.*

### 14.1 EXPOSURE VALUE

The radiation energy which, in order to produce a useful density on the film (under otherwise uniform conditions such as film quality, intensification factor of the screens, etc.) is naturally fairly similar for all exposures, is equal to an exposure of about 1/4 mR (0.00025 R). This ‘left-over energy’ is the remainder of the X-ray energy that was transported by the primary beam (before striking the object) and is determined by the kV and mA particularly. Under standard conditions and an object of ‘normal thickness’, the factors kV and mAs can be assimilated and formed into a fixed numerical value, the *exposure value*. This

number is a constant value for that exposure and those conditions within which the kV and mAs can then be individually altered according to certain rules. In this case, the influence that the Schwarzschild effect could have on the value of the mAs product itself is disregarded. It is explained in chapter 8, section 8.2.9 that the internal variations of mA and time in the mAs product are too small to be reckoned with in practical radiography.

#### 14.1.1 Basic table (standard table)

The exposure conditions are laid down in the *standard table* (also called fundamental or basic table) and include the data indicated by table 14.1 (according to Philips). In the table, the first column refers to the object (body part) and the second column to the thickness (in the direction of the radiation) in cm. The 'normal' thickness, that is a thickness one would find in an individual of normal build and normal proportions (for example 1.75 m tall and a weight of 75 kg), is indicated in the basic table.

Table 14.1

Object	Diameter (cm)	Grid (type)	Intensifying screens (type)	Focus-film distance (cm)	Voltage (kV)	mAs	Exposure value ( <i>E</i> )
Body part							

The type of grid, if any, is indicated in the third column. If no grid is used then this is indicated with a minus (-) sign. If a grid is used then it is specified whether it is a normal grid with, for example, 24 lead strips per cm and a ratio of 7, or one with 44 lead strips per cm and a ratio of 10 (these low ratio grids are indicated by 'I'). If, however, a hard radiation grid with a high ratio (for example the type with 24 strips per cm and a ratio of 13 or with 44 strips per cm and a ratio of 15) is used, then this is indicated by 'II' (for low-ratio grids, one can assume an increase in the exposure of  $2\frac{1}{2}$  times, and for high-ratio grids an increase of 4 times, in comparison with exposures without a grid).

In the fourth column one sees whether or not use is made of intensifying screens; if this is not the case, this is again indicated with a minus sign. If screens are used, then 2 dots (in the table discussed here at least) indicate the use of universal screens (intensification factor of about 10) and 3 dots the use of 'fast' screens (intensification factor of 15–20).

The fifth column indicates the focus-film distance and the sign ~ indicates that this represents an 'approximate' distance, which can differ since it concerns exposures made while screening and where the thickness of the patient can vary from case to case. The  $Ff = 100$  cm predominates in the column, since this is the usual distance for bucky exposures.

The sixth column lists the recommended kilovoltage which, along with the mAs value in the seventh column determines the radiation energy that is produced by the focus for the particular exposure. In this connection it should be mention-

ed that in the basic exposure table the factors are worked out with a particular voltage form and a particular total tube filtration in mind, since these factors obviously greatly influence the intensity of radiation that leaves the tube. In modern tables the radiation originates from three-phase voltage (six- and twelve-pulse apparatus) and a total filtration of 2.5–4 mm aluminium equivalent.

Finally, in the eighth column all the data from the previous columns (column two up to and including column seven) are assimilated, as it were, into one value, the *exposure value*. In the following paragraphs this concept and its use will be discussed more fully.

#### 14.1.2 Exposure value and mAs

As we have already said, with the same kilovoltage the exposure (therefore also the exposure value) is directly proportional to the mAs value. If the radiographic exposure requires an mAs value of twice the size (the other factors in columns 2–6 remaining the same) then the exposure value for that radiograph will be twice the size as is indicated in the eighth column. *The fact that a difference in exposure is only clearly perceived when this difference amounts to at least 25 per cent is extremely important.* Radiographs made with 2 s and 2.2 s exposure times scarcely differ. If a radiograph is clearly under-exposed, then there is no sense in choosing a slightly higher mAs value; it would be better if one chooses an mAs of twice the value (or double the exposure value by some other way).

It is sensible, therefore, to indicate alterations in exposure values (indicated by  $E$ ) in steps of 25 per cent higher or lower only. One step higher thus signifies (starting from 100 per cent) 125 per cent, two steps higher  $1.25 \times 125 = 156$  per cent and three steps higher  $1.25 \times 1.25 \times 1.25 \times 100 = 195$  per cent. Three steps up, therefore, means an approximate doubling, three steps down an approximate halving, of the original  $E$  value.

If one takes the following series of  $E$  values, 0.10, 0.12, 0.16, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.80 and 1.0, then one will see (on careful examination) that

**Table 14.2 Exposure values ( $E$ ) used in the tables and graphs**

0.1	0.12	0.16	0.2	0.25	0.3	0.4	0.5	0.6	0.8
1	1.2	1.6	2.0	2.5	3.0	4.0	5.0	6.0	8.0
10	12	16	20	25	30	40	50	60	80
100	125	160	200	250	300	400	500	600	800
									1000

every following  $E$  value is 25 per cent higher than its predecessor. This series can be repeated three times by multiplying by the factors 10, 100 and 1000, and then one obtains  $E$  values from 10 to 1000\*. These values, shown in table 14.2, can be assimilated and plotted on a graph. Every value is 25 per cent above the previous value. Some values are expressed in round figures.

\*Here we are concerned with an arithmetic series of 0.1 to 1000 with a multiplication factor of about 1.25.

### **14.1.3 Exposure value, mAs and kV**

In a similar manner to the changes that can be made in the mAs product without altering the photographic quality (thus,  $40 \text{ mAs} = 1/10 \text{ s} \times 400 \text{ mA}$ , or  $2/10 \text{ s} \times 200 \text{ mA}$ ), one can also bring about changes in the mAs and kV (which together determine the  $E$  value) within this  $E$  value. For every exposure several combinations of kV and mAs are possible, which produce an almost equal image quality. A simple test teaches us immediately that the influence of kV is many times greater than that of the mAs. If, for example, the voltage is increased by 10 per cent and the mAs decreased by 10 per cent, then one obtains a very much over-exposed radiograph. In order to obtain a correct exposure there are several rules of thumb in existence which can be of use in practice.

#### ***14.1.3.1 First rule of thumb: for an increase of 10 kV halve the mAs***

The first rule is that if one applies 10 kV more then one should halve the mAs product (every time); if one chooses 10 kV less then the mAs product should be doubled. This (rather inaccurate) rule gives the best results in the 60–90 kV range; outside this range the rule is less satisfactory.

*Example:* A radiograph produced by 80 kV and 10 mAs can also be produced by 90 kV and 5 mAs, or 70 kV and 20 mAs, or 60 kV and 40 mAs.

#### ***14.1.3.2 Second rule of thumb: for a voltage increase of 15 per cent halve the mAs***

A better approximation of the relationship between kV and mAs for a greater mAs range is produced by the 15 per cent rule of thumb: a 15 per cent increase in voltage allows the required mAs product to be decreased by 50 per cent; a 15 per cent decrease in voltage requires a doubling of the mAs value.

*Example:* A radiograph produced by 80 kV and 10 mAs can also be produced by  $(80 + 15 \text{ per cent}) = 92 \text{ kV}$ , and 5 mAs, or by 68 kV and 20 mAs, or 58 kV and 40 mAs.

If both these rules of thumb are compared then one can see that they almost correspond in the 60–80 kV range. Thus, the change from 60 to 70 kV according to the first rule compares to the change from 60 to  $(60 + 15 \text{ per cent}) = 69 \text{ kV}$  according to the second rule. Similarly, the change from 70 to 80 kV corresponds to the change from 70 to 80.5 kV, thus, a good similarity. Outside the 60–80 kV range, however, the values increasingly diverge. For example, the mAs is halved when 40 kV is altered to 50 kV and 100 kV is changed to 110 kV according to the first rule, whereas the second rule in this case indicates values of 40 to 46 kV and of 100 to 115 kV. For this reason, the first rule cannot be applied in those ranges. The second rule produces satisfactory and useful but not yet optimum results.

#### ***14.1.3.3 Influence of kV according to the exponent p***

Extensive experiments have accurately determined the relationship between kilovoltage and the mAs product for equal exposure (the same exposure value). This relationship between kV and mAs can be determined for certain conditions of

exposure (enumerated in columns 2–5 as indicated above in section 14.1.1) by a *constant* value which thus expresses the exposure value. The formula states:

$$\text{Exposure value } (E) = kV^p \times \text{mAs} = \text{constant}$$

The determination of the exponent  $p$  has produced the value  $p = 5$ , so that (always under certain exposure conditions)  $kV^5 \times \text{mAs}$  must be *constant*.

*Example:* If a certain exposure is satisfactory with 70 kV and 20 mAs and one changes to 80 kV, then the new mAs product can be calculated from  $70^5 \times 20 = 80^5 \times X$ , from which the value for  $X$  (10.3 mAs) can be deduced. (N.B.: From this the usefulness of the first and second rule in this kilovoltage range is obvious).

#### 14.1.3.4 Value of the exponent $p$ (6-3)

The exponent  $p$  has turned out not to be a constant. Whereas it was originally common practice to take  $p = 5$  over the entire diagnostic range of voltages, the current use of lower, higher and very high kilovoltages has made it desirable to apply corrections in certain cases. Although, of course, there are no abrupt transitions but gradual ones, the value  $p = 6$  has been generally chosen for kilovoltages up to 40 kV and for the 40–100 kV range a  $p$  value of 5; for the voltage range 100–125 kV the  $p$  value is taken as 4, and for voltages higher than 125 kV a value of 3 has been given to  $p$ .

This low value of 3 must also be used for exposures without intensifying screens and for photofluorography. The value of 3 is also more satisfactory when it concerns thin objects (extremities), whereas a value of 5 is necessary when thick objects are radiographed. The fact that radiographs produced with softer radiation have greater contrast than those with higher voltages is irrevocable. Nevertheless, practice has taught us that almost similar radiographs can be produced with higher or lower kilovoltages than those with which one started (for example those in the basic exposure table), provided that the changes in voltage are not too great and *provided that the exposure values remain the same*. Voltages which differ by 20 kV or even more produce nearly similar radiographs, not only with regard to the density but also as far as the contrasts are concerned. The retention of the correct exposure value appears in this respect to be much more important than a very precise choice of kilovoltage\*.

With low scatter (for example by means of very careful beam limitation and high radiation contrast, with the use of barium, for example) one can scarcely differentiate between radiographs produced at 60, 70, 80, 90, 100 and 120 kV.

However, it is understandable that such a wide range of usable kilovoltages is not available for radiographs with less radiation contrast; in this case one limits oneself to the useful kilovoltage range which one could call the *tolerant voltage range* (which extends in both directions from the basic value to several tens of kilovolts).

Finally, in order to be able to read off the relative exposure value, kV and mAs without calculations, graphs have been produced in which the kV values and mAs

\*It is often claimed that a voltage difference of 5 kV can be clearly seen on a radiograph. This is so when the mAs value has not been altered according to the above equation; the one radiograph is then over-exposed and demonstrates different density and different contrast. With a correct exposure, however, a difference is not perceptible between the radiographs that differ by 5 kV.

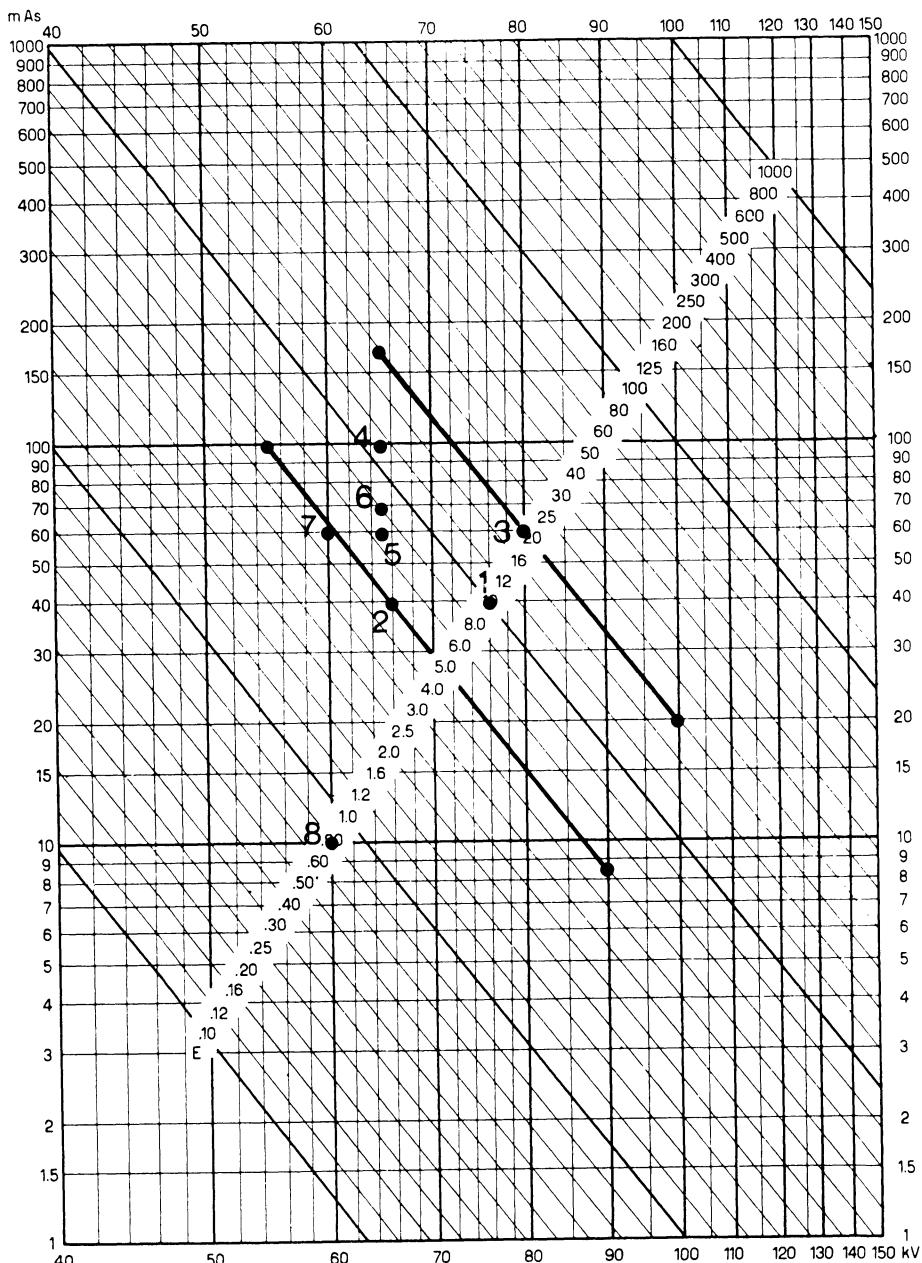


Figure 14.1 Exposure graph (Philips) with the exposure points for exposures 1-8 from table 14.3 drawn in. Horizontal lines: mAs. Vertical lines: kV. Oblique lines:  $E$  values according to  $kV^p \times mAs = \text{constant}$ , where  $p = 5$  up to 100 kV,  $p = 4$  from 100 to 125 kV, and  $p = 3$  from 125 to 150 kV. The latitude regions for the exposures are indicated by means of heavy lines.

values are plotted logarithmically on the abscissa and ordinate, respectively, and the  $E$  values from 0.1 to 1000, based on the  $p$  value (6-3) are represented as oblique lines (figure 14.1). When another kilovoltage is chosen, one can read off the mAs product that belongs to the same  $E$  value immediately. Every next  $E$  line represents an  $E$  value that always differs from the previous one by 25 per cent.

The value that one allots to  $E$ , taken by itself, can be an arbitrary one, provided their mutual differences are always 25 per cent. On the *basic exposure graphs* that have been discussed and illustrated here, however, a certain real value has been awarded to the  $E$  lines, namely, the one that represents the mAs value which the particular radiograph would require at a kilovoltage of 100 and a particular voltage wave-form\*. The  $E$  line 20 runs through the intersection of 100 kV and 20 mAs,  $E$  line 5 through the intersection of 100 kV and 5 mAs, etc. From this, for these graphs, it follows that  $E$  value = mAs value at 100 kV.

#### 14.1.4 Basic exposure table and basic exposure graphs

A basic exposure table or standard exposure table is usually compiled experimentally. Such tables are in use, more or less extensively, in various forms: as a little booklet, a chart, a revolving disc, a type of slide-rule, etc., and are usually supplied with the apparatus. It is recommended that such a table be used in combination with exposure graphs.

After the above explanation the concept and use of graphs should no longer present any difficulties. Table 14.3 represents part of the complete basic exposure

Table 14.3

No.	Body part (object)	Thickness (cm)	Grid Type	Intensifying screens Type	Focus-film distance (cm)	kV	mAs	$E$
1	Skull (p-a)	20	II	..	100	75	40	9
2	Skull (lat)	16	II	..	100	65	40	4.5
3	Skull (axial)	34	II	..	100	80	60	20
4	Sinuses (45°)	22	II	..	100	65	100	11
5	Petrosus bone (Stenvers)	18	II	..	100	65	60	7
6	Mastoids (Schüller)	18	II	..	100	65	70	8
7	Optical foramen	18	II	..	100	60	60	7
8	Mandible	10	—	..	100	60	10	0.8

table (for six- and twelve-pulse apparatus) shown later. The values indicated in this table are marked on the exposure graph (figure 14.1) and are called the *exposure points* for the particular exposures.

There are no objective means of measuring the size of the tolerance range. It can be easily indicated on a graph by means of a heavy line on the particular ex-

\*It is obvious that many radiographs would never be taken at 100 kV, but ' $E$  = mAs at 100 kV' has proved to be a good starting point.

posure value line of which the left (top) end indicates the lowest and the right (lower) end the highest usable voltage.

The extent of this tolerance range and its position depend on the subjective considerations of the person who compiled the table. In this way, the right extremity (the highest voltage that is thought to be useful) would produce a radiograph with too little contrast according to many people's taste, or the left extremity would require too high an mAs product, which (for example with an apparatus of the medium category) would entail too long an exposure time (too great a  $U_m$ ). When compiling one's own table and one's own graph (for which, apart from the recommended data on the completed tables and graphs, there are always blank tables and charts available) one can, if desired, indicate the optimum exposure point according to one's own taste and determine the higher as well as the lower kV values of the tolerance range, and mark this with a heavy line.

Several examples taken from table 14.3 may clarify the use of the exposure graph further. For exposure no. 2, 65 kV, 40 mAs,  $E = 4\frac{1}{2}$  is indicated as the exposure point on the basic table. The tolerance range for this exposure is on the line  $E = 4\frac{1}{2}^*$ , shown as a heavy line from 55 to 90 kV. At 55 kV, according to the graph, 100 mAs is required and at 90 kV 9 mAs. The tolerance range in this case, therefore, includes a difference of 35 kV. The radiograph produced at 55 kV will, however, be considered 'too soft' by many, and the exposure time (at a tube current of 200 mA, 0.5 s) will be considered to be too long. Similarly, the 90 kV radiograph (in spite of the advantageous exposure time, etc.) could be considered to be unsatisfactory due to too low a contrast. Restriction of the tolerance range and determination of the exposure point can be carried out according to one's own taste.

The remaining tolerance ranges can be read from the graph; thus, for exposure no. 3, for example, the data 80 kV 60 mAs  $E = 20$ , from 65 to 100 kV with the corresponding mAs values 175 mAs and 20 mAs (at 100 kV  $E = \text{mAs}$ ).

## **14.2 EXPRESSION OF EXPOSURE FACTORS BY MEANS OF A POINT SYSTEM**

Apart from directly relating the kilovoltage and mAs value, as happens when the  $E$  values are determined, one can also allot a number of points to the kilovoltage and mAs separately, as well as to other factors, and by adding these up arrive at a point value which refers to a particular exposure under particular circumstances. Also, in this case, every point above this value will indicate a 25 per cent increase in exposure and every point below this value a 25 per cent decrease in exposure. Similar to the facts explained above, (see section 14.1.2) for the  $E$  values in this case, three points above the original value will mean almost a doubling ( $1.25 \times$

\*The intermediate values have been omitted from the graph to avoid a confused mass of lines. These can be easily determined by means of interpolation. The intermediate  $E$  values may be expressed in round figures towards the nearest  $E$  line that is illustrated, since, after all, this rounding effect is always less than the (perceptible) 25 per cent. In the given case, therefore, the  $E = 4\frac{1}{2}$  may be rounded off to  $E = 5$ .

$1.25 \times 1.25$ ), and three points less, a halving, of the exposure\*. Also with this table, which has been used by Siemens, the standard table contains the data of the conditions under which the radiograph was produced and this is shown in table 14.4 (part of a large table).

In column 4 of table 14.4, a type of grid is indicated with a grid factor of about  $2\frac{1}{2}$ . In column 5, 'normal' screens indicate an intensification factor of about 10, and 'fast' screens indicate a factor of about 20. The point value is analogous with the fully explained  $E$  value, but in contrast to the  $E$  value it does not have a fixed point of contact ( $E$  value is mAs at 100 kV). Within a certain point value, one can,

**Table 14.4 (according to Hoxter, Siemens) for two-pulse (four-valve) voltage**

Body part (object)	Thickness (cm)	Focus-film distance (cm)	Grid (type)	Intensifying screens (type)	Points (no.)	Recommended kV	mAs
Kidneys	19	100	Pb 8/40	normal	32	66	100
Bladder (axial)	21	100	Pb 8/40	normal	36	70	200
Stomach (folds)	22	70	Pb 8/40	fast	26	77	12
Stomach (general)	22	70	Pb 8/40	fast	28	81	16
Duodenal cap	22	65	Pb 8/40	fast	29	85	16

**Table 14.5**

(1) Kilovoltage values expressed in point values

kV	40	41	42	44	46	48	50	52	55	57	60	63	66	70
Points	0	1	2	3	4	5	6	7	8	9	10	11	12	13
kV	73	77	81	85	90	96	102	109	117	125	133	141	150	
Points	14	15	16	17	18	19	20	21	22	23	24	25	26	

(2) mAs expressed in point values

mAs	1	1.25	1.6	2	2.5	3.2	4	5	6.4	8	10	12.5	16	20	25	32	40
Points	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
mAs	50	64	80	100	125	160	200	250	320	400	500	640	800	1000			
Points	17	18	19	20	21	22	23	24	25	26	27	28	29	30			

\*The relationship between the point system and logarithms is obvious from the following. With an  $E$  value difference of a factor  $x$ , the point difference is  $10 \log x$ . Example: when the  $E$  value is doubled,  $x = 2 \cdot \log 2 = 0.3010$ , and in numbers of points this amounts to: factor  $2 = 10^X \cdot 0.3 = 3$  points (in round figures).

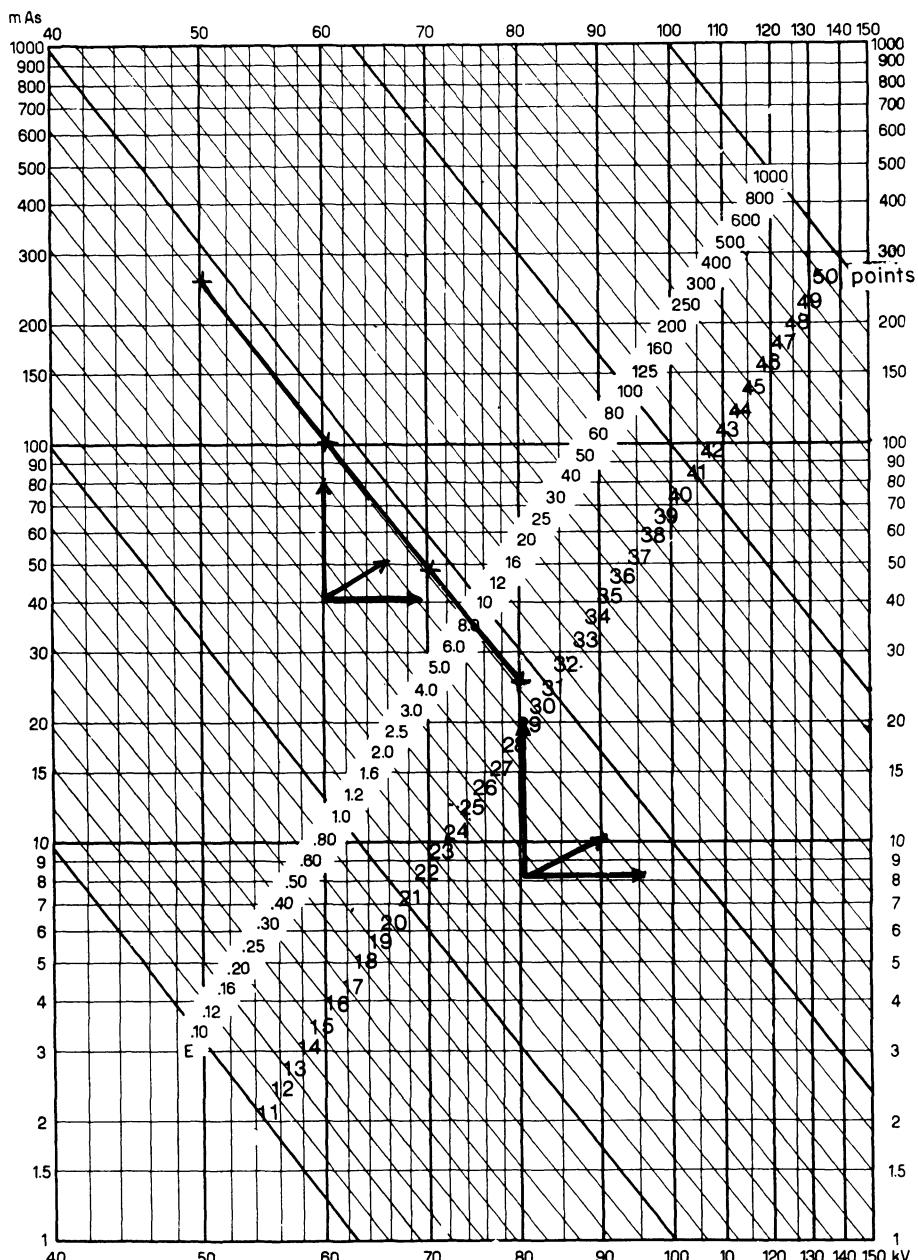


Figure 14.2 Exposure graph with some exposure points indicated by means of E values and point values.

just as within a certain  $E$  value, make several combinations of kV and mAs values. Table 14.5 serves this purpose. From the above tables, one can read off the exposure data or alter them.

*Example:* 32 points are indicated for a kidney exposure and 66 kV and 100 mAs are recommended; 32 is really  $12 + 20$  (taken from the kV and mAs point values). One could also choose a higher kilovoltage, 80 kV (16 points), for example, and leave  $32 - 16 = 16$  points for the mAs value, namely, 40 mAs. At 60 kV (10 points) the mAs product would amount to 20 points, that is 160 mAs.

It is indicated that with three-phase voltage the point value of an exposure can be decreased by two points for twelve-pulse kilovoltage (this is further explained in section 14.3.3.1). If this is applied to the above exposure then this means a point value of  $32 - 2 = 30$  for a six-pulse voltage; 60 kV (10 points) and 100 mAs (20 points) can then, for example, be chosen as the exposure point. Other combinations could be: 50 kV and 250 mAs, 70 kV and 50 mAs, 80 kV and 25 mAs, etc. When we plot these values on the exposure graphs they appear to lie exactly on  $E$  line 8.0. An  $E$  value of 8.0, therefore, corresponds with a point value of 30. In figure 14.2 this example is shown and with the  $E$  values the corresponding point values are also mentioned. Therefore, the exposure graph avoids any confusion over the subdivision of point values in kV points and mAs points and enables us to see all combinations immediately, at a glance.

### 14.3 COMPILING ONE'S OWN EXPOSURE TABLE

*It should be mentioned at the beginning that compiling and using an exposure table are only of value with a completely reliable and standardised processing-room technique.* Only then can one make use of the factors mentioned in the basic tables without needless and costly experimentation and introduce the possible necessary alteration, and compile one's own exposure table, adapted to one's own technique and circumstances. The conditions that must be fulfilled in order to achieve a reliable processing-room technique have been fully discussed in chapter 10. When compiling one's own exposure table, one should differentiate between two situations.

#### 14.3.1 The data in the basic table (2–5 inclusive) can be followed

In this case one is concerned with a given object thickness and, moreover, one has available the grid and intensifying screen types stated, and one can also realise the stated focus-film distance. Thus, one takes a trial exposure (preferably of the skull and/or the thorax) according to the values indicated. If the result is satisfactory then this means that the given  $E$  value is applicable and not only will good results be achieved for this exposure but also for all other exposures when this basic table is followed (after all, this shows that one's own exposure technique is equal to the exposure technique that was followed when the basic table was compiled).

If, however, the trial exposure appears to be over- or under-exposed then this

is proof that the given  $E$  value for one's own technique is too high or too low. One will have to take one or more exposures again with lower or higher mAs values (depending on the case in question) until one achieves the desired exposure. The ratio of the required mAs product to the stated mAs product then provides at the same time the ratio between one's own  $E$  value for that exposure to the stated  $E$  value. One needs to do no more than (without further experimentation) multiply all the stated  $E$  values in the basic exposure table by the ratio factor that has been determined in order to obtain one's own  $E$  values.

*Example:* If the stated 40 mAs appears to be insufficient and if 60 mAs produces a satisfactory exposure then the  $E$  value in the table should be multiplied by  $60/40 = 1\frac{1}{2}$ . This also obtains for all other  $E$  values, after which one can fill in one's own tables or graphs.

In the above it is assumed, as it were, that one starts at the beginning and that one compiles one's own table with the aid of a basic exposure table and exposure graph. However, in practice, this will often be different: there will already be an exposure table which has been compiled either with or without experiment and, since it is considered to be satisfactory, is being used. In that case, one's own data can be plotted on the blank exposure graph with which the  $E$  value for that exposure is determined at the same time. The graph then provides the possibility of using other kilovoltages and the corresponding mAs values required can then be read off directly. One can, if desired, also add one's own tolerance range for that exposure on the  $E$  line. It is not only interesting to compare one's own data with those of the standard table but also important. If one's own  $E$  values are higher, then the exposure will require more radiation than is indicated and one should then strive to reach the indicated  $E$  value (or point value), or, even better, reach lower values. The standard table, therefore, can be a rough guide as to the quality of one's own exposure technique and possibly be a stimulus for improving this. The second possibility is rather more complicated.

#### **14.3.2 The data provided by the basic table (2-5 inclusive) cannot be simply followed**

This is the case with:

- (1) different voltage wave form,
- (2) varying object thickness,
- (3) varying type of intensifying screens,
- (4) varying focus-film distance.

The type of tube and type of film used can also be different. It is obvious that the data from the basic table must then be converted in order to correspond with the new conditions, which as far as the thickness is concerned, for example, can vary from patient to patient. The new  $E$  value has to be obtained by multiplying by a certain factor which has to be determined, and which could be greater or smaller than 1. Since only steps of at least 25 per cent cause a noticeable effect (similar to what has been discussed in section 14.1.2), correction factors are considered which

show steps of this size, whereby one can limit oneself to the largest correction factor = 10. Since every  $E$  value step (in future  $E$ -step), as well as every point (in the point system), indicates a transition of 25 per cent towards the adjacent line, the correction factors can also be expressed in these steps (or points), which greatly facilitates their use in practice.

Table 14.6 shows the relationship between the correction factors and alterations in the number of points; with factors  $> 1$   $E$ -steps must be raised or points must be added; with correction factors  $< 1$ ,  $E$ -steps must be lowered or points must be subtracted.

**Table 14.6 Relationship between correction factors and  $E$ -steps or points**

Correction factors < 1	0.1	0.12	0.16	0.2	0.25	0.3	0.4	0.5	0.6	0.8	1
<i>E</i> -steps (down)											
Points (fewer)	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
Correction factors > 1	1	1.25	1.6	2	2.5	3.0	4.0	5.0	6.0	8.0	10
<i>E</i> -steps (up)											
Points (more)	0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10

*Example:* With a correction factor of 0.5, one will have to move three  $E$ -lines to the left (by doing this one reaches half the  $E$  value). In the point system, three points will have to be subtracted. This also indicates a decrease to one-half the exposure. With a correction factor of 1.6 one will have to move two lines towards the right on the graph or add two points in the point system.

### 14.3.3 Corrections and adaptations of the exposure factor $E$ and the number of points

The conditions that necessitate the correction of the standard values for the benefit of one's own table will now be discussed in turn. The ultimate purpose of this is to obtain one's own  $E$  value or number of points for greatly diverging factors with the greatest chance for an immediate good result.

The data or factors that occur in a standard exposure table are obtained with a technical installation that can be considered as 'standard'. However, even here there is a possibility of variations which can express themselves in different exposure values.

#### 14.3.3.1 Influence of the kilovoltage wave form

In the case of constant potential supply the effective kilovoltage ( $kV_{R.M.S.}$ ) is equal to the peak kilovoltage ( $kV_p$ ). With three-phase equipment (= rotary current apparatus) such as six-valve apparatus (or twelve-valve apparatus) the  $kV_{R.M.S.} = 0.95$  (0.98)  $kV_p$ , whereas for a four-valve unit and a half-wave apparatus the  $kV_{R.M.S.}$  is equal to 0.7  $kV_p$ . This means that the average hardness of the radiation is at its lowest value when using a four-valve or half-wave apparatus. *Due to the great influence of the voltage (hardness of the radiation) on the exposure value, the mAs needed for an exposure with pure d.c. voltage will therefore be less than*

*with four-valve voltage and half-wave equipment.*

In practice, we have to deal with, on the one hand, single-phase alternating voltage (one-pulse, not rectified; two-pulse, rectified by means of four rectifiers), on the other hand, the three-phase alternating voltage (six-pulse, rectified by means of six diodes; twelve-pulse, rectified by twelve rectifiers).

Table 14.7 gives the conversion factors and the number of *E*-value steps or points when changing to another of the three equipment types mentioned.

**Table 14.7 Correction factors and number of *E*-steps with respect to the use or change to a different voltage form**

	One-phase (1 or 2-pulse)	Three-phase (6-pulse)	Three-phase (12-pulse)
Starting from a two-pulse generator (four valves):			
Correction factor	1	0.6	0.5
<i>E</i> -steps or points	0	-2	-3
Starting from a six-pulse generator (six valves):			
Correction factor	1.6	1	0.8
<i>E</i> -steps or points	+2	0	-1

*Example:* When changing from a four-valve to a six-pulse apparatus, the *E* values will have to be multiplied by the factor 0.6. On the graph this can be accomplished by moving two *E*-lines towards the left. In the point system this means a decrease in the point value by two points.

(N.B.: In the example discussed in section 14.2 this has already been mentioned; namely, a decrease from 32 to 30 points.)

*From the above it is apparent that the exposure value with six-valve equipment amounts to only 3/5 of that with four-valve apparatus and only 1/2 with twelve-valve voltage.* Since the six- and twelve-valve units are steadily continuing their successful advance, the standard exposure tables are also being based on these types of apparatus more and more.

#### **14.3.3.2 Influence of the anode material**

The fact that the X-radiation which is emitted by the anode depends both quantitatively and qualitatively on the metal upon which the focal spot is made, was discussed in section 1.2. Therefore, for example, the amount of radiation produced is proportional to the atomic number of that metal and, with equal kV and mA a metal with an atomic number that is 50 per cent lower will also produce 50 per cent less radiation. Since, however, in almost all tubes in medical diagnostic radiography use is made of tungsten anodes (or tungsten pastilles), upon which the focus is located, in practice one will never have to deal with variations or corrections of exposure values in this respect. The special mammography tubes with

their molybdenum anodes are an exception to this. However, it is not difficult to determine the correct exposure factors for this special apparatus and limited application.

#### 14.3.3.3 *Influence of the filter*

If one uses a different filtration than was used with the standard exposure table, this could lead to variations in the exposure value. The total filtration undergone by the radiation (apart from that caused by the patient) before it reaches the patient is caused by all the matter situated between the focus and the film. The total filtration consists of

- (1) the inherent filtration of the tube,
- (2) the extra filtration added,
- (3) the sum of the other substances which filter the radiation.

(1) The inherent filtration of the tube affects the emergent radiation both quantitatively and qualitatively; it therefore has an obvious effect on the exposure value required. The inherent filtration of modern X-ray tubes is about 1.5 mm aluminium equivalent, which means that quite a lot of soft radiation still leaves the tube. With thick objects a large part of this soft radiation never reaches the film, but provides an undesirable contribution to the radiation dose received by the patient—both the skin dose and the integral absorbed dose. In tubes that are alike in every respect but differ in their inherent filtration, the exposure data for a given radiograph will differ, which will, for example, be reflected in a different mAs product at the same voltage: the highest mAs product corresponds to the highest filtration.

(2) In order to reduce the proportion of radiation that does not contribute to image formation and, thus, protect the patient, extra filtration is introduced which, together with the inherent filtration, constitutes sufficient absorption of the soft radiation components. If, for example, the inherent filtration is 1.5 mm aluminium equivalent then by addition of 1.0 mm or 2.0 mm aluminium equivalent, for example, the total filtration is brought to 2.5 mm or 3.5 mm aluminium equivalent. Especially when a fairly high voltage is used (100 kV and higher) it is advisable—and in some places even compulsory—to use quite heavy extra filtration. At voltages above 125 kV a total filtration of as much as 5 mm aluminium equivalent or a combination of 0.1 mm copper and 1 mm aluminium is recommended. Naturally, when the filtration is increased the exposure value required is also increased, but this increase is relatively slight since, after all, it is mainly the radiation that never reaches the film (thus, does not contribute towards the image formation) that is filtered out. The extra filtration should also be considered to include materials that make up the tube accessories, attached to the tube, such as a light-beam diaphragm, certain parts of this (for example the mirror) and possibly a dosimeter chamber for the measurements of the integral dose (see sections 3.8 and 15.12).

(3) Further substances between the tube and the film also contribute to the filtration, such as the table-top used for the investigation and any covering that this table may have, etc. It goes without saying that the total filtration due to these causes must not be an appreciable amount. The rest of the material between

the patient and the film also has a filtering effect which influences the exposure value. These include, for example, the wall of the serial changer, the material between the lead strips of the grid used, the wall of the dosimeter for the automatic exposure device, and the wall of the cassette itself; they all increase the exposure value.

All the materials mentioned in 1, 2 and 3 together filter in a manner that varies from installation to installation. In general, its influence is negligible, but if the exposure values should unexpectedly differ from those calculated or read off, the possibility of an effect due to filtration somewhere between the focus and the film should not be overlooked.

The (total) tube filtration is also becoming more standardised, which dispenses with the need for corrections. However, one should realise that in a much used diagnostic X-ray tube the focus (or focal track) can become very rough with cracks and fissures. The X-rays that originate in these cracks usually no longer have a clear path toward the tube window, but are absorbed or weakened in the walls of the fissures. This manifests itself in a considerable increase in inherent filtration, and causes a noticeable decrease of the useful quantity of radiation with the same kV and mAs. A review (that is an increase) of the exposure values then becomes an urgent necessity. If this need occurs then medically speaking it is better that the tube is replaced. It is true that the radiation to the patient does not increase, but the exposure times do become longer and thus the  $U_m$  increases.

#### **14.3.3.4 Space-charge effect ('Durchgriff')**

When the space-charge effect ('Durchgriff') is large, then the X-rays will also be generated at low values of the high tension. The effective hardness of the X-rays produced is then lower than at small space-charge effect. It is obvious that when, for example, the standard exposure table has been compiled by means of a tube with a great Durchgriff, then the milliamperes that flow in the tube will have less effect on average than when (at the same kilovoltage) they flow with the same current value in a tube with a small Durchgriff. In this latter tube, therefore, the mAs value (or the exposure value) would be less. With tank units one can really recognise this effect, but in the 'large' tubes the differences are not so great, and in practice one does not need to correct for this. When six-valve, twelve-valve or pure d.c. are used, the Durchgriff effect does not occur, since the high voltage is kept up continually because of sufficiently low ripple.

#### **14.3.3.5 Correction with respect to a different object thickness**

Frequently, the body part to be examined will have other measurements than the 'normal' value marked in the basic exposure table. Under-estimation of the thickness leads to under-exposure and over-estimation to over-exposure, resulting in the need for changes (if possible) in the development process in the processing room and non-optimum results. Unfortunately, it is not always possible to assess correctly the content and consistency of every individual body part to be radiographed beforehand. In fact, all we can really do is judge from external dimensions such as the diameter or circumference of the part. When using tables or rules of thumb with reference to these dimensions, we should, therefore, not be surprised if now and then the results obtained are unsatisfactory.

