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PUBLICATION 85

Avoidance of Radiation Injuries from  
Medical Interventional Procedures



Pergamon

# Annals of the ICRP

Published on behalf of the International Commission  
on Radiological Protection

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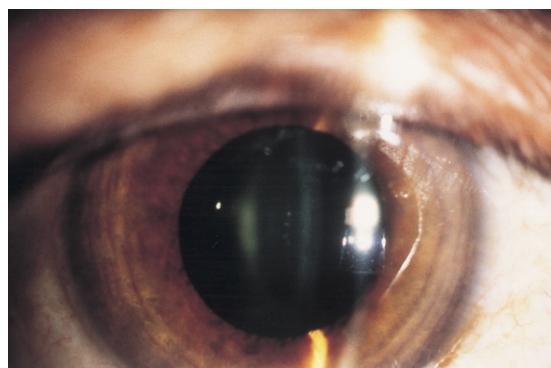
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# Avoidance of Radiation Injuries from Medical Interventional Procedures



*Above:* Photograph of the patient's back 21 months after a coronary angiography and two angioplasty procedures within a three day period; assessed cumulative dose 15,000 to 20,000 mGy. The patient has consistently refused skin grafting after excision of necrotic tissue. (Photograph courtesy of F. Mettler.)

*Below:* Cataract in the eye of an interventionist after repeated use of old x-ray systems and improper working conditions related to high levels of scattered radiation. (Photograph courtesy of E. Vaño.)



An information publication for the medical profession from the International Commission on Radiological Protection

# Annals of the ICRP

ICRP PUBLICATION 85

## Avoidance of Radiation Injuries from Medical Interventional Procedures

Editor  
J. VALENTIN

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## Editorial

### NEWS OF THE WORLD

The last meeting for the current 1997–2001 term of the International Commission on Radiological Protection (ICRP) took place in the United States in October 2000. After having met with its four standing Committees, the Main Commission took a number of important decisions. Two new ICRP reports were approved for publication; five new members were elected to the Commission for its next, 2001–2005, term; 20 new members were appointed to the four Committees; and a formal Task Group on New Recommendations was launched.

The Commission also reviewed drafts of forthcoming reports; reviewed the continuing work of its Committees; reviewed reactions of the international radiation protection community to initial proposals concerning new ICRP recommendations; and gave advice to its recently launched Task Group on Protection of the Natural Environment.

Each Committee discussed the scope of new, consolidated ICRP Recommendations, tentatively scheduled for approval in 2005, and their own contributions to the development of those Recommendations. They also reviewed the various projects and draft reports under their aegis. The Commission members participated in the meetings of the Committees and assisted in the progress of their work. The four Committees reported that progress to the Commission at the end of the meeting.

In connection with the meeting, the Commission also arranged a well-attended briefing session and reception for bodies interested in radiological protection.

During its Bethesda meeting the Main Commission approved two new reports from Committee 3 for publication. These were: Prevention of Accidents to Patients Undergoing Radiation Therapy; and Managing Patient Dose in Computed Tomography. These follow two previous reports from Committee 3, which had already been approved by the Commission, on Pregnancy and Medical Irradiation (*ICRP Publication 84*) and the present report on Avoidance of Radiation Injuries from Medical Interventional Procedures.

The Main Commission for its next term has established two Task Groups. The first Task Group is to be chaired by Lars-Erik Holm and is concerned with Protection of the Environment. It is intended to review the Commission's Policy, which is essentially that if humans are protected to the degree thought necessary, then other species are adequately protected. Some further information about this Task Group and its plans are shown on the Commission's Internet web site, [www.icrp.org](http://www.icrp.org).

The second Task Group is established to take forward the development of the next recommendations of the Commission. It will be chaired by the Chairman of the

Commission and consist of the Vice-Chairman and four Committee Chairmen from the 2001-2005 term. The Commission reviewed the comments received at the IRPA 10 meeting held in Hiroshima during May 2000, together with those offered by the four Committees. It was agreed that there should be an open literature publication to describe the progress made and the issues to be addressed in the next stage of the preparation of the Recommendations. The time-scale for their production is the term of the new Commission and Committees. Information about this project is also available through our web site, [www.icrp.org](http://www.icrp.org)

At the October 2000 meeting, elections were held for members to be invited to serve for the 2001-2005 term. There were five retirements from the Commission: Dan Beninson, Charles Meinhold, Hiro Matsudaira, Jean-Claude Nénot, and Leonid Ilyin. Those elected were Greta Dicus (USA), Yasuhito Sasaki (Japan), Annie Sugier (France), Rudolf Alexhakin (Russia), and Abel González (Argentina). The Chairmen of the four Standing Committees are Roger Cox (Committee 1), Christian Streffer (Committee 2, replacing Alexander Kaul who in 1999 had announced his intention to retire from ICRP at the end of the 1997-2001 term), Fred Mettler (Committee 3), and Bert Winkler (Committee 4). The final membership of the Main Commission and all of those appointed to the four Committees, as well as the existing emeritus members, is of course shown on our web site, [www.icrp.org](http://www.icrp.org). Starting with the next issue, this information will also appear in print in the *Annals of the ICRP*.

The new Commission will meet again with the four Committees at the beginning of September 2001 in The Hague, Netherlands, when the Dutch Ministry of Environment will be the hosts. A whole series of important decisions and exciting new ideas are likely to emerge at this first meeting of the new Commission and Committees. For those of you who are keen to keep abreast of developments within ICRP, my advice is obvious - watch this space!

JACK VALENTIN

## CONTENTS

PREFACE .....	5
ABSTRACT .....	7
1. INTRODUCTION .....	9
Main points .....	9
1.1. History .....	9
1.2. Safety and interventional techniques .....	11
1.3. Purpose of this document .....	13
1.4. References for Introduction .....	13
2. CASE REPORTS .....	15
Main points .....	15
2.1. Background.....	15
2.2. Injuries .....	15
2.3. References for Case reports .....	22
3. RADIOPATHOLOGY OF SKIN AND EYE AND RADIATION RISK .....	25
Main points .....	25
3.1. Introduction .....	25
3.2. Radiopathology — skin .....	26
3.3. Radiopathology — eye .....	28
3.4. References for Radiopathology and radiation risk .....	30
4. CONTROLLING DOSE.....	33
Main points .....	33
4.1. Factors that affect dose to patients.....	34
4.2. Factors that affect staff doses.....	38
4.3. Procurement .....	40
4.4. References for Controlling dose .....	42
5. PATIENT'S NEEDS.....	45
Main points .....	45
5.1. Counselling on radiation risks .....	45
5.2. Records of exposure .....	46
5.3. Follow-up .....	46
5.4. Information to personal physician .....	46
5.5. Advice to patient .....	47
5.6. System to identify repeated procedures.....	47
6. INTERVENTIONIST'S NEEDS.....	49
Main points .....	49
6.1. Knowledge .....	49

6.2. Training .....	49
6.3. Continuing professional development .....	50
6.4. Audits .....	50
6.5. Development of new procedures .....	50
<b>7. RECOMMENDATIONS .....</b>	<b>51</b>
<b>ANNEX A: PROCEDURES LIST .....</b>	<b>53</b>
<b>ANNEX B: PATIENT AND STAFF DOSES .....</b>	<b>55</b>
Annex B1: Patient doses in interventional procedures .....	55
Annex B2: Staff doses in interventional radiology .....	56
<b>ANNEX C: EXAMPLE OF CLINICAL PROTOCOL .....</b>	<b>59</b>
<b>ANNEX D: DOSE QUANTITIES .....</b>	<b>61</b>
D.1. Absorbed dose .....	61
D.2. Patient dosimetry for skin injuries.....	61
D.3. Other dosimetry .....	61
D.4. Staff dosimetry for occupational dose .....	62
D.5. References for Annex D .....	65
<b>ANNEX E: PROCUREMENT CHECKLIST .....</b>	<b>67</b>

## PREFACE

Over the years, the International Commission on Radiological Protection (ICRP), referred to below as ‘the Commission’, has issued many reports providing advice on radiological protection and safety in medicine. Its *Publication 73* is a general overview of this area. These reports summarise the general principles of radiation protection and provide advice on the application of those principles to the various uses of ionising radiation in medicine and biomedical research.

Most of these reports are of a general nature, and the Commission wishes to address some specific situations where difficulties have been observed. It is desirable that reports on such problem areas be written in a style which is accessible to those who may be directly concerned in their daily work, and that every effort is taken to ensure wide circulation of such reports.

A first step in this direction was taken at the Commission’s meeting in Oxford, United Kingdom, in September 1997. At that time, on the recommendation of ICRP Committee 3, the Commission established several Task Groups to produce reports on topical issues in medical radiation protection.

The current report is the result of the work of one of those Task Groups. The terms of reference of this Task Group on avoidance of radiation injuries in interventional procedures were to produce a targeted document for the prevention of radiation injuries in interventional procedures, with reference to both patients and staff. The Task Group was requested to consider all likely deterministic effects, techniques to reduce dose, and patient follow-up to detect delayed effects. Furthermore, the report was to discuss practical protection strategies.

The membership of the Task Group was as follows:

C. Sharp (Chairman)  
E. Vaño

K. Faulkner  
M. Wucherer

H. Nakamura

Corresponding members were:

J. Cardella  
M. Rosenstein

J. Hopewell  
T. Shope

M. Rehani  
B. Worgul

The membership of Committee 3 during the period of preparation of this report was:

F.A. Mettler, Jr. (Chairman)	J.-M. Cosset	M.J. Guiberteau
L.K. Harding (Secretary)	J. Liniecki (Vice-Chairman)	S. Mattsson
H. Nakamura	P. Ortiz-Lopez	L.V. Pinillos-Ashton
M.M. Rehani	H. Ringertz	M. Rosenstein
Y. Sasaki	C. Sharp	W. Yin
W.Y. Ussov		

This report aims to serve the purposes described above. In order to be as useful as possible for those purposes, its style differs in a few respects from the usual style of

the Commission's publications in the *Annals of the ICRP*. For instance, an overview of 'Main Points' is given at the beginning of each new chapter. Several colour figures are also included in order to illustrate more clearly the nature and characteristics of radiation injuries that can be encountered after interventional radiology procedures.

The report was approved for publication by the Commission through postal ballot in September 2000.



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# Avoidance of radiation injuries from medical interventional procedures

ICRP Publication 85

Approved by the Commission in September 2000

**Abstract-**Interventional radiology (fluoroscopically-guided) techniques are being used by an increasing number of clinicians not adequately trained in radiation safety or radiobiology. Many of these interventionists are not aware of the potential for injury from these procedures or the simple methods for decreasing their incidence. Many patients are not being counselled on the radiation risks, nor followed up when radiation doses from difficult procedures may lead to injury. Some patients are suffering radiation-induced skin injuries and younger patients may face an increased risk of future cancer. Interventionists are having their practice limited or suffering injury, and are exposing their staff to high doses.

In some interventional procedures, skin doses to patients approach those experienced in some cancer radiotherapy fractions. Radiation-induced skin injuries are occurring in patients due to the use of inappropriate equipment and, more often, poor operational technique. Injuries to physicians and staff performing interventional procedures have also been observed. Acute radiation doses (to patients) may cause erythema at 2 Gy, cataract at 2 Gy, permanent epilation at 7 Gy, and delayed skin necrosis at 12 Gy. Protracted (occupational) exposures to the eye may cause cataract at 4 Gy if the dose is received in less than 3 months, at 5.5 Gy if received over a period exceeding 3 months.