The factors by which the 'normal' exposure value should be multiplied vary widely from thin to fat. If we assume a value of 1 for the normal case then we can

Table 14.8 Correction factors

Very gaunt (lean or thin)	0.5	Thick-set (robust)	1.5
Gaunt	0.6	Stout (heavy)	3.0
Slim	0.8	Extremely corpulent	6.0
Normal	1.0		

apply the scale in table 14.8 for the part of the body in question. Both the very thin (emaciated infants) and the extremely corpulent patients fall outside these (very rough) qualifications. The category in which one places the part of the body in question depends on how one estimates it, and in the course of time and with experience one acquires a good eye for this. This 'external' evaluation naturally says nothing about the 'internal' composition of the tissues involved, but in general this does not vary much in terms of the effective atomic number. However, one will notice from time to time that a mistake has been made about a particular patient, the unexpected absorption showing that he is unusually 'solid' from an X-ray point of view.

One can usually omit corrections for varying dimensions of the skull, as the absorption of X-radiation in skull X-rays is mainly determined by the bony structures; greater dimensions do not (necessarily) mean thicker skull bones.

One comes closer to the goal of a correct exposure if one measures the object (in cm) and compares the result with the 'normal' dimensions given in the table. There are various rules of thumb for use in this connection. The rule of thumb for the mAs value correction is: *each cm increase in tissue (object thickness) requires an increase of 25 per cent in the mAs value, and each decrease of 1 cm a decrease of 25 per cent in the mAs product*. The rule of thumb for the kV correction is: *each cm increase in tissue thickness requires an increase of 5 per cent in the voltage, each cm decrease a decrease of 5 per cent in the voltage*. For voltages in the diagnostic range of 60–90 kV this works out to 3–4 kV/cm of tissue. Here it is also easier to make use of moving the *E* lines or adding or subtracting points. Since, in this case we are concerned with 25 per cent steps per cm, the correction table 14.6 can be used. In table 14.9 the lower limit is assumed to be 4 times as thin and the upper limit 6 times as thick.

In the exposure graph shown in figure 14.2 are indicated:

Table 14.9 Correction values and number of *E*-steps or points with respect to varying thickness

<i>Thicker than normal</i>									
No. of cm	0 (normal)	+1	+2	+3	+4	+5	+6	+7	+8
Correction factor	1	1.2	1.6	2.0	2.5	3	4	5	6
No. of <i>E</i> -steps or points	0	+1	+2	+3	+4	+5	+6	+7	+8

<i>Thinner than normal</i>							
No. of cm	0 (normal)	-1	-2	-3	-4	-5	-6
Correction factor	0.8	0.6	0.5	0.4	0.3	0.25	
No. of <i>E</i> -steps or points	-1	-2	-3	-4	-5	-6	

- (1) Exposure point 60 kV 40 mAs and the changes in a three-step (points) higher value (60 kV 80 mAs, 69 kV 40 mAs, 66 kV 50 mAs).
- (2) Exposure point 60 kV 100 mAs (30 Siemens points) with three other combinations of kV and mAs (50 kV 250 mAs, 70 kV 50 mAs, 80 kV 25 mAs).
- (3) An example of alteration of exposure data, starting from exposure point 80 kV 8 mAs, equal to 25 points, when the  $E$  value has to be increased by 4 steps (or a corresponding number of points). One may go in an arbitrary direction towards the new  $E$  line (this example is similar to the one in (1)).

These examples demonstrate the usefulness of the graphs, both for the  $E$  value (Philips) and the point values (Siemens).

*Example:* When a radiograph is produced of a part of the body of normal thickness with, for example, 60 kV and 40 mAs ( $E = 3.0$ ), then with the same conditions but a 3 cm thicker object one would arrive 3 lines further on, namely, on the line  $E = 6$  (see figure 14.2 where this example is illustrated). At the same kilovoltage this is equal to 80 mAs. If the mAs remains at 40 then 69 kV would be required. In the first case, one should follow the (vertical) voltage line in an upward direction, in the second case, one should follow the horizontal mAs line towards the right to the third point of intersection with the diagonal lines. It goes without saying that one could arbitrarily continue in an oblique direction 3 lines further on and choose, for example, 66 kV and 50 mAs (expressed in points one would move from 26 points to 29 points).

#### 14.3.3.6 Correction for the use of a (different) grid

In general, one has to deal with only two or three types of grid in practice, and these are usually characterised by the number of lead strips per cm and their ratio (see chapter 6, section 6.3.6.7). In practice, it is important to know by how much the exposure must be increased in order to obtain the same density on the film as without the use of a grid. It is true that this *grid factor* does not indicate the degree of improvement in contrast; it indicates by how much the exposure should be increased. For very thin, stationary, non-focused, fine-line grids a grid factor of about 1.8 can be assumed; for the ordinary, moving, usually focused grids (with a ratio of 7 or 10) assume a factor of  $2\frac{1}{2}$ , and for the moving, high-voltage grids (with a ratio of 12 or more) a factor of 4 (the movement of the grid does not influence the grid factor).

**Table 14.10 Correction factors and number of  $E$ -steps or point correction with respect to the use or change of grid, starting from exposures without grid (factor = 1)**

	No grid	Fine-line grid	Normal grid	High-voltage grid
Correction factor	1	1.8	2.5	4
$E$ -steps or point correction	0	3	4	6

If one changes to another grid, one should realise first of all that: *a higher grid factor requires a greater exposure value* (or, at the same kilovoltage a higher mAs product). The relationship is expressed by

$$\text{mAs with new grid} = \frac{\text{new grid factor}}{\text{old grid factor}} \times \text{mAs that was used with the old grid}$$

Instead of the conversion with the ratio factor, one could also move the *E* lines on the graph, or alter the number of points according to table 14.10.

(N.B.: Some values are in round figures).

**Examples:** Changing from a fine grid to a normal grid the *E* value becomes 2.5/1.8 times as great. Without this calculation one could move the *E* line 1 line towards the right. In the point system 1 point is added to the number of points. Changing from a high-voltage grid to a normal grid one would, therefore, decrease by 2. On the exposure graph this means a move of 2 lines towards the left and the number of points is decreased by 2.

It should be noted that when the beam is narrowly restricted in cross-section by means of a diaphragm (as, for example, for a 9 × 12 cm radiograph), the scattered radiation is reduced to such an extent that even without a grid the contrast is greatly improved. The absence of part of the scatter in this case, which would otherwise contribute to the photographic density, would cause the radiograph to be under-exposed and, thus, a greater mAs product should be selected than when taking this radiograph without beam restriction. Beam limitation in this case, therefore, has a scatter-grid effect, and thus also requires an increase in the mAs value by a factor that is almost equal to the value of a grid factor. Thus, a general stomach radiograph 24 × 30 cm with grid could require the same electrical factors as a detail radiograph (spot film) such as 9 × 12 cm taken without a grid.

A similar effect occurs in macroradiography. Here, some of the scattered radiation makes no contribution to the density because of the influence of the inverse square law, since the distance between the source of scatter (the object, that is the patient) and the film is increased. Here also, therefore, an increase in the mAs product by a factor of 1.5-2 is necessary (see section 12.3).

Just as in the case of strict beam limitation, one can often omit the use of a grid. Compared with a non-enlarged radiograph with grid, the macroradiograph without a grid does not require a higher or lower exposure value. It follows, therefore, that the grid factor of a grid is not constant, but depends on the field size and object-film distance—apart from the voltage and thickness of the object. When these first two factors differ widely from the standard values, the normal grid factor can no longer be used without correction. It generally decreases with the amount of scattered radiation emerging from the object. There is thus little point in using a grid in combination with strict beam limitation and macroradiography; in fact, the use of a grid is sometimes not advisable in such cases, as there is little scattered radiation to remove, and the grid always absorbs a certain amount of primary radiation. The contrast-improving factor (see section 6.3.6.7) of the grid is then middling or even poor in these cases. In practice, however, the grid factor is taken as constant in all cases where a grid is used.

#### 14.3.3.7 Correction in connection with the use of (different) screens

The use of different types of intensifying screens more often than the use of different grids occurs in connection with the desired definition or short exposure times. The compromise is made by the universal or normal screens with a factor of about 10. The fine-grained screens are slower and have a factor of about 6. For the fast screens one can assume a factor of about 20\*. This classification represents a useful practical arrangement for the very many types available under different names and with different factors. By far the most often used screens are the universal types, and most exposure tables are based on these.

Changing to another type of screen means that one should first of all realise that *a higher intensification factor requires a lower exposure value* (or, with the same kilovoltage a *lower mAs product*). The relationship is expressed by

$$\text{mAs with screens} = \frac{\text{mAs without screens}}{\text{intensification factor}}$$

when one deals with a change from a radiograph without screens to the same radiograph with screens. This is of little practical significance, as few radiographs are taken without screens. Of greater practical importance is

$$\text{mAs with new screens} = \frac{\text{intensification factor old screens}}{\text{intensification factor new screens}} \times \text{mAs with old screens}$$

It is true that the intensification factors do not have a constant value, but depend, amongst other things, on the quality of the incident radiation (increases at higher voltages). In routine practice, the intensification factor of a certain type of screen can, however, be considered to be constant unless it is stated otherwise.

Instead of conversion with correction factors one can also find the new exposure value or point value easily by moving the *E* lines or by altering the number of points. To this table 14.11 gives a decisive answer. (N.B.: Some values are in round figures.)

**Table 14.11 Correction factors and number of *E*-steps or point correction with respect to the use or change of intensifying screens, starting with exposures with screens with a factor of 10**

	No screen	High definition ( <i>f</i> 6)	Normal ( <i>f</i> 10)	Fast ( <i>f</i> 20)
Correction factor	10	1.6	1	0.5
<i>E</i> -steps or point correction	+10	+2	0	-3

\*In view of the recent development in the field of intensifying screens (use of rare earths; see chapter 8, section 8.3.6), however, factors considerably higher still can be expected.

*Example:* Changing from normal screens with a factor of 10 to fine-grained screens with a factor of 6 requires an addition of 2 points; thus, on the exposure graph one should move 2 lines towards the right. When changing to film without intensifying screens, one moves 10 lines towards the right. When changing from normal screens to fast screens, 3 points should be subtracted. On the graph this means that one should move 3 *E* lines towards the left.

#### 14.3.3.8 Correction with respect to the focus-film distance

If an exposure is made at a different distance than is given, then one can simply apply the inverse square law to the exposure value. Expressed in the mAs product this means

$$\text{new mAs} = \frac{\text{new distance}^2}{\text{old distance}^2} \times \text{old mAs}$$

If one changes to a different distance one should realise first of all that *a greater distance requires a greater exposure value* (or at the same kilovoltage a greater mAs product) (table 14.12). A rough rounding of figures (which one can easily calcu-

Table 14.12

<i>Ff</i> (cm)	50	70	100	120	150	200
mAs	25	: 49	: 100	: 144	: 225	: 400
product	1	: 2	: 4	: 6	: 9	: 16

Table 14.13 Correction factors and *E*-line shifts or point correction with respect to deviations from the assumed 100 cm standard distance

Distance (cm)	50	70	100	120	150	200
Correction factor	0.25	0.5	1	1.5	2.25	4
<i>E</i> -steps or point correction	-6	-3	0	+2	+3	+6

late mentally or remember) is sufficient in this case. The distances in table 14.12 (in cm; top row) are in proportion to the mAs products listed in the second row or in round figures for use in practice as stated in the third row.

Instead of conversion with correction factors one can also, in this case, easily find the new exposure value or point value by moving the *E* lines or by altering the number of points according to table 14.13. (N.B.: Some values are in round figures.)

**Example:** If one decides to take a radiograph of the spine at an  $Ff$  of 1.50 m instead of at 100 cm, then this means 2.25 times as great an  $E$  value. In practice, one can apply this immediately without calculation by moving the  $E$  line 3 steps towards the right or by adding 3 points to the number of points.

#### **14.3.3.9 Correction for film quality**

It is obvious that the sensitivity of the film must have a bearing on the mAs product required. The greater the sensitivity of the film the lower the mAs value. Since, apart from the sensitivity, the gradation also plays an important part (see section 8.2.9) the correction of the exposure value of a different film type is not as simple to give as, for example, for a different grid factor. One should also consider the film and intensifying screens more or less as a single unit which reacts jointly to the exposure. Thus, the sensitivity of a film may become completely different when it is used in combination with other screens than the screens previously used which, for example, emit a luminescent light of a different colour. Since virtually all brands of X-ray film are not only highly sensitive, but also have a steep gradation (rich in contrast), one can almost consider them rather standardised at the moment, and the characteristics do not vary to such an extent from the film used for the standard exposure table that a correction factor is necessary. However, since we can still expect new types of film to be developed, with either greater speed or greater definition as prime purpose, one should keep possible correction in mind. At present, there are already extremely sensitive films for which a correction factor of 0.6–0.8 can be assumed; this corresponds with an  $E$ -line movement or point correction of –1 to –2. There are also ultrafine-grained films in use, for example, for mammography, also for which correction factors ( $> 1$ , as they are less sensitive) or an  $E$ -line movement or point correction (in this case positive values) are available. As these techniques are still being developed, and since there are still no standardised values, no attempt will be made to compile a table at this stage. In practice, it is recommended that only one type of film and as few different types of intensifying screens are used as possible.

#### **14.3.3.10 Example of determining one's own data; validity**

When applying the above-mentioned corrections (if necessary) the drawing up of one's own exposure data has become just a matter of taking a few readings.

**Example:** The basic table (see section 14.1.4) indicates the following data: thickness 20 cm, grid factor  $2\frac{1}{2}$ , screen factor 10, focus-film distance 100 cm, kilovoltage 70 kV, mAs value 60 and  $E$  value 10 (six-valve apparatus). However, when for this particular exposure, the data are different, namely, thickness 21 cm, screen factor 6, and the exposure is made with a four-valve unit, then one has to deal with three correction factors, all of which are greater than 1, namely 1.2 and 1.6 and again 1.6. Their product amounts to about 3 which means that, for this exposure, the exposure point on the  $E$  line (in round figures) becomes  $3 \times 10 = 30$ . One can find the new  $E$  line without calculations by taking the necessary steps from  $E$  line 10, namely  $1 + 2 + 2 = 5$  (see tables 14.7 and 14.11). This means that by taking 5 steps higher up from  $E$  line 10 the new  $E$  line 30 is reached where one can again determine the most suitable combination of kV and mAs as exposure point.

When applying the point system, the course of events is similar: four points are added to the number of points indicated, after which one can look through the kV and mAs lists of points.

Once one has compiled an exposure table then one should not imagine that this can be maintained unchanged for years, since the development of the X-ray photographic aids has by no means yet been concluded. The tendency towards better definition will continue to influence the technique; the striving towards less movement unsharpness  $U_m$  (shorter exposure times) as well as less geometrical unsharpness  $U_g$  (finer focus) and a decrease in screen unsharpness  $U_i$ . An exposure table, therefore, just like so many other factors in radiography, is not static but dynamic.

#### 14.4 THE RELATIONSHIP BETWEEN HIGHER KILOVOLTAGES, TUBE LOADING, FOCUS SIZE AND DOSE

It has been pointed out again and again that one can obtain satisfactory or at least for certain purposes very useful radiographs with higher kilovoltages than is usual in routine practice if one keeps strictly to the exposure value. Here we are concerned especially with radiographs taken with voltages over 100 kV. It is meaningful to ask oneself whether the high kilovoltage technique has any advantages and, if so, what these advantages are. However, first of all (even if small) a disadvantage: at high kilovoltages the mAs values required are small (at 120 kV possibly even less than 1 mAs). A mistake (in setting the controls, etc.) of 2 mAs at 5 mAs means a mistake of 40 per cent, at 20 mAs only 10 per cent. Therefore, the exposure factors are more critical and the risk of incorrect exposure is greater than at low kilovoltages.

However, the advantages are important. If, for example, one alters the kilovoltage by a factor  $a$  then the intensity of exposure changes by a factor of  $a^5$ , the tube load only by factor  $a$  (therefore, this is directly proportional) and the skin dose of the patient by a factor of  $a^2$  (at most  $a^3$ ). In order to clarify the above here are some considerations: If one should take a radiograph with twice the kilovoltage (with the same mAs), then this means a doubling of the tube load (the number of watt-seconds is doubled because tube load = kV × mAs). At twice the kilovoltage and the same mAs product, the skin dose is increased by 4-8 times. The photographic effect of twice the kilovoltage with the same mAs product is increased by a power of 5, thus  $2^5 = 32$  times. The consequences of these power relationships are great and many-sided and are best explained with the aid of a numerical example\*.

*Technique A:* Given a certain radiographic exposure requires 60 kV 64 mAs. It is taken with 400 mA at 0.16 s, a tube with rotating anode, focus 1.2 mm (load 24 kW). The kilovoltage is now doubled to 120 kV so that the mAs product can be divided by  $2^5 = 32$  and  $64/32 = 2$  mAs. However, the tube would be overloaded with 120 kV and 400 mA (48 kW); in order to obtain the same load the current value is cut by one-half ( $60 \times 400 = 120 \times 200$ ) (is again 24 kW). The new exposure, therefore, can be:

\*This example has been chosen for didactic reasons; it is very diagrammatic and takes neither other  $p$  values into account nor the type of apparatus (1-, 2-, 6- or 12-pulse generators)

**Technique B:** Controls set at 120 kV 2 mAs (200 mA for 0.01 s) (24 kW). In this way, one obtains the shortest possible exposure time and so avoids movement unsharpness ( $U_m$ ). If, however, the original time (0.16 s) was found to be sufficiently short then the radiographic exposure can be adjusted as follows:

**Technique C:** Controls set at 120 kV 2 mAs (as follows: 12.5 mA and 0.16 s) (tube load 1.5 kW). The smaller load requires a focus with a much smaller loading capacity (1.5 instead of 24 kW); therefore, the surface area of the focus needs only to be 16 times as small as in the first two cases (technique A and B), or  $\sqrt{16} = 4$  times smaller linear dimensions, so that this exposure can be made with a 0.3 mm focus instead of a 1.2 mm focus. In this way the geometrical unsharpness  $U_g$  due to the nature of the case becomes much less (four times as small). This is possible with the use of a double-focus tube 1.2/0.3 mm.

It is possible also, by means of low-powered equipment but with high voltages, to take heavy exposures with sufficiently short exposure times.

Now some facts concerning the dose. Assume that with technique A the patient receives an exposure of 1 R on his back. By doubling the kilovoltage this would become (assuming the third power relationship) 8 R. Due to the gains made by the factor of 32 (technique B and C), however, this exposure becomes  $8/32 = 0.25$  R, or a dose of about 2.5 mGy (0.25 rd). If a second power is assumed, then the exposure becomes only  $4/32 = 0.12$  R or a dose of about 1.2 mGy (0.12 rd).

*Therefore, at higher kilovoltages the patient receives a smaller skin dose.*

As far as the integral absorbed dose is concerned the principle is the same as that for the skin dose. The decrease of the integral absorbed dose with an increase in kilovoltage is less pronounced, however, than the decrease in the skin dose.

**Conclusion:** Using a higher kilovoltage enables one to decrease the  $U_m$  (shorter exposure time) and the  $U_g$  (choice of finer focus) and is an advantage as far as the dose is concerned. At the same time the life of the tube is lengthened.

Apart from the medical reasons, the use of high kilovoltage is also attractive for technical reasons. This will be further explained later (see section 14.6.6).

## 14.5 AUTOMATIC DENSITY CONTROL

It is evident from the above that the ideal exposure value for a given part of the body varies from one patient to another owing to differences in thickness and composition. If the same exposure data are used for radiographing, say, the lungs of a group of patients, some of the radiographs will turn out under- or over-exposed. Even when the corrections mentioned in the previous paragraphs, such as those related to thickness and so on, are applied by experienced radiographers, there will still be a number of faulty results. For this reason, attempts have been made to replace the individual decision and estimation factor by an objective automatic mechanism, which can ensure a correct exposure every time, and in this they have succeeded.

This automatic mechanism was first proposed by Franke as long ago as 1929, under the name *automatic exposure timer*; however, at the time it did not come into general use because of the technical difficulties involved, which could not be

adequately solved. At present, however, various types of automatic exposure devices are available. *An automatic exposure timer is a device that terminates the exposure when a pre-selected amount of radiation reaches the film.* There are two main types of automatic exposure devices, whose principles of operation are different:

- (1) the exposure timer that makes use of *ionisation*,
- (2) the exposure timer that makes use of *fluorescence*.

#### 14.5.1 Automatic density control by means of ionisation

The automatic exposure timer that is based on the ionising effect of X-rays consists of a very sensitive, flat ionisation chamber that is placed between the patient and the cassette (when a grid is used then usually between grid and cassette) (figure 14.3).

This ionisation chamber should be constructed in such a way that there is no possibility of uneven radiation absorption which would cause it to be visible on the radiograph as an interfering shadow. The ionisation current produced by the X-rays is used to charge a condenser. When the charge on the condenser reaches a certain pre-set value, the exposure is terminated.

The most common position of the ionisation chamber is in front of the cassette. Although the ionisation chamber is made in such a way that it does not show on the film it does, however, represent a filter that absorbs X-rays, even if the amount is small. With modern equipment, positioning of the ionisation chamber behind the cassette only occurs in some portable units, where the chamber is placed behind the cassette in a special drawer as a separate unit (for example Nanomobil). Placing an ionisation chamber behind the cassette has a disadvantage. Part of the radiation is absorbed and scattered by the cassette and its contents, and thus does

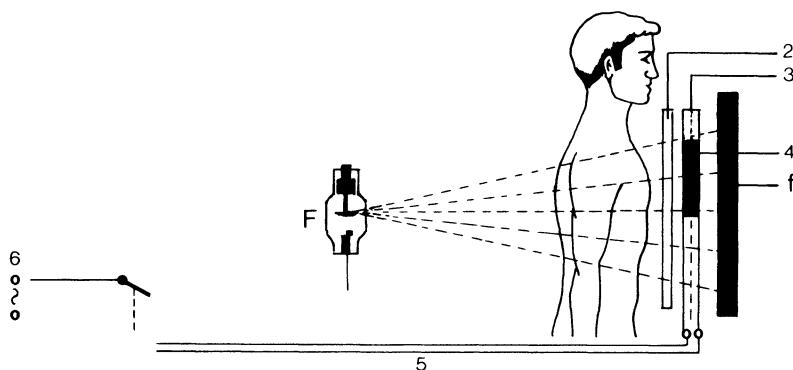


Figure 14.3 Automatic exposure by means of an ionisation chamber. The beam emerging from X-ray tube F penetrates the patient, the grid (2) and the ionisation chamber (3), in which the measuring field (4) has been selected in such a way that this gives a true measurement ('dominates') for the correct density of the film (f). As soon as the exposure is sufficient the ionisation chamber switches off the high voltage via the supply cables (5) and thereby terminates the exposure.

not reach the ionisation chamber. This would not matter if it was not for the fact that the decrease in radiation intensity caused by this is naturally dependent on the radiation quality. With low kV (soft radiation) the absorption is many times as great as with a high kV. The exposure behind the cassette, therefore, depending on the radiation quality, is a factor of 2–6 lower than that in front of the cassette. The measurement, and with that the density of the film, therefore, becomes extraordinarily dependent on the kilovoltage.

#### 14.5.2 Automatic density control by means of fluorescence (photo-electric method)

The method of automatic exposure, which makes use of luminescence, is based on the capture of radiation on a fluorescent screen placed behind a cassette (*photo pick-up*). In this pick-up device, which contains a very sensitive photocell, a *photomultiplier* tube, this light is transformed into an electric current, which is proportional to the intensity of the fluorescent light which, as is the case in the ionisation method, charges a capacitor to a pre-set value. When this charge is reached, the exposure is also terminated via the timer. Instruments built according to this principle are called *phototimers*. Originally, it was not possible to construct the phototimer in such a way that the wall of the measuring chamber absorbed a minimum of radiation. This photo pick-up, therefore, had to be placed behind the cassette, so that its image would not show on the film; this, as described above, has its disadvantages. In this case, cassettes had to be used that had lids without lead, since otherwise the X-rays were unable to reach the photocell in sufficient quantities. Moreover, the various cassettes with their screens all had to have identical absorption.

For the same reason the bucky table with a cassette tray, which is radiolucent, is essential for use with this type of phototimer; in general, an ordinary cassette tray provided with an opening in its centre was used for this purpose. For exposures with a fluoroscopic screen or image intensifier the photocell is usually directed to the centre of the image field by means of an optical system.

Hitherto, the newest development in the field of automatic exposure timers makes use of a measuring chamber, where again use is made of small fluorescent screens, which absorb little radiation and are placed in front of the cassette, similar to the ionisation chamber method. The light is led via a transparent flat sheet to the outside of the image plane and here is ‘caught’ by a photocell (a photomultiplier). A signal is produced by means of an electronic device, when the proper exposure is reached, and this terminates the exposure in the control panel. Exposure times of less than 0.01 are possible with all modern methods, even those that use ionisation chambers.

#### 14.5.3 Automatic exposure timers in practice: the dominant

Originally, automatic exposure was almost exclusively used in photofluorography in mass examinations of the chest. Here it is particularly important, because a series of photofluorographs is made on one film strip and, thus, no individual corrections can be made for under- or over-exposure by over- or under-developing, respectively. For these investigations, which are primarily carried out with the aid

of the fluoroscopic image method, the photo pick-up can simply be directed towards the fluorescent screen in the light-tight hood.

The automatic exposure technique later began to be applied in routine diagnostic X-ray technique for all kinds of examinations, and instruments of both the ionisation and the fluorescent type have been designed for use with serial changers, bucky tables and wall stands. Care should be taken that the most important part of the object, as far as the particular radiographic image is concerned, controls the exposure time and, therefore, the density. This important object part was called the '*dominant*' by Franke. If the dominant does not determine the density, it may happen that insignificant details influence the exposure time in an undesirable way. If, for example, in a chest X-ray, the pick-up is directed towards the strongly absorbing mediastinum and the exposure time were determined by this, then in this case the exposure would be terminated much too late and the lung fields would be considerably over-exposed. Therefore, for an ordinary chest X-ray the lungs represent the dominant.

If, however, one wishes to radiograph the thoracic vertebrae, then these become the dominant that should determine the density. If the lung fields were taken as the dominant in this case, the exposure would be terminated much too soon and, whereas the lung fields would here give an excellent picture of the pre-selected density, the vertebrae would be greatly under-exposed, so that one could not judge their condition from the radiograph.

Similarly, it is clear that radiation falling outside the object would terminate the exposure too soon, leading to under-exposure of the parts of interest. For this reason, automatic exposure devices should permit the setting up of the part to be radiographed (field of measurement) so that it conforms with the dominant. In many cases one has either the possibility of making a choice from several fields of measurement or the ability to move the field of measurement.

When a light-beam diaphragm is used it is desirable that it is known where exactly in the illuminated field the dominant areas are situated. This has become possible by indicating this on the transparent perspex window of the light-beam diaphragm along with the usual centering cross (figure 14.4).

It goes without saying that standardisation of processing-room technique as well as of the films and intensifying screens used is a strict requirement for good results with an automatic exposure device. As far as the intensifying screens are concerned, it is advisable to restrict oneself to screens of a certain type and make (for example universal), since otherwise differences in exposure may be produced. When changing to different films and/or intensifying screens, the sensitivity of the automatic exposure timer should be adjusted. In most automatic exposure devices, apart from the choice of placing the measuring field(s) in connection with the dominant, it is also possible to choose one of different densities. With this *density selector* one can increase or decrease the sensitivity of the measuring system with which one can obtain a greater or lesser density, as the case may be. This can be adjusted (for example, for a 50 per cent higher and a 50 per cent lower sensitivity) when the apparatus is installed.

The task of the automatic exposure device is to stop the exposure (in this case the X-radiation) at a particular moment. Theoretically, if one applied a sufficiently high kilovoltage (also for the heaviest objects) and a current value that is low enough that a long exposure time would not lead to overloading, the automatic

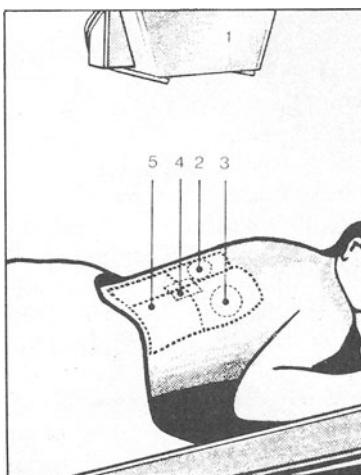


Figure 14.4 The possibility of adjustment of the dominant fields by means of a light-beam diaphragm. The illuminated field on the patient (5) by means of the light-beam diaphragm contains, apart from the projection of the wire cross (for centering and positioning), the image of the location of the round dominant fields (2 and 3) and the central rectangular dominant field (4). These fields, therefore, indicate where the precise dominant positions are located in the ionisation chamber with respect to the patient.

exposure device could produce radiographs of most different parts of the body. It is true that the radiographs would have similar densities, but there would be no question of optimum image quality, that is neither optimum contrast nor optimum definition. It is therefore essential that when automatic exposure devices are used the exposure factors are adapted to the individual requirements of every exposure.

This, first of all, is true in connection with the penetrability of the object as far as the kilovoltage is concerned on which (in relation to the movement unsharpness) the exposure time depends to a great extent. With almost all units free choice of current value is then no longer possible as this is automatically adjusted. With this pre-selection of the kilovoltage and tube current value, that is coupled with this, together determining the maximum permissible load on the tube, the automatic exposure device then ensures a choice of the correct time within this range which, therefore, can be the maximum suitable time for the permissible load on the tube.

This is clearly illustrated with serial radiographs of the duodenal cap, when the patient is turned in every desired position and the radiographs all show equivalent densities without having to adjust the apparatus in any way. With this, of course, the exposure time for the p-a projection is shorter than for example, in the oblique projection.

In many units suitable for automatic exposure control the different objects (body parts) are subdivided into several groups according to their required exposure value ( $E$ ); a particular combination of exposure factors with latitude in the exposure time is valid for each group. When changing to an investigation of

another body part such as the gall bladder, for example, the exposure factors, among other things, should be altered; in any case the kilovoltage should be decreased. Automatic exposure does not only signify a simplification, but also an improvement in the radiographic technique. With this, one has the freedom to choose a higher kilovoltage when a radiograph has to be taken of a very obese patient for example. It is true that the automatic exposure device would ensure the correct density even without this alteration in the kilovoltage, but the exposure time could become too long. Likewise, one can purposely choose an extra high kilovoltage for a rapidly moving object of normal thickness, in order to shorten the exposure time. If we again take the duodenal cap investigation as an example, then without automatic exposure control the exposure factors would have to be adjusted according to the position of the patient: p-a, lateral or oblique. The same is true for thicker or thinner subjects. If, however, one works with an automatic exposure device, this adjustment is omitted, although the setting must be such that even the greatest amount of absorption that can be expected can be coped with. Therefore, the factors should be based on an  $E$  value that is, for example, four times as high as is indicated in the basic table for normal absorption. If these, for example, amount to 80 kV 95 mAs for an  $E$  value of 30, then one should alter them as follows: for example, 80 kV 380 mAs for an  $E$  value of 120 (see exposure graph). This, of course, has the consequence that the automatic exposure device switches off within these values, before the maximum load of the focus has been reached and, therefore, the exposure could have been shorter.

A disadvantage of the automatic exposure device is, therefore, that the kilovoltage and the corresponding current value and time for every exposure has to be based on the thickest object likely to be encountered. The result of this is that the pre-set exposure time is relatively long. During this long exposure time the tube cannot withstand as high a current as in a short one. This means that in those cases where the exposure time is shorter, and these are the majority, the tube is not optimally loaded and, therefore, there may be some loss of definition especially in some rapidly moving objects.

#### 14.5.4 Adjustment of the exposure time limits in automatic exposure units

In connection with this, it is of importance to fix our attention briefly on two (technical) concepts which play a part in automatic exposure control. These are the upper exposure-time limit and the lower exposure-time limit.

*Upper time limit.* For a particular permissible tube loading there is a particular maximum permissible length of exposure (at a given kV and mA). If this is exceeded the tube is overloaded and ruined. In the modern control panels the maximum tube current (mA) depends on the kilovoltage (kV) and is tied to the exposure time adjusted on the control panel. If one chooses a longer exposure time, then the adjusted tube current is lower. If one has underestimated the attenuation in the object and thereby chosen a pre-adjusted (maximum) exposure time that is too short, then the apparatus will switch off when it reaches this time before the necessary exposure that produces the correct density has been reached. The result will then be an under-exposed radiograph. It is then said that the *upper time limit* has been exceeded. The automatic exposure device can take measures against

over-exposure, but when the pre-adjusted time is too short it cannot act against under-exposure. In some units, when an incorrect exposure is made because the time limit has been exceeded one is warned by means of an audible signal.

**Lower time limit.** The shortest interval of time that is possible between the beginning of the exposure and the termination is determined by the inertia of the timing device and is called the *lower time limit*. In the older system this amounts to  $\pm 0.05$  s (50 ms) and in the latest apparatus with electronic timers (thyristors) fractions of a millisecond.

Modern systems that have not yet been equipped with thyristor timers have a lower limit of  $\pm 0.005$  s (5 ms). Knowledge of the lower time limit is of importance because it could happen that when too high a kV (and/or mA) is chosen for a part of the body that absorbs little, the required exposure time could turn out shorter than the shortest possible switching time. This causes incorrectly (over-) exposed radiographs. This could occur in older units especially. However, also with modern units, equipped with (anode) photofluorographic cameras, which photograph the viewing screen of an image intensifier, the lower time limit could easily prove to be too long for the very short exposures required with these and an over-exposure could be the result.

#### 14.5.5 Automatic exposure control with maximum load on the focus

This automatic full loading has as its aim the selection of a combination of exposure factors so that the focus just attains the maximum permissible temperature at the end of the exposure (the maximum load). With this one can distinguish between two possibilities:

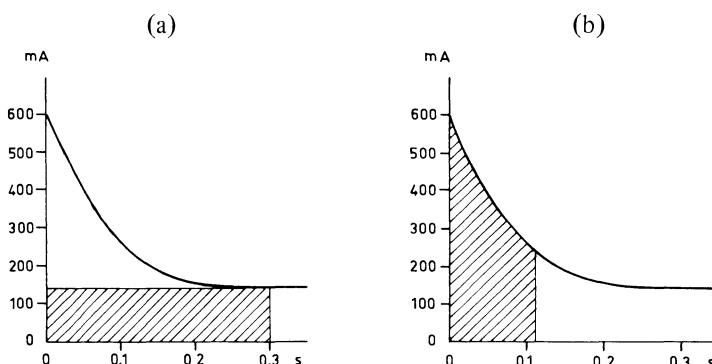


Figure 14.5 Curves that indicate the maximum permissible load at a particular kilovoltage, expressed as the relationship between tube current (mA) and time (s). Example: 39 mAs are required. (a) *Constant current*: for example 130 mA for 0.3 s ('isowatt' as kV and mA do not change). The maximum permissible load is reached at the end of the exposure. The energy applied is represented by the shaded area. The focus is underloaded at the beginning of the exposure. (b) *Falling load*: Right from the start of the exposure the focus temperature is driven up to its maximum permissible and then, following the curve, the current (mA) is reduced and the exposure is terminated when the shaded area is equal to that in (a). It is obvious that with this technique the exposure time is considerably shorter.

#### 14.5.5.1 *The maximum load is reached after a previously known and adjusted exposure time*

With this method (the most common for the hitherto current apparatus) the required exposure factors (kV, mAs) are adjusted for the exposure and both the kilovoltage and the current value remain constant throughout the entire exposure time (constant loading, *iso-watt* as the  $kV \times mAs$  remains the same). At the end of the exposure time the optimum temperature of the focus is just reached and continuation of the exposure would destroy the focus. Figure 14.5a shows such an exposure where the rectangular surface represents the tube load in kWs.

#### 14.5.5.2 *The optimum load is reached immediately and is maintained throughout the time of exposure: falling load*

As a result of the fact that with automatic density control the exposure time is not known in advance, a new technique was devised which was introduced by Bouwers as early as 1936: *the falling load*\* (see figure 14.5b).

The principle of this method is simple: one starts by supplying so much energy to the focus that it almost immediately reaches its maximum permissible temperature. The initial value of the current (at the beginning of the exposure) is thus always the same, no matter what the exposure time. Soon after the exposure is initiated the current falls gradually so as to create an equilibrium between, on the one hand, the energy supply to the focus and, on the other hand, the energy given up by it (heat dissipation). However, it should be ensured that the decrease in current value does not (as would certainly happen) entail an increase of the kilovoltage; the kilovoltage should remain constant throughout the entire time of exposure. Therefore, the existence of first-rate voltage compensation is a condition for the application of this falling load technique.

The load thus gradually decreases during the exposure. By means of successful mains resistance and voltage compensation (chapter 15, section 15.4.2) the kilovoltage can be held at a constant level with the decreasing current value, so that the method has acquired real practical value. It is clear that the advantages of this falling load method will give best results in conjunction with an automatic exposure device, since the focus will then be fully loaded right from the very first moment, and is maintained so that the shortest possible exposure time is really achieved. Moreover, pre-setting a time limit is unnecessary since overloading of the focus is excluded. Only by application of this falling load method is everything taken out of the focus, as it were, and under the given conditions both the  $U_g$  and  $U_m$  are at their minimum.

#### 14.5.6 *Adjustment of density with automatic exposure technique*

When the automatic exposure device is assembled, it is adjusted to the correct average film density with the use of a certain type of film, intensifying screens and cassettes. With the latest constructions other adjustments can be chosen by the radiographer by means of push-buttons appropriate for slow (fine-grained), normal

\*At the time, falling load was not widely accepted in radiography, since at the high initial current values a considerable loss in voltage occurred, due to which the goal one aimed at could not be achieved unless a three-phase unit and low mains resistance were available.

and fast screens, for example. By means of a step regulator or a continuous regulator it is possible to vary the density in a positive or negative sense to obtain a particular average (for example when taking a penetrated soft tissue radiograph). This is also of importance when a great deal of scatter is expected from obese patients, and the exposure should not be terminated too early because the scatter influences the measuring chamber to a greater extent (as it is situated nearer the patient) than the film.

The adjustment of density is therefore in two parts:

(1) A pre-adjusted sensitivity regulator which is set at a particular average density for use with a particular type of film, intensifying screens and cassettes. This only needs to be adjusted when one changes to other materials.

(2) An adjustable density regulator, which can be manipulated by the radiographer in order to satisfy individual wishes.

#### **14.5.7 Automatic exposure control with image intensifier photography and X-ray cinematography**

In chapter 9, sections 9.7 and 9.8 it was explained how the brightness of the secondary screen of the image intensifier is held at a constant level (*brightness stabilisation*) also by the means of the pick-up unit of the automatic exposure device. The method of fluorescence in this case (still) predominates over the ionometric method. Not only does this brightness stabilisation play a large part in fluoroscopy (by fine adjustment of mA and/or kV practically without inertia) with varying penetrability of the object, but also in image intensifier photography.

It is clear that a constant image brightness is at the same time a basis for constant density of radiographs—*density stabilisation*. The automatic exposure device ensures that the correct density is always produced on the large-size radiographs. This process is similar for the image intensifier photographic technique, but in a much more rapid sequence when it concerns rapid series or X-ray cinematography. Especially in the latter a uniform density of all the cine frames is extremely important and an absolutely essential condition for satisfactory X-ray cinematography. Also in this case, no corrections can be carried out during development and it is certainly undesirable and often even impossible to repeat such an examination if it is spoiled by incorrect exposure. Practically all installations for image intensifier photofluorography (for example a 70 mm rapid-sequence camera) and cine radiography are therefore equipped with automatic exposure devices.

#### **14.5.8 Automatic exposure control with tomographic examinations**

The latest development in the field of automatic exposure devices is its application in tomographic investigations. In this case the intensity of the emitted radiation is measured in the direction of the central ray behind the object. By means of an electronic device this intensity remains constant throughout the time of tube swing. The exposure value is adjusted in such a way that the correct film density is obtained for the length of tube swing used (= length of exposure time) so that the correct film density is reached. Throughout the time that the beam passes obliquely through the object an equal amount is contributed to the photographic

density as when the beam passes vertically through the object (here the intensity of the beam is automatically decreased). The effective panning angle is thereby increased and more efficient blurring is the result.

#### 14.5.9 Summary

It goes without saying that standardisation of the processing-room technique and also of films and intensifying screens used is a requirement of utmost importance for good results with an automatic exposure device. In the case of intensifying screens, not only is it necessary to use only screens of the same type (for example, universal) but also to restrict oneself to one manufacturer only, otherwise differences in exposure could still occur.

One can use automatic exposure devices with two different aims in view:

- (1) The most important purpose can be the extreme simplification of the control of the X-ray unit and the determination of the exposure factors.
- (2) The aim can be the avoidance of an incorrect estimation of the absorption in the patient and with that of the required exposure time (which can happen even to an experienced radiographer).

### 14.6 EXPOSURE WITH THE USE OF HARD RADIATION AND SOFT RADIATION: ADVANTAGES AND DISADVANTAGES OF THEIR APPLICATION

In chapter 6 the fact that radiation contrasts decrease with harder radiation (higher kilovoltage) was discussed. This occurs chiefly for the following two reasons:

- (1) There is less difference between the attenuation coefficients of the various substances in the body at higher kilovoltages.
- (2) There is an increase in the amount of scattered radiation that emerges from the object.

#### 14.6.1 Use of hard rays: high-kilovoltage technique

Whilst it is true that one can harden a heterogeneous beam of radiation by means of increased filtration, a truly harder radiation (with smaller  $\lambda_{\min}$ ) can only be achieved by increasing the kilovoltage (chapter 2, section 2.3.1.6, and chapter 3, section 3.7.3). The X-ray photons produced by a higher kilovoltage have greater energy and in many cases are desirable or even essential (thick objects, short exposure times) to obtain the desired radiographs. Fortunately, in by far the most cases the radiation contrasts are not so critical that for every type of radiograph only one radiation quality, as it were, would be useful. On the contrary: contrasts on a radiograph produced, for example, with 120 kV, are very comparable with those produced by 80 kV or even 60 kV if the new mAs value has been carefully determined according to one of the methods described above and, moreover, if all the measures are taken to decrease the effect of scatter, such as accurate beam limitation, the use of a grid, etc.

For example, if one compares two chest radiographs, one produced by 120 kV and the other produced by 60 kV, then one sees that the contrasts between lung tissue and ribs are much smaller at 120 kV, but that the contrast in the lung tissue itself is only slightly less. Moreover, the details of the lung tissue are now visible through the ribs and other bony structures and even the lower part of the trachea and the bifurcation are outlined against the spinal column (see chapter 2, section 2.3.1.4).

The great loss in contrast in bony tissue is due to the diminishing attenuation coefficient in the 50–150 kV range. The attenuation coefficient of substances with lower atomic numbers such as soft tissue and air does not diminish to such a great extent in this range so that differences in density between, for example, air-containing tissues on the one hand, and tissues without air on the other, produce good contrast also at higher kilovoltages. Therefore, lung tissue, which after all consists of materials with low atomic numbers and of different densities, is visible in good detail also at considerably higher voltages.

If one takes into consideration that the disadvantage normally associated with the use of higher kilovoltages, namely, the loss in contrast, does not play a part in some radiographical examinations (barium) and can even be an advantage (transparent ribs), then it is no wonder that the radiographic technique with high kilovoltages (*high-kilovoltage technique*, or *hard-radiation technique*) has gained an important position in various examinations.

#### 14.6.2 Lower dose with high-voltage technique

The amount of radiation that emerges from the irradiated object, and becomes available for the formation of the image, is relatively greater with harder radiation. The incident exposure, therefore, can be smaller at high kilovoltages than at low kilovoltages. Moreover, the exposure of the film-screen combination which is necessary for the formation of the image is also less at higher kilovoltages. As a result the skin dose and the integral absorbed dose are decreased. This latter decrease is not very spectacular, however, and under certain circumstances can even be completely lost if a high-voltage grid with a high ratio and high bucky factor are used in order to improve the contrasts. In general, one can assume that with high-voltage technique dose is saved, especially when one also applies greater added filtration with higher voltages than is applied with the more usual voltages. The soft components of a radiation are, after all, largely absorbed in the body and do increase the skin dose and integral dose, but contribute little to the formation of the image. It is therefore logical to filter them out before they reach the object. As has already been mentioned, the total filtration must amount to at least 5 mm aluminium equivalent for kilovoltages above 100–120 kV; 0.1 mm copper + 1 mm aluminium added filtration, for example, is suitable for this purpose.

A conscious limitation of the dose is essential for radiographs taken in the vicinity of the gonads, especially of young persons and pregnancy cases, as well as in X-ray cinematography and other examinations with many exposures, or often repeated examinations (rapid sequence radiographs for the investigation of vessels, tomography, etc.).

It should be mentioned that the emerging radiation increases with higher kilovoltages, and that, moreover, the scattered radiation has greater penetrating power.

Therefore, a greater part of the body is exposed to radiation. Thus, for example, the skin dose for a chest X-ray decreases at higher kilovoltages; the dose received by the gonads, however, could become relatively higher at higher kilovoltages, in spite of the possible associated considerable decrease in mAs value; this is due to the increase in scatter which strikes this area. Because of the great risk of gene mutation that could occur after irradiation of the gonads, this problem deserves more attention and the genetic dose is an important factor in the evaluation of a particular investigation technique.

With the application of high voltages in diagnostic X-ray examinations it is therefore even more important than with the use of lower voltages to limit the beam as much as possible and so increase the distance between the irradiated volume and sensitive organs such as the gonads.

#### 14.6.3 Use of finer focus with high voltages

The mAs product required is inversely proportional to the *third* or even to the *fifth* power of the tube kilovoltage. On the other hand the load on an X-ray tube (determined by the product of voltage, tube current and time, that is  $kV \times mA \times s$  or Ws) is proportional to the *first* power of the kilovoltage. This means that for the same density the load on the focus is considerably reduced when the kilovoltage is raised. Therefore, the focus can be finer due to which the geometric unsharpness decreases (see the example in section 14.4, technique C p. 360).

There are three reasons for the substantial drop in the mAs product needed for an exposure at higher kilovoltages:

- (1) Increased production of X-rays (increased tube efficiency),
- (2) Reduced absorption of X-rays by the patient,
- (3) Increased efficiency of the film-screen combination.

Because of these reasons, foci of smaller dimensions can be used not only in macro-radiography (where they are obligatory), but also in routine radiography (much more than was formerly the case). In view of this it should again be pointed out that the use of six- and twelve-pulse units are preferable to two-pulse units because in the six-pulse apparatus the radiation energy (the average kilovoltage) is at a much higher level. This advantage of increased production of X-rays is especially important for a focus of low thermionic loading capacity (fine focus).

#### 14.6.4 Greater definition with high-voltage technique

Apart from the application of a finer focus (reducing  $U_g$ ) described above, the greater efficiency of a low mAs product at high voltages can be of advantage as far as the exposure time is concerned (see technique B in section 14.4). Short exposure times reduce the risk of movement unsharpness. This is especially important with radiography of rapidly moving organs, for example, the heart, the blood vessels and the intestines (especially the small intestine). In general, a decreased  $U_m$  is achieved. The modern development of extremely fast screens also contributes to this.

Instead of shorter exposure time one can also make use of less-fast intensifying screens, which have a thinner layer, and thus produce less unsharpness. As a result one can achieve a lower  $U_i$ .

Shorter exposure times impose greater demands on the precision of the timers. As mentioned earlier, a discrepancy of 0.01 s in an exposure lasting 0.1 s represents an error of 10 per cent, but the same discrepancy in an exposure lasting 0.02 s represents an error of 50 per cent. With modern timers, however, exposure times of 0.01 s and even less than 1 ms can be realised with great accuracy. One can also utilise the higher kilovoltages in order to have more radiation energy at one's disposal and so increase the focus-film distance. By doing this one achieves less magnification, less distortion and (usually) less geometrical unsharpness.

#### 14.6.5 Some criticisms of high-kilovoltage technique

Against the clear advantages of the use of high kilovoltages mentioned above there are some disadvantages which in practice, however, can practically always be avoided or diminished. It has already been mentioned that for certain exposures great care should be taken in the extra protection of the gonads. Technically speaking, extra protection for the tube, cables, fluoroscopic screen, stand and surroundings should also be provided without increasing the physical effort on the part of the radiologist and other personnel. The greater demands of the timing device or the automatic exposure device should also be satisfied. The most important problem in high-voltage technique is effective protection against scattered radiation. The methods and measures at one's disposal for this purpose were discussed in chapter 6.

Since scattered radiation is harder when the primary radiation is harder, the grid has to satisfy special demands. These demands have been met satisfactorily in the form of *high-voltage grids* (see section 6.3.5.8). For macroradiography, as we already know, longer object-film distances are used, and only a weakened scattered radiation reaches the film. Also, for non-enlarged radiographs, the object-film distance may be increased to advantage, but in this case, the distance between focus and film must also be increased in order to reduce geometric unsharpness and distortion. This was first applied in the *Grödel technique*, which in its original form for chest radiography used an object-film distance of 25 cm and a focus-film distance of 300 cm.

Although high-voltage technique can be carried out with the usual films and intensifying screens, one should take care to choose suitable films and a processing technique that encourage as steep a gradation as possible.

The use of voltages between 150 and 250 kV for diagnostic purposes has been the subject of many investigations for a long time. The purpose of this was the same, that is to obtain more information with a lower dose and/or still shorter exposure times. However, it has been proved that little if any gain is to be expected in this respect, since the value of the exponent  $p$  (see section 14.3.4), which up to 150 kV has already been reduced from 5 to 3, decreases still further. The realisation of such high kilovoltages (about 200 kV) in a diagnostic X-ray department necessitates much greater technical and other efforts (tube, cables, high-tension generator, radiation protection, weight balancing, financial aspects, etc.) and do not seem justified.

#### 14.6.6 Applications of high-kilovoltage exposure technique

The scarcely perceptible loss of contrast in the lung structures and the advantage of the 'transparent' ribs have made chest radiography one of the major fields of application of high-voltage exposure technique. The associated reduction of the mAs product also allows exposure times to be shortened, which is of particular advantage with regard to respiratory and cardiac movements. With the investigation of the oesophagus-stomach-intestines with contrast media, the higher voltages offer obvious advantages. The mucosa is then presented in good relief owing to the greater penetration of the thin layers of opaque medium. Here too, of course, shorter exposures are a great advantage. When air is used as a contrast medium, as for the examination of the cavities in the brain, for example, one can utilise the fact that the bony structures themselves cause less interference at higher kilovoltages, whereas the contrast between the air and soft tissues is maintained. Higher kilovoltage exposures are also applied in bronchography, for lateral radiographs of the lumbar vertebrae, for radiography in pregnancy cases, etc. Due to the lower tube load and lower skin dose and in general also the lower integral absorbed dose, higher kilovoltages are also used in cineradiography and for large numbers of radiographs taken in rapid sequence for cardiac and blood-vessel investigations, for example.

The application of high kilovoltages is also attractive for technical reasons, since the associated mAs product per exposure is less and, therefore, the load on the tube is also less. This is particularly demonstrated when rapid series exposures and X-ray cinematography are performed. In the latter case both the frame speed and the total filming time can be considerably increased in comparison with those when lower kilovoltages are used. The only drawback which prevents a more widespread application is the fact that the loss of contrast, which arises in many cases (with the examination of small vessels by means of iodine-containing contrast media) at higher kilovoltages, is no longer acceptable. Neither the use of high-kilovoltage grids nor other methods of contrast improvement are able to compensate for this lack of radiation contrast in the primary radiation. However, the high-voltage exposure technique has been adopted to such an extent that a special section devoted to the application of kilovoltages up to 150 kV is included with every modern exposure table (see table 14.14). Here also, the necessary exposure data can be deduced by means of a graph or point system from the basic or standard data, in a similar way to that described in section 14.1.3.5.

### 14.7 THE USE OF SOFT RADIATION, MAMMOGRAPHY

When a soft radiation mixture is used (in which even the hardest components have only a small amount of photon energy and have a fairly long  $\lambda_{\min}$ ) it is possible to demonstrate small differences in absorption in the object with a satisfactory radiation contrast for the purpose of taking radiographs. This problem occurs when taking radiographs of soft tissue parts which do not differ or scarcely differ from each other as far as the effective atomic number (about 7.2) and/or the density is concerned. This is the case with the *breast*, where the skin, subcutaneous and other fatty tissue, glandular tissue, lacteal ducts and muscle tissue at the breast wall demonstrate such a uniform attenuation of X-rays that the differences that

do exist can only be made visible by means of soft radiation.

Mammography, therefore, has been developed almost entirely in the direction whereby particular attention has been paid to the construction of the tube. Since the construction of beryllium windows ( $Z = 4$ ) the emergence of soft radiation from the tube is no longer any problem. In order to make the production of the necessary radiation (with a photon energy produced by about 30 kV) as great as possible in the mixture, the greater part of which is absorbed in the breast, tubes have been constructed which have a molybdenum anode ( $Z = 42$ ) and are provided with a beryllium window. These tubes produce a Bremspectrum at about 35 kV of which the wavelength with the greatest intensity is practically equivalent to the characteristic radiation emitted by the molybdenum anode and is superimposed on the Bremspectrum.

This characteristic radiation (produced by a transition from L to K orbits) is filtered along with the Bremsstrahlung (by means of a sheet of beryllium) after it has passed through the beryllium window, causing the ultimate radiation to be predominated by a wavelength  $\lambda =$  about 0.07 nm to such an extent that in practice it can be considered to be practically monochromatic radiation.

Thus, today, mammography is performed almost entirely with tubes that have molybdenum anodes. Radiographs of the breast that are made with this radiation are particularly rich in contrast. As extremely small details can also be of great conclusive importance in the diagnosis (minute and very minute calcifications), apart from good contrast a high degree of definition is also desirable. The investigation is thus preferably made on special fine-grained films without intensifying screens or at most with extremely fine-grained intensifying screens.

In this field, development is also still in full swing. In this manner, the use of vacuum cassettes with one very high-definition screen and a fine-grained film entails extremely high resolving power, whilst with the use of a non-screen film a considerably greater sensitivity is achieved. This is of particular importance in mass surveys. However, also in this case it does appear that the use of a grid specially constructed for the purpose does produce a considerable gain in image quality.

Almost as a matter of course, soon after the earlier days of tubes with stationary anodes, tubes with rotating anodes and even ones that rotate at 9000 r.p.m. and have very fine foci have been constructed for mammography, especially for the possible discovery of tiny flecks of calcium on the radiograph. The prime purpose of mammography is early detection of carcinoma of the breast and at the moment this investigation is growing towards a type of mass survey and in some countries steps have already been taken in this direction. Unfortunately, instead of a reassuring influence it can in some cases promote a cancer phobia.

It is obvious that with this examination the exposure (because of low voltage and great attenuation) is high and only because of its strictly localised nature (outside the really vital organs) and the aim of this examination is it justified. One should be warned against frequent repeats of the examination. Much work is being done on the development of still more sensitive materials and still higher resolving power. Already great advances have been made in this direction.

In completing this chapter a complete exposure table is illustrated which can be used as a basic exposure table in the sense described above.

Table 14.14 Basic exposure table

Body part	*	**	***	****	kV			V		
	cm	G	S	Ff	kV	mAs	E	kV	mAs	E
<i>Skull</i>										
Skull (p-a)	20	I	..	100	75	40	9			
Skull (lat)	16	I	..	100	65	40	4.5			
Skull (axial)	24	I	..	100	80	60	20			
Sinuses (half-axial)	22	I	..	100	65	100	11			
Petrosus bone (Stenvers)	18	I	..	100	65	60	7			
Temporal bone (Schüller)	18	I	..	100	65	70	8			
Optical foramen (Rhese)	18	I	..	100	65	60	7			
Mandible (oblique)	10	-	..	100	60	10	0.8			
<i>Trunk</i>										
Ribs, upper (a-p)	20	I	..	100	60	25	2			
Ribs, lower (a-p)	22	I	..	100	65	60	7			
Sternum (oblique)	23	I	..	100	60	65	5			
Sternum (lat)	30	I	..	100	60	90	7			
Clavicle (p-a)	15	I	..	100	60	15	1			
Scapula (a-p)	16	I	..	100	60	25	2			
Scapula	17	I	..	100	60	50	4			
Cervical vertebrae (a-p)	12	I	..	100	60	45	3.5			
Cervical vertebra (oblique/lat)	11	-	..	150	60	25	2			
Thoracic vertebrae (a-p)	22	I	..	100	65	70	8			
Thoracic vertebrae (lat)	30	I	..	100	70	80	13			
Lumbar vertebrae (a-p)	20	I	..	100	70	60	10			
Lumbar vertebrae (oblique)	25	I	..	100	75	85	20			
Lumbar vertebrae (lat)	30	I	..	100	80	150	50			
Pelvis (a-p)	19	I	..	100	65	70	8			
Sacrum-coccyx (a-p)	19	I	..	100	70	60	10			
Sacrum-coccyx (lat)	30	I	..	100	80	200	60			
<i>Upper extremities</i>										
Shoulder joint (a-p)	13	-	..	100	55	10	0.5			
Shoulder joint (axial)	12	-	..	100	55	10	0.5			
Humerus (a-p/lat)	9	-	..	100	50	10	0.3			
Elbow (a-p/lat)	7	-	..	100	50	6	0.2			
Forearm (a-p)	6	-	..	100	45	8	0.16			
Forearm (lat)	7	-	..	100	45	10	0.2			
Wrist (a-p)	4	-	-	100	50	50	1.6			
Wrist (oblique)	5	-	-	100	50	65	2			
Wrist (lat)	6	-	-	100	50	80	2.5			
Hand (a-p)	3	-	-	100	50	30	1			
Hand (oblique)	4	-	-	100	50	50	1.6			
Finger (a-p/lat)	2	-	-	100	50	20	0.6			
<i>Lower extremities</i>										
Hip joint (a-p)	19	I	..	100	65	65	8			
Hip joint (lat)	20	-	..	100	65	40	5			
Femur (a-p/lat)	15	I	..	100	65	20	2			
Knee joint (a-p)	12	-	..	100	55	13	0.6			
Knee joint (lat)	10	-	..	100	55	10	0.5			

Table 14.14 *Continued*

Body part	*	**	***	****	kV			V		
	cm	G	S	Ff	kV	mAs	E	kV	mAs	E
Tibia (a-p)	11	-	..	100	55	8	0.4			
Tibia (lat)	9	-	..	100	55	6	0.3			
Ankle joint (a-p)	10	-	..	100	55	8	0.4			
Ankle joint (lat)	8	-	..	100	55	6	0.3			
Calcaneum (lat)	8	-	..	100	55	6	0.3			
Calcanium (axial)	10	-	..	100	55	8	0.4			
Forefoot (dorso-plantar)	6	-	-	100	50	45	1.5			
Forefoot (oblique)	7	-	-	100	50	65	2			
Toes (a-p/lat)	3	-	-	100	50	30	1			
<i>Thoracic cage</i>										
Lungs (p-a)	21	-	..	150	55	13	0.6			
Lungs (lat)	29	-	..	150	70	20	3.5			
Heart (p-a)	21	-	..	200	75	4	1			
Bronchography (p-a)	21	I	..	~70	75	10	2.5			
Bronchography (oblique)	24	I	..	~80	80	15	4.5			
Bronchography (lat)	29	I	..	~90	90	15	9			
Trachea (p-a)	12	I	..	~70	65	30	3.5			
Trachea (lat)	11	I	..	~90	65	20	2			
Oesophagus (oblique)	27	I	..	~80	80	12	4			
<i>Abdomen</i>										
Stomach series, folds (p-a)	20	I	..	~70	85	15	6			
Duodenal cap 1 (oblique)	21	I	..	~70	85	18	8			
Duodenal cap 2 (oblique)	23	I	..	~80	85	30	12			
Stomach, entire, folds (p-a)	20	I	..	~70	80	20	6			
Stomach, entire, filled (p-a)	20	I	..	~70	80	30	10			
Colon (p-a)	20	I	..	~70	85	15	6			
Colon, sigmoid (lat)	30	I	..	~90	100	80	80			
Appendix (p-a)	20	I	..	~70	85	15	6			
Kidneys, general view (a-p)	20	I	..	100	65	70	8			
Kidneys, detail (p-a)	20	I	..	~70	65	50	6			
Gall bladder, general view (p-a)	20	I	..	100	60	100	8			
Gall bladder, detail (p-a)	20	I	..	~70	60	65	5			
Hysterosalpingography (p-a)	20	I	..	~70	70	20	3			
Pregnancy (a-p)	32	I	..	100	85	50	20			
Pregnancy (lat)	30	I	..	100	90	50	28			
<i>High-kilovoltage technique</i>										
Lungs (p-a)	21	II	..	150	150	2.5	10			
Lungs (lat)	29	II	..	150	150	7	30			
Stomach series, folds (p-a)	20	I	..	~70	150	1.5	6			
Duodenal cap 1 (oblique)	21	I	..	~70	150	2	8			
Duodenal cap 2 (oblique)	23	I	..	~80	150	3	12			
Stomach, general view, folds (p-a)	20	I	..	~70	125	3	8			
Stomach, general view, filled (p-a)	20	I	..	~70	125	5	12			

**Table 14.14** *Continued*

Body part	*	**	***	****	kV			V		
	cm	G	S	Ff	kV	mAs	E	kV	mAs	E
Pregnancy (a-p)	32	I	...	100	125	8	20			
Pregnancy (lat)	30	I	...	100	125	13	30			
Lumbar vertebrae (a-p)	20	II	..	150	125	30	80			
Lumbar vertebrae (oblique)	25	II	..	150	125	50	125			
Lumbar vertebrae (lat)	30	II	..	150	125	80	200			

cm = object thickness in cm

G = recommended grid

— = without grid

I = grid 24 lead strips per cm,  $r = 7$  or 44 lead strips per cm,  $r = 10$ II = grid 24 lead strips per cm,  $r = 13$  or 44 lead strips per cm,  $r = 15$ 

S = recommended screens

— = without screens

.. = Universal screens

... = Ultra-rapid screens

Ff = focus-film distance in cm

~ = average distance, varying with fluoroscopic adjustment

V = magnification?

# 15

## Diagnostic X-Ray Apparatus

### 15.1 VARIOUS FORMS OF HIGH TENSION SUPPLIED TO THE TUBE

In principle, all diagnostic X-ray machines have the same construction and consist of: a junction to the mains supply, connection to the high-tension (H.T.) generator (with built-in filament transformer) via a switching mechanism (varying from a simple clock-work timer to a complicated panel of switches), and connections of the generator poles (either with H.T. cables or without) to the anode and cathode of the X-ray tube.

In addition to this, since the general introduction of protective measures against H.T., the insulation of the entire H.T. section is surrounded by a continuous metal sheath, which is earthed. In chapter 1, section 1.9, the design principle of the Metalix apparatus, first shown in 1928, was introduced; it incorporates protection against H.T. (and undesired radiation). The conditions for the flow of current through the tube (that is it can only take place when the anode is positive in relation to the cathode) has also been thoroughly discussed in chapter 1. If the anode is negative and the cathode positive, then the flow is blocked, that is no current flows in the tube and the radiation is interrupted.

#### 15.1.1 Half-wave apparatus, opposite phase is suppressed; single-pulse generator

When a transformer is connected to an alternating voltage with a frequency of 50 cycles per second, by itself, this interruption occurs 50 times per second; *the alternating voltage sine wave-form, which consists of a positive and negative phase, is only able to produce X-rays during one of the phases, namely, the phase when the pole of the transformer, which is connected to the anode, is positive*. If only one of the phases asserts itself in this way, whilst the other phase ‘does not come through’, one speaks of *half-wave apparatus*. The phase that is suppressed, as it were, and does not produce X-rays, is also called the *negative phase* or *opposite*

*phase*; here the anode is negative in relation to the cathode. However, due to the absence of electron emission from the anode, transport of electricity to the cathode is impossible so that the tube is without current in this negative phase.

In the following figures the symbols indicated earlier will be used for X-ray tubes, valves and (other) rectifiers. As practically all valves have been replaced by solid state rectifiers, rectification will be indicated by the symbol  $\rightarrow$ , where the arrow indicates the direction of the electric current (opposite to the flow of electrons). In a closed electric circuit, one should always end up at the anode of the X-ray tube if one follows the direction of the arrow. The anode of an X-ray tube is indicated by an oblique line ( $\searrow$ ) and the hot cathode by a bent line ( $\rightarrow$ )).

#### 15.1.1.1 Half-wave apparatus without valves (self-rectifying)

Since the current in an X-ray tube can only flow in one direction one speaks of rectification. If the tube itself prevents the flow of current in the other direction, then one calls the tube *self-rectifying* (figure 15.1). One should take note of two points in connection with the construction or use of this type of apparatus (most small portable tank units are of this type).

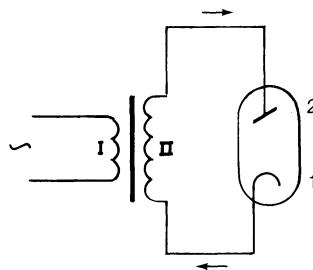


Figure 15.1 Diagram of a half-wave apparatus, self-rectifying (without valves). I. Primary winding of the H.T. transformer connected to the mains supply  $\sim$ ; II. secondary winding of the H.T. transformer. 1. Cathode filament (the filament circuit is not shown); 2. anode of the X-ray tube. The arrows indicate the direction of the electric current.

(1) The load on the tube may, in no case, be so high that the anode becomes hot, causing it to emit electrons due to thermionic emission and, during the phase in which the anode is negative a flow of electrons would occur from anode to cathode. The cathode is not designed to withstand this bombardment and is invariably destroyed; the tube is then ruined. This phenomenon is known as back-fire. This should, of course, be avoided and these units are so constructed that the focus is loaded to a relatively low level, certainly nowhere near the melting point since, particularly at the highest temperatures, electron emission increases very rapidly. The focus is therefore relatively large and the load relatively low. The recommended cooling off periods should also be strictly observed.

(2) Since the X-ray tube conducts current only during one-half of the sine wave, whereas the other half of the wave is not used, the voltage of the unused phase (also called *inverse voltage*) is higher than that of the loaded phase (*useful voltage*). It is obvious that the insulation of the apparatus and the tube must be calculated to withstand the inverse voltage. At present all units are fully equipped with an

earthing connection, which in small machines is ensured by means of a connecting flex with three conductors plugged into a three-terminal earthed socket. Connection to a two-terminal socket is only permitted if provision is made for a separate earth connection.

In many radiographic units, particularly tank units with the H.T. transformer and X-ray tube in the same housing, the H.T. and filament windings are on the same transformer core (figure 15.3). It will be evident that with this arrangement the H.T. and the filament voltage are produced simultaneously. Since the heating of the filament takes a certain amount of time, immediate production of X-radiation is, therefore, not possible. Although attractive by virtue of its simplicity, this system can be used only in very small apparatus and is not suitable for radiography using very short exposure times.

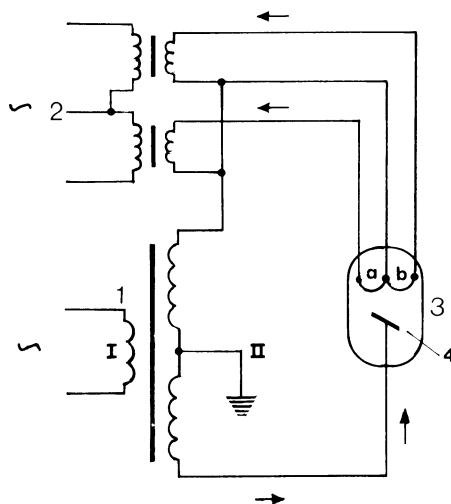


Figure 15.2 Half-wave rectification with a dual-focus tube. 1. H.T. transformer in which the secondary winding is earthed in the centre (mains voltage  $\sim$ ); 2. filament current transformer for two filaments (a and b); 3. dual-focus tube; 4. anode. The arrows indicate the direction of the current.

In order to overcome the disadvantage of the warming-up time in these types of machines to some extent, a method of switching has been devised whereby the filament is pre-heated to some extent (while X-rays are not yet being produced) before the exposure. This system is very simple. One supplies the voltage from the low-tension supply on the primary side of the combined H.T. and filament transformer via a resistance of such a value that a (lowered) filament voltage is produced during 'the preparatory phase' of the exposure, so that the filament of the X-ray tube will reach the approximately correct temperature but, whereby the equally lowered H.T. (in combination with the space-charge effect of the X-ray tube, which has already been discussed) will remain below the value at which current can travel across the tube. As soon as the exposure button is pressed this resistance is short-circuited, whereby the voltages reach their full value, and

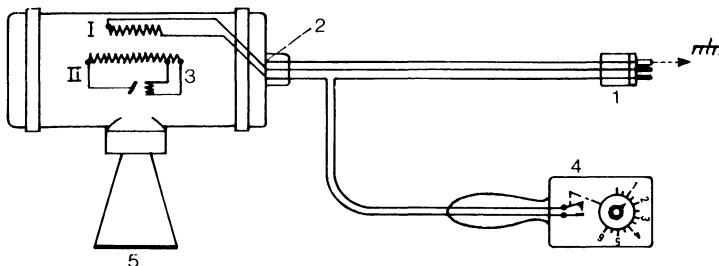


Figure 15.3 Diagrammatic reproduction of a tank unit with manual timer switch. I. Primary winding of the H.T. transformer; II. secondary winding of the H.T. transformer. 1. Three-terminal plug (with earth); 2. earthing point on the shielding; 3. spur for filament current; 4. hand switch with clock-work timer, resistance, preparation contact and exposure contact inside; 5. cone (or light-beam diaphragm). For the sake of simplicity, only one voltage step is shown; moreover, the fluoroscopy circuit is not indicated.

the X-ray tube produces X-rays virtually immediately. When the timer ends the exposure the voltage of the primary side is disconnected. Usually, in these types of units, the preparation switch is combined with the time switch and the current supply is switched in via the resistance as soon as the timer is set by turning the time switch for the exposure time.

#### 15.1.1.2 Half-wave apparatus with valve(s) and/or rectifier(s)

In order to protect the tube against the danger of backfire and against too high a voltage during the unused half of the phase, rectifiers are used, which protect the tube against a flow of current during the phase when the anode is negative. These rectifiers are usually contained in the same tank as the H.T. transformer, immersed in oil. In principle, one valve in series with the X-ray tube, as shown in figure 15.4, is sufficient but, as symmetry is desirable from the point of view of the load and the insulation of the H.T. cables, not one but at least two valves are invariably used in practice. *One- and two-valve H.T. generators constitute half-wave apparatus*

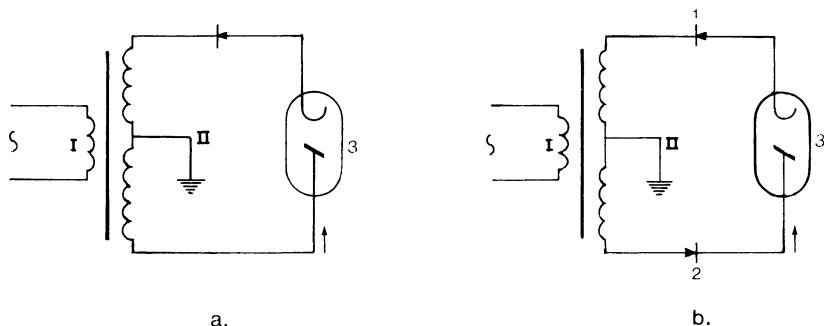


Figure 15.4 Half-wave generator (a) with protection of the X-ray tube by means of two rectifiers (b). I. Primary winding of the H.T. generator; II. secondary winding of the H.T. generator (earthed in the centre). 1. Rectifier on the cathode side; 2. valve on the anode side; 3. X-ray tube (the filament current circuit is not shown).

tus safeguarded against backfire in the X-ray tube. A high anode temperature need not be feared and, hence, the focus can be subjected to a higher load per  $\text{mm}^2$  than with half-wave apparatus without valves. In other words: without valves the focus must be larger for the same load than with valves, because the focus in the first case must remain cooler. Half-wave apparatus with only one or two valves is, however, used only very rarely.

### 15.1.2 Apparatus in which the negative phase is utilised, two-pulse generator

More than half a century ago the (negative) *inverse phase* was converted into a (positive) *useful phase* by rectification. The mechanical rectifiers of the past, due to their great interference with radio and television of today, would now be categorically prohibited. Apart from this, they would not be able to cope with the energies that are used today. Besides rectification by means of valves that still exists, the solid-state type of rectification has now been so well-developed that one can already consider rectification by means of valves obsolete.

#### 15.1.2.1 Rectification by means of four valves; four-valve 'Graetz circuit'

By means of an ingenious (Graetz) circuit, four rectifiers are arranged between the terminals of an X-ray tube in such a way that the anode is connected with the plus terminals and the cathode with the minus terminals during both phases. Figure 15.5 demonstrates such a circuit; the X-ray tube is situated on the diagonal of a square the sides of which are formed by the four rectifiers. This circuit is therefore also called a *bridge circuit*. Figure 15.6 shows what happens to the voltage by means of this circuit. With every period of the alternating current both the positive and the negative phase halves cause a current to flow through the tube, hence the name *two-pulse generator*.

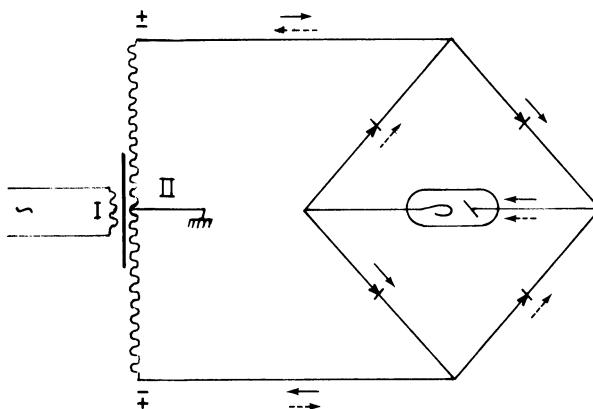


Figure 15.5 Diagram of a four-valve Graetz circuit (bridge circuit). I. Primary winding of the H.T. transformer; II. secondary winding of the H.T. transformer (with earthing in the centre). The X-ray tube is located as a diagonal in a square. The solid arrows indicate the direction of the current during one half of the cycle; the dotted arrows indicate the second half-cycle. The direction of the current always remains the same in the X-ray tube.

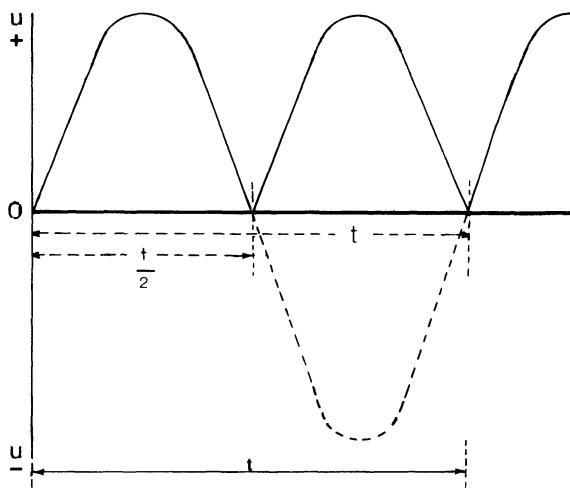


Figure 15.6 Type of voltage with a two-pulse (four-valve) generator. The moment the voltage reaches the zero value on the transformer terminals (after every half-cycle) and assumes an opposite value, the positive voltage is sent to the anode along another path by the rectification, so that the anode always receives a positive voltage.  $t$ . Time of one cycle;  $t/2$ . time of one half-cycle;  $U+$ . positive transformer voltage;  $U-$ . negative transformer voltage; O. zero point of the voltage. The dotted line represents the negative half-cycle of the transformer voltage, which is converted into a positive half of the tube voltage (solid line).

#### 15.1.2.1.1 High-tension (H.T.) cables

Apart from the compact tank units, in which the H.T. transformer and the X-ray tube in direct contact with each other are contained in the same tank or housing, the connection between the H.T. transformer and the tube is made by means of H.T. cables.

X-ray tubes were once connected to the H.T. generator by means of what are known as open H.T. leads but this method is now obsolete; apart from the risk of electric shock to patient, operator and other personnel, the movement of the tube would be severely limited. In order to be able to manoeuvre the X-ray tube in such a way as is required by modern X-ray techniques, H.T. cables, which are very flexible and are, moreover, not dangerous if touched, should be used. Modern H.T. cables are built up from a core, which comprises three copper conductors individually insulated for low voltage (the filament voltage) covered with a layer of semi-conducting rubber. The purpose of this layer is to distribute the electric field over a large area, due to which the risk of breakdown of the cable insulation becomes less. This conducting rubber is in turn encased in rubber, thus providing insulation against high voltage; a woven metal-wire sheath, which is earthed, surrounds this. This is then surrounded by cotton or synthetic material protecting the cable against bumps, abrasions, etc., and improving its appearance (figure 15.7).

The earthed cable sheath is in earthed contact with the transformer tank and tube shield by means of a metal screw-on ring on the cable plug. H.T. cables are supplied in various lengths complete with plugs to fit the H.T. generator and tube

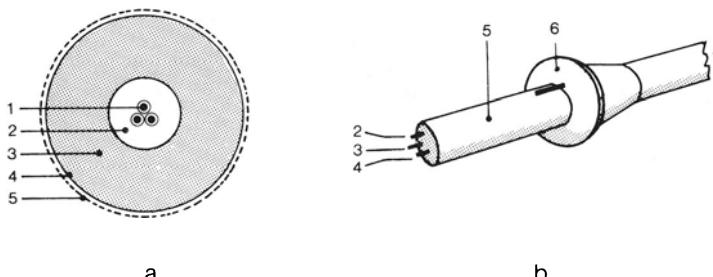


Figure 15.7 Section of a three-core high-voltage cable (a) and a cable plug in a high-voltage cable (b).

a: 1. Three conductors separately insulated for low voltage; 2. layer of semi-conducting rubber; 3. layer of insulating rubber for high voltage; 4. earthed sheath of woven metal wire; 5. woven sleeve (of textile or synthetic material).

b: 1. End of high-voltage cable; 2, 3, 4. end pins of the three conductors; 2. pin for mutual contact of both filaments; 3. pin for large-focus filament; 4. pin for small-focus filament; 5. fixed insulation material; 6. metal ring which brings about the earthing.

shield. The anode cable as well as the cathode cable are usually made in an identical manner (three-core)\* as this simplifies the problem of maintaining an adequate stock for replacing cables for both purposes. For use as anode cable, the conductors can possibly be mutually short-circuited as only one conductor is necessary.

If one H.T. generator is used to supply several X-ray tubes then an H.T. switch is required for changing from one tube to the other.

The longer the H.T. cable, the greater the *cable capacitance*. Longish cables function in much the same way as smoothing condensers, the effect being noticeable at low tube currents as, for example, in fluoroscopy. With such currents the X-ray tube voltage is likely to be constant instead of pulsating. The cable capacitance in which an electric charge is stored during current flow is the reason why, even after the exposure is switched off, current still flows through the X-ray tube for a short time and thus producing X-rays. The lower the fluoroscopic current setting (thus, the 'colder' the cathode filament), the longer this extra X-radiation keeps up. This causes the well-known phenomenon that occurs in fluoroscopy with the aid of image intensifier television (where the tube current is kept very low; for example 0.2 mA), due to which one can still see the patient as a television image after the screening has been switched off, while he steps down from the table.

#### 15.1.2.1.2 Influence of capacitance on the circuit

The cable capacitance mentioned above can prevent the voltage across the X-ray tube from decreasing all the way down to zero in spite of the fact that the transformer voltage at the end of every half period is zero. The condenser-like effect of the cables (after all, an H.T. cable with its charged core and earthed sheath at some distance from it represents a condenser), therefore, causes the wave form to be less pronounced, and one then speaks of *smoothing*. In many units extra condensers are built in, and they are made in such a way that they effect a certain amount of smoothing by means of subsequent delivery of energy when the supply of

\*Some modern H.T. cables contain four cores (one for supplying voltage to the grid of a special X-ray tube).

energy from the transformer decreases. The greater the charge on the condenser the greater the smoothing and the more so the lower the tube current\*.

#### 15.1.2.1.3 Comparison of single- and two-pulse generators with respect to tube load and focus size

The peak current through the tube is greater with a single-pulse generator than with a two-pulse generator at the same exposure. If one applies 20 mA s for 0.4 s then this means that in both cases the average current strength is 50 mA. However, the two-pulse generator has the use of the full 0.4 s and the single-pulse generator only 0.2 s (since the tube is without current for half the time). In this latter case, therefore, the current strength during the working phase must be twice the size and this means twice as great a load on the focus. Therefore, for the same size focus the load can be higher in a four-valve unit (where the current peaks are lower) than in the case of half-wave units.

#### Summing up

The use of one or more rectifiers allows one to work with a smaller focus with the same (average) tube load.

#### 15.1.3 Units connected to three-phase voltage

With the ever greater loads that the X-ray tubes had to endure it became more and more difficult to obtain the necessary energy from the mains supply. It is true that this is usually necessary for very short times only (fractions of seconds) and the consumption of electricity (in watt-seconds or in kilowatt hours) is low, but at the moment of the X-ray exposure the required high power must be available for delivery. With a two-pulse unit, an exposure of 100 kV and 500 mA, for example, means a potential of  $0.7 \times 100 \times 500 = 35$  kW. However, still greater power is applied with tubes that can endure 70–100 kW, for instance.

##### 15.1.3.1 Three-phase voltage; three-phase current (rotary current)

Very powerful units are usually connected to three-phase mains supply. Three-phase current actually consists of three single-phase alternating currents, which follow each other, as it were, and differ from each other in phase by 1/3 of a cycle, or 120°. These three alternating currents are fed to the primary winding of a three-phase transformer (which actually comprises three individual a.c. transformers) in which the supplied voltages are transformed into high voltages. The three secondary windings can be connected to each other by means of a star- or triangular- (also called delta) shaped circuit. Figure 15.8 demonstrates these circuits.

##### 15.1.3.1.1 Three-phase apparatus, six-pulse generator

When with a three-phase transformer the three secondary windings are arranged in a star circuit, and the midpoint of the star is earthed. The voltage at the three other ends of the secondary windings is directed by means of six rectifiers in such

\*In therapy, such a high degree of smoothing has been achieved by means of very large condensers that the voltage variations (with 10 mA tube current, for example) are so small that one can speak of stable or constant potential, in spite of the alternating voltage delivered by the transformer.