Practical actions to control dose to the patient and to the staff are listed. The absorbed dose to the patient in the area of skin that receives the maximum dose is of priority concern. Each local clinical protocol should include, for each type of interventional procedure, a statement on the cumulative skin doses and skin sites associated with the various parts of the procedure. Interventionists should be trained to use information on skin dose and on practical techniques to control dose. Maximum cumulative absorbed doses that appear to approach or exceed 1 Gy (for procedures that may be repeated) or 3 Gy (for any procedure) should be recorded in the patient record, and there should be a patient follow-up procedure for such cases. Patients should be counselled if there is a significant risk of radiation-induced injury, and the patient's personal physician should be informed of the possibility of radiation effects. Training in radiological protection for patients and staff should be an integral part of the education for those using interventional techniques. All interventionists should audit and review the outcomes of their procedures for radiation injury. Risks and benefits, including radiation risks, should be taken into account when new interventional techniques are introduced.

A concluding list of recommendations is given. Annexes list procedures, patient and staff doses, a sample local clinical protocol, dose quantities used, and a procurement checklist.  
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*Keywords:* Interventional radiology; Radiation protection; Erythema; Necrosis; Cataract



## 1. INTRODUCTION

### Main points

- Interventional radiology (fluoroscopically-guided) techniques are being used by an increasing number of clinicians not adequately trained in radiation safety or radiobiology.
- Patients are suffering radiation-induced skin injuries due to unnecessarily high radiation doses. Younger patients may face an increased risk of future cancer.
- Many interventionists are not aware of the potential for injury from procedures, their occurrence, or the simple methods for decreasing their incidence utilising dose control strategies.
- Many patients are not being counselled on the radiation risks, nor followed up for the onset of injury, when radiation doses from difficult procedures may lead to such injury.
- Interventionists are having their practice limited or suffering injury, and are exposing their staff to high doses.
- Occupational doses can be reduced by reducing unnecessary patient dose and by the correct procurement and use of equipment (including the use of shielding devices).

### 1.1. History

(1) Since the late 1960s (Margulis, 1967), the use in medicine of interventional procedures utilising radiology has increased significantly and continues to grow, the numbers doubling every 2-4 years in some countries as shown in Figs. 1.1 and 1.2.

(2) The basic concept is of ‘keyhole surgery with x-ray vision’ (Thomson, 1997), although in today’s practice the vision can also be provided by other modalities, e.g. ultrasound, MRI, and CT. This publication deals solely with the fluoroscopic use of x rays, which can be conveniently defined as:

*Procedures comprising guided therapeutic and diagnostic interventions, by percutaneous or other access, usually performed under local anaesthesia and/or sedation, with fluoroscopic imaging used to localise the lesion/treatment site, monitor the procedure, and control and document the therapy.*

(3) Although originally developed by radiologists, early in the evolution of fluoroscopically-guided techniques cardiologists entered the field and worldwide still represent the speciality with the highest number of procedures. However, interventional radiology (the term commonly used for these fluoroscopically-guided techniques and used in this document to describe this practice) has been ‘discovered’ by many other specialities, and the list of non-radiologists using fluoroscopy is growing

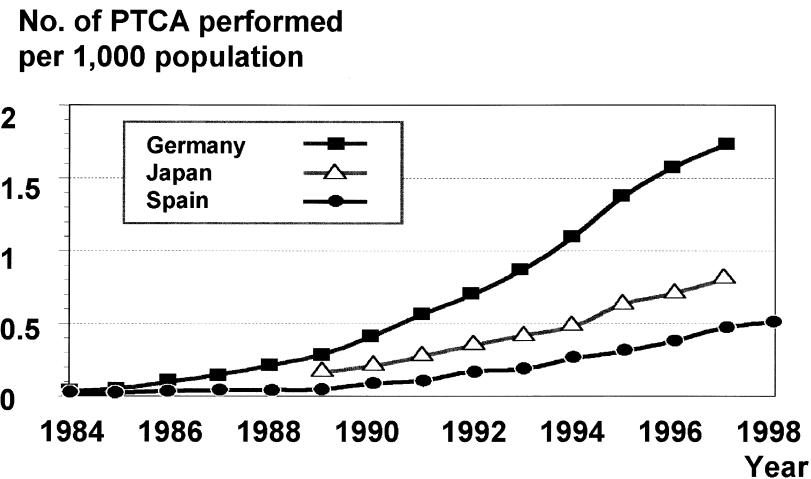


Fig. 1.1. The number of percutaneous transluminal coronary angioplasties (PTCA) performed per 1,000 population and per year in Germany, Japan, and Spain. For many years, the rates of increase in interventional procedures have been high when compared with other fluoroscopic examinations. Figs. 1.1 and 1.2 give, respectively, the annual frequencies and the corresponding annual rate of increase in PTCA for the last ten to fifteen years in Germany (Gleichmann et al., 1997), Japan (Takeyama, 1997), and Spain (Spanish Soc. Cardiol. 1998). The annual rate of increase is in the range of 10 to 20 percent. In many countries, the ratio of annual frequencies of diagnostic angiographic examinations to interventional procedures, for example of coronary angiography to PTCA, is decreasing continuously. There appear to be two reasons: first, the significant increase in interventional procedures; and second, the development of alternative angiographic imaging techniques like CT or MR. The importance of interventional procedures, as part of all angiographical examinations in radiology and cardiology, is therefore growing. While the number of interventional procedures is around 1% of all x-ray procedures, the radiation exposure to individual patients can be very large. If radiation protection is not improved in these procedures, the increasing frequency of interventional procedures could lead to a significant increase in the number of avoidable radiation injuries.

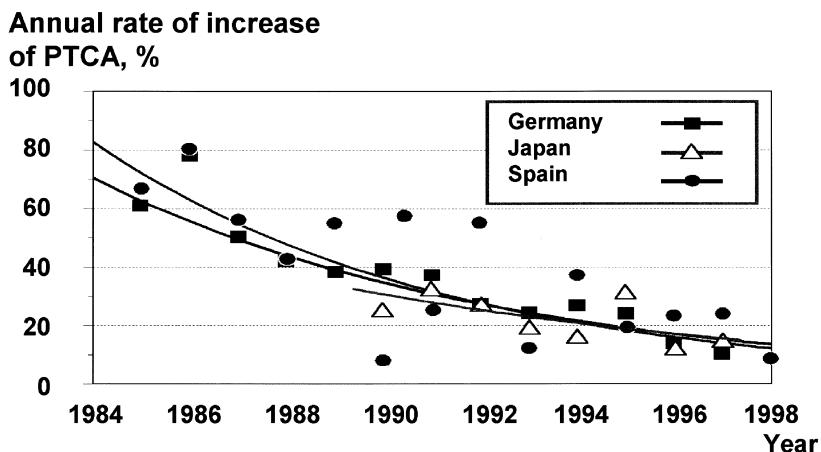


Fig. 1.2. The annual rates of increase of PTCA in Germany, Japan, and Spain (for references, see caption for Fig. 1.1).

(e.g. urologists, gastroenterologists, orthopaedic surgeons, vascular surgeons, traumatologists, anaesthesiologists, paediatricians). It is likely that practitioners in most specialities will become ‘interventionists’ and increasingly use such techniques in the near future. As many non-radiologists are increasingly using these techniques, and most have had little radiation protection training, there is an urgent requirement for a document to inform them of radiation risks and how to minimise them in their everyday practice.

## 1.2. Safety and interventional techniques

### 1.2.1. The patient

(4) Interventional radiology offers to medicine in all countries, no matter the stage of development, the opportunity to treat a greater range of pathologies, in more patients and at lesser cost. Interventional techniques reduce the need for expensive operating suites and extended hospital in-patient admissions. They also reduce most of the risks to the patient by the use of minimally invasive techniques and through lesser requirements for general anaesthesia. Additionally, they may allow therapy of lesions not previously accessible, although with concomitantly greater risks (Taylor and Rodesch, 1995).

(5) Diagnostic and therapeutic decisions in medicine are based on an understanding of the natural history of disease and the balance of the risk and benefits of treatment in each case. Many patients will be treated for life-threatening disease and hence the justification of the procedures is relatively straightforward; however, there is evidence that some techniques are being used when there is no clear clinical indication (Lange and Hillis, 1998). Unfortunately, there is growing evidence that many interventionists have a less than ideal understanding of the risks of radiation-induced injuries from x rays.

(6) Since the early 1990s, reports of radiation-induced injuries to patients’ skin have steadily increased, spanning the whole spectrum of skin injury from erythema to ulcers requiring major plastic surgery, as graphically illustrated on the frontispiece of this document (FDA, 1994, 1995; Shope, 1996, Schmidt et al., 1998, Vaño et al., 1998a, SSK, 1997). These reports are likely to represent a small fraction of the actual cases, particularly as such problems are usually manifest after the patient has left the interventionist’s care- appearing from several days to months after the procedure. Many of these injuries are avoidable- all of the severe ones are! This is particularly important as the severest lesions can lead to permanent disability and chronic intractable pain. Most occur because interventionists are not aware of the radiation doses that are delivered to skin. Annex A provides a list of common procedures, with indications of the relative level of dose and likelihood of repeated exposure. In neuroradiology, there is a particular risk to the eyes of cataract, if the radiation primary beam passes through the orbit.

(7) It is also important to note that reports of injuries are not limited solely to the use of older equipment, but also new and digital equipment, which can produce high dose rates. Users of such interventional fluoroscopic equipment must bear in mind

that multiple image acquisitions (between 50 and  $> 1000$ ), either digital or analogue, add further to the total skin dose, in addition to that derived fluoroscopically.

(8) There are also possible longer-term effects for surviving patients- mainly induction of cancers. Many patients are in their later years and interventional techniques are undertaken to improve quality of life. Such patients will often not survive long enough to develop a radiation-induced cancer. However, a significant and increasing proportion of patients are in middle or early adult life and some are children. If cured of their primary disease, many will have a life span sufficient to develop radiation-induced cancers in organs irradiated during interventional procedures. Children, particularly those with life-threatening disease in very early life, are at the greatest risk as a consequence of the substantial radiation doses they incur doing investigations. These children may subsequently develop leukaemia within a few years as a result of the irradiation of bone marrow, and breast cancer (Vaño et al., 1998a) or thyroid cancer as a result of chest or neck irradiation. The International Commission on Radiological Protection considers that there is no dose below which there is zero risk (ICRP, 1991) and therefore minimising the risk by confining the irradiation field and constraining the dose is highly desirable.

(9) Informed patient consent is an essential component of medical practice and hence counselling the patient (or the guardian in the case of a child) on the risk of a procedure is mandatory. Non-radiation risks such as embolism, stroke, and contrast medium allergy are discussed routinely, but the possibility of radiation injury is rarely mentioned. In those cases where it is judged that there is a risk of a radiation-induced erythema, or injury that is more serious or significant likelihood of future radiation-induced malignancy, this potential outcome should be discussed with the patient when informed consent is sought. Such counselling should include consideration of techniques that avoid the use of ionising radiation (if appropriate). Post-procedure there may be a need to counsel patients in cases where the procedure has been unusually difficult and the possibility of radiation (and other) effects has increased, with arrangements for appropriate follow up.

### **1.2.2. The staff**

(10) Patients are not the only people at risk. Staff receive doses from scattered radiation, but may not be aware of this fact nor aware of the risk this represents. Indeed, before the late 1960s attempts at interventional radiology had been curtailed, mainly because of the radiation hazards involved, primarily to those performing the fluoroscopy (Margulis, 1967). Such doses can still be high (Vaño et al., 1998a), particularly when equipment not specifically designed for interventional radiology is used (Vaño et al., 1998b, 1998c). In some countries, cumulative radiation doses to the hands, eyes, and thyroid may restrict the number of procedures that interventionists can undertake and there have been disturbing reports of radiation injuries to clinicians, including cataract (Vaño et al., 1998d).

(11) Staff doses correlate with patient doses, in that higher patient doses result in an increased amount of scattered radiation in the interventional suite (Williams, 1997). Additionally, staff doses can be considerably increased if inappropriate x-ray

equipment or inadequate personal protection is used (Vaño et al., 1998b, 1998c). These doses can be received not only by interventionists, but also by other staff necessarily present in the room. As well as reducing doses to patients, without compromising the clinical purpose, simple and cost-effective procedural and equipment measures have been shown to reduce significantly all staff doses (Vaño et al., 1998b).