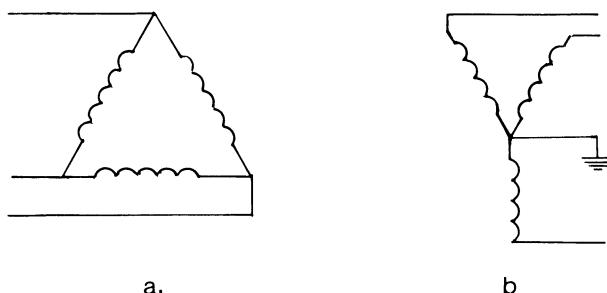


Figure 15.8 Triangle or delta circuit (a) and star circuit (b) of the secondary windings with three-phase voltage. In a star circuit the centre point is often earthed.

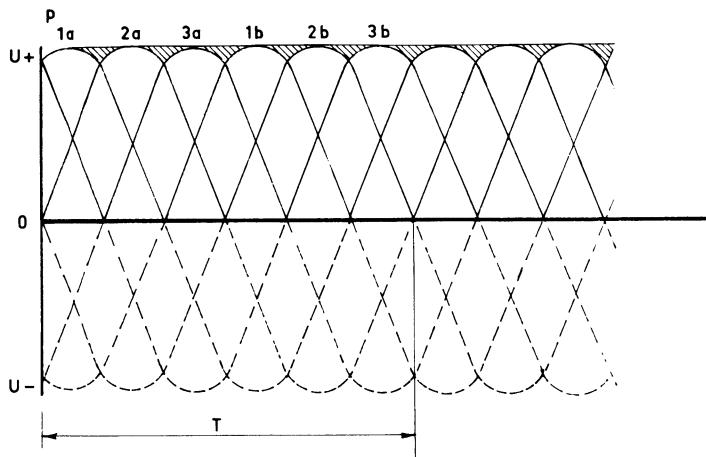


Figure 15.9 Wave form with a six-pulse generator. During one cycle, each of the alternating currents supplies two pulses (indicated by p 1a 1b, p 2a 2b, p 3a 3b); the ripple is in between (shaded areas).

a way that the anode is always supplied with positive voltage and the cathode with negative voltage. Although each of the three alternating voltages in itself (just as with the two-pulse circuit) returns to the zero value, this is not the case with the voltage that results from the cooperation between the three voltages, as is obvious from the voltage course, which shows partial overlapping of the voltage curves (figure 15.9). It is also obvious that during the period of 1 cycle (1/50s) six voltage elevations occur, which reach peak voltage, hence the name *six-pulse generator*. The depression between the top values is called the *ripple* and here amounts to 13 per cent.

In figure 15.10 the set-up of a six-valve (six-pulse) apparatus is shown diagrammatically. An additional advantage of the three-phase connection is that the required power is delivered by three supply lines instead of (as is the case in a single-phase circuit) two supply lines. In practice, this means that high power is better supplied by six-pulse generators than by single- or two-pulse generators.

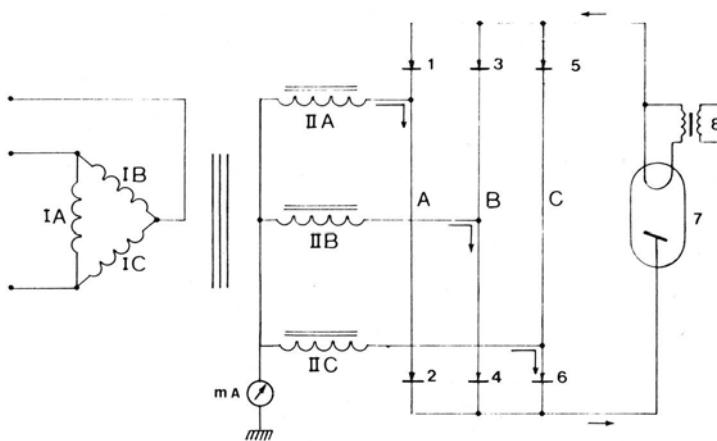


Figure 15.10 Diagram of six-pulse apparatus. The ends of the three secondary windings (IIA, IIB and IIC) of the H.T. generator are connected with the earth on one side. On the other side each end goes to two rectifiers (1–6), which ensure that only the positive voltage (in the direction of the arrows) can reach the anode of the X-ray tube (7). The filament current transformer is indicated by (8). The three phases regularly increase and decrease individually their part in a combined voltage (and current), which is offered to the tube and flows through it. The tube current is read from the milliammeter.

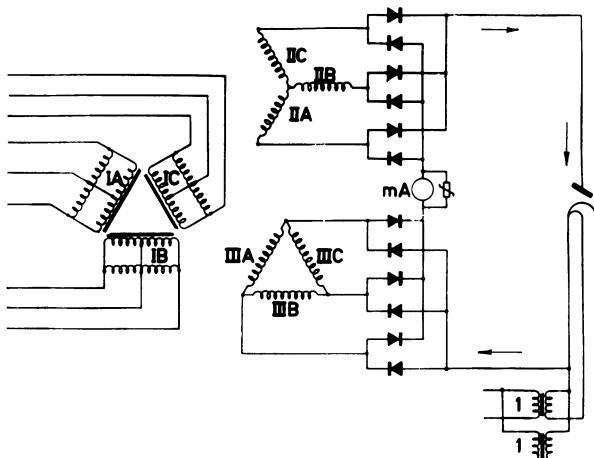


Figure 15.11 Simplified diagram of a three-phase generator with twelve valves (twelve-pulse generator). IA, IB and IC are the primary windings of a three-phase transformer. IIIA, IIIB and IIIC are the secondary windings in star circuit with connected rectifiers 1–6. IIIA, IIIB and IIIC are the secondary windings in delta circuit with connected rectifiers 7–12. Both rectification systems are earthed on one side, and there is a connection in the tube circuit; the current is indicated by the milliammeter. 1. Filament transformers for the filaments of the (dual)-focus tube.

### 15.1.3.1.2 Twelve-pulse generators; twelve-valve apparatus

Finally, in order to approach the ideal of a constant high voltage across the tube still further, the secondary windings of the three-phase H.T. transformer have been split into twice three cores, of which three are connected in a star-shaped circuit and the other three in a delta circuit. The plus and minus voltage of both groups each has a 'clear' path to the anode or cathode, each via six valves, whereby the

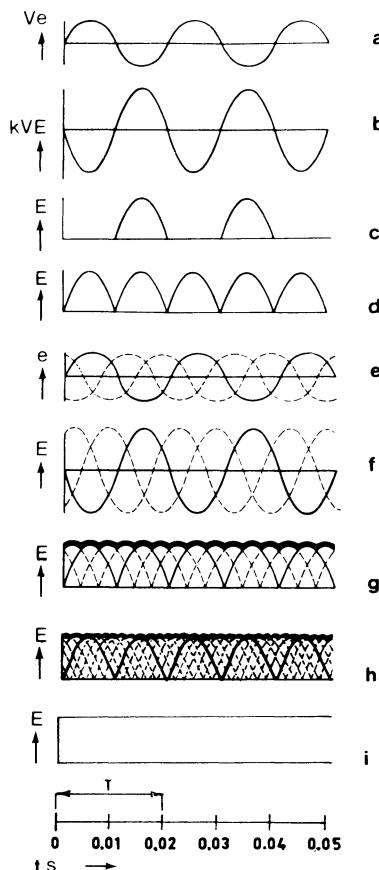


Figure 15.12 Reproduction of various voltage forms. Ve: low voltage; kVE, E: high voltage; T, time of one cycle (0.02 s); t, time. a-d are related to single-phase alternating voltage; e-h are related to three-phase alternating voltage; i is related to pure, direct current.

- Single-phase primary voltage.
- Secondary single-phase high voltage without rectification.
- Negative phase is suppressed; half-wave voltage (single-pulse voltage).
- With four-valve rectification = two-pulse voltage.
- Primary three-phase voltage.
- Secondary three-phase high voltage without rectification.
- Six-valve rectification which gives six-pulse voltage.
- Twelve-valve rectification which gives twelve-pulse voltage.
- Pure constant high voltage (d.c.). In g and h the ripple (of 13 per cent and 3 per cent, respectively) is clearly visible. There is no longer a ripple in i.

six pulses of the one group, because of a difference in phase, fall exactly between those of the other group, resulting in twelve pulses, between which the ripple is even smaller than is the case with the six-pulse generator (namely, 3.4 per cent against 13 per cent).

In figure 15.11 a simplified scheme of a twelve-pulse generator is shown, where the divided circuit on the secondary side (star and delta circuit) is clearly noticeable.

Figure 15.12 once again illustrates the different voltage wave forms, that can be used in X-ray apparatus. As far as the X-radiation that is produced is concerned, the relatively small difference between the maximum and minimum voltage with three-phase voltage results in a different ratio between  $kV_p$  and  $kV_{eff}$  than is the case with single-phase voltage. The penetrating power of X-rays with the same thermionic load on the focus is higher for a tube that is connected to a six-valve apparatus than with a four-valve or half-wave unit, because the value of  $kV_{eff}$  in the first case is so much higher ( $0.95 kV_p$  against  $0.7 kV_p$  with four-valve and half-wave units), and because the voltage has such an important effect on the quality and quantity of the X-radiation (see section 14.3).

Moreover, because of the occurrence of the already mentioned high peak values in current strength at a certain effective current strength through the tube with four-valve (and half-wave) apparatus, the effective tube load cannot be raised to the same value as in pulse apparatus. Therefore, a tube connected to a six-valve or twelve-valve apparatus and which allows a certain load to be placed upon it can withstand a much smaller load when connected to a four-valve unit (for this see the tube-rating charts of the manufacturers).

The above facts are important when choosing a generator. Similarly, in the case of tomographic apparatus, where, in general, a low current strength (mA) is sufficient since the exposure time that is chosen must be fairly long (depending on the tube-swing time), it is still recommended that a six- or twelve-valve unit be installed, as the permissible tube load and the ultimate production of radiation determines the result. By taking tomograms of a lumbar spine in a lateral projection of a patient who is heavily built, for example, the success of an examination (without ruining the X-ray tube for good by overloading it) can be dependent on the use of a six- or twelve-valve unit.

#### 15.1.4 Condenser-discharge apparatus

Condenser-discharge units form a class of their own. They can be of great value where the electricity mains supply is poor, or where current has to be generated privately. However poor the electricity supply may be, the condenser is charged up until it is 'full', as it were, and one then has the required energy at one's disposal, quite independently of the mains. These units are obviously indicated in remotely situated hospitals and sanatoria with poor electricity supply and 'in the field' (military operations, expeditions, etc.) Quite a small transformer may be used, although, in this case, it takes longer to charge the condenser. For a given exposure value a specific electrical energy is necessary, which can be expressed in  $kV$  and mAs. When this energy is stored in a condenser, the required exposure can be made by discharging the condenser via the X-ray tube. The energy required can be varied, either by changing the capacitance of the condenser, or by varying the

charging voltage, the latter being the method most commonly adopted. By making use of a grid-controlled X-ray tube one can also have a smaller part of the charge at one's disposal. There are different methods by which this can be effected. First of all, one can make it one's object to store the necessary energy (but no more) by charging the condenser, which is calculated for this load, for a particular type of exposure or group of exposures (for example extremities, lungs) and by adjusting to the thickness of the object, for example, a particular degree of charging can be arranged. By discharging the condenser through the X-ray tube (which, electrically speaking, represents a variable resistor) the required X-radiation can be produced. The voltage decreases sharply during the exposure; the effective exposure time is generally very short. Here, one cannot speak of a certain mAs value at a certain voltage, as is the case with other X-ray apparatus, since the voltage is not constant. An exposure table for such a condenser-discharge apparatus is usually always determined empirically (by experiment), and cannot be sufficiently accurately deduced and calculated from a standard exposure table. One can also make it one's object to make *all* exposures, even the heaviest, with a condenser apparatus. However, the charge required for this purpose is so large that it cannot be stored in condensers of acceptable dimensions. For this and other reasons, the condenser remains connected to the H.T. side of the circuit in such a way during the exposure that subsequent delivery of energy is immediately possible, so that the voltage does not decrease too much. For less heavy exposures, the condenser can be discharged down to a certain level of charge by means of a switch valve; the discharge through the tube produces radiation. The complete constancy of the results achieved (given a constant processing-room technique) and the independence from the variable, poor electricity supply have won a good name for condenser-discharge apparatus. After virtually completely disappearing there is now mention of a distinct revival, especially in units of low and limited power, with which very short switching times (milliseconds) can be achieved.

## 15.2 CLASSIFICATION OF APPARATUS

In practice, one deals with half-wave, four-valve, six-valve, twelve-valve and condenser-discharge apparatus, which can be fairly arbitrarily classified into light, medium and heavy categories.

### 15.2.1 Light category

The small units, chiefly half-wave apparatus, in which the tube and transformer are built into one housing, the so-called tank units, belong to the light category. The oil contained in these units serves as insulation and at the same time as cooling agent. The tank-type construction makes it possible to dispense with the H.T. cables, and this contributes greatly to mobility, manoeuvrability and reliability of the equipment. Not only have these small, handy units become indispensable everywhere because of the ease with which they can be moved from one place to another (even to the sickbed of a patient at home), but they also produce radiographs of excellent quality due to their relatively hard radiation (great penetrating power, tubes with small 'Durchgriff') and a reasonably fine focus in their field of application (chiefly that of extremities). Voltages to 90 kV and current values to 20 or 30 mA are used with these.

### 15.2.2 Medium category

New tank units are even equipped with (four) solid-state rectifiers and allow high loads to be placed on the X-ray tube (to about 50 mA at 125 kV) and as small two-pulse units can be counted among the light-medium category.

The range of the four-valve units extends from the light-medium category to the heavy category, depending on their construction and electrical power. There are different variations available in the 100 kV 50 mA to 150 kV 500 mA range and thereby they can fulfil the highest requirements. The single-pulse (half-wave) units have virtually disappeared from the medium category.

### 15.2.3 Heavy category

In addition to several powerful two-pulse units (which are practically only considered if connection to three-phase is impossible) only six- and twelve-pulse units belong to this category. They can supply tube voltages to 125 kV or 150 kV (in exceptional cases even to 200 kV) at currents to 1000 mA. These electrical values sometimes exceed the capacity of the tube, but they still have practical value in cases where simultaneous exposures are made in two directions and the electrical energy is divided between two tubes. This occurs when examinations such as angiography and cerebral angiography are carried out. Special programme selectors are used in these cases. If three-phase connection is possible, then two-pulse apparatus is scarcely ever considered. In videodensitometry, where the absorption of radiation is measured by a contrast medium, which has been injected, (from which important conclusions can be drawn concerning the function of the heart and vessels) a sufficiently constant high voltage as is supplied by six- and twelve-pulse generators is also required. The importance of three-phase units in tomography, etc., has already been mentioned (see section 15.1.3.1.2).

It should again be pointed out that working with rectified voltage does not mean that this would give rise to radiation of one wavelength (monochromatic radiation). One also comes in contact with a complete spectrum of wavelengths with rectified voltage, where the shortest wavelength is determined by the peak voltage, according to Duane and Hunt's formula (see section 2.1). There is, however, a greater percentage of hard radiation when dealing with rectified voltage, or, in other words: the average hardness of the X-rays produced by practically constant rectified voltage is greater than that produced by pulsating rectified voltage.

## 15.3 CHOICE OF TUBES AND FOCI

Small apparatus is built as single units with the tube incorporated (tank units), thus leaving no freedom of choice of focus. The smallest unit in this group is the dental apparatus Oralix with 50 kV and 7 mA and a focus of about 1.0 mm. Since the single-pulse generator usually associated with these units offers limited possibilities (fixed voltage, fixed milliamperage) the capabilities are relatively low and the focus rather large. A somewhat larger type can be equipped with, for example, the possibility of choice between two voltages and various milliamperages and a double-focus tube. Strict attention should be paid to cooling-off periods in order

to avoid over-heating of the focus (and backfire in the tube). However, as the demands on tube ratings and definition with the increasing use of tank units in the plaster room, operating theatre, etc., are becoming greater, single-pulse generators are increasingly being replaced by two-pulse generators with rectification, and the heavier types of the light category are even equipped with rotating anode tubes with double focus. Focus sizes of 0.6/1.2 mm or 1.0/2.0 mm, for example, are used. Due to this the transition from the light category to the medium category has become completely blurred.

In units that are connected to the tube by means of cables one can choose the tube, which is not the case with tank units, and the question arises as to which tube one should choose. Tubes with stationary anodes are now seldom considered. Due to the increasing demands of modern radiographic techniques they are being replaced by tubes with rotating anodes.

Modern units of the medium and heavy categories are always supplied with rotating anode tubes, and these usually have two foci, one of 0.6 mm and one of 1 mm for example, and are suitable for voltages to 125 or 150 kV. Facilities are often provided for connecting several tubes. This is in fact the rule in the heavy category. On the whole a double-focus tube is preferable to a single-focus tube even though it may be possible or desirable to use only one of the foci at the time the apparatus is brought into use. The difference in purchase price is relatively little, and is more than offset by the greater range of application.

The tubes are classified according to their capability or their foci (see section 1.6). The type of focus used is determined by the incidental demands. On the whole, foci between 0.3 and 0.6 mm are considered fine, and those between 1.0 and 1.5 mm are considered broad. The tube loads can vary between 10 and 150 kW. Usually a small focus is employed for fluoroscopy. There is little or no sense in using a very fine focus (for example 0.3 mm) since the low  $U_g$  that is achieved in this way cannot assert itself due to the much greater  $U_i$  of the system (fluoroscopic or image intensifier screen, screen of the television monitor). For fluoroscopic purposes a 0.6 mm focus, is, in this respect more than satisfactory.

As far as radiographs are concerned that demand a much greater loading capacity (stomach radiographs, for instance), the broader focus should be brought into operation automatically, when switching over from fluoroscopy to radiographic exposures. Since fluoroscopy demands a low capacity, one would use the fine focus for this. Obviously here movement unsharpness does not play a part, whereas the lesser geometric unsharpness can play a part (due to the usually short focus-film distance with a relatively long object-film distance).

If the X-ray tube is of a modern type with an anode that rotates at a very high speed, then even with the 0.6 mm focus sufficiently short exposure times at high voltages can be achieved for various objects. The 0.6 mm focus is then loaded about as much as the 1.0 mm focus of a tube in which the anode rotates at normal speed.

Apart from the applications in fluoroscopy the fine focus is also of great use for radiographs that are required to show fine structures, such as skeletal structure (callus formation, etc.) with which materials capable of high definition (small  $U_i$ ) should be used. For this same purpose, macroradiography (direct radiological enlargement) carried out in order to procure enlarged radiographs has awakened new interest (see section 12.3). The 0.3 mm focus constructed for this purpose (causing

a  $U_g = 0.3$  mm with an enlargement of 2) proved unable to withstand the loads that are required in normal use, but it can still be recommended for special cases. The 0.1 mm focus which has lately been recommended has even lower ratings, but is capable of greater magnification. The 0.6 mm focus, on the other hand (especially with high-speed rotating anodes) has a high rating and enables it to produce a satisfactory macroradiograph (about  $1\frac{1}{2}$  times)\*. For bucky exposures at the usual distance of 1 m a 2.0 mm focus should be considered as being too large, and a focus of 1 mm is more suitable. However, if one wishes to have the possibility of macroradiography then in this case a double focus tube of 0.3–1.0 mm is recommended.

For tomography, especially with lateral projections of the spine and transverse tomograms, the 1.0 mm focus could possibly prove to be insufficient and a 2.0 mm focus should then be given preference (then especially in combination with three-phase apparatus). A 2.0 mm or a 1.2 mm focus is more usual for chest radiographs because of the long focus-film distance and the short exposure times that are required.

For X-ray cinematography with image intensifier the 0.6 mm focus is particularly suitable.

The specially constructed tubes (with molybdenum anodes), preferably the ones with rotating anodes, are designed for mammography.

### ***Summing up***

It is recommended that preferably double-focus tubes be used, particularly those in which the anodes rotate at high speeds (9000 r.p.m.) or otherwise the 3000 r.p.m. types. The tubes are suitable for 125 or 150 kV, depending on the equipment available. As far as the dimensions of the focus are concerned, the following is recommended:

- for gastro-intestinal examinations: 0.6 and 1 mm (or 0.3 and 1 mm).
- for tomograms and chest exposures: 0.6 and 1.2–1.8 mm; extra cooling can be of advantage with intensive use.
- for macroradiography: 0.3 mm or smaller.
- for X-ray cinematography: 0.6 mm and 1.0 mm.
- for bucky exposures: 0.6 and 1 mm (possibly 0.3 and 1 mm).
- for CT-scanning: 0.6 and 1 mm.

### **15.4 Connection of the apparatus to the mains; automation**

All X-ray apparatus of all types are connected to an electricity mains, which supplies alternating voltage. The connecting terminals (for example electric socket) can be compared with the terminals of an electrical source such as a battery, for example. The ‘open’ voltage in this case is the e.m.f. (electromotive force) which drops to the terminal voltage or *working voltage* on connection with the electric circuit. This drop in voltage, or *voltage loss*, on loading is caused by the resistance

\*There can be considerable differences in the actual focus sizes due to the permissible tolerances (see chapter 1, section 1.8). In this way, a 0.3 mm focus can approach the dimensions of a 0.6 mm focus and a 0.6 mm focus the dimensions of a 1 mm focus, which can have an unfavourable effect in macroradiography.

in the conductor and is equal to the resistance  $\times$  current strength in the electric circuit. In this case the resistance is formed by the resistance in the cables and/or wires from the generating station to the place where the connection is located and is called mains resistance. The lower this resistance (short, thick, supply conductors), the lower will be the loss in voltage when a load is connected. Therefore, it is usual to locate a powerful branch of the generating station, a so-called transformer hut, near a place where a large consumption of current may affect the current supply, and it can function as an electrical source with short supply wires.

#### **15.4.1 The significance of mains voltage compensation**

The electric mains voltage is not constant, but fluctuates depending on the load. In the evenings the mains are heavily loaded by domestic and street lighting; during the day the load is mainly determined by the requirements of industry and household appliances. In towns, where there is a great deal of industry, considerable load variations are expected around the lunch hour, when powerful electric machines are suddenly switched off or on. Even where the mains network is stable, voltage variations amounting to about 5 per cent above and below the nominal mains voltage are always to be reckoned with. Less-stable mains networks can easily vary by 10 per cent.

Since both the high voltage and the filament voltage for the X-ray tube and the valves are derived from the mains voltage via transformers, they are subject to the same fluctuations, which must, therefore, be avoided as far as possible. Especially, since the tube kilovoltage has great influence on the photographic density, the effective kV must coincide with the pre-set value on the control panel. A stable filament supply is equally important, since the current strength and, hence, the intensity of the radiation, depends on this.

For these reasons, it is essential to eliminate the influence of mains voltage fluctuations. On the control desk this is done by means of a mains compensation control, usually in conjunction with a voltmeter with only a single mark on the dial indicating the correct value of the mains voltage. If the mains voltage is too high or too low, the meter needle will not lie exactly on the mark, and must be set to the correct value by turning the mains compensation control knob to the left or right as appropriate. Essentially, this amounts to changing the ratio between the number of primary and secondary windings on the autotransformer, so that the secondary voltage always corresponds to the pre-set value. It is extremely important that the mains voltage has the proper value if good and reproducible results are to be obtained.

Modern apparatus is therefore often fitted with *automatic mains-voltage stabilisation*. If this is not the case, then the person in charge of the control of the apparatus should check frequently to see whether the mains voltage meter indicates the correct value.

#### **15.4.2 Voltage drop and its compensation: stabilisation**

When the correct primary voltage is pre-set by means of the mains compensator switch at the time of switching the apparatus on, then this does not mean that this voltage remains constant throughout the loadings that follow (screening and

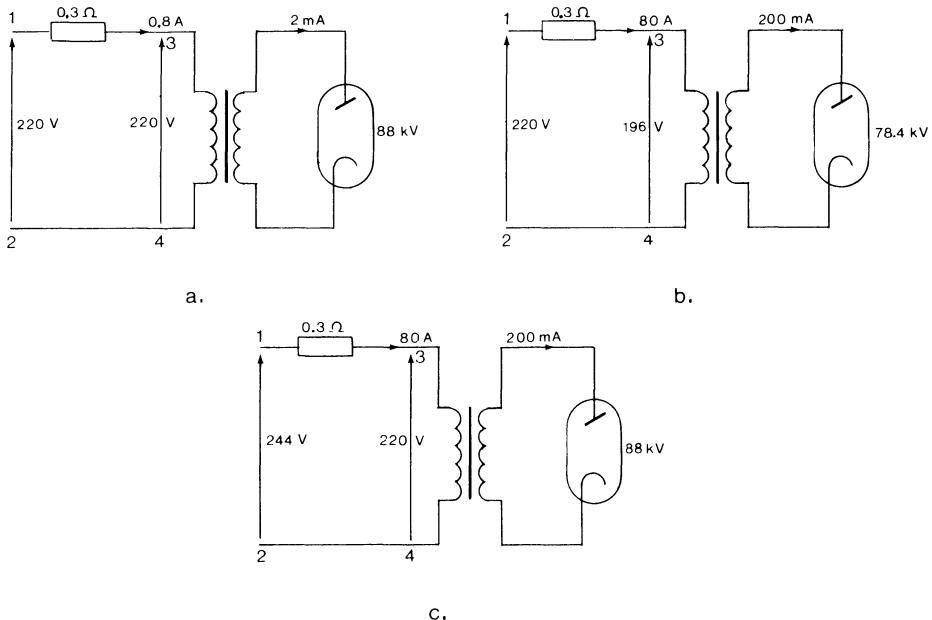


Figure 15.13 Effect of the resistance in the primary circuit; voltage compensation. For the sake of simplicity, Ohm's Law is applied here, and there are no assumed losses, etc. One sets out with a mains resistance of 0.3 ohm. The supply voltage is between 1 and 2; between 3 and 4 is the voltage of the primary winding of the high-voltage transformer.

- Situation with fluoroscopy.
- Situation with higher tube current; the voltage decreases sharply.
- Situation with higher tube current when the voltage has been compensated. For further explanation see text.

exposures). On the contrary: with every load, current flows through the circuit, which is formed by the mains supply wires and the conductors in the apparatus itself, hence, with the mains resistance and internal resistance of the apparatus.

Figure 15.13 shows diagrammatically the loss in voltage (voltage drop) that occurs when large current strengths are used. In order to safeguard against a drop in voltage in the H.T. circuit in which the X-ray tube is located, the voltage drop that occurs on the primary side should be compensated for by increasing the voltage coming from the mains supply. Voltage stabilisation can be achieved by means of this voltage compensation. This is made clear in figure 15.13. Here a resistance of 0.3 ohm and a transformer ratio of 1:400 is assumed. With a mains connection of 220 V and a tube voltage of  $400 \times 220 \text{ V} = 88 \text{ kV}_{\text{R.M.S.}}$ , with a tube current of 2 mA, the primary current will amount to  $400 \times 2 \text{ mA} = 0.8 \text{ A}$ . The voltage drop caused by this, that is  $0.8 \times 0.3 = 0.24 \text{ V}$  can be ignored, and the supply voltage (between 1 and 2) maintained (figure 15.13a).

The situation becomes completely different with a tube load of 200 mA and the same primary voltage. The primary current would amount to 80 A, the voltage drop 24 V, and the primary current through the H.T. transformer (between 3 and 4) would become  $220 - 24 = 196 \text{ V}$  and the tube voltage would decrease accord-

ingly to  $78.4 \text{ kV}_{\text{R.M.S.}}$  (figure 15.13b). Thus, in order to obtain the desired voltage of  $88 \text{ kV}_{\text{R.M.S.}}$  across the tube one should compensate for this voltage drop and ensure that (between 3 and 4) 220 V are again applied to the primary side of the transformer. By raising the supply voltage (between 1 and 2) to  $220 + 24 = 244 \text{ V}$  one has achieved the voltage compensation (figure 15.13c). This raising of the voltage takes place with the help of an autotransformer of sufficiently high power (formerly this was done by means of manual correction, but at present this is done automatically, electrically). In table 15.1 these different situations are again shown.

Table 15.1

	Supply voltage (V)	Primary transformer loss (V)	Tube current (mA)	Tube voltage (kV)*	Primary current (A)	Primary voltage loss (V)	Secondary voltage loss (kV)
Screening	220	220	2	88	0.8	0	0
Radiograph	220	196	200	78.4	80	24	9.6
Radiograph	244	220	200	88	80	0	0

\*For reasons of simplification the tube voltage is given in  $\text{kV}_{\text{R.M.S.}}$ . Normally the tube voltage is given in  $\text{kV}_p$ .

From the above (very much simplified and schematic) example, it is obvious that in order to achieve reliable and constant results, a compensation of the primary voltage in proportion to the tube load is essential. Apart from as low a mains resistance as possible (the maximum permissible mains resistance is indicated for every apparatus) also the construction of the unit (generator, conductors, etc.) should be such that the combined resistance remains low. With the earlier transformers the voltage drop on the secondary side sometimes amounted to as much as 10 kV per 100 mA. Modern transformers lose at most 3 kV per 100 mA on the secondary side, but even then it is necessary that the voltage on the primary winding of the transformer keeps its required value.

With older types of apparatus the voltage indication is calibrated in kV, before the loads are applied. In modern apparatus automatic voltage compensation is always present and the indicated kV values are valid for every load across the tube. The primary voltage of the H.T. and filament transformers is stabilised. This is of special importance with the use of a double-focus tube, as the tube rating of the foci can differ considerably (for example 30 or 50 kW). The stabilisation makes certain that the kilovoltages do not change. Stabilisation shows its advantage even more when several tubes (usually with a double focus) are connected to the same apparatus.

## 15.5 OPERATION OF THE APPARATUS

As far as the operation of the apparatus is concerned it is obvious that directions cannot be given for all the possible units, but that only the essential points can be brought to our attention. With this guidance, in conjunction with the instructions for use supplied with the given apparatus, everyone will be able to make himself sufficiently familiar with the properties and features of the apparatus concerned.

### 15.5.1 Free choice and automatic control

A distinction should be made between units that allow free choice of exposure factors and those in which the tube load is automatically selected. In the case of the free-control units, all adjustments of current, voltage and time can be made independently from each other. In the case of automatic tube loading, on the other hand, these adjustments are more or less rigidly integrated.

Nowadays, one finds very few units with complete free choice in view of the risk of overloading the focus, possible with this type of apparatus. This is due mainly to the rather critical adjustment of the filament current, since only a slight increase may cause a considerably higher tube current, which can easily exceed the rated load on the focus. *Almost all free-control X-ray apparatus are, therefore, fitted with an overload control* which, though it allows free choice, does so only up to a certain limit.

In automatic control apparatus special measures are taken to control the load on the focus, that is always ensuring an identical load. If we recall that the load on the focus (in section 1.6 we have seen that the maximum load is the best load) has a specific value which depends on three factors, voltage, current and time, then it is clear that when two values are determined the third can no longer be freely chosen, but is dependent on the others. Assuming for the sake of simplicity a 50 kW tube, then the maximum load per 0.1 s is 50 kW, therefore, 100 kV and 500 mA if connected to a three-phase supply. These three values (100 kV, 500 mA and 0.1 s) thus belong to this focal size. If one of them is reduced, it is necessary in order to maintain the maximum load to change (thus increase) the other values accordingly. If this is not done and, for example, the same current of 500 mA is maintained with the lower voltage, the result will be an underloading of the tube. The aim with automatic full-load apparatus is always to achieve maximum load without special adjustments or hazardous experiments. After all, the aim of automation is: 'to be forced to do the right thing'.

### 15.5.2 Types of automation

One differentiates between different degrees of automation.

#### 15.5.2.1 *Fixed voltage and current, free choice of exposure time (but limited); cooling-off periods*

The simplest form is found in small apparatus, which operates with a pre-selected voltage and a corresponding pre-selected current. The current is selected at a value that the tube is capable of withstanding at the longest exposure times permitted by the time switch.

This evidently implies that with short exposure times, for which the current could be higher, the tube will be underloaded to a certain extent. Nevertheless, the maximum load is approached more closely than would be safely possible with free adjustment.

The smallest representative of this primitive form of automation are the tank units, which operate with a fixed voltage and fixed current. In view of the limited thermal capacity of these 'small units' the instructions for use usually prescribe intervals of rest to permit cooling. *Moreover, adequate cooling (possibly by means of cooling-off periods) is recommended for all X-ray tubes when radiographs are*

*taken in rapia sequence.* (Especially now that frequent use is made of serial exposures with frequencies of 6-12 exposures/s, one should pay proper attention to the tube ratings under these circumstances. The same goes for the modern tomographic apparatus, where many exposures can follow each other fairly quickly. Consultation of the tables provided by the manufacturer is strongly recommended.

#### **15.5.2.2 Voltage and exposure time free, but connected with fixed current values**

A greater adjustment to the different conditions of exposure is possible with the type of automation where, although the voltage and exposure can be chosen fairly freely, they are tied to certain fixed current values. The theory that the best results are obtained, as far as focus and movement unsharpness is concerned, when the tube is fully loaded, is usually no more fulfilled than in the type of automation described above. After all, it's the exception rather than the rule that the combination of voltage and time is such that the current strength causes the exact maximum load on the focus.

#### **15.5.2.3 Voltage and current connected and free, time free (but limited)**

The type of automation in which one or more voltage values are coupled to pre-selected current values is better. The lower currents arise with the highest voltages, of course, and the high current values are possible with low voltages. With short exposure times there is then an underloading of the focus to a certain extent; with long exposure times the automatic overload control will have to enter into operation.

#### **15.5.2.4 Groups of exposure times connected with voltage-current combinations**

This signifies a perfection of the automatic system mentioned in section 15.5.2.3. A group of exposure times belongs to a certain current-voltage combination; a group of shorter exposure times belongs to another combination. The groups of long times and lower kV-mA values also belong to this group of course, and vice versa. Underloading occurs less frequently than in the previous type of automation and here are limited to the shorter times of a time group. The full load is satisfactorily approximated with the longest exposure time.

#### **15.5.2.5 Coupling of voltage, current and time (kV and mAs)**

In large apparatus automation is carried to still greater lengths. Not only are the exposure, time and current coupled over almost the entire range, but their combination, the mAs product, is coupled to the voltage as well. The lowest current is thus found at the highest voltage that can be selected and the shortest exposure time. This does not mean, however, that the exact current value is realised to produce maximum loading for *every* exposure time and *every* voltage. Also, in this case, the rating curve is followed 'in step fashion', although the steps are much smaller than with rather inferior types of automation. The full load, in this case, is approached to an excellent degree for every exposure within the chosen time.

#### **15.5.2.6 Automation with falling load**

Whereas the automation described above is very satisfactory with pre-selected exposure time and/or mAs product at a certain voltage, this is not the case when

exposure time or mAs are unknown beforehand and still have to be adjusted by the automatic exposure control. After all, one has to adjust an exposure time or mAs value within which an automatic exposure control can operate.

If it switches off before the value of the limiting load then this means an under-loading, if not an inferior image quality (see section 14.6.3). It is for this reason that the new apparatus functions according to the principle of the *falling load*. This means that during the time of exposure the current strength is re-adjusted from high to low. Voltage compensation in this case is absolutely essential as otherwise the voltage would rise (see section 14.5.5.2 and section 15.4.2). With apparatus that is correctly constructed the maximum permissible tube load can never be exceeded although this is approached as closely as possible with every exposure (see section 14.6.4). In this way it is possible always to end up with the shortest possible exposure times (figure 15.14).

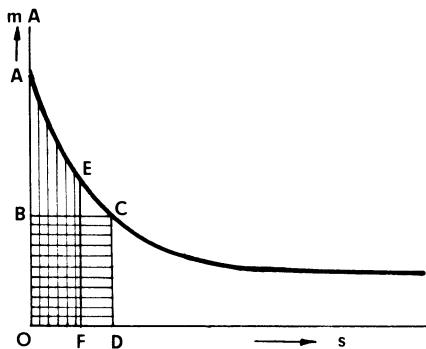


Figure 15.14 Shorter times with falling load. The curve indicates the load (at a particular voltage) in mA in relation to the exposure time (m seconds). With continuous tube load with, for example, B mA, then at C (after time D) the optimum load would be achieved and for the exposure, the area of the rectangle BCDO could represent the required energy for the exposure. However, with falling load (with the voltage remaining constant), the exposure would begin with A mA and, if one follows the AEC curve, one reaches the point E at which the area OAEF is equal to that of BCDO. Thus at time F the film would already have received the required exposure. This means the application of an equal load in a shorter time.

This falling load system became especially necessary and its advantages most appreciated in combination with automatic exposure control. Thus, one can in this case select a very long exposure time; the tube receives the load, which it can and may withstand every moment, right from the beginning (that is with the same voltage a high mA at first, which then decreases), until the required exposure is achieved. It is obvious that by decreasing current strength the automatic voltage stabilisation must ensure at the same time that the voltage does not rise, but keeps its selected value.

## 15.6 THE CONTROL DESK

The operation of a diagnostic X-ray machine varies from a simple manipulation of a switch or clock-work timer, when working with the group of small machines, to complicated switching, turning of knobs and pushing of buttons, reading of meters, etc., on control panels of heavier apparatus.

### **15.6.1 Location of control desk**

Only with low-powered apparatus such as portable units for use outside the X-ray department (in the operating theatre or on the wards) is it permissible to operate the controls in the same room, obviously with strict observance of the safety regulations of which avoidance of the primary beam, keeping one's distance and the use of adequate lead-rubber aprons and other protective materials are the most important.

The control desk for all other units is located inside or outside the diagnostic X-ray room in a protected area (or cubicle) in order to guarantee effective protection against radiation. If the control desk is situated in the room itself then a protective partition with sufficient lead and lead-glass should be present against the radiation. The diagnostic room and the control cubicle should be in communication with each other, both acoustically and visually. The visual contact is best effected directly via a lead-glass window in the adjoining wall or partition, and acoustic contact should, if possible also be direct rather than by means of microphones, etc.

### **15.6.2 Switching on and off, voltage and current adjustment**

First of all, there is a knob or switch on the control panel with which the apparatus can be put into operation. The needle on the mains voltmeter then swings over and gives a reading of the mains voltage. Modern apparatus is provided with a control for adjusting the mains voltage to a prescribed value (for example indicated by a mark on the meter), or it can take place automatically. A proper mains correction is essential for correct functioning of the apparatus. Frequently, mains compensation is achieved completely automatically. There are also controls for fluoroscopy and (usually separately) for radiography; the controls are generally marked with the symbols mA and kV.

The current is read from the milliammeter, which has a low scale (0–5 mA) and one or more higher scales (for example 0–100 mA, and 0–500 mA). It is not possible to read off these current values when the exposure times are short, for example tenths of seconds. The needle of a milliammeter, which can be pre-set, would also fall short in this case. Often such units are provided with an accurate mAs meter. Sometimes the original milliammeter is only connected with the screening circuit.

With the fluoroscopic current the milliamperage can be adjusted to the required value during screening (usually 0.1–3 mA). For screening a simple on-off switch is usually provided; for this purpose there may also be a switch mounted on the stand directly beside the fluoroscopic screen and/or a foot-switch. If an mA control switch is also present for radiography then with this the filament current and consequently the tube current is varied. Some apparatus has several fixed current values, for example 50, 100 and 200 mA. In many constructions the desired mAs product can be pre-set. Normally, the kilovoltage is regulated with a control knob; the values of the kilovoltages are marked on the knob itself or on a separate meter that has been calibrated in kV.

### 15.6.3 The timer (or time switch)

An important instrument on the control desk is the timer. This instrument has a scale on which the exposure times are calibrated, and much depends on its accuracy. Commonly known are the purely mechanical, electro-mechanical and electronic timers. A clock-work timer works mechanically, for example, with on and off switch contacts.

Electro-mechanical timers make use of a small motor, the charging or discharging of a condenser with on and off switching of relays, etc. In electronic timers valves usually play an important part, and in the modern apparatus especially, solid-state circuits with thyristors are used. Details of these are outside the scope of this book.

#### 15.6.3.1 Division of exposure times

The scale on the simpler types of time switch is often calibrated in equal intervals up to, say, 10 s, leaving little possibility for adjusting an exposure of a few tenths of a second and thus mistakes could easily occur. With modern timers this is no longer the case. Dials are distinctly calibrated for exposures under 1 s and even under 0.1 s, and mistakes are therefore practically out of the question. With respect to the calibration of the timers there is little point in keeping the subdivisions uniform over the entire range, since a difference of at least 25 per cent in the exposure value is needed to produce a perceptible change in radiographic density. It would be illogical, for example, to have a scale running from 1 s to 1.5, 2, 2.5, 3, 3.5, 4, 4.5 s, etc., since the transition from 4 s to 4.5 s, for example, (representing an exposure value only 12.5 per cent higher) will scarcely produce any perceptible difference. It is therefore more logical and better to choose the consecutive time intervals in such a way that they are increased by a (rounded) equal percentage of about 25 per cent, as is indicated by table 15.2.