### **1.3. Purpose of this document**

(12) The main purpose of this document is to provide advice that will minimise radiation risks to the patient and the attending staff. It is addressed to all interventionists and their supporting staff (including radiographers) and medical facility managers. The document only considers the radiation safety aspects of interventional procedures. The other clinical aspects are a matter for individual clinicians.

(13) In order to achieve its purpose, the document:

- provides information on interventional procedures that have produced serious radiation effects (illustrated by case histories of avoidable injuries);
- explains the basis for the biological effects of ionising radiation on skin and eyes;
- provides practical advice for controlling the procedural doses to patients and for reducing occupational doses to staff, including advice on procurement of new equipment;
- provides guidance on counselling pre and post procedure (if required) and the follow up of patients who may develop injuries; and
- makes radiation protection related recommendations for the introduction of new interventional techniques and for the training of interventionists.

### **1.4. References for Introduction**

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## 2. CASE REPORTS

### Main points

- Patient skin doses in some interventional procedures approach those experienced in some cancer radiotherapy fractions.
- Skin injuries are occurring in patients as a result of very high radiation doses during interventional procedures, because of the use of inappropriate equipment and more often poor operational technique.
- Injuries to physicians and staff performing interventional procedures have been observed recently, due to the use of inappropriate equipment, poor operational technique, and less than optimal radiation safety practices.

### 2.1. Background

(14) Unfortunately, there is a growing literature of case reports documenting inflammatory and cell-killing effect injuries to skin resulting from interventional radiology procedures (Huda and Peters, 1994; Kuwayama et al., 1994; Lichtenstein et al., 1996; Shope, 1996; Sovik et al., 1996; Nahass, 1997; D'Inca and Rogers, 1997; Stone et al., 1998; Nahass and Cornelius, 1998). There are many different instances of such inflammatory and cell-killing effect injuries, with severity ranging from erythema to severe skin necrosis. These injuries have affected mainly patients, but there are reports, both in the literature and anecdotal, of staff injuries.

### 2.2. Injuries

#### 2.2.1. Patient injuries

(15) In the vast majority of the reported cases, little or no information has been available after the event regarding the technical factors of the x-ray exposure required to estimate accurately the dose to the patient's skin or other organs. For many of the incidents, information on the total fluoroscopic exposure time or number of recorded images is not available. In many of these cases, it appears certain that the physicians performing the procedures had no awareness or appreciation that the absorbed dose to the skin was approaching or exceeding levels sufficient to cause inflammatory and cell-killing effects. The monitoring of fluoroscopic system operational parameters was not a routine practice. In some of the reported cases, efforts have been made to estimate retrospectively the dose based on typical technique factors of x-ray systems (Carstens et al., 1996) or dose measurements using patient phantoms (Huda and Peters, 1994).

(16) *Case 1:* An example of a skin injury attributable to x rays from fluoroscopy is shown in Fig. 2.1a–e. This injury to a 40-year-old man resulted from the combined effects of diagnostic coronary angiography, coronary angioplasty, and a second

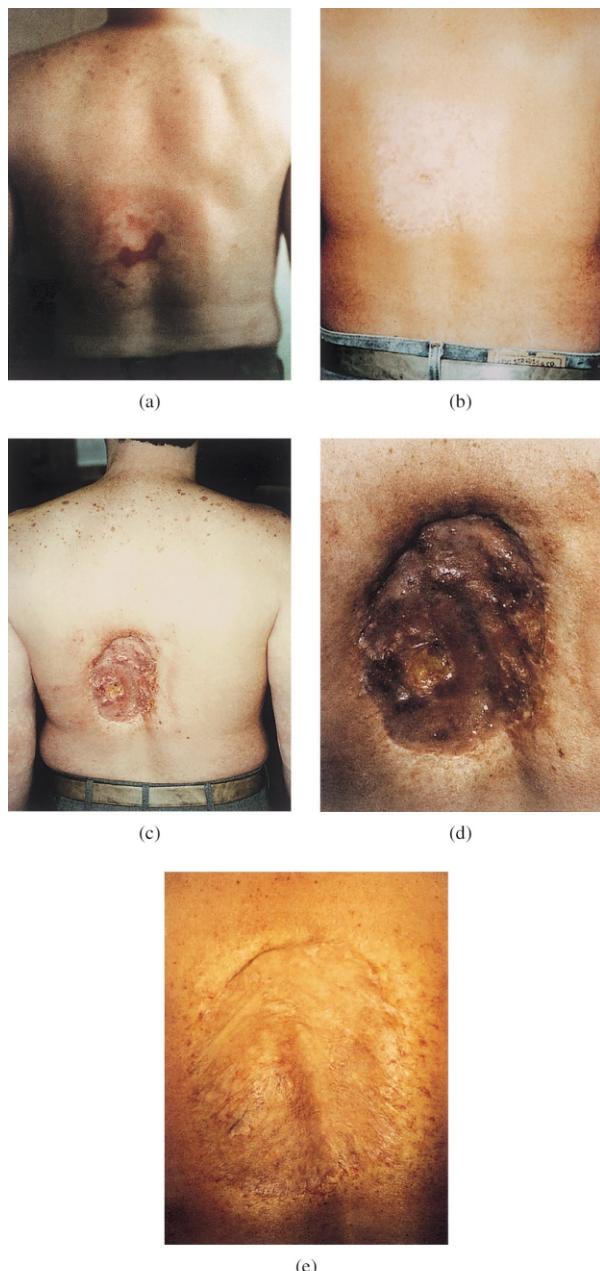


Fig. 2.1. Case 1 (photographs courtesy of T. Shope). (a) The patient's back 6–8 weeks after multiple coronary angiography and angioplasty procedures. (b) The injury approximately 16–21 weeks after the procedures. A small, ulcerated area is present. (c) The injury approximately 18–21 months after the procedures. Tissue necrosis is evident. (d) Close-up photograph of the lesion shown in (c). (e) The patient's back after skin grafting.

angiography procedure due to complications. The complications led to a coronary artery bypass graft, all occurring on the same day (Shope, 1996). Fig. 2.1a shows the area of injury six to eight weeks after the procedures. The injury was described as 'turning red about one month after the procedure and peeling a week later.' Eight weeks after the procedures, it had the appearance of a second-degree burn. Fig. 2.1b shows the condition after some 3 months (the exact date of the photo is uncertain) with the appearance of a healed burn, except for a small ulcerated area near the centre. Skin breakdown with progressive necrosis continued over the following months (Fig. 2.1c, 2.1d). The injury eventually required a skin graft (Fig 2.1e). The magnitude of the skin dose received by this patient is not known. However, from the nature of the injury, it is probable that the absorbed dose to the skin exceeded 20 Gy (Wagner et al., 1994). (See Annex D for definition of the gray). It is of considerable concern in this case (and others) that the interventionist was unaware of the dose levels being delivered and that insufficient information was available to reconstruct the dose retrospectively.

(17) *Case 2:* Interventional neuroradiological procedures requiring extended fluoroscopic exposure time have been described as leading to alopecia or epilation, but more severe skin effects have not been reported (Huda and Peters, 1994; Kuwayama et al., 1994; Krasovec and Trueb, 1998). A case of temporary epilation of the right occipital region of the skull has been reported following transarterial embolisation of a left paraorbital arteriovenous malformation performed in two stages, three days apart (Huda and Peters, 1994). The fluoroscopic times were recorded, and total doses in the postero-anterior projection and lateral projection of the biplane x-ray system were estimated from post-procedure phantom measurements to be 6.6 Gy and 1.7 Gy respectively. Fig. 2.2 illustrates the resulting epilation. Regrowth was reported to have occurred after 3 months, although the regrown hair was greyer than the original.



Fig. 2.2. Case 2 (photograph courtesy of W. Huda). Temporary epilation of the right occipital region of the skull 5 to 6 weeks after embolisation procedures.

(18) *Case 3:* Radiation skin injuries resulting from transjugular intrahepatic portosystemic shunt (TIPS) procedures in three patients have been described (Nahass and Cornelius, 1998). In the first case reported neither the equipment technique factors nor the total fluoroscopic exposure time was known. The 42-year-old male patient with diabetes mellitus and alcoholic liver disease had three different TIPS procedures separated by two and nine days and a total procedure time of 12 hours and 15 minutes. Six weeks after the original procedure he presented with a  $20 \times 15$  cm focally necrotic, ulcerating plaque on the midback of two weeks duration. He was treated conservatively and Fig. 2.3a shows the sclerotic plaque which was present two years after the procedure. In the other two cases injuries resulted from 90 minutes of fluoroscopy (total procedure time of four hours, 20 minutes) and from an unknown amount of fluoroscopy (total procedure time of six hours, 30 minutes). Both injuries required split thickness skin grafting. Figure 2.3b shows the ulcerating plaque that developed on the midback of the third patient 14 months after the TIPS procedure.

(19) *Cases 4 & 5:* Fig. 2.4 is an illustration of the radiodermatitis which resulted on the right arm of a 7-year-old girl in February 1997 following an ablation procedure, which required an estimated 75 to 100 minutes of fluoroscopy with the horizontal x-ray beam. Fig. 2.5 shows the chronic radiodermatitis that has resulted from two ablation procedures performed one year apart. One month following the second procedure, the patient presented to the dermatology service with lesions on the right side. Two years later, the patient had the  $10 \text{ cm} \times 5 \text{ cm}$  indurated plaque shown in Fig. 2.5 having hyper- and hypopigmentation with multiple areas of telangiectasia. Effects on the muscles in her right arm resulted in limited movement. Each procedure

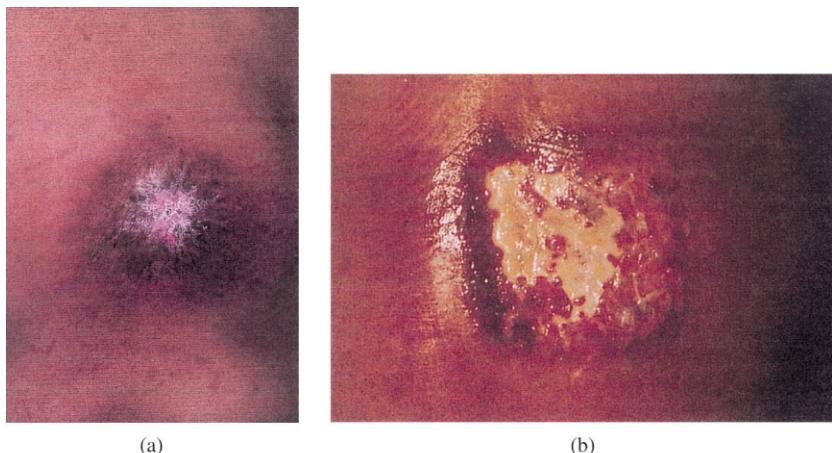


Fig. 2.3. Case 3 (photographs from Nahass and Cornelius, 1988, used with permission). (a) Sclerotic depigmented plaque with surrounding hyperpigmentation on the midback of a patient following 3 TIPS procedures. These changes were present two years after the procedures and were described as typical of chronic radiodermatitis. (b) Ulcerating plaque with a rectangular area of surrounding hyperpigmentation on the midback of the third patient described by Nahass and Cornelius, 14 months after TIPS. The ulcerated area was eventually excised and successfully treated with a split thickness graft.

was reported to have lasted 5 hours but exposure times are not available. During the second procedure, it was estimated that the horizontal x-ray beam was used during the procedure for 90 to 120 minutes. An exposure time of this length was estimated to result in a skin dose from the lateral beam of some 11–15 Gy per procedure. Several cases of skin injuries detected in patients following one or more cardiac radiofrequency catheter ablation procedures have been investigated in detail (Vaño et al., 1998a). The use of a biplane x-ray system whose geometry and image performance was less than optimum for these complex procedures was likely a contributing factor to the high skin doses associated with the lateral projections in these



Fig. 2.4. Case 4 (photograph from Vaño et al., 1998a, used with permission). Radiodermatitis in the right arm. 7 year-old patient. Photograph taken 4 months after radiofrequency ablation.