Table 15.2

0.003	0.004	0.005	0.006	0.008	0.01	0.012	0.016	0.020	0.025	0.030
0.030	0.04	0.05	0.06	0.08	0.1	0.12	0.16	0.2	0.25	0.30
0.30	0.4	0.5	0.6	0.8	1.0	1.2	1.6	2.0	2.5	3.0
3	4	5	6	8						

#### 15.6.3.2 Checking the timer

A check of the timer is of interest and importance when radiographic exposures results fail to be constant. It is advisable to carry out a check of the timer periodically (especially in institutions with radiography students). The simplest method is to pull a film under a lead plate provided with a hole (figure 15.15) causing a row of exposed points to be visible. If, for example, an exposure time of 0.1 s is selected then, since the X-radiation is not continuous but is emitted in short bursts (or pulses), a series of exposed spots will be projected onto the film. With a mains frequency of 50 cycles and with half-wave apparatus, 5 spots will be produced, with four-valve apparatus 10 spots, with six-valve apparatus 30 and twelve-valve apparatus 60 points.

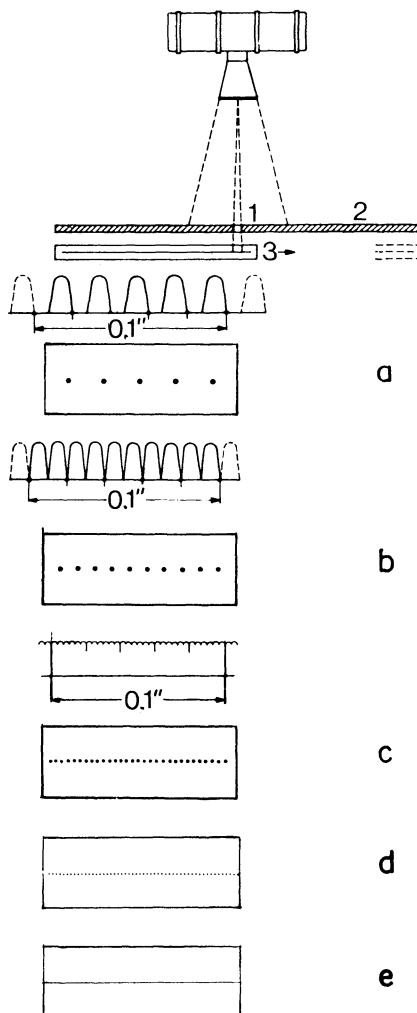


Figure 15.15 Diagrammatic representation of measurement of time by pulling a film over a certain distance. 1. Holes in 2; 2. lead sheet; 3. film which is moved in the direction of the arrow during the exposure.

- Half-wave voltage (opposite phase suppressed): one pulse per  $1/50$  ( $= 0.02$ ) s. In 0.1 s 5 dots.
- Four-valve voltage (opposite phase rectified): one pulse per  $1/100$  ( $= 0.01$ ) s. In 0.1 s 10 dots.
- Six-valve voltage (three-phase rectification): one pulse per  $1/300$  s. In 0.1 s 30 dots.
- Twelve-valve voltage (three-phase double rectification): one pulse per  $1/600$  s. In 0.1 s 60 dots.
- Constant d.c.: continuous exposure, thus an uninterrupted straight line.

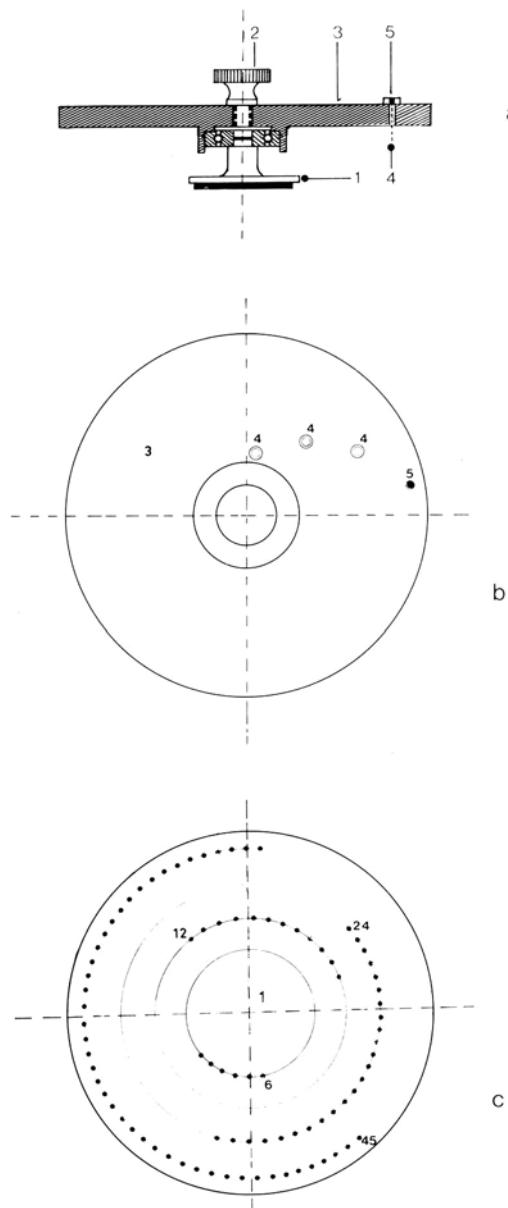


Figure 15.16 Timer check with the aid of a spinning top.

- a. Vertical section: 1. Base with vertical spindle; 2. knob for turning; 3. lead disc with holes (4); 4. holes, all but one plugged with pegs (5); 5. pegs.
- b. View from above.
- c. Result of a timer check with six-valve apparatus. From the outside inwards: 0.15 s (45 dots), 0.08 s (24 dots), 0.04 s (12 dots) and 0.02 s (6 dots). The different distances between the dots are the result of different speeds of rotation.

A better method makes use of a *spinning top*. This comprises a vertical spindle, which spins in a solid base and a horizontal, round lead disc, containing several holes at various distances from the centre. Figure 15.16 demonstrates a spinning top with seven holes, 3 mm in diameter, all but one of which are plugged with little pegs. This makes it possible to check seven different exposure times consecutively, by leaving a different hole open each time. The top is now placed on an unexposed film, and spun round slowly while the film is exposed by means of an X-ray tube placed vertically above the top. Obviously, the top will have to spin faster with a three-phase unit than with a four-valve unit or a half-wave apparatus, as the radiation pulses follow each other more quickly and the exposed points could possibly overlap each other.

### 15.7 OPERATIONS THAT CAUSE THE X-RAY TUBE TO FUNCTION

After the equipment has been connected to the correct mains voltage (possibly manually or automatically corrected) the required factors (such as kV and mAs) can be adjusted depending on the extent to which the apparatus is automated.

Various interlocking devices are incorporated into the control desk in order to simplify the operation, to prevent overloading of the tube, to avoid damage due to faulty operation, etc. The effect of these switches and safety devices is as follows:

- (1) When the apparatus is switched to fluoroscopy, radiography is impossible and vice versa.
  - (2) For long exposures a reduced tube current is automatically selected.
  - (3) If the kV is raised the tube current is lowered (usually proportionally).
  - (4) With higher loads due to choice of higher kV or mA settings the kV compensation is adapted to the greater voltage drop to be expected.
  - (5) When a different focus is selected, the tube current is automatically adjusted to the rating of this focus.
  - (6) If the apparatus is switched to radiography, the milliammeter is automatically shunted to a higher range.
  - (7) If the exposure time is shorter than 1 s then the milliammeter no longer gives a reliable reading and is automatically disconnected and an mAs-meter is possibly switched in.
  - (8) When the apparatus is switched to radiography, the anode of a rotating anode tube is brought up to full revolutions during the preparation time.
  - (9) When auxiliary devices such as bucky grid, serial changer, tomograph, etc., are selected, these are then interconnected to the timer.
  - (10) The time switch as such is switched off by:
    - (a) tomography. In this case the on and off switching is done by the movement mechanism of the tomograph. The time must exceed the time of tube-swing otherwise the exposure will be terminated too soon (see section 8.1.1).
    - (b) use of automatic exposure: the automatic exposure control terminates the exposure. Also in this case, the time should be set for a longer period than is expected (see section 14.6.4).
    - (c) X-ray cinematography (pulse technique). In this case the camera determines the beginning and the end of every image (frames per second, etc.).
- In all cases, a, b and c, a safety device is usually incorporated, which automatically

terminates the exposure (or series of exposures) after a certain length of time, in case of failure in the automatic exposure control and when overloading of the tube is imminent.

The majority of the above operations occur automatically. The advantage of the extremely easy operation of automatic equipment is even more obvious than the advantage of automatic correct loading of the tube. Especially when working with several foci, automation signifies a great practical facility, since without any trouble or risk one can change over to the other individual characteristics of a different focus. After all, every focus has its own nomogram, its own rating curve. It is possible for modern apparatus of the heavy category to have several tubes connected to it. By means of high-voltage switches the number of connected foci can be greatly increased (6 and more). The control desk in that case has a knob, the *focus selector*, with which the desired focus can be switched into operation. The automatic change-over to another focus is extremely efficient; for example, screening always takes place with a fine focus (for example 0.6 mm), and for radiographic exposures the broad focus automatically enters into operation. When doing a stomach examination, for example, this guarantees a fluoroscopic image with good definition and short radiographic exposure times.

### 15.8 THREE-KNOB OPERATION, TWO-KNOB OPERATION AND ONE-KNOB OPERATION

With respect to the automatic control system of an apparatus, one often hears mention of three- and two-knob operation. With the former, kV, mA and time are selected separately; with the latter the last two settings are combined to the mAs product, where the two factors mA and s are usually indicated separately. If the time factor is not indicated separately then this should be regarded as a serious deficiency. After all, it is the direct influence of the time factor (in seconds) which determines the  $U_m$  so that one should be able at least to control the exposure time.

In the case of automatic exposure with falling load, control with one knob is often the only possibility. In this case the voltage only has to be selected, whilst the mAs value is determined by the automatic density control.

Some apparatus is automated to such an extent that as well as automatic maximum loading they also have the facility for automatically selecting specific percentages of underloading (for example 60 per cent of the maximum load). This may be of importance when, for example, at the lowest voltage and the shortest exposure time the exposure value with the maximum load on the tube may be too high for the object in question, and where other factors for increasing the exposure value (such as increasing the focus-film distance), are not practicable. However, appreciable underloading does not lead to an increase in the life of the tube as is sometimes erroneously thought. By slight underloading (for example 80 per cent of the maximum) the focal track does remain in good condition for a longer period.

A control for cutting out the automatic loading is also frequently provided; this enables one to select freely an arbitrary current value for certain purposes (for tomography, cineradiography etc.). In such cases, however, the overload protection should remain.

### 15.9 SOME CONSIDERATIONS REGARDING EQUIPMENT

It falls outside the scope of this book to discuss fully the electro-technical details of the various constructions of X-ray apparatus. It is evident from the above, however, that one attempts to approach full load conditions of the focus as nearly as possible for the benefit of optimum definition (by achieving minimum  $U_g$  and  $U_m$  for those conditions). Hence, half-wave equipment is vanishing at an increasing rate and, as to the heavier types, four-valve apparatus is making way for three-phase equipment with six and preferably twelve rectifiers with which the (ideal) rectified voltage is achieved to within a hair's breadth, as it were.

Finally, in order to reduce the great 'ripple' associated with four-valve voltage, condensers can be connected in parallel to the X-ray tube, and because the crests

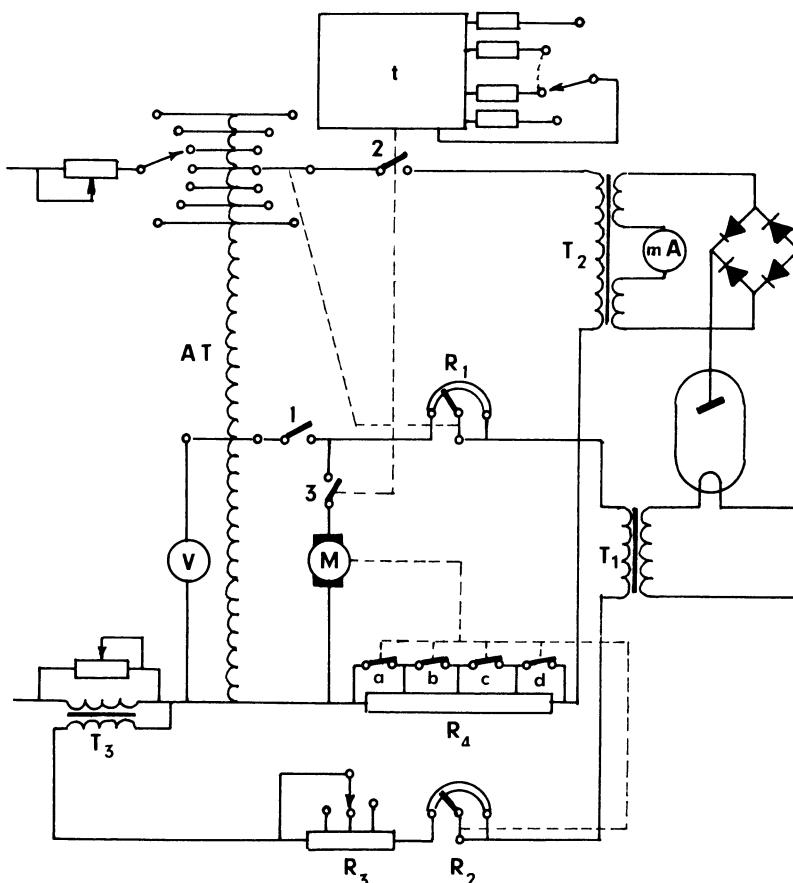


Figure 15.17 Diagrammatic representation of a two-pulse generator with falling load. On the extreme left: mains voltage supply (adjustable) to the autotransformer AT. 1, 2 and 3. Switch contacts;  $T_1$ . filament current transformer;  $T_2$ . H.T. transformer for the X-ray tube;  $T_3$ . variable transformer;  $R_1$ . continuous adjustable resistance (potentiometer type);  $R_2$ ,  $R_3$  and  $R_4$ . adjustable resistances; a. b. c and d. switch contacts; V. voltmeter; mA. milliammeter; M. falling load motor. For further explanation see text.

of the waves become wider these are called 'smoothing' condensers. With X-ray cinematography, especially when one uses four-valve apparatus, smoothing is essential. Not only is the tube loading then improved, but at the same time the occurrence of uneven density from frame to frame is avoided (this could happen when one frame is exposed while the voltage is at its peak value and the next, when the voltage is in a voltage 'trough'). With the use of six-pulse and twelve-pulse voltage this uneven exposure (even with a large number of frames per second) does not arise. The use of extra condensers for further smoothing of the voltage is in this case practically not applied. Due to the smoothing influence of the cable capacitance (especially with extremely long cable lengths) the small ripple, which is still present with twelve-pulse generators, practically disappears. When we were dealing with falling load apparatus we learned that the shortest possible exposure time results if a focus is fully loaded, when making a radiographic exposure. For the sake of completion an outline of a four-valve apparatus with falling load will now be shown and explained (figure 15.17).

When preparing for the exposure, contact 1 (figure 15.12) closes across the potentiometer  $R_1$ , the circuit on the primary side of the filament transformer  $T_1$  and the resistances  $R_2$  and  $R_3$  and the secondary side of the Variac transformer  $T_3$  to the autotransformer AT. The voltage is indicated on the voltmeter V (possibly regulated with  $T_3$ ). The filament current thus begins to flow, and indeed flow at its highest permissible value; it has been pre-set with the help of the resistance  $R_1$  and  $R_3$ . The resistance  $R_2$  is set at its lowest value at the beginning of the exposure.

When contact 2 is closed, the circuit across the primary winding of the H.T. transformer and (parallel to the resistance  $R_4$ ) contacts a, b, c and d, and the entire autotransformer is closed and, therefore, the X-ray tube receives a certain high voltage which matches the high filament current value. At the same time, contact 3 is closed causing the falling load motor (M) to function, which brings about the following effect: first, an alteration in the position of the needle of the potentiometer  $R_1$  due to which the resistance (in the filament circuit) increases and the tube current decreases, and, secondly, contacts a, b, c and d open consecutively, causing the resistance  $R_4$  (in the primary H.T. circuit) to increase in four steps and the voltage across the primary winding of the H.T. transformer to decrease accordingly. By means of mutual cooperation between the settings of  $R_1$  and  $R_4$ , the rise of voltage with a decreasing tube current is prevented (which would otherwise occur due to the diminution of the losses); therefore, when the tube current decreases, the voltage remains constant. This is the principle of falling load, which, therefore, achieves loading the focus to its maximum load at every moment of the exposure. When the exposure is completed,  $R_1$  and  $R_4$  automatically return to their original values.

### 15.9.1 Influence of mains frequency

It should also be mentioned that not only are there variations in the voltage values in mains electricity supplies in different countries, but also variations in the frequency. Whereas adapting equipment for deviations in voltage is relatively simple (by means of a built-in autotransformer or by means of an extra transformer), adjustment to another frequency is virtually impossible. Fortunately, in Europe at any rate, there is already widespread standardisation (which is progres-

sing) and the mains frequency is 50 Hz; the most common voltage is 220 or 240 V. However, the frequency in America is usually 60 Hz and the voltages also differ. Due to this, synchronous clocks, which are constructed for 50 Hz here in Europe, cover 72 min in America. H.T. transformers, which have been accurately constructed so that they suffer from as little loss as possible with respect to magnetisation of the soft iron core, etc., cannot be connected to another frequency unless this is specifically mentioned. The same is true for tubes with rotating anodes in which the speeds, instead of 3000 and 9000 r.p.m. would amount to 3600 and 10 800 r.p.m. respectively, at 60 Hz.

### **15.10 BREAKDOWN OF EQUIPMENT, CONSTRUCTION OF MODULES**

It is in every respect understandable that, in view of the complicated construction of X-ray apparatus and the high loads (mechanical and electrical) on many of its parts, breakdowns can and do occur. The range of repairs necessary varies from a simple renewing of a flex or plug to days of searching by specialised X-ray service engineers with sometimes the result that the trouble cannot be cured and renewal is necessary. This last tendency, when repairs are often more expensive than replacement (analogous to the 'waste economy' in daily life), also happens in the world of X-ray, and industry consciously and increasingly avoids repair (by, for example, no longer supplying parts of 'obsolete' types) and strives towards replacement. The more complicated the construction of an apparatus the greater the risk of breakdown, especially when climatic influences (particularly tropical temperatures with a high degree of humidity) also play a part.

In order to simplify the servicing and reduce the length of time work in the department is interrupted, manufacturers of X-ray equipment have followed the example of other manufacturers of technical apparatus. X-ray equipment is split up into several combinations of parts which, as such, form individual units called modules. A signal system is connected to this, so that when breakdown occurs, it indicates immediately in which module one should investigate the cause, and this can then at once be passed on to the manufacturer. Then, the serviceman, equipped with a replacement module can change the defective module, thereby curing the breakdown. In the factory or laboratory the possibility of repair can be investigated and possibly carried out.

### **15.11 THE RELATIONSHIP BETWEEN THE CONTROL DESK AND THE STAND; REMOTE CONTROL; TÉLÉCOMMANDE**

With conventional fluoroscopy, and also with image intensifier fluoroscopy, with or without television, which usually involves 'directed' exposures on spot-film cassette, 70 mm film or cine film, the examiner is located near the patient, beside the table and operates the necessary knobs and switches there. These are, as it were, tapped from the control panel; the controls can also be manipulated from there by the radiographer, if she so desires.

Now that fluoroscopic images can be perceived much more easily (and better) on the television screen than on the conventional fluoroscopic screen or even on the image intensifier (without television), it is no longer necessary for the radiologist

to remain in front of the fluoroscopic screen or image intensifier screen. There are obviously other reasons why he should sometimes be there, such as for palpation, compression, seeing whether pressure on certain parts causes pain, injection (bronchography, salpingography, retrograde pyelography etc.), accurate turning of the patient into a desired position, etc. etc., but, without a doubt, there are many examinations that do not require direct contact with the patient. As a result a remote control system has been developed (*télécommande*, by Chérigé and others, Paris), in which all movements of stand, serial changer, etc., no longer need to be controlled directly from the stand; the control can be situated 'elsewhere', even in an adjoining room. Whilst not taking things too far, by making visual and acoustic contact with the patient either too artificial or too poor, this remote control can definitely have some advantages, such as complete protection from radiation and less physical effort as far as the investigator is concerned.

Undoubtedly, the argument of complete protection (for the investigator, not the patient) has such great psychological influence (especially on those who, in spite of the well-known adequate protection, still have a certain radiation phobia) that they are endeavouring to adapt more and more examinations to remote control. In this way, the manually directed and varied compression, which plays such an important part in stomach-intestinal examinations, has been mechanically imitated as far as possible. They are also attempting to modify the administration of barium enemas and other relatively simple manual injections, so that these can be performed from a distance. If the radiographer has to intercept due to the reduced contact between the investigator and the patient (for example by holding the tubes and canulas, etc.), then for her, remote control does not signify a reduction of radiation. There is no point in carrying out simple and safe manipulations from a distance just for the sake of it, and it seems more sensible and preferable to remain near the patient for a large number of examinations.

Remote control equipment also alters the appearance of the control desks; notably, the inclusion of (duplicated) push-buttons and levers for controlling the movements of the patient and table, which formerly were only found on the stand itself, such as tilting and sliding of the table-top, tube, serial cassette, etc. The modern remote control panels, therefore, contain a large number of knobs and switches, which are operated by the examiner in his cubicle, like a pilot in his cockpit. However, in order not to become entirely dependent upon remote control, the controls for selecting voltage density or brightness with automatic exposure and stabilisation, etc., are often duplicated on a separate simplified control panel, which can be operated by the examiner in the immediate vicinity of the patient.

Now that the television screen replaces the fluoroscopic screen, the conventional set-up, in which the tube is located behind (or under) the table and the fluoroscopic screen (or image intensifier) is situated in front (or above) the table, is no longer necessary. This arrangement is exactly reversed in the case of remote control units, and the tube is located in front (or above) the table. This arrangement has advantages (a rather more unimpeded access for the patient) and disadvantages (for example a much less favourable protection against radiation as far as bystanders are concerned). Remote control undoubtably has gained a permanent place for itself alongside the conventional arrangement; however, it will not replace it.

In figure 15.18 a simple remote control arrangement is demonstrated and the following particulars, which have been described above, are visible:

- (1) The investigator is not found near the patient, but operates the apparatus from a distance.
- (2) The tube is located above the table; the image intensifier and television camera are under the table-top.
- (3) The television monitor may be placed anywhere suitable.
- (4) The compression can also be controlled from a distance.

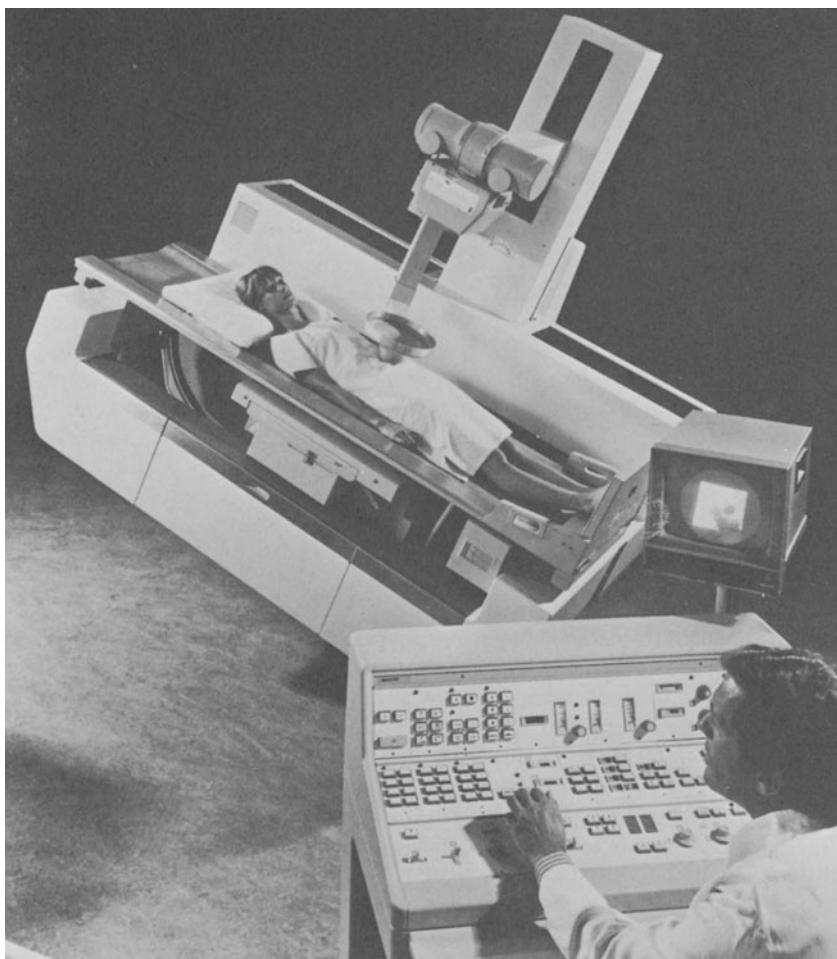


Figure 15.18 Modern remote-control universal stand. The apparatus illustrated here is the Diagnost 120 of Philips.

### 15.12 DIAGNOSTIC DOSEMETER

The *diagnostic dosimeter* also belongs to the diagnostic X-ray equipment. This is an instrument which, hitherto, has not been found in many X-ray departments, but it deserves, without a doubt, widespread use. Its purpose is to determine the amount of radiation received by the patient during a diagnostic X-ray examination, and to limit this dose as far as possible. A considerable part of the applied dose is contributed by fluoroscopy. One of the first measures, which has already been used for some time to give some idea of the dose received, was to include a 'fluoroscopy timer' on the control panel. This can be set to a certain time and thus give the examiner an indication (warning) of how long he has been screening at any particular moment. Of course, this time gives a very incomplete impression of the dose received, since neither the voltage and the current nor the field size are taken into account. The special diagnostic dosimeters are therefore much better in this respect. In sections 3.8.2 and 3.8.3, the function of this dosimetry, with which at present the amounts of radiation are measured in  $R \times cm^2$  as well as the deduced interpretation, that is the integral absorbed dose, were fully discussed.

*Brief summary.* The ionisation produced in the measuring volume (= radiated surface  $\times$  thickness of the measuring chamber) causes a charging of a condenser and this charge can be measured and/or read. The integral absorbed dose within the body is the sum of all the absorbed doses (in Gy or rad), in all the unit volumes (for example of 1 mg) and is expressed in joules or watts. This integral absorbed dose can be considered proportional to the measured  $R.cm^2$  product. There is no fixed ratio in existence; the ratio grad/ $R.cm^2$  is increased if the body part in question is thicker and when the radiation is harder.

Table 15.3

H.V.T.1 in mm aluminium	Maximum value of the pulsating tube voltage (four-valve voltage)	No. of grad equal to $1 R.cm^2$ in the incident beam of radiation
2.5	70	7
2.5	90	8.5
3.5	90	10
5.0	120	12

Table 15.3 (according to Mellink) shows clearly that this proportion almost doubles when changing from 70 to 120 kV. Therefore, one does not achieve accuracy by any means with this  $R.cm^2$  dosimetry, but one does gather a very useful impression of the amount of radiation received during an examination. In departments in which training of radiologists and/or radiographers takes place, the didactic value of this diagnostic dosimetry should not be underestimated.

# 16

## Diagnostic Stands and Accessories

In order to perform an X-ray examination, whether it be by means of screening or radiographs, the X-ray tube must be mounted in some way or another. This is usually accomplished by means of a fixture known as a *stand*. The stand may be combined with an X-ray table and various accessories. Diagnostic stands should be built in such a way that they facilitate the examination and, therefore, when they are being constructed, the many medical requirements should be taken into account. There are many stands which vary greatly in construction from the simplest type (a single column) to the most elaborate equipment, which satisfies the high demands in modern hospitals. It would exceed the scope of this book to enter into detailed descriptions, and we shall limit the following discussion to the more important general features.

A small group of mobile units is separate from the very large group of diagnostic units, which have a permanent, fixed position.

### 16.1 TRANSPORTABLE UNITS

It is frequently desirable for a stand to be mobile or portable and not to be permanently fixed.

#### 16.1.1 Portable stands

Transport of a stand is especially necessary in the exceptional cases when the radiograph has to be taken at the patient's home, when he cannot be taken to a hospital, clinic, etc. A very good example is a case of a doubtful fractured hip; however, a serious lung affliction can also be an indication. Today, because of the increased concern about radiation protection, fluoroscopy under such primitive circumstances is scarcely ever carried out; for the taking of radiographs, however, simple, collapsible or foldable stands are considered for this purpose. With the aid of a

small tank unit excellent radiographs can be produced, which can be conclusive and influence possible transport and further treatment of the patient. However, the image of a radiologist X-raying outside his department has all but disappeared. There are still a large number of transportable units and stands in existence for use in the field. These belong to the medical equipment of the armed forces or an expedition and are often robust and heavily constructed, often only being transportable with super-human power or by mechanical means. In a very short period of time a stable stand (possibly with the ability to screen as well) can be set up in an efficient manner. In this respect, the transportable photofluorographic units for mass lung surveys on the 70 × 70 mm or 100 × 100 mm film size are well known.

In general, generators of the medium category (one- or two-pulse) are connected to these stands, but the condenser type apparatus is also of value in these situations.

#### 16.1.2 Mobile stands

A simple mobile unit attached to a folding arm is found useful for dental radiographs (the folding arm may also be mounted on the rest of the dental apparatus, figure 16.1). As an independent unit it renders excellent service in a radiology



Figure 16.1 X-ray installation for dental radiography combined with the rest of the dentist's apparatus. 1. Hand grip; 2. X-ray apparatus (tank unit); 3. localising cone with interchangeable diaphragm; 4. folding arm.

department due to its rapid and easy adjustment. Thus, one avoids the manipulation of normal X-ray tubes, which are large and clumsy for this purpose. Radiation protection is facilitated due to the low kilovoltage and narrow, clearly indicated beam. Great use is made of mobile units in hospitals especially. An easily moved unit that takes up little space and allows flexible and accurate adjustment of the central beam in various directions is indispensable for both radiography at the bedside and in the operating theatre and plaster room.

One of the simplest X-ray units is the small mobile stand with which one can take radiographs without a bucky. An example of this is illustrated in figure 16.2.

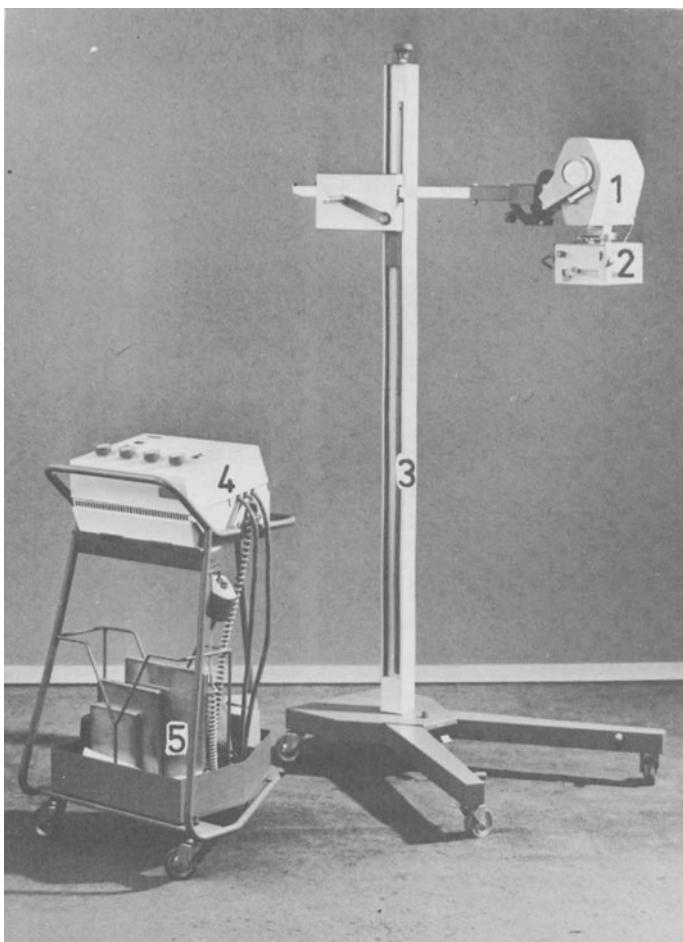


Figure 16.2 Mobile stand which can be dismantled. 1. X-ray tube (tank unit); 2. light-beam diaphragm; 3. column on a pedestal; 4. control desk with hand switch; 5. trolley for cassettes, which can be detached from the stand.

It consists of a base on wheels, a column and a sliding cross-arm to which the X-ray tube (in a tank unit) is fixed.

Some of these stands can be dismantled so that they may be transported to the patient's bed-side at home. Of course, only generators with limited power can be used in combination with these stands. It is true that this limits their field of application; nevertheless, they are well known for the work they are capable of doing.

With all these units, the former (handy) centering pointers with distance scale and the cones have now been replaced by a light-beam diaphragm, which enables more accurate adjustment to the area to be exposed, and facilitates radiation protection (see chapter 11, section 11.3.4.2). The small tank units that are mounted on these mobile stands are equipped with a tube with a stationary anode (and often with a single 2 mm focus). A limited choice of kilovoltage is possible (for example to 90 kV).

The demands made on the mobile units are becoming increasingly greater, as the low power of the small tank units is rather inadequate, especially for use in the operating theatre. Heavy, single-pulse units (for example a type of heavy tank unit, or more often in the conventional construction of tube, cables, transformer and control desk) are considered for this purpose, when the necessary mains connection (thick supply wires, low mains resistance) is indeed present. However, they are being successfully replaced by the two-pulse (four-valve) units of the light, medium and even heavy categories. The stands that carry this apparatus but which still permit great freedom of movement as far as the tube is concerned are fairly heavy, and are sometimes motor-driven. The tubes, which were formerly often stationary anode tubes, are at present practically without exception dual-focus tubes with rotating anodes. The field of application includes the types of fractures that require heavier exposures (vertebrae, pelvis, skull), operative cholangiography, abdominal survey radiographs, etc., usually combined with the use of a stationary grid, in so far as is necessary for check radiographs in the operating theatre or plaster room. These units are not suitable for fluoroscopy and only with the aid of a separate fluoroscopic screen or cryptoscope could one view a fluoroscopic image. The method formerly used has now been completely abandoned due to reasons of radiation protection.

Due to the great revival of fluoroscopy by means of image intensification (with or without television) a new type of stand has been developed with a U- or C-shaped arm. At one end of the C the X-ray tube is situated (usually in the form of a tank unit) and at the other end the image intensifier with Vidicon camera is attached. The C-arm is placed around the object to be screened, which is usually positioned on an extension table or operating table. As it is possible to give the C-arm very great mobility by sliding it in a lengthwise direction, and turning it in several directions, one can adapt to the existing situation in an excellent manner, whilst the tube always remains centered to the image intensifier (figure 16.3).

In the most modern constructions, the beam is automatically limited by a circular device and its maximum diameter is automatically limited to the size of the primary screen of the image intensifier, when set for 'fluoroscopy'. When set up for 'radiography' then, with the aid of a light-beam diaphragm, one can adjust to the desired field size. The image is viewed on the television monitor. When one wishes to take a radiograph, the cassette, possibly together with a grid, can be fixed against the image intensifier.

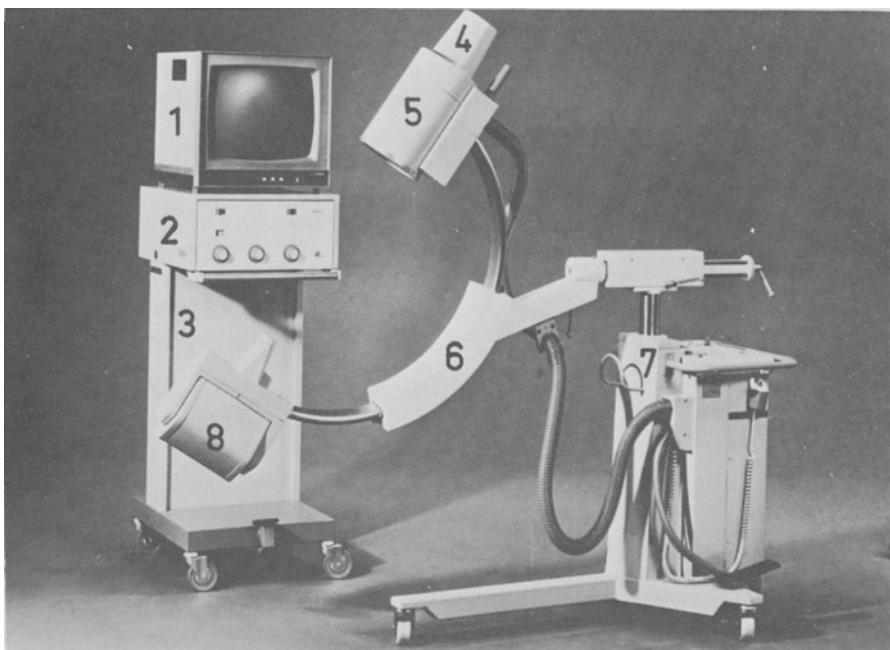


Figure 16.3 Mobile stand for fluoroscopy with image intensifier and television and radiographic exposures. 1. Television monitor; 2. television controls; 3. mobile frame; 4. television camera; 5. image intensifier; 6. support onto which the C-arm with the X-ray tube and image intensifier are attached and which can be rotated, raised and lowered; 7. control panel and power supply unit for image intensifier; 8. X-ray tube (tank unit).

The success of this C-shaped unit has led to the construction of much heavier stands, which have proved especially important for heart and blood-vessel examinations. The heaviest types are no longer mobile, but are permanently set up in the respective departments (or suspended from the ceiling), namely, in the operating theatre, room for angiographic examinations, plaster room, etc. The U-shaped arm is often preferred to the C-arm, as there is more space for the object. The distance between the focus and image intensifier is about 80–100 cm in the smaller mobile types.

## 16.2 FIXED STANDS

By far the most stands are permanently fixed; not only are they placed (and usually fixed) on the floor, but often they are attached to the ceiling by means of ceiling rails. It is true that in this latter case a special, robust ceiling construction is required, but it has the great advantage of leaving the floor area clear.

### 16.2.1 Stands with fixed table-tops (non-tilting)

These are in the minority since it is usually necessary to examine the patient in several positions utilising the force of gravity.

### 16.2.1.1 Vertical stands

One still comes across these as simple fluoroscopic stands for the benefit of lung examinations but, both due to the development of photofluorography and the decrease in the number of tuberculosis cases, their significance has practically disappeared. They consist of a vertical sheet of radiolucent material against which the patient may lean, with a foot-stool at the bottom, which can be adjusted in height. The fluoroscopic screen can be moved up and down and from side to side in front of the patient. The tube, which is connected to the fluoroscopic screen, then moves with the screen behind the sheet of radiolucent material (figure 16.4).

These simple fluoroscopic stands (in as far as they are still used) are being increasingly replaced by image intensifiers. Formerly, it was possible to move the tube and fluoroscopic screen independently, thereby enabling a orthodiagnostic examination to be carried out. This system, however, carries the risk that the

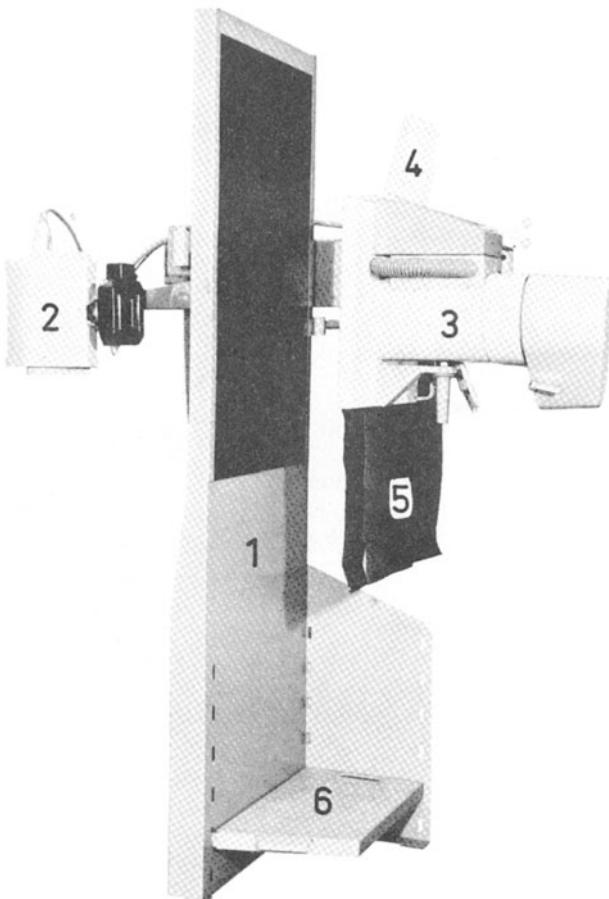


Figure 16.4 Vertical fluoroscopic stand with image intensifier. 1. Back rest for patient; 2. X-ray tube (tank unit); 3. image intensifier with optical system; 4. cough guard; 5. lead-rubber protective apron; 6. foot rest.

X-ray beam could pass beyond the circumscribed limits of the screen, thereby endangering the radiologist; the system has therefore been completely abandoned. Nowadays, the X-ray beam of all units with which fluoroscopy is possible is aligned with the centre of the fluoroscopic screen and the movements of the tube and screen are coupled together in such a way that at every position of the unit (horizontal, vertical, etc.) this centering is maintained. Under no circumstances may the beam pass outside the lead-glass and/or lead shielding of the fluoroscopic screen, when the diaphragm is completely opened. By folding the fluoroscopic screen or other construction out of the way then, if desired, a cassette possibly with the use of a grid (fine-line grid), can be placed in position for the taking of a radiograph.

The *vertical wall stands* without screening possibilities are used more often; cassettes of different sizes can be placed in these at adjusted heights, and the exposure takes place by means of a tube from another stand. This is most often used with chest radiographs at 150 cm and telecardiograms (teleradiography of the heart) at 200 cm focus-film distance. Thus, in this case there is no connection between the tube and the cassette stand; the centering and field limitation take place quickly by means of a light-beam diaphragm.

The *bucky wall stand* or *upright bucky* offers more possibilities; it is provided with a moving grid, and can produce excellent bucky exposures of the patient in an erect position. This is of special importance for the investigation of the spinal column under load-bearing conditions, both in the a-p and lateral directions. On specially constructed stands, radiographs of 80 × 30 to 120 × 30 cm (two to three films of 30 × 40 cm above one another) can be taken as teleradiographs (at 2 m and more) of the whole vertebral column with one exposure.

Apart from the strictly vertical or horizontal set-up, one comes across (especially in the case of wall stands) types transitional with the following group.

#### **16.2.1.2 Horizontal stands**

Strictly horizontal fluoroscopy with the tube below and the screen above the table is practically no longer used, and the examination table known as the trochoscope, which was only suitable for this arrangement, has therefore also disappeared. The taking of radiographs with the patient lying in a horizontal position is still an important part of the radiological procedures. This is carried out on the stand that is generally called the *bucky table*. Actually, this is a very simple stand: a good radiolucent table-top (wood and some synthetic materials appear to cause very little absorption), immediately below that the grid and underneath that the tray in which the cassette is placed. The drive of the grid movement is electrically coupled (formerly mechanically) to the beginning of the exposure.

In some bucky tables the grid is interchangeable, for example, for one with a higher ratio for use with high-kilovoltage techniques. If, as in automatic exposure timers, the exposure time is not known beforehand, a continuously moving grid such as an oscillating or reciprocating bucky should be used. This type of bucky mechanism also minimises the risk of the stroboscopic effect, that is streaks on the radiograph even with extremely short exposure times (see section 6.3.6). The tube is usually mounted on a vertical column, which may run on floor rails along the whole length of the table. The tube can be adjusted in longitudinal and transverse directions as well as in height, the latter, for example, to between 40 and 120 cm above the table-top by means of counter-weights or a spring counter-poise

mechanism. Usually one works at the optimal focus-grid distance, that means a distance (in general 100 cm). Moreover, the tube can in most cases be rotated around the axis of its cross-arm at right-angles to the length of the table. Usually, the column and the cross-arm can be coupled with and centered to the bucky diaphragm for the most common exposures with a vertical beam; moreover, the cross-arm is usually calibrated for the use of stereographic technique (see section 12.2.1). For oblique projections (skull exposures, etc) the tube column is not coupled and the beam must be specially centered; this is made easier by means of a degree and centimetre graduation.

The column attachment of the tube is increasingly being replaced by ceiling suspension systems, which give complete freedom of access to all sides of the table. With this system too it is possible to adjust the height of the tube and to move it along the length and breadth of the table, as well as to rotate it on its horizontal axis.

For macroradiography one is required to take radiographs with the object brought nearer to the tube. A cassette tray without a grid is very useful for this purpose, as one can, as it were, lower it away from the table-top, while the tube-table distance can be altered at the same time to obtain the desired magnification factor (usually 1.5-2). By fitting such a table with a transparent surface good advantage can be taken of the more exact centering and beam limitation offered by a light-beam diaphragm. Especially for radiographs of the skeletal system, when one is concerned with small changes, this method is indicated, for example in the case of early rheumatism.

Macroradiography (see section 12.3) has lately again roused the interest of many, because of the appearance of tubes with a very fine focus (0.1 mm). This method seems very suitable for the portrayal of the smallest ramifications of blood vessels by means of selective angiography. This has led to the construction of very special macroradiographic units.

Another important factor is that the bucky table should be the right height to allow for convenient transfer of patient from bed or trolley, and should be easily accessible to walking patients. For the latter purpose a handy foot-stool or step should be considered an indispensable accessory.

Every bucky table should have a good *compression band* (or *bucky binder*) since, as we have mentioned, compression is one of the most important means of limiting scattered radiation. A compression band, combined if necessary with a rubber balloon, or (in more modern versions) plastic-foam cushions, can provide very efficient compression, especially with corpulent patients, thus shortening the exposure time and greatly improving the contrast. They can also be used to help the patient suppress his respiration during an exposure, which especially with patients of low intelligence, is by no means superfluous. Good, effective compression can, for example, practically eliminate respiratory movement blur in exposures of the kidneys or gall bladder.

There are two new trends in bucky radiography:

#### 16.2.1.2.1 *The floating table-top*

Since the tube and grid must of course remain centered with respect to each other and their combination (again a U-shape) can only be shifted in a lengthwise direction, the centering of the patient with respect to the beam has to take place by shifting the patient. A floating table-top, however, can be moved over a fairly long

distance in a lengthwise direction (for example 120 and 70 cm), and in a crosswise direction ( $2 \times 12$  cm). The patient simply needs to lie on approximately the centre of the table-top and any further adjustment with respect to the beam (light-beam diaphragm) is carried out by the (easy) shifting and fixation of the table-top. This is not an essential but a much appreciated improvement in practice.

#### **16.2.1.2.2 Bucky radiographs after fluoroscopy with image intensifier television**

The use of screening for the correct positioning before taking a radiograph (at least with the non-dynamic processes or stationary objects) is contestable. The image intensifier and television camera in this case are found under the table and, after obtaining the correct position, the bucky tray with the cassette is slid in front of the image intensifier and the exposure is made. Although by screening briefly the extra radiation dose is little (absolute and relative), one must ask oneself if this perfecting of the examination is sufficient motivation to justify the extra dose (and extra cost). The routine positioning on the bucky table (vertebral column, pelvis, intravenous pyelogram, skull, etc.) is, after all, in general, carried out very satisfactorily by properly trained personnel. In any case, screening does not give rise to an immediate correct position for difficult views (Schüller, Stenvers, etc.), so that then an unjustified, long screening time could occur.

#### **16.2.2 Stands with tilting table-top**

As has already been mentioned, it is necessary in most cases to be able to carry out an X-ray examination both in a vertical and horizontal position as well as at a particular angle. It is often desirable to continue the motion beyond the horizontal position, in which case one speaks of the *Trendelenburg position*. This is indicated in degrees. At  $0^\circ$  Trendelenburg the patient lies in an exactly horizontal position, at  $90^\circ$  Trendelenburg he will be 'standing on his head'. In order to make these investigations possible, many tilting tables have been constructed. These allow the table-top and beam direction (that is tube and tube arm, cassette tray and possibly image intensifier and accessories) to rotate around a horizontal axis. Normally, it is possible to tilt the stand from the vertical ( $90^\circ$ ) via the horizontal ( $0^\circ$ ) position to a Trendelenburg position. Simple stands allow a tilt of up to  $15^\circ$  Trendelenburg\*, the complicated stands to  $90^\circ$  Trendelenburg (which, in practice, is scarcely ever used).

Practically all stands are moved by means of a motor. One should always keep in mind that powerful forces are involved, so that a foot-stool or similar object can cause a considerable amount of damage to a radiographic table or X-ray tube.

#### **16.2.2.1 Stands with one tube fixed to the table**

The X-ray tube of practically all modern units of this type is coupled along one side of the table-top to the image intensifier and serial cassette changer by means of the so-called *carriage*; thus, also in this case, the U-shape. The tube is then found under or behind the table-top. The distance between the tube focus and the table-top is usually fixed at 40–50 cm. On the other hand, the distance between

\*If a greater Trendelenburg is required with these simple stands then one can 'make do' by turning the patient (head at the foot-end of the table); when doing this, one should not forget to fasten the patient securely.

the screen and the table-top can be varied, usually between 10 and 40 or 50 cm, in order to allow for object thickness. In this connection it should be remembered that, as a consequence, the focus-screen distance or focus-film distance varies with the object thickness.

Formerly, the up and down movements of the tube, fluoroscopic screen, etc., were usually balanced by means of counter-weights. These were often attached to cables and hung elsewhere in the room via ceiling rails. The balancing by means of weights meant that always the mass of the moving part of the stand plus the (equally heavy) counter-weight had to be brought into motion; thus, a great inertia was present. At present, now that the installations are practically all equipped with image intensifiers, the balancing is carried out by means of a spring mechanism, so that it is much easier to bring the whole mechanism into motion or to stop it (the inertia of the counter-weight is now no longer present). It is therefore of importance, when a new X-ray department is set up, to ensure that the ceilings are made sufficiently strongly, and that the ceiling joists are placed judiciously, keeping in mind the possibility of ceiling-suspended apparatus (see section 15.2.4 of this chapter). In the most up to date stands the counter-weights or springs are fixed in the stand itself. Moreover, the operator is often helped with the movement of the mechanism by means of an electric motor. It must be possible to lock the carriage to which the fluoroscopic screen or the image intensifier is attached in any desired position by one simple manipulation, since rigid and completely vibration-free fixation is essential for radiography. On the other hand, however, it is sometimes desirable to move the fluoroscopic screen or image intensifier away from and towards the table-top, the so-called *compression movement*, whilst all other movements are locked, or to be able to lock the compression movement whilst the other movements, parallel to the table-top, can still be carried out.

The control levers and knobs should be mounted on the screen carriage in a convenient position, so that they can be easily reached. The diaphragm control may be mechanical by means of Bowden cables or electrical. There is usually a transparent 'cough guard' fitted on top of the fluoroscopic screen. The screen frame should be fitted with lead-rubber protective material, which usually projects at both sides and hangs down below the frame in overlapping flexible strips and protects the radiologist against scattered radiation. With the rather more perfected units one does not content oneself with bringing a cassette into place after screening as this wastes a great deal of time, instead it is incorporated in an important accessory, the *serial cassette changer*. This important part of the stand will be discussed in more detail later.

#### 16.2.2.2 Stand with a single tube attached to a column

A unit which is regarded as a combination stand, that is a fluoroscopic stand and bucky table, offers many more possibilities, and therefore can be included in the group known as the *universal stands*. Here too, the bucky is fitted beneath the table-top and the stand is provided with a separate column on which a tube for taking bucky radiographs is mounted. The column runs on floor rails, which are often extended to a position in front of the table-top to allow vertical bucky exposures to be made; this can be particularly important in examination of the spinal column.

For fluoroscopy the tube is coupled to the carriage of the table and the column can follow the movement, when the table is tilted. For bucky exposures the situation is simple; the column and tube are coupled with respect to the horizontally positioned table.

The change-over from ordinary vertical fluoroscopy (or what is more, from trochoscopy, that is horizontal fluoroscopy) to radiography employing the bucky, requires quite a number of manipulations, and involves the risk of inaccurate centring. For this reason, universal stands employing two tubes are to be preferred without a doubt. The addition of an under-table tube is perfectly justifiable from the point of view of economy, since the cumbersome process of swinging the tube from the above-table to the under-table position is obviated and the exposures are divided between the two tubes. Also, with regard to choice of focus, the two-tube system is to be preferred.

#### **16.2.2.3 Stands with two tubes**

The majority of the universal stands are provided with two tubes, an under-couch tube and a tube attached to the column. All examinations with fluoroscopy are carried out with the under-couch tube (fixed tube), whereby (if desired) a radiograph in the chosen position can follow immediately.

Since chest (lung and heart) examinations still constitute a considerable section of all screenings, in some units the fixed tube is attached to a sliding arm. By pushing a button the tube is positioned at a greater distance from the table-top, when the table is in a vertical position, so that without further adjustments radiographs with the 'tube at the correct distance' can be made under fluoroscopic control. Often the grid is also interchanged automatically for one that is focused for that exact distance. At the same time the diaphragm opening is automatically reduced to the exact size of film to be covered. Equipment provided with these automatic refinements (for example Pantoscop with Distator, Siemens) enables one to carry out these examinations with great speed.

Well-constructed stands are equipped with many automatic safety devices to guard against accidental wrong operations and/or omissions. For example, the tilting of the table-top, when the tube is in the way, is impossible. If this movement were not blocked then the tube could be hit and cracked when the table is tilted. All bucky exposures are made with the tube, which is above the couch (on a column or suspended from the ceiling). The majority are made with the table-top in the horizontal position, but if desired, they can also be taken with the table-top in a tilted or vertical position. In the latter case the tube which is attached to the column is situated in front of the stand. This tube, apart from being capable of these bucky exposures, is always ready for lung and heart radiographs at 150 and 200 cm and for exposures of patients who are brought to the X-ray department on their beds or trolleys and have to be examined in such situations.

The cassette stand attached to the wall, which can be adjusted in height, is particularly useful and has already been described in section 16.2.2.1.

#### **16.2.3 The serial cassette changer**

An important and more or less focal point in the parts of a stand is taken up by the *serial cassette changer*. Whereas formerly the serial changer was an accessory which had to be attached separately (for example at the position of the fluoros-

copic screen), today every universal stand is equipped with some type of serial changer attached to the X-ray tube on the U-shaped carriage. By means of the serial changer, the time necessary for the placing of a cassette in order to take a radiograph of an image perceived during fluoroscopy is considerably reduced. Thus, a serial changer makes the recording of ' fleeting images' possible by means of radiographs and this is of great importance, especially in stomach-intestinal investigations, but also with other examinations, where the positioning is done under fluoroscopic control\*. The serial changer consists chiefly of a fluoroscopic screen (at present usually replaced by an image intensifier) and a lead-lined box-like space, in which a cassette can be placed; the latter can be transported to the exposure position in front of the image intensifier. This transport (back and forth) should be very rapid, so that the exposure can be made within the shortest possible time (at most 1 s) after fluoroscopy takes place. Usually, several successive exposures are made on one film. In this way, for example, subdivisions can be made, so that four exposures can be made on a 18 × 24 cm film, 2, 4 or 6 exposures on a 24 × 30 cm film, and 3 exposures (each 10 × 40 cm) on a 30 × 40 cm film. Always another section of the film must be brought into the path of the X-rays; thus, the cassette should arrive in a different position every time. Other types of apparatus use different subdivisions, and some cannot accommodate the larger cassette sizes.

In modern serial changers this subdivision and positioning of the cassette at the correct spots for the successive exposures is automated, so that the radiologist only has to select a given exposure series on the programme selector; the serial changer then looks after the rest, even setting the diaphragm to the required aperture in certain constructions.

Although it is impossible to discuss all the different types of serial changers here, it would seem worthwhile to mention their basic principles. At the moment when the radiologist switches over from a fluoroscopic examination performed at, say, 90 kV and 0.5 mA, to radiographic exposures, the following sequence of events should take place:

(1) fluoroscopy is switched off;

(2) the rotating anode of a dual-focus tube is rapidly brought to the required number of r.p.m. for exposures (when the fine focus is used for fluoroscopy, the anode already rotates but not at a fast enough rate);

(3) the filament current must suddenly be increased so that a much greater electron emission takes place, which is in keeping with the required hundreds of mA;

(4) if fluoroscopy is carried out with a 0.6 mm focus, and the radiographic exposure requires a broader focus, a switching-over must be made;

(5) the cassette must be moved along and brought into the right position (depending on the subdivision of the film pre-selected) and the diaphragm opening adjusted accordingly;

\*Actually, all positioning for radiographic exposures is 'aimed' or 'directed', but the indication 'directed radiographs' is better reserved for those radiographic exposures that are positioned and centered with the aid of screening. On the other hand, 'blind' exposures are those where one does not first screen, that is the positioning and centering is done according to instructions or experience.

(6) since this type of exposure usually takes place with the use of a grid, the grid should be set into motion;

(7) the exposure should be made as rapidly as possible with the selected exposure factors.

To save time and prevent mistakes, all the above manipulations should, where possible, be performed automatically by a single switching operation. No matter how automatically and quickly operations 2-5 may be activated, still a certain loss of time occurs, which is indicated as *preparation time*. This preparation time always amounts to at least 0.8 s during which the remaining manipulations can easily be carried out. This preparation time seems short, but in practice still appears to be inconveniently long, when rapidly changing images have to be recorded (for example duodenal cap exposures). With the more highly developed serial changers, all the above-mentioned operations are fully automated, that is executed by a push on a single button. Moreover, the exposed cassette is brought back automatically to its starting position and fluoroscopy switched on again. Only in very simple serial changers are these operations still carried out manually, in which case the risk that the various exposures may overlap still exists.

In general, not only must the radiologist get accustomed to a new serial changer (with respect to its operations and controls), but also the radiographer with respect to assisting, etc. What appears to be difficult in the beginning often turns out to be perfectly simple and straightforward after a few weeks of practice. Serial changers are also fitted with compressors, which are mainly used for stomach examinations. There are various types of these, and the radiologist can choose the one he prefers. In general, one has a flat compressor and a compressor with an eccentric hump (hump on the lower side), which is especially useful for the examination of the duodenum; a cylindrical type is very suitable for making a deep depression, when examining corpulent patients.

In examinations of the stomach frequent use is made of a *distinctor* or *palpation spoon*, which enables the radiologist to exercise palpatory compression on the patient without having to place his hands behind the fluoroscopic screen, which would expose them to primary or secondary radiation. The palpatory part of the distinctor is fitted with a metal ring, so that the radiologist can see on the fluoroscopic screen exactly where he is applying compression. Some radiologists much rather palpate by hand; others are so adept at manipulating the distinctor that they are no longer prepared to run the undoubted risk involved with manual palpation even with lead-rubber gloves. Unfortunately, the modern serial cassette changer with its attached image intensifier and, therefore, bulky construction, seriously impedes the use of the palpation spoon. One will in these cases again often limit oneself to the use of the compressor attached to the serial cassette changer.

Depending on the radiologist's training, the palpation spoon will either be considered as indispensable or obsolete.

#### **16.2.3.1 70 mm and 100 mm cameras as accessories\***

Constantly, more and more demands are being made on exposures taken with the aid of screening, and the long preparation time (about 0.8 s) and the waiting time

\*Now a 110 mm camera has been added alongside these two types.

between two successive exposures are considered too long. The image intensifier and television combination has not only profoundly changed and improve fluoroscopy, but it has also created the possibility of taking photographs of the 'anode image' in rapid sequence and even of cine films. In these cases the image intensifier is equipped with an 'image divider', to which a television camera (Vidicon or Plumbicon) and a 70 or 100 mm camera is attached. The entire system is mounted onto the serial cassette changer. Since usually shorter exposure times and lower tube voltages are used with an image intensifier, the image quality of moving objects (due to smaller  $U_m$ ) and thicker objects (due to better contrast) is often better than that of the conventional large-size radiographs. In spite of this, it is desirable that the possibility of taking large-size radiographs remains. One reason is that one of the disadvantages of the present day image intensifier is that the size of the input phosphor limits the size of the object to be radiographed to a diameter of 25 cm\*. For the taking of survey films of larger body parts (thorax, abdomen, both kidneys, etc.) after fluoroscopy, the possibility of exposing larger sizes (for example 24 x 30 cm lengthwise and crosswise) in the serial cassette changer is, therefore, indispensable. The situation is more favourable in fluoroscopy, when a light intensifier is used which, as has already been mentioned, can produce a larger primary image. There is then a use for this type of intensifier whereby, for example, the Delcalix (Oude Delft) can produce a round primary image of up to 30 cm diameter. Compared with the X-ray image intensifier the light intensifier has the disadvantage that the applied exposure rate is greater and the resolving power is less. For the purpose of fluoroscopy a television installation is combined with the light intensifier; today it is equipped with a special type of Image Orthicon tube and this combination is expensive, complicated and heavy. The 'light intensifier type' (for example Delcalix) is unsuitable for radiographs of the anode image.

#### 16.2.4 Ceiling suspension units

A great number of stands have a part of their construction, not on the floor but suspended from the ceiling in some way or another. In these cases, one then finds the single or multiple ceiling rails on which a steel plate mounted on several wheels can be moved and secured. A spring type of suspension can in this way ensure flexible mobility of accessories such as an image intensifier with built-in camera and possibly the serial changer, without undue exertion on the part of the operator. Gradually, the constructions have become heavier and the sturdy telescopic columns permit great variations in distance in a vertical direction apart from the horizontal linear movement along the ceiling rails. The tube is attached to a cross-arm, which can be moved and rotated and is fixed to the lower end of the suspended system; this gives great freedom of movement to the tube. This is a method of attaching an above-couch tube and makes a conventional column superfluous. Thus, in this case, when the table is in a horizontal position, it is accessible from all sides. Another step further is the situation in which the ceiling attachment makes use of two individual systems perpendicular to each other; they can be moved with respect to each other, so that the attachment plate of the suspension system can be moved to every desired position of this system.

In general, the ceiling attachment is used for the tube; in other cases also a com-

\*The newer image intensifiers have already reached a screen diameter of 35 cm.

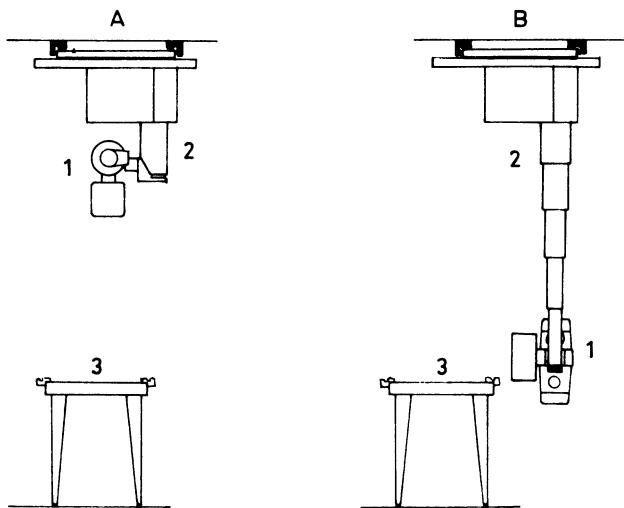


Figure 16.5 Diagrammatic representation of a simple ceiling suspension unit.

- A. Closed telescopic suspension column (vertical radiation).
- B. Extended suspension column (horizontal radiation). 1. X-ray tube with light-beam diaphragm; 2. telescopic suspension column; 3. radiographic couch.

plete image-intensifier unit (image intensifier with built-in camera, television monitor, etc.) can be attached to this (figure 16.5). With many stands one sees several pieces of equipment suspended from the ceiling nowadays, all belonging to one table. The ceiling suspension of a part (tube, image intensifier, etc.) that has to be used under the table is illogical and, therefore, not often done. In this case, fixed attachment to the stand or attachment to a column is only considered. Also for this reason, the use of a fixed under-table tube and ceiling-suspended image intensifier combination can be considered the most usual set up.

The type of construction in which the entire stand is attached to the ceiling is especially useful in a special procedure room, operating theatre or in the plaster room. The floor space remains entirely free, and in these cases this can be much appreciated. Figure 16.6 shows such a suspended unit.

The electronic control of the ceiling suspended units has been perfected to the utmost degree, so that the tube and other equipment can be moved with the greatest ease, and the physical exertion that used to be necessary to move and rotate the apparatus has practically been eliminated.

### **16.2.5 Universal stands with tube above (in front) of the couch**

The development and widespread application of the automatic exposure technique finds expression in the modern universal stands. The ionisation chamber, which is placed in front of the film, causes, in principle, an unwelcome increase in the table-top-film distance, since, formerly, without ionisation chamber this distance was about 4 cm and later with automatic exposure control it amounted to about 8 cm. The greater object-film distance is unfavourable as far as the definition is

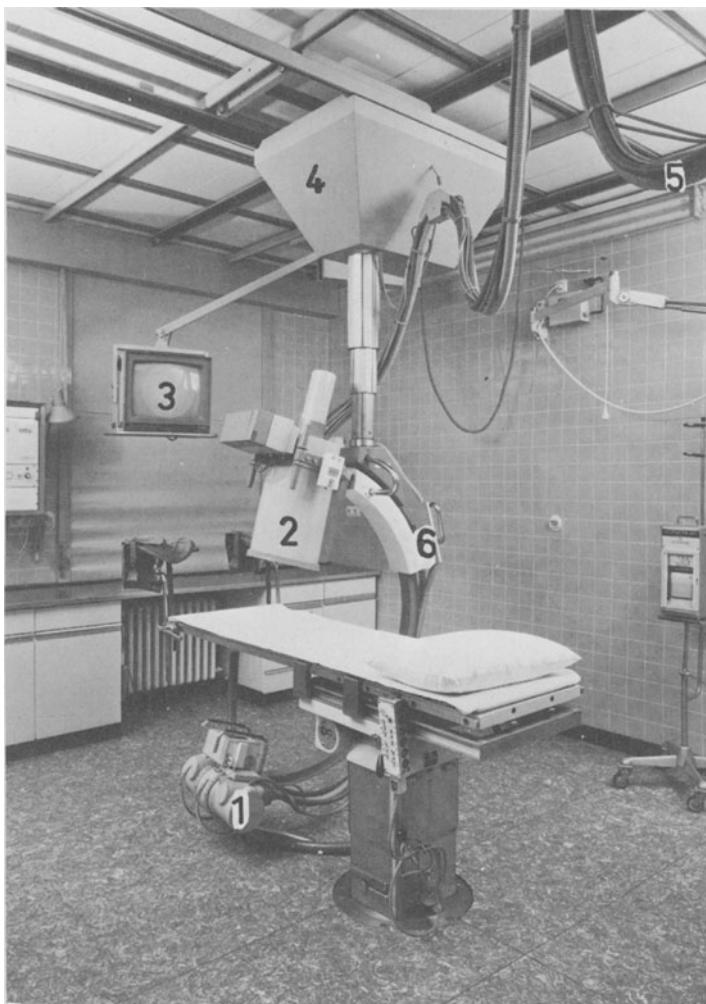


Figure 16.6 Ceiling suspension unit with C-arch. 1. X-ray tube; 2. image intensifier; 3. television monitor; 4. mobile metal plate to which the apparatus is attached; 5. H.T. cables; 6. C-arch.

concerned (geometrical unsharpness) and for the object size that has to be projected. However, for these reasons, the thickness of the present day ionisation chambers has been reduced to 8 mm, so that the disadvantages are greatly reduced. Due to the more compact construction of the image intensifier and camera and the acceptance of suspending larger pieces of equipment, the situation of a tube above the table and an image intensifier combination under the table has been made possible with the advantage of easier access to the patient and more space around the patient. An admitted disadvantage of this arrangement, however, is the fact that more scattered radiation from the patient can reach the examiner. If,

for example, the patient lies on a horizontally positioned table, and the tube emits radiation from beneath in an upward direction, then a relatively large amount of scatter is absorbed within the patient. If, however, the tube emits its radiation from above, then a considerable amount of scattered radiation can emerge from the uppermost layers and strike the examiner. In this case, therefore, extra care should be taken with respect to radiation protection. With stands that have the tube situated above the table and where no provision of any kind is made to protect against the scattered radiation which emerges from the patient, no radiological workers should be permitted anywhere near the stand while fluoroscopy is switched on, or radiographic exposures are being made. One should always post oneself behind walls, which are lead-lined for the purpose; these should provide sufficient protection against the intense scattered radiation. For all radiological procedures, when one must be near the patient during fluoroscopy or radiographic exposures (for example heart catheterisations, exposures under traction, for arteriography, hysterosalpingography, etc.), preference should be given to the stands where the X-ray tube is underneath the table, and sufficient measures have been taken to protect against scattered radiation (and primary radiation). Moreover, protective lead-lined clothing must also be worn.

#### **16.2.6 Remote control units (télécommande)**

Now that the fluoroscopic images can be more easily (and better) perceived on a television monitor than on a conventional fluoroscopic screen or on an image intensifier, it is no longer *essential* for the examiner to be present immediately in front of the apparatus, that is in the immediate vicinity of the patient. It is true that his presence is still *desirable* for many reasons, such as palpation, compression, the determination of whether pressing at a particular spot causes pain, injection (bronchography, salpingography, retrograde pyelography, etc.), turning the patient to a desired position, etc., but there are a number of investigations where the presence of the examiner and direct contact with the patient is no longer necessary. As a result of this and in view of the ideal radiation protection (of the investigator) the principle of *remote control* has been developed (télécommande, according to Chérigié, Paris) in which all movements of the stand, its parts and accessories no longer need to be controlled directly from the conventional position of the examiner near the fluoroscopic screen (or image intensifier), but can take place elsewhere, even in a separate room. This method of control of the apparatus 'at a distance' has, without a doubt, some great advantages, such as the already mentioned total radiation protection and a reduced physical effort as far as the examiner is concerned. The radiologist is seated behind a lead-glass partition, where he can carry out all the operations that are necessary for the examination by means of switches and push-buttons, which activate little motors; he can follow the fluoroscopic image on the television screen (armchair diagnostic radiology). This, on the whole, reminds one of the bridge of a ship from where one navigates the ship and gives orders (figure 16.7).

The patient is required to follow instructions given to him, and he should be aided if necessary by the radiographer. *The radiologist in that case must ensure that the excellent radiation protection is not limited to himself only.*

With a remotely controlled unit the radiation protective measure of having the

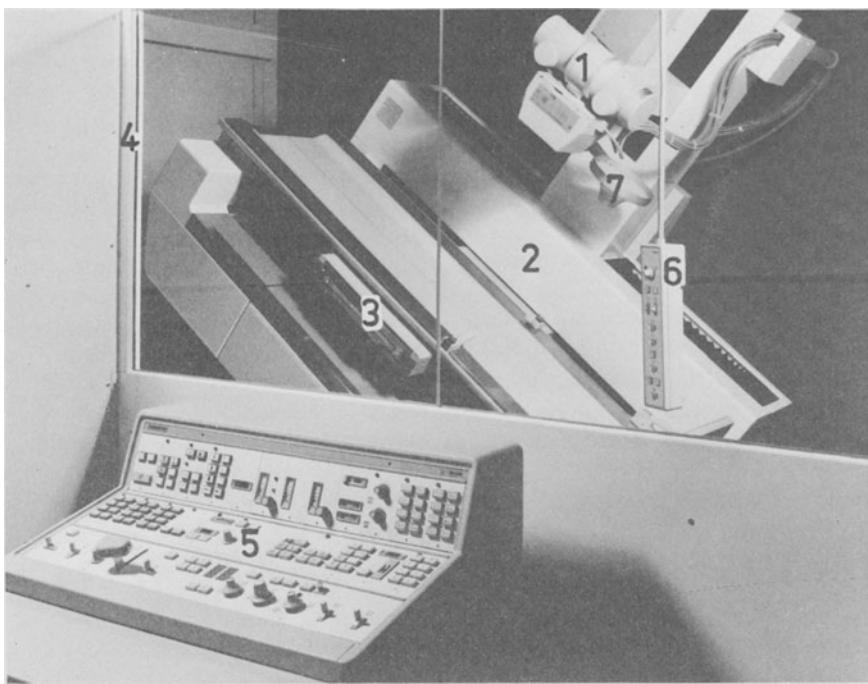


Figure 16.7 Remote-control stand. 1. X-ray tube with light-beam diaphragm (above couch tube); 2. table in angled position; 3. serial cassette changer, grid; 4. protective (lead-glass) partition; 5. control panel for remote control; 6. controls for use near the patient; 7. compressor folded out of the way.

tube under the table is no longer essential, and for many reasons it is particularly attractive to have the tube above the table and the image intensifier and serial cassette changer under the table. Such stands can also be used as bucky tables, even with tomographic possibilities.

There is also an increasing tendency to mechanise the operations that require personal action on the part of the radiologist and to carry these out 'from a distance'. First of all, palpation or variable compression has been mechanically and electronically imitated as closely as possible by the motility and adjustable pressure of a compression cap, which can either be attached to, or is separate from, the serial cassette changer. After gaining a certain amount of skill in the management ('steering') of this type of apparatus, the results can be considered satisfactory although this robot-like spoon misses the finer nuances that are possible with manual control. In addition, the administration of contrast media from a distance, for example, the barium enema, has also been realised, but it is in such cases in particular that the patient still needs help from nearby, and thus the radiographer has to enter into the field of radiation. In these cases, remote control could become a danger instead of a protective measure. It therefore seems sensible to avoid exaggerated mechanisation and not to make remote control a *goal*, but only to consider it a very welcome possible method of examination, in some cases. Exaggerated

aims of getting 'away from the patient' have, in fact, for him, less-agreeable psychological consequences on a human level, due to being left alone and especially due to seeing those persons who should assist him flee away.

Remote control certainly does not entail a saving in dose as far as the patient is concerned; on the contrary, usually minor adjustments in the positioning (rotation, etc.), whether on command or by means of motorised devices, take longer than when simple manual corrections, for example with a stomach examination, are carried out in a moment. Also, in this case, the question of whether one votes for, against or abstains with respect to remote control is influenced by one's training.

Usually, it is possible to carry out both techniques, namely, at a distance from a control cubicle and nearby with the aid of a switch unit, which comprises a mobile control panel upon which the most important knobs are duplicated. With the almost exaggerated mechanisation, for example movement of the table-top, diaphragm, grid, tube, etc., the number of knobs and relays have increased alarmingly. One should always realise that exaggerated perfection usually involves complicated constructions and circuits, which increases the risk of breakdown.

#### **16.2.7 Tomographic accessories**

Although tomography belongs to the daily routine procedures, it is much less frequently carried out than ordinary bucky exposures, so that in the smaller departments a special tomographic apparatus is not considered for several reasons (lack of room, price, etc.). In these cases an accessory construction is available for use with a bucky table or universal stand, usually known as a *tomographic attachment*. This device ensures the coupling of the tube and bucky movements in opposite directions, so that the plane through the fulcrum is projected sharply (see section 12.1.1). These tomographic accessories are only suitable for linear blurring, but there are already modern tomographic attachments with which both linear and circular and elliptical blurring plus zonography is possible. The results of these types of tomographic set-ups can be excellent. These attachments are usually only possible with the table in a horizontal position, but there are constructions available where tomographic attachments can also be fitted with the table in a tilted and even vertical position.

### **16.3 SPECIAL STANDS**

Although, in principle, practically all radiological examinations are possible with a universal stand, the enormously rapid development of super-specialisation in cardiology, gastro-enterology, neurosurgery and urology, and the refinement of the methods in normal specialties (e.g. fenestration and other operative methods in otorhino-laryngology, etc.) has made increasing demands on diagnostic radiology of the organs in question. The routine examination carried out with the conventional apparatus and stands is not sufficient.

The principles (not their operation) of some special stands will now be discussed.

### 16.3.1 Tomographic stands for tomographic cuts parallel to the body axis

Due to the consequences arising from the factors that influence the definition (and thickness) of the projected layer (discussed in chapter 12, section 12.1.2) and which can lead to artefacts, a transition has resulted in more complicated blurring patterns (see section 12.1.4).

The hypocycloidal and spiral movements are the ultimate in tomography. They are realised in robust and heavy stands of which some are not only able to carry out vertical and horizontal tomography, but also tomography with the patient positioned at any arbitrary angle. At the same time, much use is made of strict beam limitation and subdivision of large film sizes so that several exposures can be made on one film. The most modern tomographic units are equipped with a serial cassette changer, which enables examinations to be carried out much more rapidly (be careful not to overload the tube), with which the radiographer no longer needs to walk back and forth from the controls to the table quite so often to replace the cassette. Moreover, the adjustment of the fulcrum height can be done from the control panel (in some units this is done automatically) and also read off there. It is then possible to take six successive 'cuts' on a subdivided film from behind the control panel. One is also able to choose the various blurring movements (for example linear, circular, spiral movements) and the panning angle by push-button control.

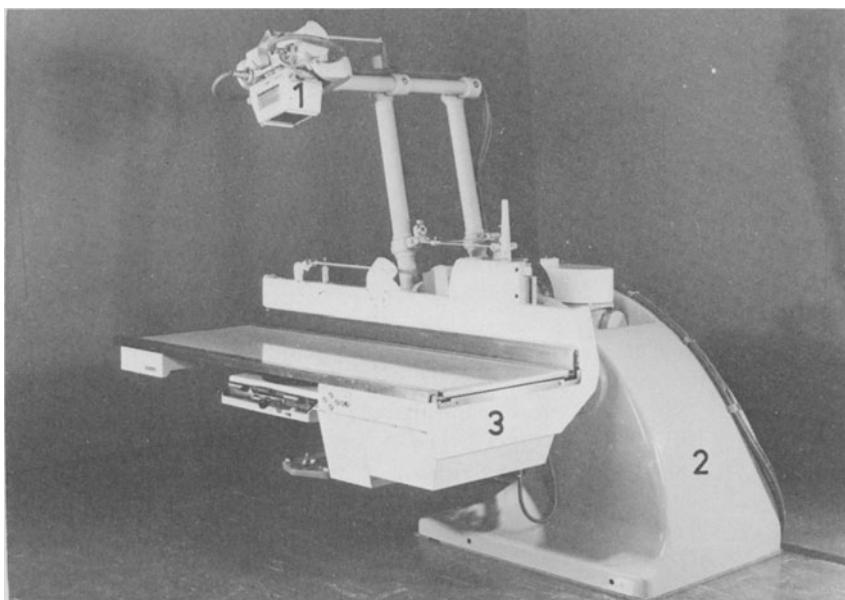


Figure 16.8 Tomographic unit. (The Polytome (Philips-Massiot) is illustrated). 1. X-ray tube with light-beam diaphragm; 2. pedestal for stand which is heavily built; 3. couch, adjustable from the vertical to the horizontal.

Figure 16.8 gives an example of a modern tomographic unit (Polytome U) which is equipped with all refinements regarding angling, floating table-top, positioning with the aid of an image-intensifier television, subdivision of film size, automatic termination of the series, etc. For the benefit of the diagnosis of conditions affecting the temporal bone especially, this perfected form of tomography produces valuable data. In general, these perfected tomographic units are also very useful as bucky tables.

The possibility of simultaneous tomography was pointed out in section 12.1.6; it is true that the accessories described there make this method possible, but it is (still) seldom done.

### **16.3.2 Stands for tomographic cuts at right-angles to the body axis**

The special stands for *transverse tomography* are completely different and much more limited in their application (see figure 12.6). In this case the tube attached to the column may be used. The actual stand consists of a type of revolving chair for the patient; another vertical axis with a horizontal platform on top for the cassette is coupled to this and rotates synchronously. Correct centering is in this case exceptionally critical; the focus and both axes of rotation must lie exactly along a line. A deviation of only a few millimetres makes the already vague image even worse and could even make it entirely useless. A sturdy construction is required for this.

Installations have been developed in which the patient does not move; in this case the tube and the cassette tray are fixed to a large U-shaped stand, which moves around the patient in its entirety.

Transverse tomography is now seldom used. This method of examination is at present being replaced by CT-scanning (computerised tomographic scanning; see section 12.1.9).

### **16.3.3 Stands for computerised transverse axial scanning (CT-scanning)**

The intensive development of this method, which has been in use since 1972, has made special demands on the apparatus and stands. As far as the X-ray generator and tube are concerned, one can say that an ordinary powerful installation and a normal tube, such as are necessary for gastro-intestinal examinations, are entirely satisfactory. The extremely narrow beams that are necessary do not have to originate from a particularly fine focus; they are produced by very strict collimation at some distance from the focus by means of a collimator. The mechanical demands are very heavy, however. The jerky rotation of the tube and detectors around the patient must take place rapidly and smoothly, and the object must be immobilised as carefully as possible in order to avoid movement unsharpness with the relatively long exposure times (at least several seconds).

Practically without exception as a solution for these problems, a stand has been chosen in which the tube-detector combination carries out the rotation in a plane more or less perpendicular with respect to the horizontal table-top on which the patient lies. A CT-scanning stand resembles the well-known stands used in rotation radiotherapy, where the source of radiation rotates around the patient, and the beam of radiation remains centred on a pre-determined tissue volume (the 'focus').

Less usual is the situation in which the ring is in a fixed position (vertical, horizontal, or in-between) and the patient is turned.

The first applications of the scanner were always concerned with the skull, which was fixed by means of a close-fitting volume of water, and as far as the path of radiation was concerned between focus and detector it was also equalised. With the later and present day more-general applications of CT-scanning the whole body is considered for this type of examination (*whole-body scanning*). The patient can be positioned on the table and moved in relation to the ring in order to project the desired cut. The type of construction in which the table takes up a fixed position and the ring can be moved is less used due to the greater mass of the ring. Figure 16.9 shows an example of a stand that is available.