Fig. 2.5. Case 5 (photograph from Vaño et al., 1998a, used with permission). Chronic radiodermatitis; atrophic indurated plaque. 17-year-old patient. Photograph taken 2 years after 2 consecutive ablations.

procedures. The reader is referred to the references for a detailed description of these cases and the process used to reconstruct the radiation doses associated with these procedures.

(20) The U.S. Food and Drug Administration has received more reports of radiation injuries associated with radiofrequency catheter ablation of cardiac arrhythmias than for any other procedure. Case reports describing injuries from this procedure have been published (Nahass, 1997; Vaño et al., 1998a). Several of the injuries have resulted or been made more severe when patients underwent several procedures, in some cases in different health-care facilities, in attempts to obtain a successful outcome. These instances illustrate the need for physicians to have information regarding radiation exposures associated with prior interventional procedures. Many of these cases also show the characteristic that has been typical of these types of radiation injuries in that the patients, at some interval following the radiological procedure, have contacted dermatology specialists with complaints related to skin conditions. The connections to the radiological procedures have in many cases only been made after some delay or initial attribution to other factors.

### **2.2.2. Staff injuries**

(21) *Case 6:* Due to the long radiation exposure times associated with many interventional procedures, these procedures also have the potential for increased occupational exposures from scattered radiation for the clinicians performing them. There is very limited information available on verified occupational inflammatory and cell-killing effect injuries resulting from interventional procedures. While there have been many reports or estimates of the levels or rates of scattered radiation exposure to the staff performing these procedures, there is only one known published report documenting such injuries. Vaño (1998b) describes ophthalmologically

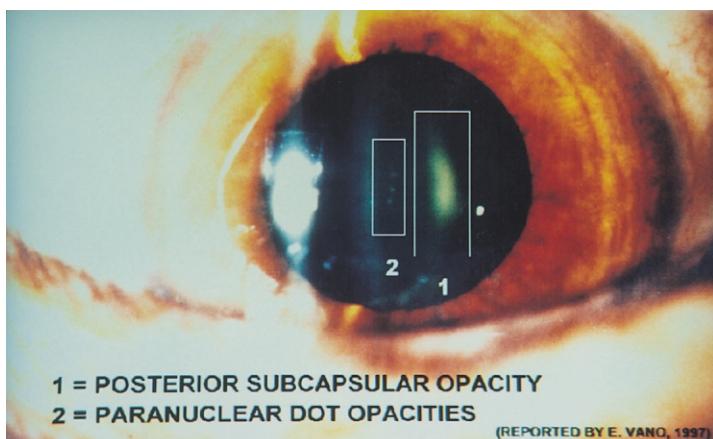
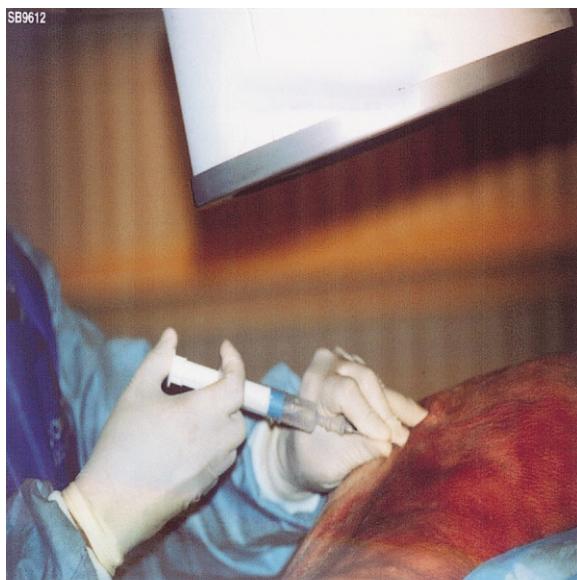
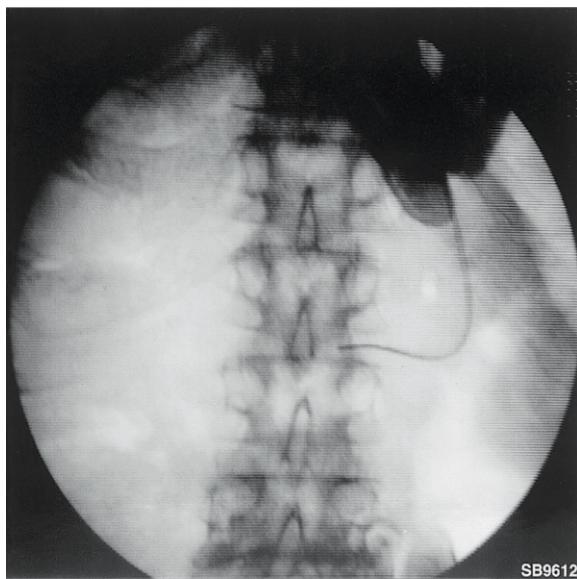


Fig. 2.6. Case 6 (photograph from Vaño et al., 1998b, used with permission). Radiation induced opacities in the lens of a specialist in interventional radiology subjected to high levels of scattered radiation from an over-table x-ray tube.



(a)



(b)

Fig. 2.7. Fluoroscopic guidance of placement of spinal stimulation electrodes, illustrating practices that can result in direct x-ray exposure of the hands of the physician performing the procedure (photographs courtesy of S. Balter). (a) Physician's hand in the area of the x-ray beam. If exposures are made in this circumstance, the hands receive direct exposure. (b) As a consequence, the hands are visible in the resulting image.

confirmed lens injuries in the eyes of two interventionists and two nurses. These injuries occurred in two facilities using systems with over-table x-ray tubes that caused increased levels of scattered radiation exposure to staff who remained in the room during the procedures (Fig. 2.6). Estimates of the lens doses to the interventionists in these two facilities indicate that the threshold for inflammatory and cell-killing effect injuries from fractionated or protracted exposures was exceeded in less than four years.

(22) The U.S. Food and Drug Administration has received several anecdotal reports of skin changes or injuries to the skin of the hands of anesthetists, who are performing increasing numbers of procedures for pain relief using fluoroscopically-guided spinal stimulation (Wagner and Archer, 1998). These procedures are typically performed with mobile ‘C-arm’ systems. The patient is in a supine position and with the x-ray beam directed laterally across the back. If the beam is not properly collimated, there is a potential for the interventionist’s hands to be exposed to direct x-ray beam unless extreme care is exercised during the placement of the stimulation needles under fluoroscopic guidance. Reports have been received of anesthetists who have performed a large number of such procedures and who have experienced skin changes on their hands characteristic of radiation-induced injury. No specific descriptions of the injuries or the doses received are available. Fig. 2.7 illustrates practices observed in a training course for physicians who were receiving instruction in procedures for pain relief by means of electrical stimulation of the spine. The images demonstrate a lack of care to prevent irradiation of the hands of the physician performing the procedure.

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### **3. RADIOPATHOLOGY OF SKIN AND EYE AND RADIATION RISK**

#### **Main points**

- Acute radiation doses, delivered to tissues during a single procedure or closely spaced procedures, may cause:
  - a) erythema at 2 Gy;
  - b) cataract at 2 Gy;
  - c) permanent epilation at 7 Gy;
  - d) delayed skin necrosis at 12 Gy.
- Protracted exposures to the eye, e.g. those experienced by interventionists, may cause:
  - e) cataract at 4 Gy if dose received in less than 3 months (5.5 Gy, if dose received over a period exceeding 3 months).

#### **3.1. Introduction**

(23) Exposure of tissues to x rays can result in the development of both inflammatory and cell-killing effects or induction of malignancy. The probability of inflammatory and cell-killing effects, of which skin desquamation and ulcers are one type, is dose-related once the dose exceeds a significant threshold; this threshold for skin is relatively high, but can be exceeded in interventional procedures. Malignancy may occur even at low doses, but the exact dose-response relationship is not accurately known.

(24) Following the irradiation of the skin with single doses of x rays several distinct waves of radiation response may be seen, depending on the total dose, the dose rate, and the pattern of exposure. The potential risks of skin damage resulting from fluoroscopy have been identified (Wagner and Archer, 1998) and their time of onset and the associated threshold doses are given in Table 3.1. Without knowing the actual dose rate(s) of various modes of operation, an interventionist can inadvertently reach the thresholds. Columns 4 and 5 of Table 3.1 show the impact of typical (realistic) dose rates in terms of minutes to reach the thresholds. This emphasises the importance of knowing the dose rates being delivered by specific equipment. Any ‘rule of thumb’, e.g. 100 minutes, should not be used unless it represents the impact of actual dose rates.

(25) The pathophysiological mechanisms leading to the development of many of these changes, which are also seen after radiotherapy or accidental industrial exposure, are now relatively well established (Hopewell, 1986; Seiber and Hopewell, 1990). The relationship of the different changes is also now well understood. However, the interpretation of skin changes in an individual case does, to a major extent,

Table 3.1

Potential effects of fluoroscopic exposures on the reaction of skin and lens of the eye

Effect	Approximate threshold dose (Gy)	Time of onset	Minutes of fluoroscopy at typical normal dose rate of 0.02 Gy/min (20 mGy/min = 2 rad/min) <sup>c</sup>	Minutes of fluoroscopy at typical high dose rate of 0.2 Gy/min (200 mGy/min = 20 rad/min) <sup>c</sup>
<b>SKIN<sup>a</sup></b>				
Early transient erythema	2	2–24 hours	100	10
Main erythema reaction	6	≈1.5 weeks	300	30
Temporary epilation	3	≈3 weeks	150	15
Permanent epilation	7	≈3 weeks	350	35
Dry desquamation	14	≈4 weeks	700	70
Moist desquamation	18	≈4 weeks	900	90
Secondary ulceration	24	> 6 weeks	1200	120
Late erythema	15	8–10 weeks	750	75
Ischaemic dermal necrosis	18	> 10 weeks	900	90
Dermal atrophy (1st phase)	10	> 52 weeks	500	50
Telangiectasis	10	> 52 weeks	500	50
Dermal necrosis (delayed)	> 12	> 52 weeks	750	75
Skin cancer	none known	> 15 years	N/A	N/A
<b>EYE<sup>b</sup></b>				
Lens opacity (detectable)	> 1.2	> 5 years	> 50 to eye	> 5 to eye
Lens/cataract (debilitating)	> 5	> 5 years	> 250 to eye	> 25 to eye

<sup>a</sup> Potential effects of fluoroscopic exposures on the reaction of the skin. Adapted from Wagner and Archer (1998) with reference to Hopewell (1986).

<sup>b</sup> Potential effects of fluoroscopic exposures on the lens. Indicates the doses that can produce detectable but non-symptomatic radiogenic changes and those doses capable of causing significant visual impairment or debilitation.

<sup>c</sup> Without knowing the actual dose rate(s) of various modes of operation, an interventionist can inadvertently reach the thresholds. Columns 4 and 5 show the impact of typical (realistic) dose rates in terms of minutes required to reach the thresholds. This emphasises the importance of knowing the dose rates being delivered by specific equipment. Any ‘rule of thumb’ e.g. 100 minutes, should not be used, unless it represents the impact of actual dose rates.

require knowledge of the sequence of changes observed. This is not always the situation with reported cases of overexposure in radiological procedures and hence uncertainties as to interpretation exist.

### 3.2. Radiopathology–skin

#### 3.2.1. Early effects

(26) In both patients and medical personnel, exposure of the skin may lead to the development of several waves of erythema or a reddening of the skin. An early response (early transient erythema) is seen a few hours after doses of > 2 Gy, when

the exposed area is relatively large. This is related to changes in vascular permeability. The main erythematous reaction, whose onset is after approximately 10 days, develops as a consequence of the inflammation secondary to the death of epithelial basal cells. A late wave of erythema may also be seen with an onset at about 8-10 weeks after exposure. This has a bluish tinge and represents dermal ischaemia.

(27) The reaction of the epidermis to radiation exposure is the most extensively documented. The cells most at risk are the basal cells of the epidermis; these are gradually lost after irradiation leading to the development of epidermal hypoplasia within 3-5 weeks of exposure. The severity of the clinical changes that are associated with epidermal hypoplasia depend on the size of the radiation dose. Hypoplasia is identified clinically as either dry desquamation or moist desquamation. Fig. 2.5 shows radiation dermatitis, a consequence of epidermal hypoplasia; Fig. 2.1a shows peeling of the skin, at approximately 6-8 weeks post exposure, which is classical moist desquamation. The timing depends on the turnover-time of epidermis in the individual patient, but is usually 4-6 weeks after exposure.

(28) In cases of very high dose exposure the healing of moist desquamation, a process that depends on cell proliferation and the migration of viable cells, may only occur slowly. In these cases, there is a progressive loss of dermal tissue, referred to as secondary ulceration. Such ulceration can be significantly enlarged if infection supervenes. Fig. 2.1a also has the appearance of a secondary ulceration burn some 6-8 weeks after exposure. Secondary radiation-induced ulcers heal slowly by a process of field contraction and fibrous tissue formation (scarring), as with any burn or excision wound in skin.

(29) In cases where moist desquamation heals within a few weeks, damage to the dermal structures may be avoided. However, the exposed areas of skin may subsequently develop late inflammatory and cell-killing effects or stochastic (cancerous) changes. In much the same way that radiation produces hypoplasia in the epidermis it will also inhibit the proliferation of matrix cells in the base of a growing hair: this may be transient, leading to hair thinning, or can produce alopecia or epilation (Fig. 2.2), with the eventual regrowth of hair. However, hair loss may be permanent (Seiber and Hopewell, 1990; Seiber et al., 1986). Cases of this type are described in the present publication. Again, like epidermal hypoplasia, this reaction is seen within a few weeks of exposure.

(30) If severe and persistent early radiation-induced changes are avoided, a range of late occurring lesions may still develop. Such inflammatory and cell-killing effect lesions of the skin may be variable in their expression. A late phase of erythema is identified by a distinct dusky or mauve ischaemia. It has been well characterised in experimental models (using pigs whose skin most closely approximates to human skin) after irradiation with single doses or fractionated doses involving a small number of large doses/fraction of x rays (Archambeau et al., 1985; Hopewell and van den Aardweg, 1988). The latency for the development of necrosis is 9 to 16 weeks, cf. Fig. 2.1b (Hopewell and van den Aardweg, 1988; Archambeau et al., 1968; Barabanova and Osanov, 1990). Similar effects will occur after fractionated doses (resulting in a high cumulative dose to an area of skin), a potential problem if procedures are repeated or several procedures undertaken.

### **3.2.2. Late effects**

(31) Late skin changes occur from 26 weeks after irradiation and are characterised by a thinning of dermal tissue, telangiectasia, and the possibility of late necrosis. Dermal thinning has been well documented in pig skin (Hopewell et al., 1979; Hopewell et al., 1989). Clinically, it is recognised as subcutaneous induration (Gauwerky and Langheim, 1978) and may have been erroneously referred to as subcutaneous fibrosis. Induration and telangiectasia were characteristic of one of the cases reported by Vaño et al. (1998) after two years. Telangiectasia is a repeatedly documented late change in human skin after radiotherapy exposure and is rarely seen earlier than 52 weeks. It then increases in both incidence and severity for up to at least 10 y after irradiation. The rate of progression of telangiectasia is dose-related (Turesson and Notter, 1986). Late necrosis may be promoted by trauma, or other factors, at any time.

## **3.3. Radiopathology–eye**

### **3.3.1. Mechanisms**

(32) Ionising radiation can damage a variety of ocular tissues. Many of the effects may be secondary to altered nutrition, e.g., the result of primary effect on the vasculature responsible for aqueous humor production. In the human, the blood-aqueous barrier is somewhat radioresistant, certainly requiring more than a single dose of 5 Gy and perhaps as much as 20 Gy of fractionated doses of x rays to facilitate breakdown (Ellsworth, 1969; Merriam et al., 1972). However, when this occurs, the resulting altered intraocular environment can adversely affect the lens, cornea, and intraocular pressure. If these effects persist, as can happen following fractionated doses of 30–40 Gy delivered in 3–4 days (Ellsworth, 1969), permanent visual disability can be the outcome.

(33) Except for direct effects on the lens, effects on the vasculature generally mediate the major influence of radiation on the eye. Many radiopathies of the eye require relatively high single or fractionated doses and become apparent only after extended latent periods. The notable exception is the opacification of the lens known as cataract. While three primary tissues have received considerable attention (the cornea, the lens, and the retina), it is important to recognise that a failure in systems other than the refractory media and the photosensitive tissues can result in the ultimate loss of ocular function. Damage to adnexal secretory tissues can affect the tear-film, which ultimately could cause the cornea to keratinise and opacify.

### **3.3.2. Inflammatory and cell-killing effects**

#### *Lens*

(34) About 90 percent of all individuals over 65 years of age have some sort of opacity in the lens, although visual acuity may not be affected sufficiently to cause visual impairment and require surgical intervention. For this publication, a cataract

is considered to be a loss of transparency of the lens, but only one that affects visual acuity is considered clinically significant.

(35) It is reasonably certain that everyone, if sufficiently long-lived, will develop compromised lens transparency (Cinotti and Patti, 1968). At least 50 percent, and perhaps as many as 75 percent, of these opacities are associated with cortical changes, i.e., changes associated with the superficial substance of the lens. The remainder are nuclear, i.e., they represent changes in the deeper portions of the lens. The latter cataracts are due to changes in the protein and/or deep membrane systems in the lens and are for the most part reflecting photochemical effects. The cortical changes, however, are frequently associated with an altered cellular morphology and may be due to an interference in the continued normal growth and differentiation of the tissue (Rothstein et al., 1982; Worgul et al., 1989). Such changes can occur from an accumulated exposure to various physical agents such as ionising and non-ionising radiation.

(36) The unique biology of the lens is the basis for its predominant pathology, i.e., cataract. The sole function of the lens is to refract incoming light onto the retina. A failure in organisation and/or metabolism results in opacification. As the lens grows throughout life, there is considerable opportunity for errors in growth and differentiation. These errors are compounded by the confinement of the cells within the limiting capsule. Also, as the lens depends on a rather extensive system of cellular communication, a failure in the cortex or the most superficial regions in the lens can cause the entire tissue to fail eventually. This is likely to be the basis of the eventual complete opacification of the lens by a number of physical agents (including ionising radiation), which have a primary effect in the lens epithelium.

(37) Utilising data on the development of cataracts in radiotherapy, it has been determined that an exposure of 0.15 Gy/yr to the eye should be the maximum occupational exposure, assuming a 30-year work exposure (ICRP, 1991; NCRP, 1993). Historically, the response of the lens to radiation has been thought to be inflammatory and cell-killing effects- related to dose with a threshold. For single doses, work suggests a 2 Gy threshold for cataract, with 5 Gy being necessary to produce a progressive disease. However, recent work suggests that there is evidence that lens opacification, without loss of vision, can result from exposure to doses as low as 0.2 Gy (Klein et al., 1993).

#### *Malignancy*

(38) Skin cancers that might be directly attributable to interventional radiological procedures have not been specifically documented, but melanoma is thought not to be related to ionising radiation exposures. However, there are well-documented case reports of basal cell and squamous cell cancers that are attributed to radiographic and radiotherapy exposure (Shore, 1990).

(39) The stochastic effects of radiation exposure in ocular tissues are not well known. While in the case of the lid-skin there is no reason to expect the response to differ from that of skin elsewhere, the evidence for radiogenically induced neoplastic disease in the eye is relatively sparse (Leff and Henkind, 1983; Roarty et al., 1988). The probability of radiation carcinogenesis in the ocular tissues is extremely low and the overwhelming concern for ocular morbidity should focus on inflammatory and cell-killing effect changes in the adnexal skin and cataractogenicity.

(40) Protection of the thyroid is of concern to most interventional radiologists. However, there is little proven risk for persons exposed over the age of 20 years (Ron et al., 1995).

(41) There is also an increased probability of a future malignancy in other organs that are irradiated, especially the breast, thyroid, and bone marrow, and particularly in children.

### 3.4 References for Radiopathology and radiation risk

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## 4. CONTROLLING DOSE

### Main points

- **The patient dose of priority concern is the absorbed dose in the area of skin that receives the maximum dose during an interventional procedure.**

The serious radiation-induced skin injuries are caused by prolonged irradiation of the same skin site resulting in absorbed doses that exceed the threshold for the skin effects. To help avoid and monitor for these serious skin injuries, the facility administration and interventional physician should adopt the basic steps described below. Annex B1 gives examples of patient skin doses received from the commonest procedures as listed in Annex A.

- **Each facility should include in the local clinical protocol for each type of interventional procedure a statement on the radiographic images (projections, number, and technique factors), fluoroscopy times, air kerma rates, and resulting cumulative skin doses and skin sites associated with the various parts of the interventional procedure.**

This information should be obtained with the help of a qualified medical physicist or equivalent specialist, and should be for the fluoroscopy equipment installed at the facility. Each protocol would be for the nominal conduct of the interventional procedure at that facility, recognising that actual procedures will vary considerably due to the complexities of the specific case. This statement in the protocol provides the interventional physician baseline levels for patient skin dose that permits comparison to irradiation conditions and resulting skin doses occurring during actual procedures. Some examples of useful statements in a clinical protocol are given in Annex C.

- **Each interventional physician should be trained to use information, displayed at the operator's position, on the level of 'patient skin dose' occurring during an actual procedure.**

The displayed information should be easily interpreted in comparison with the nominal clinical protocol and the threshold levels for skin injury. The most useful display is the air kerma (in mGy or Gy) that has accumulated up to the current point during the procedure. The display should be for a reference location that is a surrogate for the entrance skin surface of the patient. This will generally lead to an overestimate of the maximum cumulative skin dose, since it will be accumulated over all entrance skin sites. Additional useful displays are (a) the air kerma rate (in mGy per minute) during a fluoroscopic segment at the same reference location noted above, and (b) the total fluoroscopy time (in minutes). Such displays would permit ready comparisons with the local clinical protocol.

- **Interventionists should be trained on practical techniques to control the cumulative absorbed dose in the skin for normal circumstances, and additional techniques when the procedure is unexpectedly prolonged and thresholds for serious radiation-induced skin injuries are being approached.**

These techniques should be addressed in the clinical protocol, under headings such as ‘controlling absorbed dose in the patient’s skin for normal procedures’ and ‘avoiding patient skin injuries when unexpectedly prolonged procedures are encountered’.

- When the maximum cumulative absorbed dose in skin for an actual procedure appears to approach, equal, or exceed the following values, it should be recorded in the patient record, along with the location and extent of the skin site: 1 Gy (for procedures that may be repeated); 3 Gy (for any procedure).

Table 3.1 gives the absorbed dose thresholds for radiation-induced skin effects.

- Determination of the maximum dose in the skin is difficult and often only a rough estimate can be made.

Many modern pieces of fluoroscopic equipment constantly change the technical factors during a procedure. Equipment should be purchased with some device (e.g. cumulative air kerma indication) to help the interventionist assess the magnitude of skin dose. If only fluoroscopic time is known, interventionists should be aware that this is a very rough guide to patient dose. A prudent assumption is that the fluoroscopic time multiplied by the maximum output of the machine could represent the maximum skin dose received by the patient, but the locations of the x-ray field during the procedure also need to be taken into account.