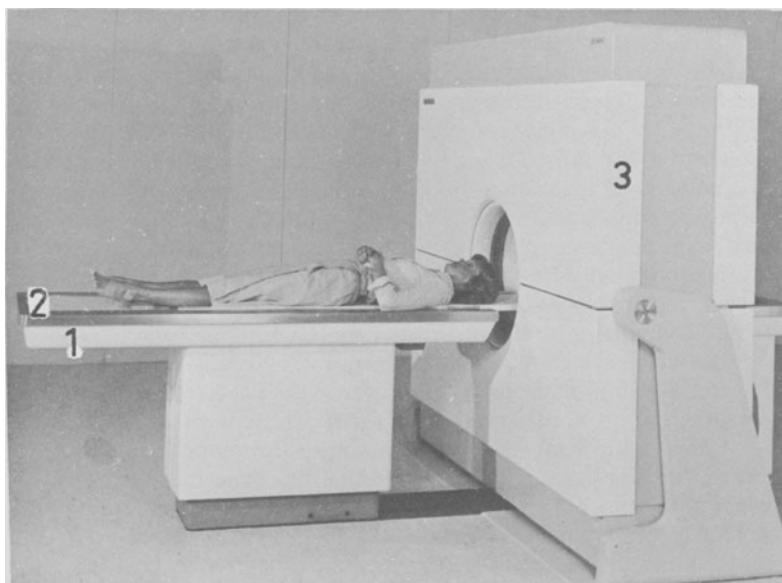


Figure 16.9 Stand for whole-body scanning. 1. Table-top on which 2 is located; 2. cradle on which the patient lies (this can be moved cranially in the opening up to the desired section); 3. shield in which the X-ray tube and detectors (which can be rotated) are housed.

#### 16.3.4 Stands for neurological examinations

Due to the great development of radiological examinations of the brain and spinal canal, and because of the therapeutic possibilities created by neurosurgery, neuro-radiology has developed into a 'super-specialty' with special demands on the X-ray equipment. Myelography (with positive and negative contrast) can still give very satisfactory results with conventional stands (universal stands, preferably equipped with tomographic attachments), especially when the serial cassette changer is used. The radiographs taken after positioning under fluoroscopic control of a herniated disc, etc., can provide a clear diagnosis.

The problems concerned with blood-vessel investigations, in the skull especially, are more difficult. There is little sense in screening in this case, as the position of the skull for this examination is well known and can be adjusted without much difficulty; the usual views are a-p and lateral. Rapid-sequence technique, either with the conventional large-size films (for example A.O.T.) or with cameras via the image intensifier (film size 70 or 100 mm) is considered for this. The main purpose of the examination is to obtain some images of the arterial phase, an image of the capillary phase and one or two projections of the venous phase, usually in a certain sequence, with different intervals and with the aid of a programme selector. The superiority of the large-size film is being affected to an increasing extent by the excellent information which the fast cameras in combination with the newest image intensifier phosphors and optical systems can provide and also by the longer series of exposure (and with that less dose). Cerebral angiography has been improved to such an extent that small and even minute changes in the blood vessels can be portrayed with sometimes great diagnostic and therapeutic consequences. Through this, great interest in macroradiography has again been revived: macroradiography combined with electron-optical enlargement in the image intensifier can indeed make the hitherto tiny, vague details reasonably visible. Cineradiography is also used for this purpose, but the information per frame is clearly inferior to that of the larger size films, and the advantage of cine-radiography—moving images—plays practically no part in the skull.

The information provided by the portrayal of the ventricles of the brain by pneumoencephalography is of the greatest importance; this is done by means of a lumbar puncture and the injection of air. As the air, which has been introduced, rises to the part which is highest, one can arbitrarily (by changing the patient's position), direct the air in the cerebral ventricles to the right, left, to the front or on one side, etc., and thus project the various parts of the ventricular system selectively. A horizontal beam is used most often for this purpose, but also angled positions in all directions are used. The image-intensifier television is of great significance in this type of examination in choosing the correct and exact position before the radiographs are taken. The arch or U-shaped stand has been shown to be the best for this purpose; the head remains more or less in one position, and the central ray passes through it in the desired direction. Since the patient has to be placed in different positions, the arch or U-shaped type of construction is very large, and the special stand concerned with this is particularly heavily constructed, as is clearly seen from the example in figure 16.10 (Neurodiagnost of Philips).

It is possible to perform these examinations with an ordinary examination chair, a bucky table and an A.O.T.-rapid-sequence changer, but a very special chair is to be preferred in which the patient can be completely somersaulted whilst the skull remains in line with the central ray. This chair is called the isocentric chair. Obviously, the patient has to be very firmly fastened and only be permitted to remain in an upside-down position, 'on his head', for very few moments. Figure 16.11 provides an impression of this complicated equipment, where, naturally, the isocentric chair should be considered as an accessory.

Since blurring by means of tomography (for example with air myelography) is also important, these stands have also tomographic possibilities, usually with a linear movement. A certain amount of magnification with tomography cannot be avoided, and sometimes a certain degree of magnification (for example 1.4 times)

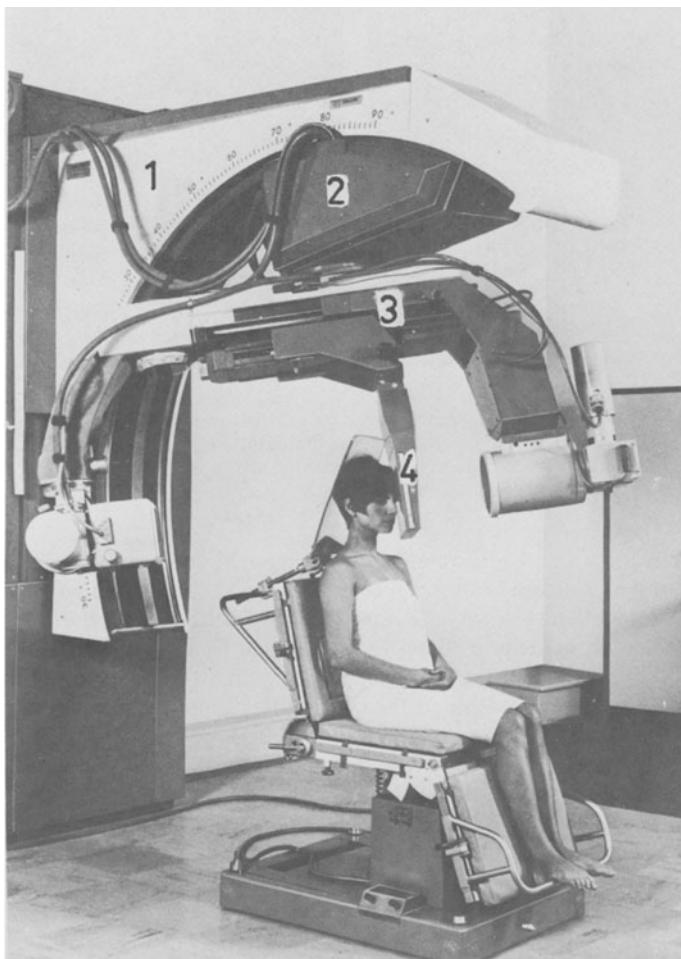


Figure 16.10 Special stand for neuroradiological examinations. 1. C-arch along which the trolley (2) can be moved; this allows the arm (3) which carries the X-ray tube and image intensifier with television combination to be rotated; 4. cassette.

is deliberately chosen as has been advocated above. Depending on the nature of the examination that one wishes to carry out with this stand and apparatus, one would position within the U an ordinary examination chair, a table-top, an arteriography table or the above-mentioned special 'somersault' chair.

By far the greatest number of radiographs are taken with the aid of a grid, either moving or stationary. In the latter case only fine line grids (44 lines/cm) are considered.

In the above, we have discussed, described and illustrated equipment of the 'super class' for neuroradiological investigations by means of which, among other

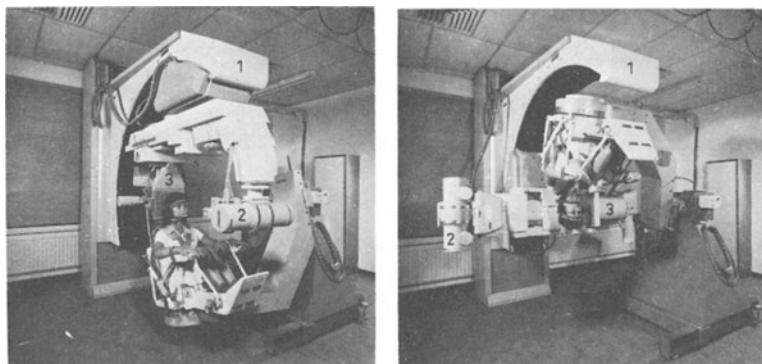


Figure 16.11 Stand for neuroradiological investigations with isocentric chair. 1. Stand as in figure 16.10. 2. X-ray tube; 3. image intensifier combination with cassette holder.

Left: In this position the patient sits in an upright position in the chair.

Right: Illustration of the upside-down position.

things, all movements and adjustments are mechanised and automated as much as possible. However, this does not mean that with this all the wishes of all investigators have been satisfied. For these reasons there are also various other types of stands available. These include Mimer (Siemens) and Neurocentric (G.C.R.), which are constructed in a different manner, emphasising other points and problems of the investigations, omitting some of the possibilities and adding others, so that the situation, when a new piece of equipment has to be acquired, often is 'too much choice'. Still, the perfecting of stands is continuing, both in the super class and medium and simple categories.

Only the principles have here been emphasised; detailed descriptions should be read in brochures and critically evaluated.

### **16.3.5 Special stands for gastro-intestinal investigations**

Also in the case of gastro-intestinal examinations is it necessary to be able to view and photograph the part to be examined (stomach, colon, gall bladder, etc.) in different directions. Apart from tilting the patient (with universal stands this is possible to 90° Trendelenburg), an oblique direction of the central ray with respect to the median plane of the patient can be obtained by rotating the patient around his longitudinal axis. In order to save the patient the trouble of rotating himself on the table-top, the table-top itself can be constructed in such a way (or a type of 'cradle' can be attached to the table-top) that the patient can be rotated around his longitudinal axis and fixed. There are, however, also stands available with a U-shaped construction where, on the one side the tube and on the other end the serial cassette changer-image intensifier combination can be rotated and turned from its normal position (that is the central ray is always perpendicular to the table-top). By means of these eccentric directions one manages to project the organ in more than the normal, usually sagittal, directions, and, for example, can direct the central ray from the uppermost right side of the patient to the lower

left. Therefore, one can direct the rays obliquely. With this type of apparatus it is possible to exploit the double-contrast investigations of the gastro-intestinal tract completely, making use of the force of gravity and directing the central ray and positioning the patient in such a way that an optimum portrayal of the desired part of the organ is obtained (for example Orbiscope of Siemens, and Diagnost-200 of Philips).

All these movements are electronically mechanised and often automated in such a manner that they can be performed without much thought and manipulation. Most of these stands can also be operated by remote control. As has already been mentioned, the rapid-sequence series on 70 or 100 mm film sizes is replacing the large sizes.

By far the greatest number of gastro-enterological X-ray examinations are performed on universal stands (in so far as one is not dealing with an angiographic examination), the automation of which has been perfected to a very high degree. At the same time, remote control is often requested. Figure 16.7 shows an example of this.

### 16.3.6 Special stands for urology

Diagnostic radiology of urological problems has expanded considerably due to the possibilities of rapid-sequence exposures after fluoroscopy in retrograde pyelography, cystography and micturating cystography, and especially because of arteriography. Apart from the conventional possibilities with large film sizes in intravenous urography, the all-round urological tables offer most of these possibilities. These, however, are not considered for the average radiological department on account of the limited number of these investigations. These departments can manage with a universal stand with which the indispensable fluoroscopy (image-intensifier television) and the possibility of rapid sequence and cineradiography is present. At the same time one should be able to take ordinary bucky exposures (for survey radiographs and intravenous pyelograms). A (slight) tilting of the table top is desirable (to, for example, 15° Trendelenburg).

'Blind' bucky exposures on their own (with, for example, retrograde pyelography), even if of excellent photographic quality, have much less diagnostic value than the exposures made at exactly the correct moment on a single film or in series.

### 16.3.7 Special stands for angiography

The greatest diagnostic gain made in radiology during the last decade has been in the field of angiography. After being limited to the portrayal of veins for many years, imaging of the arteries, after a slow start, has made enormous progress and practically every single artery can be portrayed angiographically today.

#### 16.3.7.1 Tables for direct angiography (without the introduction of a catheter)

##### 16.3.7.1.1 Phlebography

The imaging of peripheral veins, *phlebography* (for example for the investigation of varices), is usually performed by means of a simple puncture and manual injection. Due to the slow blood flow, one has plenty of time, without hurry, to

take various radiographs by changing cassettes or moving on a conveyor belt with film. A conventional bucky table or a universal stand, possibly equipped with a simple tunnel to change cassettes, is quite satisfactory for this purpose.

Portrayal of the portal system (*splenoportohepatography*) demands a more rapid sequence of exposures, similar to the imaging of the vena cava (cavography) which is rendered visible by injecting into the femoral vein. A rapid series cassette changer, possibly even an A.O.T., will have to be added to the stand as an accessory, and either controlled manually or via a programme selector. Due to the large dimensions of the field that has to be portrayed the use of a 70, 100 or 110 mm camera is not considered because of the (too small) 25 cm image intensifier image.

#### *16.3.7.1.2 Lymphography*

Lymphography does not make any great demands as far as the table is concerned either, the injection apparatus with a rate of flow that can be regulated is the most important accessory. After injection it must be possible to take radiographs (large ones) without any hurry, with grid. A bucky table with a table-top which can be slid over a large distance (80 cm) is very suitable for this purpose.

#### *16.3.7.1.3 Abdominal aortography (translumbar aortography)*

By means of a manual puncture on the left side of the lumbar vertebrae followed by an injection (usually manually performed) of the contrast medium, filling of the abdominal aorta and all its branches is achieved. Aortography provides (by different methods) the possibility of exposing a series of six long cassettes of the 120 × 30 cm size, for example, within a few seconds (making use of fine-line grids of that same size), in this way the vessels from the diaphragm to the feet are portrayed. With some tables the table-top is moved against the direction of blood flow, as it were, and stopped briefly, so that a 30 × 40 cm radiograph can be exposed; this is done in three stages from the diaphragm to the feet. Such a table is actually also very suitable for lymphography. Fluoroscopy before radiographic exposure is entirely unnecessary, due to the excellent 'blind' positioning that is possible in this case; any way screening with aortography tables is usually not possible. Programming of the exposures is also possible here, so that the whole radiographic procedure is performed automatically.

#### *16.3.7.2 Stands for selective angiography, when a catheter is introduced into a vessel*

Fluoroscopy is indispensable with angiography, when a catheter is introduced into a blood vessel (for example, according to the Seldinger method) or a particular area (both kidneys, for example), or if only the area supplied by one vessel has to be shown (semi-selective and selective, respectively). The tip of the catheter, which is opaque to X-rays, is followed on the fluoroscopic image and is directed to the desired location. By means of a trial injection of a small amount of contrast medium (see chapter 8) one can determine whether or not the catheter is positioned correctly. After this, the amount of contrast medium necessary (of the chosen concentration) is rapidly injected with a special pressure injector.

Due to the extremely rapid distribution of the contrast medium and its subsequent dilution (which causes the vessels to be invisible again) rapid to extremely rapid sequence of exposures is essential. Both the large-size cassette changer

(A.O.T. type and the 70 (or 100) mm image-intensifier exposures with their rapid rate of up to 6 images/s) are considered for this purpose. The image intensifier can only portray an object as large as its own size, which in many cases is unsatisfactory.

For still faster sequence, X-ray cinematography with its 24, 50 or even more frames per second is suitable. In general, an X-ray image intensifier of 25 cm diameter is employed. With the all-round angiographic stands both the X-ray tube and image intensifier can be used under or above the table-top. It has already been pointed out that due to the screening periods of sometimes several tens of minutes during catheterisation, strict radiation-protection measures are essential: strict beam limitation by careful collimation for as long as only the catheter tip has to be watched, and reduction of the radiation intensity in order to achieve an image which is only just perceptible and not as bright as possible, and adaptation to a darkened environment. If these measures are carried out, a great service will have been rendered to the patient as well as to the examiner and other personnel.

Figure 16.12 shows a universal 'angio table', upon which all the investigations described above can be performed, both with and without screening. With a floating table-top the patient can be positioned with the body part in question above the A.O.T. and be radiographed.

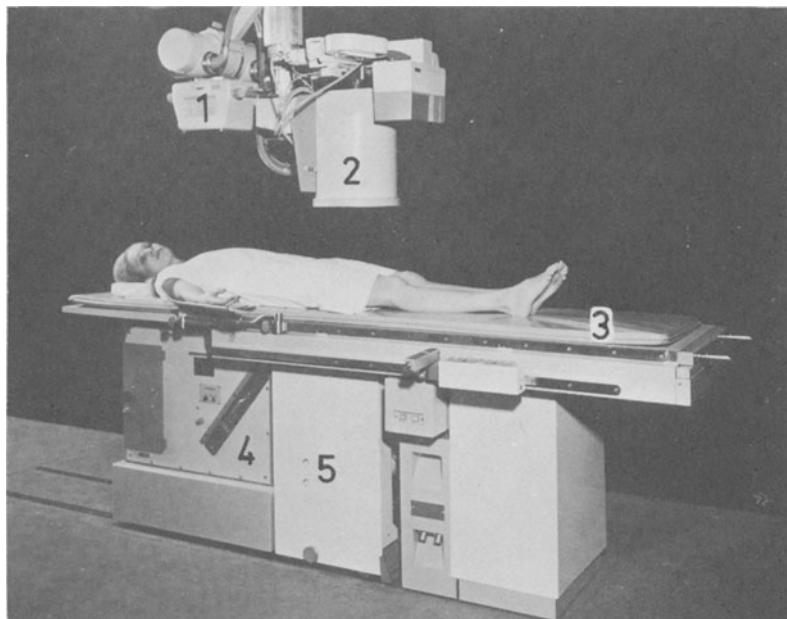


Figure 16.12 Example of a relatively simple table for angiography. The stand comprises a ceiling-suspended X-ray tube (1) and image intensifier (2) which can be placed in any position desired. The table-top (3) can be slid lengthwise over a great distance. An A.O.T. (4) and an X-ray tube (5) (for example in a tank unit) may be located under the table. A 70 mm rapid-series camera as well as a cine camera are attached to the image intensifier. A cradle, which can be rotated, can be attached to the table.

Although a stand with the described possibilities is sufficient for by far the greatest number of vessel investigations including cardiography (imaging of the heart), the latter especially does, however, make particular demands. For arteries and veins, projection on a flat plane (that is in one direction only) is, in general, completely satisfactory. This is entirely different in the case of the heart. Here, the position of the valves, for example, and also the volume of the ventricles play a large part, and this requires projection in three dimensions and, therefore, several projection directions. In general, two directions are chosen that are at right-angles to each other. This does not by any means signify standardisation to perpendicular (vertical) and lateral (horizontal) directions only, with the patient in a purely supine position. On the contrary: by means of fluoroscopy a more favourable direction is chosen by rotating the patient, and then the two beams at right-angles to each other are used. For this purpose, the installation must have two A.O.T.s, two tubes and two fully equipped image intensifiers at its disposal, all of which can be operated simultaneously. This is particularly important for children, who can only tolerate a limited amount of contrast medium; it should be attempted to complete the entire investigation with a single injection, if possible. In order to avoid unnecessary scattered radiation the exposures are not taken at the same time, but alternately, for which special devices of the two X-ray generators are used.

Because of advances in heart surgery, not just the replacement of heart valves and the introduction of pacemakers, but especially the successful operations for



Figure 16.13 Stand for angiocardiacorangiography with multiple angulation possibilities.  
1. U-shaped construction on which is attached: 2. the X-ray tube; 3. image intensifier-television combination; 4. second image intensifier-television combination (ceiling suspended).

arteriosclerosis of the coronary arteries, a more exact and accurate diagnosis of this common condition has become important. Only excellent resolving power with respect to the installation and accurate positioning of the patient and, thus, the vessels in question, can provide the decisive information necessary in this case. Still greater flexibility of movement of the stand than in the constructions mentioned above is essential for this purpose. For this, one has gone back to the U-shaped construction and furnished it with new possibilities and capabilities, especially with regard to the use of oblique projections (angulations) in caudo-cranial (and in the opposite) directions. Usually, for this, the combination of X-ray tube with a 25 cm image intensifier is used (preferably with electron-optical enlargement), and equipped with a 70 mm camera and cine camera (figure 16.13).

Also with this table the use of one or more A.O.T. changers can be considered. However, the rapid-sequence image intensifier in combination with 70 (100) mm photography is replacing the large-size A.O.T. radiographs, since the reproduction of detail with these 70 and 100 mm films is equal or even better than that of the large films and, also, the dose is considerably lower.

A fully equipped 'angio installation' consists of a catheterisation table, a duplicated image intensifier-television-X-ray tube combination (for vertical and horizontal projections) which, moreover, are provided with cinematography possibilities with pulsed X-radiation and provisions for rapid-sequence image intensifier photography. The combination with sheet-film or roll-film changers creates the possibility for taking large film series also, often with a third (above the table) X-ray tube. The installation may be complemented with video recorders, which record the fluoroscopic image on magnetic tape. Basically, as this apparatus should be supplied by two H.T. generators, it is obvious that the fitting out of such a specialised room for angiocardiological examinations is extremely expensive.

Apart from the very impressive X-ray installation, a modern room for angiocardiology contains a large number of recording devices for electrocardiography, blood pressure, etc., to which the patient is connected. Often there exists a connection with the X-ray apparatus in the sense that the exposure can be taken at a particular moment (for example chosen in the electrocardiogram). Injection apparatus and, last but not least, resuscitation equipment completes the 'angio room' which has been perfected to the utmost with respect to the installations.

#### ***16.3.7.3 Stands for photofluorography***

A special type of stand constitutes the photofluorographic stands; the height adjustment, at least for vertical examinations, is made either by means of a counter-balanced movement of the tube, screen and hood assembly, or by means of a lifting platform on which the patient stands. These stands are often mobile. If photofluorography is also used for exposures other than chests, then the hood assembly (which is often bent for this purpose) is placed in a stand that allows it to be used vertically or horizontally, both above and below the table.

#### ***16.3.7.4 Stands for mammography***

Due to the development of X-ray tubes with a molybdenum focus, a new door has been opened to mammography. In these tubes the weak components of the radiation mixture predominate. This is caused by the great contribution made by the

characteristic K-radiation of molybdenum (about 17 keV), when the tube is supplied with voltages of about 30 kV. A molybdenum tube filter ensures, moreover, that part of the harder components of the Bremspectrum are changed into characteristic molybdenum radiation. The 'long-wave' radiation causes a fairly well-defined radiation contrast due to penetration of soft tissues with this radiation mixture, which produces greater absorption differences. It is obvious, therefore, that this is the tube indicated for mammography. Because of the fact that this type of radiation spectrum requires a high exposure and that, moreover, the molybdenum cannot tolerate very high temperatures, such tubes are often water-cooled (see chapter 1, section 1.10.4). The low kilovoltages that are used and which

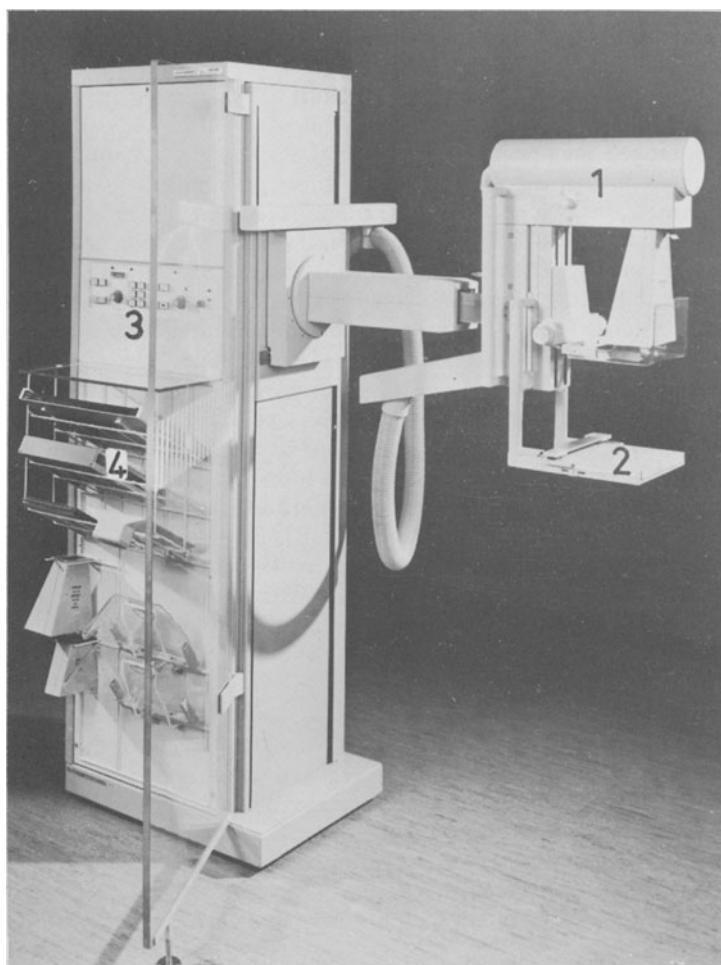


Figure 16.14 Stand and apparatus for mammography. 1. X-ray tube with collimator and compressor; 2. platform for the positioning of the breast; 3. controls; 4. films, cassettes and accessories.

usually are not available on conventional control panels, make the construction of special H.T. generators, which are capable of producing between about 25 and 40 kV, desirable. Sometimes, use is made of the already existing H.T. apparatus which then has to be adjusted to deliver the required low kilovoltages.

Mammography demands great flexibility of the tube and film holder, so that the proper projections can be taken. The possibility of applying adjustable compression should be present, as well as field limitation; sometimes, both these are carried out with the aid of a specially shaped cone, closed at the lower end with a thin flat sheet of synthetic material. Sometimes, these two operations are separated: field limitation is achieved with the aid of a short cone, whilst compression is performed with a separate compressor. Automatic exposure control, either according to the ionometric or photometric principle, makes the use of a measuring chamber behind the film essential, since this chamber would otherwise doubtless become visible on the radiograph due to the weak radiation mixture.

The above considerations have led to the construction of special stands for mammography. With these, it is often possible to examine the patient not only in a standing or sitting position, but also when lying down. The tube with its attached cone, the compressor, and film holder with measuring chamber for the automatic exposure device are usually connected to each other with the aid of a C-arch or U-arch, which can be turned in various directions. This combination can be adjusted in height and coupled to the stand in which usually also the H.T. generator and automatic exposure device are incorporated. This apparatus is available in various forms. We list (as the oldest) the Senograph of G.C.R., which has now been followed by the Senomax (with greater power and equipped with both a molybdenum and a tungsten focus, the latter being used for xeroradiography), the Diagnost M of Philips and the Mammomat of Siemens. Figure 16.14 shows such a stand, especially suited for out-patient examinations (and this is on the increase). Also, in this field, development has by no means been concluded. Some newer stands, for example, have a special moving grid to attenuate stray radiation, thus improving image quality.

### 16.3.8 Some considerations

The construction of new stands is in some respects characterised by luxurious perfectionism, as is also the case in the automobile industry. Sometimes one asks oneself if the designers are of the opinion that they are dealing with a group of invalids for whom every mechanical movement signifies an unprecedented and, therefore, an inadmissible exertion and for whom only operation by means of push-buttons can be considered. As long as this perfectionism is not expensive and is still purposeful we need not have any objections, but if one is of the opinion that every operational simplification is dependent on devices that are liable to break down and which can only be repaired or replaced by experts, one asks oneself whether this tendency can actually be called a healthy one. The use of some refinements is, to put it mildly, very dubious indeed, and the advantage is scarcely great enough to justify the possibility of breakdown, which would 'paralyse' the investigation. This is true for an automatic, pneumatic or electric transport system (among others) of the cassette in the serial changer, instead of the simple, trouble-free control by hand. However, an automatic cassette transport system is necessary

when working with remote-control apparatus and, thus, this can be called sensible. The electric brakes instead of the mechanical ones also make sense, and to continue, all measures that guarantee better protection against radiation without the need for extra attention in the implementation of such measures can be considered an improvement. Thus, the automatic diaphragm which permits a beam size which, at the outside, is no larger than that which just covers the selected film size, can be considered an improvement. Likewise, the floating table-top, which can be moved in a lengthwise and crosswise direction, is also an obvious improvement.

Both the progress in the many technical fields to which radiology submits, and the advance in medical knowledge, which is partly connected with the first, are the reasons why the specifications of the apparatus constructed by the manufacturers change constantly. Mechanisation and automation are replacing human labour to an increasing extent. They can have a higher degree of standardisation and safety as a result.

In diagnostic radiology one can scarcely call any component part standardised, and personal taste and preference, therefore, play an important part in the choice of a piece of equipment. More doubtful, however, are the great number of alterations ('improvements') which the manufacturers think they ought to introduce, due to which existing installations, which often function perfectly, become obsolete very quickly, and a premature stoppage of delivery of spare parts and service forces one to acquire new equipment, which does not necessarily mean an improvement. Once again, one can compare this to the automobile industry: continual restlessness and the bringing forward of 'improvements', which often do not deserve the name, and coercion in the direction of the 'throw away and buy new' mentality ('waste economy'), where the buyer is pressed rather than being the motivator.

A greater degree of uniformity and standardisation in the construction of X-ray generators, control panels, stands and accessories would be a great advantage in radiology. However, this will probably remain a Utopia, and the differences in constructions will continue for a long time to come.

In view of the frequent technical changes, everyone involved in radiological investigations should continually and carefully follow the expansion of procedures and alterations in constructions critically.

# Index

- Abbe's law of optics 176
- abortion 82
- abscess 334
- absorbed dose 53, 58, 61
  - total 71, 81
- absorbed integral dose 71
- absorption 38, 46, 65, 86, 115
- absorption coefficient 45, 66, 85, 115
  - curve 65, 66
  - edge 45
  - formula 115
  - photoelectric 38, 47, 52
  - selective 46
- above-couch (table) tube 428
- accommodation 293
- acetate based film 147
- acetic acid 223
- activator 145
- actual dimensions, focus 9, 20, 21, 104
- adaptability 136
- adaptation 86, 131, 135, 144, 171
- adaptation goggles 135
- additional filter 21, 25, 351
- A.E.G. (or P.E.G.) 334, 434
- afterglow 48, 145, 164, 166
- air cooling 24
- air equivalence 61
- air insulation 24
- Al Cu filter 21, 38
- Al equivalence 21
- alpha ( $\alpha$ ) 151
- alternating current 10
- ammonium chloride 211, 223
- anaglyfen method 295, 296
- angiocardiography 314, 319, 440
- angiography 313, 314, 319, 437
  - carotid 335, 434
  - cerebral 335
- angle of the anode 7, 9, 12, 30
- Ångström unit ( $\text{\AA}$ ) 35
- annihilation radiation 42
- anode 3, 6, 7, 33
  - angle 8, 9, 10, 12, 30
  - cracks 13
  - disc 14
    - diameter of 16
    - fissures in 13
  - graphite 13
  - image of 173, 307
  - load on 11
  - material 7, 350
  - molybdenum 13, 37, 374
  - rhenium-tungsten-molybdenum 13, 15, 29
  - rotating 13, 16, 392
  - roughening 13, 29
  - stationary 10, 12, 13, 392
  - super speed 392
  - tungsten 7, 13

- anterior 243  
 anticathode 3  
 aortography 335, 438  
     translumbar 438  
 A.O.T. 314, 434, 441  
 apparatus, classification of 390  
     dental 30, 413  
     diagnostic types of 378  
     mobile 29, 379, 400, 413  
     portable 29, 379, 400, 412  
 apparent focal spot size 9  
 arteriography 313, 314, 335  
 arthrography 333  
 artifacts caused by movement 280  
 atomic number 7, 43, 46, 85, 116  
 attachments, tomographic 430  
 attenuation coefficient 45, 65, 85,  
     115  
 attenuation, influence of thickness  
     44, 115  
     X-radiation 38, 43, 46, 65, 114  
 automatic brightness stabilisation  
     117, 188, 241, 368  
 automatic control 397, 404  
 automatic diaphragm 252  
 automatic exposure 169, 189, 307,  
     360, 404  
 automatic mains voltage compensation  
     394  
 autoradiography 328  
 autotransformer 407  
 average hardness 47, 68, 349, 391  
 axial tomography 277
- babies 256  
 back-fire 379, 392  
 background radiation, natural 75  
 back screen 163, 168  
 badge, film 73  
 balance, electronic 53, 54, 61  
 balancing weights 421  
 banana fly 56  
 barium 130  
 barium lead sulphate 167  
 barium paste (for oesophagus) 330  
 barium platinocyanide 47  
 barium sulphate 330  
 barrier layer 32  
 Bartelink (planography) 261  
 base, acetate 147  
     blue 150  
     clear 150  
     density 150  
     distance (stereo radiography) 288  
     polyester 147  
 basic exposure table (chart) 338, 343  
 beam diameter 10, 12, 30, 81, 117  
     direct 79  
     horizontal 238  
     limitation 72, 79, 82, 117, 249,  
         267  
     of radiation 30  
     X-ray 8, 21, 37  
 Becquerel 328  
 beryllium 22, 328  
 betatron 3  
 Biangulix 20  
 bile ducts 332, 333  
 binocular stereoscope 292  
 binocular vision 286  
 biological effect of X-rays 54, 55, 70  
 biological, fundamental law of  
     Grothus Draper 55  
 'blind' exposures 103, 423  
 blood forming organs 76  
 blood test 84  
 blood vessels, investigation of 238,  
     334, 434  
 blurring 263, 264  
 blurring patterns, tomography 264,  
     430, 431  
 blue base 150  
 boloscope 310  
 boron 22  
 Bouwers 16, 22, 181, 367  
 brain, ventricles of 277, 333  
 breakdowns 408  
 breathing instruction 109, 256  
 bremspectrum 35  
 bremsstrahlung 2, 35  
 bridge circuit 382, 406  
 brightness 132, 135, 136, 144, 171,  
     178  
     automatic stabilisation 177, 188,  
         241  
     intensification 173, 175, 181  
     stabilisation 177, 188, 241, 368  
 bronchography 330  
 bucky 121, 256, 418, 419  
     factor 126  
     spring-loaded 122, 256  
     table 418  
     upright 418  
 Burger 133

- cable, capacitance 384  
cable plugs 24, 383  
cables 23, 24, 28, 383  
    high tension 23, 383  
caesium iodide 47, 146, 177  
calcium sickle (aorta) 94  
calcium sulphate 74  
calcium tungstate 47, 166, 167  
calibration of ionisation chamber 64  
camera 306, 316, 424, 438  
    gamma 327  
    television 182  
candela (candles) 171  
capacitance 384  
    of cable 384, 407  
capacity 10, 16  
    heat 7, 12, 29  
C-arch 296, 311, 415, 427, 434  
carcinoma due to X-rays 70, 76  
cardiography 335, 440  
carotid angiography 336, 434  
cassette 164, 168, 169, 215, 248  
    cleaning of 167, 217  
    flexible 169  
    lead backed 168, 169  
    multisection 268  
    roll film 169  
    serial 103, 420, 422  
    sizes 168  
    subdivision of 169, 267  
synchroplan 270  
transport 193  
tunnel 196  
unsharpness 112, 168  
vacuum 169, 374  
cataract 77  
catheterisation 240, 335, 428, 438  
cathode 3, 6, 33, 34  
cathode rays 1  
cathode, tungsten 4  
CAT scanning 273, 393, 432  
caudal 243  
cavography 334, 438  
Cd 171  
ceiling construction 421  
ceiling suspended apparatus 425,  
    426, 427  
cellulose acetate 147  
centering 253  
central projection 95  
central ray 8, 97, 254  
cerebral angiography 335  
cervical spine exposures 255  
chamber condenser 62  
chamber, ionisation 51, 60, 72, 169  
characteristic curve (film) 151  
characteristic radiation 2, 21, 37,  
    39, 63, 374  
    of tungsten 37, 45  
charge (electric) 59  
charged particle image 325  
chart, basic exposure 338, 343  
    exposure 339, 343, 344  
checking exposure timer 401  
checks, medical 83  
chemical fog 225  
Chérigie 409, 428  
cholangiography 333  
cholecystography 332  
chrome alum 221  
cine film 318  
Cinelix 181  
cinematography 146, 181, 231, 315  
cinematography, image intensifier  
    146  
cinematography, X-ray 146, 181,  
    231, 315, 368, 393, 404, 439  
cinescopy 89, 308, 318  
circuit breaker (overload control)  
    397  
circuit, delta 386, 387  
    Graetz 382,  
    star 386, 387  
classical scatter 40, 47  
classification of apparatus 390  
cleaning of cassettes 168, 215  
cleaning, processing room  
    214, 218  
clear base 150  
closed circuit television 183  
cloud chamber, Wilson's 42  
cloud of electrons 4  
'cocked state' 74  
collimator 327  
colour sensitivity of the eye 143  
colour X-ray films 162  
column 412, 421  
column with tube connected 421  
Comberg 310  
combination screens 163, 168, 215  
comparison of films 157  
compensation, automatic (of mains  
    voltage) 394  
    contrast 228  
    mains voltage 394, 399  
compiling exposure chart 347

- compression 118, 255, 410, 421,  
     424, 429  
 compression band 109, 419  
 compton electron 40, 52, 54, 56  
 compton scatter 40, 47, 52  
 computerised tomography 273, 432  
 condenser 52, 384, 389, 407  
 condenser chamber 62  
 condenser discharge apparatus 389  
 conductivity of heat 7, 14  
 cones 249  
 cones (eyes) 135, 143, 171, 178  
 conjugate, true 309  
 connection of apparatus to mains  
     393  
 constant load 367  
 construction, ceilings 421  
     image intensifier 175  
     modules 408  
 contact exposures 99, 260  
 contact print 228  
 contact radiography 99, 259  
 continuous spectrum 2  
 contrast 90, 114, 118, 132, 136, 147,  
     154, 296  
     compensation 229  
     gradient 133  
     improvement of 118, 126, 129,  
         147, 155, 187, 249, 255,  
         277, 298  
     levelling method 228  
     loss of (image intensifier) 178  
     media 129, 329  
     negative 130  
     objective 134  
     range (object) 158  
     perception of 115, 178  
     positive 130  
     radiation 43, 46, 49, 86, 115, 129,  
         154, 307  
     regulator 187  
     rendering of (image intensification)  
         178  
     subjective 129, 134, 135  
     transitional zone 133  
     visible 114, 154, 156  
 contrast-detail diagram 133, 136  
 control, automatic 397, 405  
     remote 408, 428  
 control panel 399, 408  
 convection, heat 24  
 convergence 292  
 conversion factor 174, 180  
 Coolidge 4  
 cooling 13, 24, 379, 397  
     air 24  
     oil 25, 26  
     water 27, 28  
 cooling-off period 397  
 copper filter 38  
 coronariography 336, 440  
 corpuscular radiation 53, 146  
 cosmic radiation 75, 151  
 cough guard 421  
 cracks, anode 13  
 cranial 243  
 critical organs 76  
 Crookes' tubes 17  
 cross-hatch grid 128  
 CT scanning 273, 393, 432  
 CT tube 22  
 Cu equivalence 21  
 Cu filter 38  
 cumulative dose 56, 70, 76, 79, 267,  
     311  
 current, alternating 10  
     direct 10  
     filament 4, 5, 397, 407  
     ionisation 52, 61  
     saturation 52  
     three-phase 385  
     tube 5, 29, 145, 389  
 curve, emission 5  
 cystography 331, 437  
 cysts 334  
  
 D 149, 152  
 dacrocystography 331  
 damage, caused by X-rays 22  
     genetic 77, 82  
     somatic 77  
 danger, high voltage 22, 378, 383  
     radiation 22, 71, 75, 77, 267,  
         305, 311  
 darkroom 192, 347  
     lighting of 151, 200  
 definition 104, 137, 262, 296, 393  
 defocusing (grid) 120, 256  
 degree of heterogeneity 67  
 Delcalix 181, 183, 425  
 delta circuit 386, 387  
 densitometer 150, 157  
 densitometry 150, 157