- When the maximum cumulative absorbed dose in skin approaches, equals, or exceeds the values given above, the facility should have a patient follow-up procedure to address the potential for serious skin injuries.

Particularly, in the case of skin doses near or above 3 Gy, the patient should be informed of what signs and symptoms to look for, and what actions the patient should take.

- A practical guide to achieving these objectives is given in Fig. 4.1.

#### 4.1. Factors that affect dose to patients

(42) Various factors will influence patient doses. These may be categorised into procedural or equipment related. Some dose control measures are consequent on the equipment design for interventional radiology, whereas procedural methods of dose control relate to how the interventional procedure is performed. A list of factors that can impact patient dose is given in Table 4.1. Many of these factors are discussed below.

(43) As always with medical exposures of patients, no dose limits apply, but guidance levels for specific procedures can be relevant. Given the need for high image quality in interventional radiology, there is a need to develop minimum standards of imaging performance and the associated dose requirements for given interventional procedures. At a recent World Health Organisation workshop on ‘Efficacy and Radiation Safety in Interventional Radiology’, consideration was given to the question of image quality standards in relation to the purchasing of equipment for interventional radiology (WHO-ISH, 1997; Faulkner, 1997). The workshop concluded that further work was necessary to establish the scientific basis for imaging performance.

***Practical actions***

**To control dose to the patient (many of these will also control dose to the staff)**

- Keep beam-on time to an absolute minimum — The Golden Rule for control of dose to patient and staff.
- Remember that dose rates will be greater and dose will accumulate faster in larger patients
- Keep the tube current as low as possible by keeping the tube potential (kVp) as high as possible to achieve the appropriate compromise between image quality and low patient dose.
- Keep the x-ray tube at maximal distance from the patient.
- Keep the image intensifier as close to the patient as possible.
- Don't over-use geometric magnification.
- Remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patient.
- Always collimate closely to the area of interest.
- When the procedure is unexpectedly prolonged, consider options for positioning the patient or altering the x-ray field or other means to alter beam angulation so that the same area of skin is not continuously in the direct x-ray field.
- For many machines, dose rate varies during the interventional procedure. Fluoroscopy time is only a very rough indicator of whether radiation injuries may occur. Patient size and procedural aspects such as location(s) of the beam, beam angle, normal or high dose rates, distance of the tube from the patient, and number of acquisitions can cause the maximum patient skin doses to be tenfold different for a specific total fluoroscopy time.

**To control dose to the staff**

- Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for minimum dose.
- If the beam is horizontal, or near horizontal, the operator should stand on the image intensifier side (to reduce dose).
- If the beam is vertical, or near vertical, keep the tube under the patient.

Fig. 4.1. Practical actions. Adapted from Wagner and Archer (1998), an excellent source for training interventional physicians in practical dose control techniques. Incorporates a list of 'Ten Commandments for minimising risks from fluoroscopic x rays' from that publication.

#### 4.1.1. Procedural methods

(44) Procedural methods relate to how the examination is performed and how the equipment is used. For example, when the procedure can be complicated and there is a risk of high skin doses, the interventionist should consider the selection of appropriate technique (i.e.: different beam incidences, collimating the radiation field as much as possible, and using low dose rate modes, as well as high filtration and the use of pulsed radiation beams on some modern systems). In some x-ray systems,

Table 4.1

Measures to control patient skin dose for interventional radiology. Adapted from WHO (in press), UNSCEAR (1988), and NCRP (1989)

Factor	Effect	Reduction factor <sup>a</sup>
Limiting number of acquired images	Lower dose	Variable
Limiting fluoroscopy time and dose rate	Lower dose	Variable
Increasing tube potential/ x-ray spectra	Reduces dose and contrast	1.5
Increasing tube filtration	Reduces dose and contrast	1.7
Using grid/air gaps	Higher dose, better image quality	...
Minimising post-patient attenuation	Carbon fibre materials reduce dose	Up to 2
Using pulsed fluoroscopy/ last image hold	Shorter fluoroscopy times and lower dose	2.0

<sup>a</sup> The reductions in dose quoted are for each factor; if several factors are implemented the total dose reduction is not necessarily additive. However, the combination of some factors may be multiplicative (Wagner and Archer, 2000).

skin dose rate increases when magnification is used. Patient size should be taken into account, as larger patients receive higher doses.

(45) Mobile C-arm fluoroscopes pose special problems for patients. C-arm fluoroscopes often allow the x-ray tube to be positioned very close to the patient's skin. This should be avoided. The operator should make sure that the x-ray tube is as far from the patient as possible and the image intensifier is as close as possible.

#### 4.1.2. Equipment aspects

(46) Dose control measures may be designed into the equipment at the outset. It is important to highlight that equipment specifically designed for interventional radiology should be used. Examples of equipment design which may result in lower doses are the following: pulsed fluoroscopy (Wagner and Archer, 2000), high beam filtration, ergonomically designed collimation, availability of edge filters, carbon fibre components, and last image hold.

(47) It is particularly important for the interventional physician to have operational knowledge of the absorbed dose in skin of the patient in order to: (a) avoid unnecessary high skin doses, (b) be able to record an estimate of skin dose when it approaches, equals, or exceeds selected threshold levels, and (c) determine when the patient's follow-up should include monitoring for serious radiation-induced skin effects.

(48) It is therefore very useful to provide the interventionist with an immediately meaningful dose display, one that correlates with the threshold levels for radiation-induced skin effects. The most useful display is the air kerma (in mGy or Gy) that has accumulated up to the current point during the procedure. Additional useful displays, for comparison with corresponding values of the local clinical protocol for the interventional procedure, are the air kerma rate (in mGy per minute) during a fluoroscopic segment, and the total fluoroscopy time (in minutes).

(49) The cumulative dose-area-product can also be available to the operator as a display. This quantity is the sum of the products of the doses incident on the patient

and the areas of the x-ray fields for all segments of an interventional procedure, and can be helpful in dose control for stochastic effects to patients and operators. However, it is not a practical method for estimating maximum cumulative absorbed dose to skin or useful for predicting deterministic effects.

#### **4.1.3. Education and training**

(50) Interventional procedures are complex and demanding. They tend to be very operator dependent with each centre having slightly different techniques. It is particularly important in these circumstances that individuals performing the procedures are adequately trained in both the clinical technique and in knowledge of radiation protection. A second, specific, level of training in radiation protection, additional to that undertaken for diagnostic radiology, is desirable. Specific additional training should be planned when new x-ray systems or techniques are implemented in a centre. A quality assurance programme for interventional radiology facilities should include radiation protection training and assessment of dose control technique.

#### **4.1.4. Dedicated interventional radiology systems**

(51) Interventional radiology procedures place great demands on the imaging capability of the x-ray system. The observation of small catheters in blood vessels, of the reflux of contrast media, or the imaging of embolic agents, are each in turn difficult imaging tasks. If complex interventional procedures are to be performed, the x-ray equipment must be capable of performing the imaging task. This in part relates to image quality but also to the ergonomics of the x-ray system. For example, in cardiology small diameter image intensifiers are used. This predicates the use of dedicated interventional radiology equipment, which meets the clinical demands of the procedures to be performed with it. Equipment for interventional radiology should be a complete system, including various protective devices. The International Electrotechnical Commission (IEC, 2000) has produced a safety standard for interventional radiology systems.

(52) Ergonomic factors influence patient doses. For example, easy archiving and retrieval of images, computerised records of fluoroscopy time, acquired images, variation of image frequency in a series, and patient dose parameters, as well as the availability of different fluoroscopy and image acquisition modes will assist in controlling doses.

#### **4.1.5. Maintenance and QA programmes**

(53) The exacting clinical demands placed upon interventional equipment in turn implies that not only is it important to specify equipment which meets these demands, it is essential that the equipment continues to do so in the future. This implies that there must be rigorous quality assurance to monitor system performance, backed up by a comprehensive maintenance programme. The importance of both is attested to by the impact of changes in equipment performance on patient doses reported elsewhere (Gill, 1992; Vaño et al. 1998a).

(54) A comprehensive quality assurance programme is integral to a policy for patient dose control with an objective of avoiding serious radiation-induced injuries. Various reports on quality assurance have been published which describe in detail specific procedures (IPEM, 1996; Borras, 1997). One overexposure incident (Gill, 1992) was traced to a lack of quality assurance, specifically the measurement of image intensifier dose-rate, and dose/frame. These measurements should be complemented by an assessment of image quality. Senior hospital management has a role to play in dose control by ensuring that quality assurance programmes are part of policy and implemented.

#### **4.1.6. Medical physics expert**

(55) Each centre performing interventional radiology should have access to expert advice on radiation protection provided by, ideally, a medical physicist, but at least by a radiographer or radiation protection officer. Advice should be available on patient dosimetry, equipment selection, and quality assurance.

#### **4.1.7. Practical advice**

(56) The application of a number of the above dose control measures can result in a significant lowering of patient doses. The crucial factor is to determine the minimum imaging performance necessary for the examination. This is a complex consideration as the choice of the optimum pulsed fluoroscopy frequency and pulsed dose/image is not always clear; it is often dependent upon operator preference, experience, and imaging expectations.

(57) The nominal clinical protocols for the same procedure vary considerably between centres. Even small changes in clinical protocol can result in dramatic changes in dose levels, for example the choice of pulse repetition frequency and dose/image in peripheral angiography (Gill, 1992; Vetter et al. 1998).

(58) Quality assurance is integral to maintaining consistently appropriate doses. Given the linkage between dose/image and image quality, it is vital that both are assessed regularly in a quality assurance programme. This is particularly relevant for any item of interventional radiology equipment that has some form of automatic control, which is virtually all units. There is the prospect of the automatic systems compensating for deterioration in performance by increasing the dose/image (Gill, 1992). Consequently, a simple check of dose/image or dose-rate and image quality should be a routine test for interventional radiology equipment. Advice on quality assurance programmes for fluoroscopy equipment may be found in the published literature (IPEM, 1996; Borras, 1997).

### **4.2. Factors that affect staff doses**

#### **4.2.1. Operating procedures**

(59) Interventional radiology procedures tend to be complex and are performed on patients who can be quite ill. As a consequence, more staff are needed in an interventional

radiology suite to attend to the patients' individual clinical needs. Thus, not only are more staff present during an interventional radiology procedure, they tend to stand close to the patient where dose-rates and scattered radiation are higher (Faulkner, 1992). The clinical needs of interventional radiology patients dictate a dedicated equipment design, in that lead protective screens are difficult to add since they would interfere with access to the patient. In some installations, over-couch x-ray tube/under-couch image intensifier configuration fluoroscopy equipment is used. This conjunction results in high dose rates in the vicinity of the patient and hence staff doses are higher (Marshall and Faulkner, 1992; Vaño et al., 1998b). Such configurations are sub-optimal for interventional procedures and should be discouraged.

(60) The problem of intrinsically higher scattered dose-rates is compounded by the extended fluoroscopy times for some procedures. The combined effect is that doses received by interventionists tend to be higher than for other groups of occupationally exposed individuals, such as those working in general radiography. Table 4.2 summarises the Commission's recommended annual dose limits for eye and skin in occupationally exposed individuals (ICRP, 1991). These dose limits and estimates of typical doses received by staff performing interventional radiology procedures yield an indication of maximum workloads. Typical doses received by staff are given in Annex B2 for a number of procedures.

(61) In general, staff doses correlate with patient doses, that is, when patient doses increase, so do the resulting staff doses. Staff doses are influenced by the equipment design and technical settings, clinical protocol, and to some degree clinical experience. As with all fluoroscopy procedures, staff working in interventional radiology should wear adequate physical protection. This must comprise of a well-designed, tailored lead apron, which distributes the weight across the individual's shoulders, or hangs the skirt on the bony pelvis, sparing the spine from the full weight of the apron. Evidence indicates that a lead apron equivalent to 0.35 mm lead will give the wearer substantial protection (Marshall and Faulkner, 1995). It is always better to shield more radiosensitive organs than having more shielding for the same organs. Thus the wearing of thyroid shields will provide the interventionist with some degree of additional protection (by a factor of between 1.5 and 3 when worn in conjunction with a 0.35 mm lead apron; Marshall and Faulkner, 1995). A medical physics expert, or similar, should be available to provide advice on exposure.

(62) Photo chromic sunglasses and spectacles with a high lead content also afford the wearer some degree of eye protection (Marshall et al., 1992). (However, a busy interventionist who has good technique should not have absorbed doses to the eyes that could cause cataracts). These devices are particularly important if technique or

Table 4.2  
Recommended occupational annual dose limits (ICRP, 1991)

Body part	Dose limit (mGy)
Lens of eye	150
Skin	500
Hands and feet	500

equipment is poor and the interventionist's eye dose is close to the limit for serious radiation-induced effects (see Table 3.1). Lead rubber or other protective gloves provide some protection to the hands (such gloves do not provide complete protection and wearing them does not provide an excuse for placing the hands in the primary x-ray beam). However, many interventionists find these gloves clumsy and disruptive of tactile sensation, which is critical to some procedures. The best protective measure for hands and eyes is for the individual to stay clear of the primary beam, but specifically the unattenuated beam i.e. at the patient entry site.

(63) Equipment manufacturers will also supply additional protective devices and attachments to equipment for interventional radiology. This includes ceiling-suspended lead acrylic viewing screens, under-table shielding attachments to the x-ray couch, and portable personal shields. These devices usually afford individuals significant protection. However, they can be cumbersome and difficult to use. Manufacturers need to develop more ergonomically useful protection devices.

(64) A relatively simple method of reducing dose to staff is by operational factors such as staff position. The patient is the source of scattered radiation. It is important to remain as far away as practical from the patient to reduce scattered doses or higher dose rates (see Annex D). The position of staff in the room relative to the patient directly influences staff doses. Dose levels decrease with distance from the patient (see Annex D). Increasing the field size and the tube potential/beam quality will both increase staff doses.

(65) Mobile C-arm fluoroscopes pose special problems for staff. If the beam is near vertical, the x-ray tube should be under the patient. Placing the tube over the patient increases operator dose from patient backscatter. If the x-ray tube is near horizontal, the operator should stand on the image intensifier side. Standing on the tube side increases operator dose from patient backscatter.

(66) The high occupational exposures in interventional radiology require the use of robust and adequate monitoring arrangements for staff. A single dosimeter worn under the lead apron will yield a reasonable estimate of effective dose for most instances. Wearing an additional dosimeter at collar level above the lead apron will provide an indication of head (eye) dose. In addition, it is possible to combine the two dosimeter readings to provide an improved estimate of effective dose (NCRP, 1995; Faulkner and Marshall, 1993). Consequently, it is recommended that interventional radiology departments develop a policy that staff should wear two dosimeters. Hand dose may be monitored using a lithium fluoride thermoluminescent dosimeter. Doses in departments should be analysed and high doses and outliers should be investigated.

(67) Staff should therefore be encouraged to wear and use the protective devices available, where appropriate (see Annex D). Scattered dose-rates at the couch side can be high (see Annex D). It is therefore important that staff know where to stand, and are advised to stand as far away from the patient (the source of scattered radiation) as practical.

### **4.3. Procurement**

(68) Procurement is the term used to describe the process of specifying, purchasing, and commissioning equipment. The procurement of equipment for interventional

radiology is a critical part of the process of dose control. The purchase of inappropriate or inadequate equipment must be avoided. In addition, x-ray equipment for interventional radiology is expensive and represents a considerable capital investment by the health care facility. With increasing financial pressures on health care budgets, it is vital that inferior equipment, which does not meet the clinical requirements and which results in high patient and staff doses, is not acquired because of financial constraints. Consequently, the specification, procurement, and commissioning of equipment for interventional radiology is crucial to a dose control strategy. The specification for the equipment should include the radiation protection attachments and the desired patient dose monitoring features. A checklist for procurement is given at Annex E.

#### **4.3.1. Specification**

(69) The first part of the process is to draft an equipment specification and a clinical justification. In drawing up a specification for interventional radiology equipment, there needs to be a critical review and analysis of equipment requirements bearing in mind the intended use of the equipment. A consideration at this stage is whether to specify a unit dedicated to one particular branch of interventional radiology (e.g.: peripheral angiography) or have a unit that will address a range of interventional procedures. Thus, an objective description of the intended use should be written, together with an estimate of the intended workload. A set of detailed equipment specifications, which include both general and specific requirements, should be written. This should include a request for a given minimum image quality and dose performance. The detailed specification should require that the equipment meet all relevant standards of the IEC, the International Standardization Organization (ISO), and the United States Food and Drug Administration (FDA) or equivalent other national standards. Manufacturers should be asked to specify what radiation protection tools are available and their effect (e.g. carbon fibre table tops) in their response to the tendering process.

(70) To some extent, the equipment requirements are task related (see Annex E for details). It is necessary to have suitable dose monitoring features. This equipment should be capable of being linked to a computer and the radiology information system (RIS). The dose display should be available at the position where the interventionist stands. Manufacturers of interventional equipment should be invited to respond to the tender document and equipment specification. The response to the tender by the various suppliers should be evaluated. The first stage is to determine which equipment meets the detailed equipment specification. A decision will then be made on the best equipment. The health care facility should then draw up a contract for purchase which includes all the relevant terms and conditions.

#### **4.3.2. Commissioning**

(71) The manufacturers will install the equipment according to the local building regulations. Installation engineers should be adequately trained in radiation protec-

tion. Once the equipment has been installed, it must undergo a rigorous series of checks. The first part of the process is an acceptance test in which the purchaser determines whether the equipment supplied meets the tender document specification, as well as whether it meets the relevant national and international standards. The supplier in the presence of the purchaser should conduct the acceptance test, although in some countries a qualified expert in medical physics might do the acceptance test on behalf of the purchaser. The supplier should demonstrate that the performance of the equipment meets the advertised criteria. It is the purchaser's responsibility to accept the equipment. A qualified expert will then perform an inspection of the installation and a critical inspection of the radiation protection facilities. This inspection may be incorporated into the acceptance testing process. Constancy testing and status testing may also be performed to establish the performance standard at the outset and the baseline for routine test results respectively. Quality assurance and a planned programme of preventative maintenance should be established.

(72) Equipment should not be used clinically until it has successfully passed an acceptance test and the radiation protection survey. The next stage is for the manufacturer to train the staff of the facility in the operation of the equipment. Ideally, an applications specialist who is familiar with and experienced in interventional radiology should perform this training. All staff that perform interventional radiology should have received practical training in radiation protection. The level and nature of this practical training will differ between different professional groups.

(73) Only after the equipment has been passed as safe and meeting the specification and the staff have been trained, the equipment should be placed into clinical use. At this stage, patient and staff doses should be monitored in line with the advice given previously.

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## 5. PATIENT'S NEEDS

### Main points

#### 1 Gy

- Patients should be counselled on radiation risks if the procedure carries a significant risk of such injury.
- Records of exposure should be kept if the estimated maximum cumulative dose to skin is 3 Gy or above (1 Gy or above for procedures likely to be repeated).
- All patients with estimated skin doses of 3 Gy or above should be followed up 10 to 14 days after exposure.
- The patient's personal physician should be informed of the possibility of radiation effects.
- If the dose is sufficient to cause observable effects, the patient should be counselled after the procedure.
- A system to identify repeated procedures should be set up.

### 5.1. Counselling on radiation risks

(74) All ionising radiation exposures have some risks, but for most interventional procedures these are small and the benefits to the patient will substantially outweigh any risk. However, the delivery of a high dose during a procedure will carry a considerable risk of injury to the skin. Such injuries will not be immediately obvious to the patient and may cause distress and/or additional discomfort to the patient. As with other procedures or treatments in medicine, the patient has the right to be informed of the possibilities of such injuries and given the opportunity to decide whether the procedure should be performed - known as informed consent.

(75) Information on radiation risks should be an integral part of the information given to the patient prior to agreement to the procedure (Fig. 5.1). It is equally important to tell the patient that other skin reactions are not related to radiation exposure, e.g. allergic reaction to contrast media. Additionally, after procedures in which doses have been high enough that injury is likely to occur, the patient should be informed of what to expect and what to do. Such procedures should be identified by the fact that they exceeded the 'normal' parameters; i.e. high dose rates were used for longer than normal or the procedure lasted for longer than normal (see below in regard to the normal range of doses).

(76) For young children, the risk of malignancy may be higher than for adults. When organs such as the thyroid and female breast are included in the field for interventional procedures, counselling should include potential carcinogenic effects.

***Information to patient for informed consent***

In addition to the normal subjects discussed with patients before any potential high-dose interventional procedure using ionising radiation, the following issues should be added:

1. Risks related to ionising radiation, emphasising that effects are normally delayed;
2. The radiation effects of multiple procedures are additive, and will be more severe if procedures are close in time.

Fig. 5.1. Informed consent.

## 5.2. Records of exposure

### 1 Gy

(77) In cases where the maximum cumulative skin dose during the procedure is estimated to be at or above 3 Gy (1 Gy or above for procedures likely to be repeated), the minimum requirement should be that the interventionist should annotate a suitable body map with the estimated doses, indicating the entry site of the beam at each stage of the procedure. The reason for choosing this level of 3 Gy (1Gy) is that repeated procedures will cause serious skin effects from the cumulative dose. The annotated body map should be placed in the patient's notes (see below in regard to a system to identify previous interventional procedures). A head map indicating estimated eye doses is desirable for interventional neuroradiology.

(78) Interventionists should, in co-operation with medical physicists, establish the nominal doses (or usual range of doses) for the procedures that they commonly perform. This will allow them to provide information on risks to patients, should they ask, and to have some idea of the probability of radiation injuries when a procedure exceeds the normal parameters (see above).

## 5.3. Follow-up

(79) For patients whose estimated skin dose is 3 Gy or greater, the interventionist should arrange for the patient to be reviewed between 10 and 14 days after the procedure. The purpose of this review is to identify skin effects (mainly erythema), which, depending on its timing, may be predictive of more serious and chronic damage. If such effects are seen, then the patient should be referred to a dermatologist with full details of the interventional procedure and likely skin doses.

## 5.4. Information to personal physician

(80) The patient's personal physician should be informed about the possibility of ionising radiation effects, along with the usual details of the procedure. The amount

of information provided should be appropriate to the estimated doses received by the patient. Generally, an information leaflet about ionising radiation effects (as discussed in this document) will be sufficient, but if the doses are known or suspected to be sufficiently high to lead to erythema, or more serious effects, further follow up by an appropriate specialist should be recommended.

### **5.5. Advice to patient**

(81) If, after the procedure, the patient is believed to have received doses sufficient to cause symptoms or observable skin effects, the patient should be informed by the interventionist or his/her staff of the possible symptoms and signs, and what the patient should do if these appear.

### **5.6. System to identify repeated procedures**

(82) A system for identifying patients who have had previous interventional procedures should be created. This system should provide details of the sites and estimated doses received by patients (see Section 5.2, Records of exposure, above). This is essential as re-irradiation of skin and organs may significantly increase the probability of radiation effects, even if the doses used in the first or subsequent procedures were insufficient, on their own, to cause such effects. Consequently, interventionists should always seek to establish whether the patient has had previous interventional procedures, together with the magnitude, entrance site, and estimated skin doses - where available. The only immediate source of information on whether procedures have been undertaken in other institutions may be the patient.