- density (closeness) 44, 46  
density 149, 151  
control 368  
curve 149, 151, 158, 165  
shoulder area 151  
errors 218, 224, 226  
range 158  
range (image) 158  
selector 363, 368  
stabilisation 368  
useful range 158, 160  
dental apparatus 29, 413  
dental films 161  
dental radiograph 79, 257, 286, 312, 391, 413  
depth, perception of 286  
detail 90, 131  
image 131  
infraliminary 132, 298  
object 131  
perceptibility 90, 102, 114, 133, 137, 146, 165, 171, 179, 281  
size of 132  
supraliminary 132, 297  
detail-diagram (contrast) 132, 136  
detector, radiation 273  
developer 206  
replenisher 209  
temperature 204, 208  
development process 49, 129, 148, 162, 203, 205  
dexter (right) 243  
Diagnost 88, 437  
Diagnost-M 443  
diagnostic dose meters 72, 83, 411  
diagnostic tubes 13, 28  
diaphragm 30, 119, 180, 250  
automatic 252  
lead, adjustable 251  
potter-bucky 121, 256  
slot 119  
diameter, anode disc 14  
diameter, beam 7, 12, 21, 30, 82, 252  
dichroic fog 225  
Dieck-Cieszynski, law of 258  
diode 30  
direct beam 79  
direct current 10  
direct-hit theory 56  
direct image 292, 293, 294  
direct measurement 59  
direct pulsating voltage 10, 384  
direct voltage 406  
direction, rays 101, 238, 243  
viewing 246  
disc, anode 13  
dissipation, heat 29  
distal 243  
distance, base (stereoradiography) 288  
focus-film 7, 98, 257  
focus-object 107, 108, 118  
object-film 91, 107, 108, 118, 297  
dictator 422  
distinctor 424  
distortion 95, 97, 99  
dominant, the 189, 253, 362  
dorsal 243  
dose, absorbed 53, 58, 70, 71  
total 70, 81  
cumulative 56, 70, 76, 79, 267, 311  
equivalent, unit of 54  
gonad 75, 82  
integral absorbed 71  
integral absorbed, measurement of 71  
limitation 71, 240, 360  
monitor 83  
permissible 77  
rate 59, 61, 83  
skin 70, 360  
volume 71, 101, 302  
dosimeter 60, 83, 411  
fountain pen shaped 83  
dosimetry 58, 71, 411  
double coated film 155  
double contrast method 130, 330  
*Drosophila melanogaster* 56  
drying 214  
fast 224  
dual focus 13, 380, 392, 396, 404  
Duane and Hunt, law of 35, 391  
duodenography 330  
Durchgriff (space-charge effect) 352, 390  
E 151  
e 45, 115  
earthing (of equipment) 197, 380, 383

- edge, absorption 46  
     effect 325  
     unsharpness 132  
 effective focal dimensions 9  
 effective kV (kV<sub>R.M.S.</sub>) 10, 349  
 effective pannin angle 266  
 efficiency, tube 7, 29  
 electrokymography 324  
 electromagnetic radiation 3, 25  
 electrometer 59, 61  
 electron, compton 40, 52, 54, 56  
     image 173, 175  
     emission 55  
     emission, thermionic 4, 31  
     optical enlargement 176, 301  
     optical reduction 176  
     optical system 174  
     photo- 38, 48, 52, 55, 173, 179  
     recoil 40, 48, 52, 55  
     secondary 38, 52  
     stream 4  
     thermal 4  
 electronic balance 53, 54, 61  
 electronic subtraction 233  
 electrons, cloud of 4  
 electrostatic lens 173, 176  
 Elke 276  
 E.M.I. scanner 273  
 emission curve 5, 6  
 emission, electron 55  
     filament 4, 30  
     light 47, 143, 166, 167  
 emulsion 46, 49, 50, 147, 153, 161  
     hardening of 221  
 'end-on' effect 93, 114, 255  
 energy, photon 2, 41, 65, 163, 327  
 enlargement 95, 107, 118, 132, 178,  
     296  
     electron optical 177, 301  
 equivalence 21  
 equivalent dose, unit of 54  
 erythema 70  
 E-value 339, 340, 348  
 exit pupil 182  
 expansion, room for 24, 25, 28  
 exponent p (power) 341  
 expiry date (film) 150  
 exposure 50, 52, 59, 70, 151, 162,  
     166, 167, 337  
     automatic 169, 189, 252, 307,  
         317, 360, 398, 404  
     blind 103, 423  
     chart 338, 342  
     chart, compiling of 347  
     contact 99, 261  
     graph 343  
     latitude 158, 161  
     measuring of 58, 63, 83  
     meter 60  
     point 343  
     range 158  
     rate of 59, 63, 64, 83, 188  
     table, basic 338, 343  
     time 110, 337, 398  
     time limits (upper and lower)  
         365, 366  
     timer, checking of 401  
     unit of 52  
     value 337, 339, 341  
 extra filtration 21, 25, 352  
 eye, colour sensitivity of 143  
     inertia of 171, 187, 295  
     lens 77  
     sensitivity 171  
     visual power of 136, 171  
 falling load 398, 405, 406  
 fan 26  
 Farmer's reducer 223  
 fast drying 224  
 fast screens 163  
 faults, film 218, 224  
 F centre 48  
 fibre optics 185  
 field of measurement 363  
 field size 72, 79  
 filament current transformer 4, 6,  
     397, 407  
 filament emission 4, 31  
 filaments 4  
 final washing 213  
 fine-line grid 119  
 finger marks 226  
 film, acetate based 147  
     age (fog) 224  
     badge 73  
     base 150  
     blue base 150  
     cine 318  
     colour of 162  
     colour X-ray 162  
     comparison of 157  
     dental 161

- film (*cont*)  
double coated 158  
emulsion 46, 49, 50, 161, 167  
expiry date 150  
faults 218, 224  
grain of 111  
hanger 215  
hopper 203  
magazine 150  
marking of 215  
non-screen 113, 161,  
    167, 374  
positive 320  
processor 192, 218  
quality 156, 358  
roll 313  
safety 147  
screen image 306  
sensitivity 150, 156, 161, 166  
sizes 168, 257, 318  
storage 150  
substratum 148  
testing of 157  
X-ray 51, 111, 148  
filter 21, 67, 80, 351  
    additional 21, 25, 351  
copper 38  
Cu 38  
extra 21, 25, 351  
fixed (permanent) 21  
inherent 21, 25  
scattered radiation 119  
total 22  
tube 67, 81, 351  
wedge 160, 313  
filtration, inherent 21, 25, 351  
fissures in the anode 14  
fistulography 331  
fixation 79, 109, 256  
fixed filter 21  
fixed stand 416  
fixer, rapid 211  
fixing bath 49, 203, 211  
flash marks 226  
flat gradation 155, 161  
flexible cassette 169  
floor covering 200  
fluid level 238  
fluorescence 47, 164  
fluorescent screen 48  
fluoroscopic screen 48, 86, 90, 113,  
    129, 143, 166  
fluoroscopically controlled examination 423  
fluoroscopy 80, 86, 102, 143, 238,  
    392  
    stereoscopic 295, 310  
    X-ray 80, 86, 171, 238  
focal spot size, apparent 9  
focal track 13  
focus 3, 6, 7, 8, 16, 29, 96, 106,  
    359, 366  
    actual dimensions 9, 20, 21, 105  
    apparent dimensions 9  
    dual 13, 393, 396, 405  
    effective dimensions 9, 10, 21,  
        106  
    Goetze 9, 12  
    load on 7, 9, 10, 11, 12, 14, 16,  
        29, 107, 317, 366, 379,  
        389, 392, 397  
    projected 14  
    selector 405  
    tolerance 20, 392  
    ultra fine 299  
    unsharpness 104, 263  
focus-film distance 9, 99, 357  
focus-object distance 107, 108, 118  
focused (grid) 119, 122  
fog 116, 149, 150, 151, 162, 201,  
    208, 224  
    chemical 225  
    dichroic 225  
    film age 224  
    light 224  
    oxidation 225  
    radiation 225  
    scatter 225  
fog proof 201  
foreign body 310  
formalin 224  
formation of image 48, 114  
four-valve apparatus 10, 350, 382  
fractionation 70  
fractures 94  
frame 318, 319  
frame, inlay 267  
frames per second 316  
Franke 363  
free control 397  
frequency, mains 407  
frequency, spatial 138  
frilling 226  
front screen 164, 168

- fulcrum (tomography) 261, 266, 268  
 full size radiographs 88, 312
- gadolinium 167  
 gallactography 331  
 gall bladder 332  
 galvanometer 52  
 gamma ( $\gamma$ ) 129, 153  
 gamma camera 327  
 gamma radiation 2  
 gas in X-ray tubes 7  
 gas insulation 27  
 gas tubes 3  
 gas valve 31  
 gasses 130  
 gelatine 148  
 genes 77  
 genetic damage 77, 82  
 genetic effect 56, 77  
 geometric unsharpness 100, 104  
     112, 118, 138, 263, 299  
 glands, sex 56, 70, 76, 82  
 Goetze focus 9, 12  
 Goetze, principle of 7, 8  
 goggles, adaptation 136  
 gonad dose 76, 82  
 gonads 56, 70, 77, 82  
 Gottheiner 316  
 gradation 129, 153, 162, 165  
     flat 154, 159  
 gradient, contrast 133  
 Graetz circuit 382, 406  
 graduated screens 163, 313  
 grain of film 111  
 grains 110, 145, 148, 151, 296, 306  
 gramgray 71  
 gramrad 71  
 graphite anode 13  
 graphs, exposure 343  
 gray 53  
 grid 119, 307  
     cross-hatch 128  
     factor 126, 354  
     fine-line 121  
     focused 120, 122  
     moving 121  
     oscillating 122  
     parallel 128  
     quality 126  
     reciprocating movement 122  
     scattered radiation 42, 47, 161
- stationary 120, 307  
 strips 119, 120, 126  
 grid-controlled X-ray tube 317, 390  
 Groedel technique 118  
 Grossmann 261  
 Grotthus Draper, fundamental biological law of 55  
 gy 53
- haemopoetic organs 76  
 Haendle 190  
 half-life 75  
 half-shadow 105, 133, 249  
 half-value thickness 66  
 half-wave apparatus 10, 379, 390  
 hanger, film 215  
 'hard' photographs 115  
 hard X-rays 4, 6, 35, 369  
 hardening of the emulsion 221  
 hardness 46, 349, 390  
     average 47, 68, 349, 391  
 harmonisation 229  
 Hasselwandler 292, 309  
 hazards, radiation 22, 70, 75, 77,  
     267, 305, 311  
 heart catheterisation 240  
 heart size 97, 99  
 heat, capacity 7, 12, 29  
     conductivity of 7, 73  
     convection 24  
     development of 29  
     dissipation 24  
     radiation 24, 37  
     units 10, 18  
 heavy category (apparatus) 391  
 heel effect 7, 9, 30  
 heterogeneity, degree of 68  
 high kilovoltage technique 33, 82,  
     98, 106, 128, 135, 369  
 high tension cables 23, 24, 383  
 high voltage 5, 23, 359, 378  
     danger of 22, 378, 383  
     switch 405  
     transformer 23, 533  
     wave form 349, 378, 386, 388  
 hip pinning 310  
 Hittorf-Geissler-Crookes' tubes 1  
 homogeneity 65  
 homogenise 67  
 Hondius-Boldingh 126  
 hopper (film) 202

- horizontal beam 237  
Hounsfield 273  
housing, tube 8, 22, 28  
H.U. 10, 17, 18  
Hunt, formula of Duane and 35, 391  
H.V.T. 66  
H.V.T., measurement of 69  
hydroquinon 207, 222  
hyperstereoscopy 289  
hysterosalpingography 331, 428
- I.R.C.P. 78  
I.D. 71, 302  
identification 245  
image, anode 173, 307, 314  
  charged particles 324  
  density range 158  
  detail 131  
  direct 292, 293, 294  
  divider 186, 316, 425  
    3 channel 186  
  electron 173, 175  
  formation 48  
  indirect 292  
  intensification, loss of contrast 178  
  intensifier 48, 86, 103, 146, 172  
    cinematography 146  
    construction 173  
    magnification 176  
    photofluorography 88, 145,  
      181, 189, 190, 257,  
      307, 314, 368, 425  
    quality 190, 240  
    rendering of contrast of 178  
  television 179, 239  
  variable 176  
  various sizes 189
- latent 49, 148  
memory 311  
mirror 294  
orthicon 183  
quality 90, 137, 178  
radiation 48, 85, 159, 242  
recording, magnetic 89, 136, 181,  
  187, 242, 282, 311, 321  
  true 133  
  visible 49
- imaging, orthogonal 94  
immobilisation 255
- improvement of contrast 118, 126,  
  129, 155, 187, 249, 255,  
  277, 297  
indirect image 292  
inertia (of the eye) 147, 171, 187,  
  295
- infraliminary detail 132, 297  
infra-red range 56  
inherent filtration 21, 25  
inhomogeneity (heterogeneity) 65
- inlay frame 267  
input phosphor 48, 146, 173  
insert, tube 28  
instruction, breathing 255  
insulation 24, 28  
  air 24  
  gas 27  
  oil 24
- insulator 51  
integral absorbed dose 71, 81, 101,  
  263, 302, 411  
  measurement of 71, 72
- integral measurement 59
- integration time (eye) 172, 295
- intensification, brightness 173, 175,  
  191  
  factor 111, 161, 165  
  factor (image intensifier)  
    173, 180  
  light 181, 425  
  photographic 223
- intensifier, image 48, 87, 103, 171
- intensifier noise 187, 242
- intensifying screens 46, 48, 51, 86,  
  110, 129, 161, 162, 215, 356
- intensity, maximum 36  
  radiation 6, 58, 65
- internal resistance 393, 394
- intralobar line 94
- intravenous investigation 332
- intrinsic unsharpness 110, 113, 138,  
  144, 146, 161, 163, 166,  
  178, 296, 301
- inverse square law 64, 94, 108
- inverse voltage 379
- involuntary movements 109
- iodine 130, 330
- ion track 42
- ion tube 3
- ionisation 3, 38, 40, 48, 51, 52, 54,  
  59, 151, 361, 411

- ionisation (*cont.*)  
 chamber 51, 59, 72, 169  
   calibration of 64  
   in automatic exposures 361  
   current 52, 61  
 ionising radiation 54  
 Isocon 183
- Janker 133, 312, 316, 318
- K-factor 126  
 kidneys 332  
 kilogramgray 71  
 kilogramrad 71  
 kilovoltage, high 46, 82, 98, 116,  
   128, 135, 369  
 kinescopy 89, 308, 318  
 kV, effective (kV<sub>R.M.S.</sub>) 10, 349  
 kV, maximum 10, 12, 36, 349  
 kymography 322
- labyrinth 196  
 labyrinth, open 195, 196  
 lambda ( $\lambda$ ) 35  
 lambda I ( $\lambda_i$ ) 36  
 lambda minimum ( $\lambda_{\min}$ ) 36  
 lanthanum 167  
 large field stabilisation 188  
 latency time 56, 70, 76  
 latent image 49, 148  
 lateral radiograph 101  
 latitude, exposure 158  
 layer thickness (tomography) 262  
 lead-backed cassettes 168, 169  
 lead diaphragm, adjustable 251  
 lead equivalence 79, 145, 195  
 lead glass 145, 400  
 lead-lined wall 79, 400  
 lead rubber 421  
   aprons 80, 83, 400  
   gloves 80  
 leak, radiation 22, 83  
 lens, electrostatic 173, 175  
   eye 77  
 lethal mutations 56  
 letters, on the film 227  
   placing of 245, 292  
 leukaemia 76  
 life of film, useful 150
- light beam diaphragm 251, 415  
 light category (apparatus) 390, 397  
 light, emission of 47, 143, 166, 167  
   fog due to 224  
   intensification 181, 425  
   photon 48, 50, 152, 174, 179  
   production of 144, 163, 166, 171  
   spot marking 168  
   ultra-violet 55
- lighting 200  
   processing room 151, 200
- lightning marks 226
- limitation, beam 72, 79, 81, 117,  
   249, 267  
   dose 71, 240
- Lindemann window 21
- line focus 8, 13  
 line, intralobar 94  
 line pairs 133, 139  
 line spectrum 37, 168  
 linear accelerator 3  
 lines of vision 293  
 Lipiodol 330  
 lithium 22  
 lithium fluoride 74  
 load, constant 367  
   falling 367, 398, 405, 407  
   maximum permissible 10, 107,  
   366, 405, 407  
   nomogram 11, 16, 18, 19, 317  
   on anode 9  
   on focus 7, 9, 10, 11, 12, 16,  
   30, 107, 317, 366, 379,  
   392, 397  
   specific 7  
   thermal 10, 18, 115, 317
- localisation 93, 310
- log *e* 152  
 log Etronic 228  
 low tension transformer 4  
 lower mandible 100  
 luminescence 47, 86, 143, 146, 163,  
   166, 181  
 lung markings 94  
 lung tissue 86  
 lymphangiography 336, 438  
 lymphogram 336
- Mach effect 133  
 macroradiographs 132, 296, 301,  
   392, 419, 434

- magazine, technique 236  
magnesium carbonate 145  
magnesium oxide 145  
magnetic image recording 88, 146,  
  182, 187, 242, 282, 311,  
  321  
magnification factor 95, 97, 299  
magnification (image intensifier) 176  
mains automatic voltage compensation  
  394  
mains, compensation 394, 399  
  connection of apparatus to 393  
  frequency 407  
  resistance 394  
  voltage 389, 393, 400  
mammography 2, 161, 373, 393, 441  
  tube 28, 37, 373, 441  
Mammomat 443  
mandible, head of 100  
  lower 100  
marking of films 215  
marks, finger, on film 227  
  lightning (or flash) on film 226  
  writing on film 227  
mAs 125, 156, 337, 339, 344, 345,  
  398  
mAs meter 400, 404  
mass 150 44  
mass survey 374, 428  
material of anode 7, 350  
maximum intensity 36  
maximum kV 10, 12, 36, 349  
maximum permissible dose 78  
maximum permissible load 11, 106,  
  366, 397, 405  
maximum voltage 10, 12, 36  
maze 195  
measurement, direct 59  
  H.V.T. 69  
  integral 59  
  integral absorbed dose 71  
measurements 309  
  pelvis (pelvimetry) 309  
measuring of exposure 58, 63, 83  
median plane 243  
mediastinum 334  
medical checks 83  
Medichrome film 162  
medium category (apparatus) 391  
Mellink 411  
melting point 7, 11, 379  
memory, image 311  
menstruation 82  
metallic silver 148, 150  
Metallix tube, apparatus 22, 378  
meter, exposure 60  
meter, mAs 400, 404  
methyl alcohol 224  
metol 207, 222  
mica sheet 22  
microröntgen 53  
microscopy, X-ray 328  
micturating urography 331, 437  
milliröntgen 53  
Mimer 436  
mirror image 294  
mirror optics 181, 306  
mirror, semi-transparent 184  
mirror stereoscope 292  
mobile apparatus 29, 379, 399, 412  
mobile stand 413  
modulation depth 138  
modulation transfer function 90,  
  137, 177, 190, 300  
modules, construction of 408  
molybdenum anode 15, 37, 374  
monitor, dose 83  
  television 182, 187, 239, 308  
monoenergy radiation 37, 391  
monochromatic radiation 37, 391  
monocular vision 286  
'mother film' 320  
movement, artifacts caused by 281  
  rotational 274, 280  
  translation 280  
  unsharpness 107, 108, 113, 156,  
  163, 255, 299  
movements, involuntary 110  
  partially involuntary 109  
  voluntary 109  
moving grid 121  
M.T.F. 137, 177, 190, 300  
mu ( $\mu$ ) 45, 115  
Muller 57  
Multix tube 22  
mutations 56, 77  
  lethal 56  
Mutscheller 78  
myelography 333, 433  
  
N-material 32  
nanometer 35  
natural background radiation 75

- negative contrast 130  
 negative phase 379, 382  
 Neurocentrix 436  
 Neurodiagnost 434  
 neuroradiology 282, 433  
 nomogram 11, 17, 19  
 nomogram, tube (load) 12, 17, 18,  
     19, 317  
 non-screen film 112, 161, 166, 374  
 noise 142, 147, 179, 183, 187, 188,  
     241, 308  
     intensifier 187, 241  
     photon 179, 241  
 nuclear medicine 327
- O 95  
 object contrast range 158  
 object detail 131  
 object-film distance 91, 107, 108,  
     118, 297  
 object thickness 352  
 objective contrast 134  
 oesophagus (barium) paste 330  
 oil 24, 25  
     cooling 24, 25  
     insulation 24  
     pump 27  
 one-knob operation 405  
 opacity 148  
 open labyrinth 194, 196  
 'open' tube 22  
 operation of X-ray apparatus 396  
 optical enlargement 132, 299  
 optics 176, 181, 182, 185, 306  
     Abbe's law of 176  
     mirror 181, 306  
 Oralix 391  
 Orbiscope 437  
 orthodontics 312  
 orthodiography 97  
 orthogonal representation or imaging  
     94  
 orthoscopy 294  
 oscillating grid 122  
 output phosphor 48, 146, 173  
 overexposure 129, 155, 218, 220  
 overframing 318  
 overhead projection 320  
 overload control 398  
 oxidation, fog 225  
 oxygen 225
- p exponent 341  
 p-material 32  
 Paatero 283  
 pair production 42  
 palpation spoon 79, 424  
 panning angle 263  
 panning angle, effective 266  
 panoramic exposures 30, 259, 286  
 pantomography 283  
 Pantoscope 422  
 paper, X-ray 170  
 parallactic shift 91, 287  
 parallax 91, 291  
 parietography 333  
 Parma, radiographic exposures according to 100  
 partially involuntary movements  
     110  
 patella 102  
 patient, care of 259  
 peak voltage 11, 12, 35  
 P.E.G. (or A.E.G.) 333, 434  
 pelvimetry 309  
 pelvis, measurements of (in pelvimetry)  
     309  
 penetrating power 4, 42, 46,  
     65, 85  
 penumbra 105, 133, 249  
 perceptibility, threshold 131  
 perception, contrast 171, 178  
     depth 287  
     detail 90, 102, 115, 131, 137,  
         147, 150, 165, 171, 178,  
         180, 238, 281  
 period 133  
 period of rest 30  
 permanent filter 22  
 permissible dose 77  
 phantom 132, 137, 157  
 phase, negative 379, 382  
 phlebography 334, 437  
 phosphor, input 48, 146, 173  
     output 48, 146, 173, 179  
 phosphorescence 48, 145, 164, 167,  
     183, 295  
 phosphors 168  
 photocathode 146, 173, 181  
 photocell 169, 362  
 photoelectric absorption 38, 47, 52  
 photoelectric method 362  
 photoelectron 38, 48, 52, 54, 55,  
     174, 179

- photofluorography 86, 88, 113, 144, 145, 170, 255, 305, 314, 441  
image intensifier 88, 146, 181, 189, 257, 308, 314, 368, 425  
photographic effect 49, 148, 156  
photographic emulsion 46, 49, 50, 147, 167  
photographic intensification 223  
photographic reduction 223  
photographs 'hard' 155  
photography of television image 308, 315, 318  
photomultiplier 362  
photo-pickup 362  
phototimer 169, 307, 362  
photon 2, 38, 48, 52, 53, 179  
energy of 2, 41, 65, 164, 327  
photon fluctuation 179  
light 48, 50, 175, 179  
noise 179, 241  
pinhole camera 104  
pinning, hip 310  
placing of letters 245, 291  
plane, selected 261, 266  
planigraphy (tomography) 261  
plugs, cable 24, 384  
Plumbicon 184, 425  
pneumocolon examination 330  
pneumoencephalography 333, 434  
pneumomediastinography 334  
pneumoperitoneum 334  
pneumoretroperitoneum 334  
point system 344, 345  
polarisation, spectacles 296  
polaroid radiography 326  
polyester base 148  
Polytome 265, 432  
portable apparatus 29, 379, 399, 412  
portable stand 412  
positioning 102, 239  
positive contrast 130  
positive film 320  
potassium bromide 207, 222, 224  
potassium carbonate 207  
potassium ferricyanide 223  
potassium metabisulphite 211, 222, 223  
potter-bucky diaphragm 121, 256  
preparation time 380, 424  
primary screen 146, 173  
print, contact 228  
prints 228  
process, development 49, 129, 149, 161, 203, 205  
processing room 192, 347  
cleaning of 217, 221  
lighting in 200  
timer 206  
processor, film 192, 218  
profile radiography 101, 312  
programme selector 315, 316  
projected focus 14  
projection, central 95  
projections, standard 102  
projector 321  
proportion (ratio) 126  
protection 79  
thermal 25  
protraction 70  
proximal 243  
pseudo-images 265  
pseudoscopy 292, 294  
pulsating direct voltage 10, 384  
pulse technique 317, 404  
pump, oil 27  
pupil, reflex 135, 172  
pyelography 331, 332, 437  
pyrocathine 222
- Q 54, 78  
quality factor 54, 78  
quality, film 156, 358  
grid 126  
image 90, 137, 178  
image intensifier 190, 240  
radiation 4, 51, 58, 65, 157  
quanta 4, 37, 38, 48, 50, 52, 53, 152, 179  
quantity of radiation 4, 46, 53, 59, 64  
quantum noise 179, 240
- rad 53  
radiation beam 30, 36  
radiation, characteristic 2, 21, 38, 39, 63, 374  
contrast 43, 46, 48, 86, 114, 129, 154, 207  
corpuscular 53, 146  
cosmic 75, 151

- radiation (*cont*)  
     hazard (danger) 22, 70, 75, 78,  
         267, 305, 311  
     detector 273  
     dose to patient 75, 115, 118,  
         239, 267  
     electromagnetic 3, 35  
     extra focal 25, 251  
     fog 225  
     heat 24  
     heterogeneous (pluroenergy) 65  
     image 48, 85, 114, 159, 242  
     intensity 6, 58, 64  
     ionising 53  
     leak 22, 83  
     monochromatic (monoenergy)  
         37, 65, 391  
     natural (background) 75  
     protection 22, 58, 70, 73, 75, 78,  
         79, 145, 192, 239, 240,  
         267, 311, 400, 409, 428,  
         429  
     protection, guide for 84  
     quality 6, 52, 58, 65, 83, 157  
     quantity 6, 52, 64  
     scatter 39, 40, 46, 63, 79, 116,  
         128, 161, 225, 255, 297,  
         302  
     secondary 42, 48  
     specific effect of 55  
     spectrum 35  
     terrestrial 75  
 radiator 27  
 radioactivity 3, 75, 328  
 radiochemical processes 55  
 radiograph 87  
 radiographic exposures 82, 242  
     with fluoroscopy 103  
 radiographic marker 215  
 radiographic positioning 102, 239  
 radiographic projections 243  
 radiographs, full size 83, 313  
     stereoscopic 257, 287, 309  
 radiography, biplane 128  
     contact 101, 259  
 radiological enlargement technique  
     118, 176, 296, 392, 419, 434  
 radiological workers 76  
 radiophotography 83, 181, 305  
 radiotherapy 7, 55  
 range, exposure 158  
 range, useful density 158, 160  
 rapid image sequence 314  
 rapid fixer 211  
 rate, dose 58, 59, 83  
 rate of exposure 59, 63, 65, 83, 188  
 rate of rotation 16  
 ratio 126, 128, 291  
 ray, central 8, 97, 254  
 rays, cathode 2  
     direction of 101, 238, 243  
 R.B.E. 54, 78  
 real focal spot dimensions 9  
 reciprocating movement (grid) 122  
 recoil electron 40, 48, 52, 55  
 recombination 52  
 rectification, self 379  
 rectifier 30  
     solid state 32, 379, 382  
 reduction (in size) 227  
 reduction, electron optical 175, 176  
 reduction factor 175, 176  
 reduction, photographic 223  
 reflex, pupil 135, 172  
 regenerating equipment 4  
 regeneration replenisher 209  
 regulator, contrast 187  
 relative biological effect 54  
 rem 54, 78  
 remote control 428  
 replenisher, developer 209  
 reproductions 227  
 resistance, internal 395  
     mains 394  
 resolution 133, 178  
 rest periods (tube) 29  
 reticulation 226  
 retina 136, 172  
 rhenium-tungsten-molybdenum anode  
     15  
 rinse, intermediate 210  
 ripening process 148  
 ripple voltage 386, 389  
 rods (eye) 136, 143, 172, 178  
 roll film 313  
     cassette 169  
 röntgen (R) 52  
 Röntgen museum 1  
 Röntgen W. C. 1  
 Rotalix 20  
 rotating anode 13, 14, 16, 392  
 rotation rate 16  
 rotational movement 274, 280  
 rotor 14

- rotary current 385  
roughening of the anode 13, 29  
rules of thumb 340  
'running in' of X-ray tubes 7
- safety film 147  
sagittal 244  
sandbag 109  
saturation current 52  
saturation voltage 52  
scanner, E.M.I. 273  
    total (whole) body 281  
scanning, CAT or CT 273, 393, 432  
scannography 326  
scatter 39, 47, 161  
    classical 40, 47  
    compton 40, 47, 52  
scattered radiation 38, 41, 47, 63,  
    79, 116, 128, 161, 225, 255,  
    297, 302  
filter 119  
fog due to 225  
grid 119, 256  
Schwarzschild effect 157  
scintigram 327  
scintillation counter 327  
scintillation crystal 327  
screen; back 163, 164  
    fluorescent 48  
    fluoroscopic 48, 49, 86, 90, 113,  
        129, 135, 143, 166  
image, film 306  
secondary 173, 178  
television 48, 183, 187, 308  
viewing 173, 178  
screens, combination 163, 168, 215  
    fast 163  
    graduated 165, 313  
    intensifying 45, 48, 51, 86, 110,  
        129, 162, 212, 356  
    slow 163  
    universal 163  
section thickness (tomography) 262  
secondary electrons 38, 52  
secondary radiation 42, 48  
secondary screens 173, 178  
sector, open and closed 316  
Seldinger 336  
selected layer 261, 266  
selected layer, alteration of 266  
selected plane 261, 266
- selective absorption 45  
selectivity 126  
selector, focus 405  
selenium (solid state rectifier) 32  
selenium (xeroradiography) 324  
self rectification 379  
Sellink 330  
semi-transparent mirror 184  
Senograph 443  
Senomax 443  
sensitivity, eye 171  
    film 148, 150, 155, 166, 358  
    spectral 200  
sensitiser 55  
sensitometry 157  
serial cassette 103, 421, 422  
serial exposures 314  
sex glands 56, 71, 77, 82  
shadow, true 133  
shock proof 23  
shoulder area of the density curve  
    162  
shoulder, density curve 151  
SI units 52, 53, 54, 58  
sialography 331  
Siemens exposure chart 345  
silicon 32  
silver bromide 49, 148, 326  
silver recovery 197, 205, 212  
    installation 197, 205, 212  
simultaneous tomography 268  
single-pulse generator 378, 415  
single-valve apparatus 381  
six-pulse generator 385, 391  
six-pulse voltage 16, 385  
six-valve apparatus 11, 18, 349, 385,  
    391  
size, detail 132  
sizes, cassette 168  
sizes, film 169, 257, 318  
sizes, various (image intensifier) 189  
skeleton 86  
skin dose 70, 360  
slot diaphragm 119  
slow motion 321  
slow screens 163  
sluice, underwater 206  
small field stabilisation 188  
sockets 24  
sodium carbonate 207  
sodium hydroxide 222  
sodium metaborate 207

- sodium sulphite 207, 222  
 sodium thiosulphite 211, 221, 223  
 'soft' photograph 155  
 soft tissue radiographs 312  
 'soft' X-radiation 4, 6, 35, 46, 47,  
     373  
 solarisation 149, 152, 228  
 solid state rectifier 32, 379, 382  
 somatic damage 77  
 somatic effect 56, 58  
 space-charge effect 252, 390  
 spatial frequency 138  
 specific load 7  
 specific radiation effect 55  
 spectrography, X-ray 2  
 spectral sensitivity 144, 200  
 spectrum 35, 143  
     continuous 2  
     line 36, 37, 168  
     radiation 36  
     X-ray 41  
 speed of X-rays 35  
 spinal canal 333  
 spinal column 313  
 spinning top 403, 404  
 splenoportohepatography  
     335, 438  
 spotlight 136  
 spring-loaded bucky 122, 256  
 stabilisation, automatic brightness  
     177, 188, 241, 317  
     brightness 177, 188, 241, 317,  
         368  
     large field 188  
     small field 188  
     voltage 395  
 stand, fixed 416  
     mobile 413  
     portable 412  
 standard position 238  
 standard projections 102  
 standard X-radiation 54  
 star circuit 386, 387  
 state, cocked 74  
 stationary anode 7, 8, 12, 392  
 stationary grid 120, 307  
 steepness (gradation) 129, 153, 159,  
     162, 165  
 Stefan-Boltzmann, law of 37  
 stem radiation 25, 251  
 stereograph, viewing of 292  
 stereoplank 290  
 stereoscope, binocular 292  
     mirror 292  
 stereoscopic fluoroscopy 295, 310  
 stereoscopic radiographs 257, 287,  
     309  
 stereoscopic X-ray cinematography  
     296  
 stereoscopy 93, 286  
     X-ray 286  
 stereotomogram 265  
 sternum 100, 264  
 stop bath 211  
 storage, films 150  
 straight-line portion (density curve)  
     151  
 stratigraphy 261  
 Stratomatic 265  
 stream of electrons 4  
 streaks (development) 225  
 strips (grid) 119, 120, 126  
 stroboscopic effect 121, 256  
 subdivision, cassette 267  
 subdivisions 423  
 subjective contrast 129, 135, 158  
 sublimate 224  
 substratum of film 148  
 subtraction 231  
 Super Rotalix 20  
 super speed anode 393  
 super tube 14, 20  
 superimposition 90, 101, 254, 260,  
     277  
 supraliminary detail 297  
 surgical image intensifier 189  
 switch, high voltage 405  
 switch, thermo- 26, 28  
 switch valve 405  
 switching on and off 400  
 symbols 33  
 Synchroplan cassette 270  
 synchrotron 3  
  
 $T_{1/2}$  75  
 table, basic exposure 338  
 table, bucky 418  
 table top, sliding 419  
 Takahashi 300  
 tandem lens system 104  
 tangent of alpha 153  
 tank units 379, 390, 415  
 tanks 203

- tapioca effect 111  
telecardiogram 100  
teleradiography 98, 312  
television 133, 147, 179, 182, 239  
    camera 183, 186  
    camera tube 183  
    closed circuit, medical 183  
    image intensifier 179, 239  
    image, photography of 308, 315,  
        318  
    monitor 183, 293, 308  
    screen 48, 183, 187, 308  
X-ray 88, 147, 171, 182, 187,  
    239  
temperature, developer 204, 208  
testing of films 157  
terminal voltage 393  
terrestrial radiation 75  
therapy 55  
therapy tubes 12  
thermal load 10, 20, 107, 318  
thermal protection 25  
thermionic electron emission  
    4, 30  
thermometer 205  
thermostat 205  
thermoswitch 25, 28  
thimble ionisation chamber 60  
thickness, object 352  
thorax, exposure 254, 422  
thorium oxide 31  
three-dimensional impression 91  
three-channel image divider 186  
three-knob operation 405  
three-phase apparatus 385  
threshold value 50, 131, 152, 165  
time, exposure 337, 398  
    integration (eye) 172, 295  
    limits, exposure (upper and lower)  
        365  
timer 381, 401, 406  
    checking of 401  
    fluoroscopic 83, 411  
    processing room 206  
T.L.D. 74  
titanium 14  
toe (density curve) 151  
tolerance, focus 20, 21, 393  
tolerance range 344  
tomogram, stereo 265  
tomographic accessories 430  
tomographic attachments 430  
tomography 93, 110, 260  
    axial 277  
    application of 267  
    blurring patterns of 265, 430, 431  
    computerised 273, 432  
    exposure 266, 368, 404  
    magnification 266  
    simultaneous 268  
    transverse 271, 432  
tomoscopy 267  
total absorbed dose 70, 81  
total body scanner 281  
total filtration 22  
total unsharpness 112  
track, focal 13  
    ion 42  
transformer, filament current 4, 23  
    high voltage 23, 406  
    hut 394  
    low voltage 4, 23  
translation movement 280  
translumbar aortography 438  
transitional zone, contrast 133  
transport, cassette 193  
transverse exposures 243  
transverse tomography 271, 432  
Trilon B 207  
Trendelenburg position 237, 420  
trochoscope 418  
true conjugate 309  
true shadow 133  
tube, above table (couch) 426  
tube, CT 22  
tube current 5, 6, 29, 144, 389  
tube-film distance 118, 125  
tube, filter 21, 67, 81, 351  
    housing 8, 22, 28  
    insert 28  
    ion 3  
    mammography 28, 37, 373, 442  
    Metalix and apparatus 22, 378  
    Multix 22  
    nomogram 12, 16, 17, 18, 317  
    ‘open’, non-shockproof 22  
    super 14, 20  
    under couch 422  
voltage 6, 30, 115, 359  
    window 8, 21, 30  
tubes, Crookes’ 7  
    diagnostic 12, 29  
    gas 4  
    Hittorf-Geissler-Crookes’ 1

- tubes (*cont.*)  
     therapy 12  
     X-ray 12, 391, 404
- tungsten, anode 7, 12, 13  
     cathode 4  
     characteristic radiation of 37, 45  
     disc 13, 15, 29
- tunnel, cassette 196
- twelve-pulse generator 388, 391
- twelve-pulse voltage 18
- twelve-valve apparatus 11, 16, 388, 391
- two-channel image divider 186
- two-knob operation 405
- two-pulse generator 382, 391, 415
- two-pulse voltage 18
- two-valve apparatus 381
- U-stand 415, 434, 436
- ultra-fine focus 299
- ultra-violet light 56
- undercouch tube 422
- underexposure 155, 218, 220
- underframing 318
- uniformity, law of 112
- unit, exposure 52
- unit volume 61, 71, 411
- units, Ångström 35  
     heat 10, 17, 19  
     SI 52, 53, 54, 58
- universal screens 163
- universal stand 421, 426, 437
- unsharpness 112, 104, 146, 163, 165, 167, 242, 392  
     cassette 112, 168  
     focus 104, 263  
     geometric 100, 105, 113, 138, 299  
     intrinsic 110, 112, 132, 138, 144, 146, 161, 163, 165, 178, 296, 301  
     movement 107, 108, 112, 163, 255, 299  
     total 112
- upright bucky 418
- urethrography 331
- urogenital system, investigation of 331
- urology 437
- useful density range 158, 160
- useful life of films 150
- useful voltage 379, 382
- vacuum 3, 5
- vacuum cassette 169, 374
- Vallebona 261
- value, exposure, 337, 339, 340
- valve 30, 379, 382
- valve switch 390
- variable image intensifier 176
- varices 335, 437
- venography 334
- ventilation 200
- ventral 243
- ventricles of the brain 277, 333
- vessels, investigation of 240, 314
- video recorder 89, 146, 183, 187, 242, 282, 311, 321
- video densitometry 391
- video signal 183, 187
- Vidicon 183
- viewing box 135
- viewing, direction of 246
- viewing screen 173, 178
- viewing stereoradiographs 292
- vignetting 125, 127, 128, 184, 306
- visible contrast 114, 155, 159
- visible image 49, 143
- vision, binocular 286
- vision, lines of 293
- vision, monocular 286
- visual power (of the eye) 136, 171
- vitamin A 136
- voltage, automatic mains compensation 395  
     drop 394  
     high 6, 23, 359, 378, 407  
     cables 23, 24, 383  
     danger of 22, 378, 383  
     switch 405  
     transformer 23, 406  
     wave form 349, 378, 385, 386, 388  
     inverse 379  
     mains 389, 393, 400  
     maximum 10, 12, 35  
     peak 10, 12, 47  
     pulsating direct 10, 384  
     ripple 386, 389  
     stabilisation 394  
     terminal 393  
     tube 6, 30, 115, 359  
     useful 379, 382, 393  
     wave form 349, 378, 385, 388
- volume dose 71, 101, 302
- voluntary movements 109

- wall stand 418  
washing 203, 210, 213  
  final 213  
water, cool 26, 27  
  cooling 24, 27, 28  
watt 10  
watt/cm<sup>2</sup>, watt/m<sup>2</sup> 53  
watt-seconds 10, 19  
wave form, high voltage 349, 378,  
  386, 388  
wavelength 2, 35, 65  
Weber-Fechner, law of 152  
wedge filter 161, 313  
weights, balancing 421  
whole body exposures (radiographs)  
  312  
Wien Max, law of 37  
Wilson's cloud chamber 42  
window, tube 8, 21, 30  
work bench 202  
writing marks (on film) 227
- damage caused by 22  
film, colour 162  
films 51, 111, 147  
fluoroscopy 80, 86, 171, 237  
image intensifier 48, 146, 171  
microscopy 328  
paper 170  
spectrography 21  
spectrum 36  
stand 412, 443  
stereocinematography 296  
stereoscopy 286  
television 89, 147, 171, 182, 187,  
  239  
tube, grid controlled 371, 390  
tubes 12, 391, 404  
  'running in' 7  
X-rays 1, 42  
  'hard' 35, 46, 369  
  speed of 35  
Xeroradiography 324
- X-radiation 11  
  attenuation 38, 43, 46, 64, 115  
  biological effect of 54, 55, 70  
  'hard' 4, 6, 35, 46, 83  
  soft 4, 6, 35, 46, 65  
  standard 55
- X-ray, apparatus, operation of 396  
  beam 8, 14, 21, 35  
  carcinoma due to 70, 76  
  cinematography 146, 181, 231,  
  315, 368, 393, 404, 439
- yellow spot 136
- Ziedes des Plantes 231, 261, 264,  
  265
- zinc cadmium sulphide 143, 146,  
  167, 177, 306
- zinc sulphide 48, 143, 167
- zirconium 14
- zonography 101, 264