## 6. INTERVENTIONIST'S NEEDS

### Main points

- Interventionists should understand the biological effects of ionising radiation.
- Basic and continuation training in radiological protection for patients and staff should be an integral part of the education for medical practitioners using interventional techniques.
- All interventionists should audit and review the outcomes of their procedures for radiation injury.
- The introduction of new interventional techniques should take account of the risks and benefits, including radiation risk.

### 6.1. Knowledge

(83) As with other areas of medicine, medical practitioners should be aware of the span and impact of all the factors that increase the risks of any medical procedure. In the context of interventional procedures, this must include an appropriate understanding of the biological effects of ionising radiation.

### 6.2. Training

#### 6.2.1. Radiological protection

(84) All medical practitioners should receive basic training in the biological effects of radiation. For those who intend to perform interventional procedures, additional training will be required, consistent with the potential to deliver doses high enough to cause serious pathological effects. Currently, this level of training is not provided to practitioners using interventional techniques, other than radiologists. At both levels of training, practitioners should receive training in radiological protection for their patients, themselves, and their staff, which would include the use of personal protective equipment and monitoring of exposure.

#### 6.2.2. Practical skills

(85) Before being allowed to perform interventional procedures, practitioners should receive training approved by the appropriate professional body, using an accredited and standardised training syllabus. After training is completed, practitioners should gain experience under supervision until an appropriate level of skill is attained. Maintenance of such skills requires a minimum level of activity and, if maintained, should lead to the minimisation of radiation exposures to the patient, the interventionist, and other staff without compromise to the therapeutic aims of the procedure.

### **6.3. Continuing professional development**

(86) Interventionists should attend suitable courses on a regular basis to maintain and develop their knowledge of the radiation protection aspects of interventional procedures.

### **6.4. Audits**

(87) Interventionists should periodically audit the outcome of their procedures, with the aim of modifying the selection of patients, choice of techniques, and operational procedures to improve clinical outcomes and reduce complication rates, including those related to ionising radiation.

### **6.5. Development of new procedures**

(88) New interventional procedures will be developed in the future to increase therapeutic efficacy and expand indications for use. These new procedures should be introduced into routine clinical practice only after appropriate objective trial(s), which will usually be part of a formal research project, have proven their efficacy. Assessment of each new procedure should include quantification of the likely radiation exposures and their consequences.

## 7. RECOMMENDATIONS

(89) It is recommended that:

1. All persons undertaking interventional procedures should be aware of the potential for and the nature of radiation injuries to patients and staff.
2. All departments performing interventional procedures should know the output parameters of their interventional radiological equipment and the typical doses delivered to patients and staff.
3. All interventional procedures should include measurement and recording of appropriate equipment technical factors used in the procedure.
4. All interventionists should be aware of the methods to reduce dose to patients and staff.
5. All interventionists should receive appropriate training.
6. All departments should set up procedures to audit practice and to ascertain radiation-induced complications
7. All departments should set up processes to identify patients previously irradiated.
8. All patients should be informed of the likelihood of radiation effects as part of informed consent.
9. All interventional equipment manufacturers should provide:
  - a) ergonomic radiation protection devices;
  - b) dose reduction features;
  - c) appropriate indicators of delivered doses.
10. Procedures for appropriate patient follow up should be established.



**ANNEX A: PROCEDURES LIST****I. Vascular interventions**

1. **Embolisation**
  - high dose* aneurysm and arteriovenous malformation
  - medium dose* tumour and varices
  - low dose* bleeding
  - likely to be repeated:* tumour and varices (frequently)
  
2. **Drug infusion**
  - medium dose* tumour (catheter placement)
  - low dose* bleeding and thrombolysis
  
3. **Angioplasty**
  - medium dose* balloon percutaneous transluminal angioplasty (PTA), atherectomy, stent & stent graft placement
  - likely to be repeated:* balloon PTA (not frequently)
  
4. **Cardiac intervention**
  - high dose* percutaneous transluminal coronary angioplasty (PTCA), radiofrequency (RF) ablation, stent placement, valvuloplasty
  - likely to be repeated:* PTCA (frequently)
  
5. **Others**
  - high dose* transjugular intrahepatic portosystemic shunt (TIPS)
  - medium dose* foreign body removal
  - low dose* filter placement, thrombectomy
  - likely to be repeated:* TIPS (not frequently)

**II. Non-vascular interventions**

1. **Drainage & puncture**
  - medium dose* percutaneous transhepatic cholangial drainage (PTCD), endoscopic biliary drainage (EBD)
  - low dose* abscess & cyst, nephrostomy, gastrostomy
  - likely to be repeated:* PTCD (not frequently)
  
2. **Percutaneous needle biopsy**
  - low dose*
  
3. **Stent placement**
  - medium dose* biliary tract, GI tract, tracheobronchus, ureter & urethra
  
4. **Coagulation therapy**
  - low dose* RF ablation, microwave coagulation, ethanol injection, laser ablation, cryosurgery
  - likely to be repeated:* all (frequently)
  
5. **Others**
  - low dose* transbronchial lung biopsy (TBLB), lithotomy

Note: 'high, medium, and low dose' refer to the cumulative absorbed dose in the patient's skin: high-hundreds of mGy, medium-tens of mGy, low-less than tens of mGy



## ANNEX B: PATIENT AND STAFF DOSES

### Annex B1: Patient doses in interventional procedures

Procedures	Skin doses	Technical details	Author, year, journal
Coronary Angiography (CA) Intervention without CA (I) Intervention with CA (I + CA)	Total cumulative exposure: CA: ~1250 mGy I: ~3600 mGy I + CA: ~3300 mGy	GE MPX-100/LUC biplane Several rooms	Cusma 1999, JACC
Cerebral embolisation (CE) Biliary stent (BS) Nephrostomy (NE)	CE: 160-180 mGy BS: 110 mGy NE: 110 mGy		McParland 1998, Br J Radiol
Radiofrequency cardiac catheter ablation	Skin injuries Accumulated skin dose 1100–1500 mGy per procedure	GE biplane old system	Vaño 1998, Br J Radiol
Radiofrequency cardiac catheter ablation	Skin injuries Total skin dose > 2500 mGy	Separation cone removed	Wagner 1998, RSNA
Transjugular intrahepatic portosystemic shunt (TIPS)	Entrance skin dose 400-1700 mGy	Philips Integris V-3000	Zweers 1998, Br J Radiol
Neuroradiologic procedures	Frontal: 1200 mGy Lateral: 640 mGy (in 25% of the cases, skin dose > 2000 mGy)	Biplane neuroradiologic system Toshiba CAS 30B/110A	Gknatsios 1997, Radiology
Radiofrequency catheter ablation (paediatric)	Maximum skin doses: 90-2350 mGy	Two institutions, patients 2–20 yrs	Geise 1996, PACE
Cardiac catheterisation and PTCA	Skin injuries Cumulative doses 11000-35000 mGy		Lichtenstein 1996, Arch Dermatol
Interventional neuroradiologic procedures	310-2700 mGy With additional filtration: 130-1230 mGy	Additional filtration to reduce doses	Norbash 1996, AJNR
Radiofrequency catheter ablation	930-620 mGy	500 patients	Park 1996, PACE
PTCA	Skin injuries Total skin dose 17000 mGy	Focal spot to skin distance 54 cm	Sovic 1996, Acta Radiol
Coronary procedures	660 mGy (max. 8200 mGy)	14 laboratories in Finland	Karppinen 1995, Rad Prot Dosim

PTCA	PTCA: ~100 mGy	Several hospitals	Vaño 1995,
Hepatic embolisation (HE)	HE: 500 mGy	Mean values reported	Br J Radiol
Cerebral embolisation (CE)	CE: 350 mGy		
Cerebral embolisation	Temporary epilation Maximum skin dose 6600 mGy	Biplane x-ray system	Huda 1994, Radiology

## Annex B2: Staff doses in interventional radiology

Procedures	Staff doses	Technical details	Radiation protection elements	Author, year, journal
Abdominal angiography	1.6 mGy/proced. at 20 cm 0.3–0.4 mGy face and neck 0.9 mGy pelvis 0.3 mGy left hand	Siemens Polystar manual injection	No details	Hayashi 1998, Cardiovasc Intervent Radiol
Cardiology, vascular, and abdominal procedures	Typical shoulder doses without protection: 0.3–0.5 mGy/proced. Reported doses in 9 locations of staff measured: 0–2.1 mGy/proced. Cardio procedures: 0.008–012 mGy/Gy.cm <sup>2</sup>	6 laboratories 10 specialists 83 procedures	In some of the installations	Vaño 1998a, Br J Radiol
Vascular and abdominal procedures	Lens injuries 450–900 mGy/year (eye dose)	2 laboratories overcouch old x-ray systems	No eye protection	Vaño 1998b, Br J Radiol
TIPS	Eff. dose: 0.004–0.028 mSv/procedure	Philips Integris V-3000		Zweers 1998, Br J Radiol
Cardiac procedures	0.009–0.040 mGy/case; dose higher when cardiology fellow in lab	2 laboratories 140 cases	ceiling mounted shields	Linley 1997, Health Phys
28 standard drainage 10 complex drainage	Finger doses 0.008–0.665 mGy, median 0.087 mGy	Siemens system undercouch tube		Vehmas 1997, Br J Radiol
Cardiac procedures 140 cases	0.010–0.040 mGy/case	2 laboratories, 371 cases with cardiology fellow	Ceiling mounted shields	Watson 1997, Health Phys
Vascular and liver biliary drainage	0.001–0.002 mSv/Gy.cm <sup>2</sup> to body, neck, and hands for vascular procedures 0.007–0.029 mSv/Gy.cm <sup>2</sup> in neck and hands for biliary drainage	2 x-ray rooms Philips Integris 3000 GE L-U	Ceiling mounted screen in only one room	Williams 1997, Br J Radiol

Coronary angiography PTCA	Neck dose 0.05 mGy/proced	Philips Integris 3000C	Movable shield	Zorzetto 1997, Cathet Cardiovasc Diagn
Cardiology procedures	Under apron: 0–5.6 mGy/month Above apron: 0–25.2 mGy/month	12 physicians, 448 proced./y cardiovascular lab GE MPX Phase 5	Aprons 0.5 mm lead, thyroid shields, mobile shields	McKetty 1996, Health Phys
Coronary angiography	0.21–0.37 mGy/proced. at thyroid level 0.3–0.54 mGy/proced at left hand	Philips Polydiagnost C2 (reduction of staff doses using 12,5 f/s)	Ceiling mounted screen 1 mm Pb	Steffino 1996, Br J Radiol
Coronary	Eff. dose: 0.05 mGy/ proced. 0.5 mGy/proced (eye dose) 1.1 mGy/proced (hands)	14 laboratories in Finland	In some laboratories protective eyeglasses	Karppinen 1995, Rad Prot Dosim
Cerebral angiography Arterial embolisation	0.013 mSv/proced (eye) 0.011–0.025 mSv/ proced (above apron)	CGR DG 300	Waist height lead shield	Marshall 1995, Br J Radiol
Coronary procedures	Until 8 mGy/h near the patient (projection 90 LAO)	Philips Integris BH 3000 Isodose curves		Marx 1995, AAPM
Paediatric cardiac catheterisation	0.088 mSv/ proced (lens) 0.180 mSv/proced (thyroid) 0.008 mSv/proced (eff. dose)	18 procedures U-arm, Toshiba KXO-2050		Li 1995, Health Phys
Interventional procedures	Mean annual effective dose 3.2 mGy (range 0.37–10.1 mGy)	28 radiologists, 17 institutions, dosimeters over collars and under apron		Niklasen 1993, Radiology
Cardiac catheterisation	0.015–0.053 mSv/proced (eye)	Three centres, five x-ray units	Ceiling mounted screen protective eye shields	Pratt 1993, Br J Radiol
Cardiac catheter ablation	0.28 mGy/proced (left eye) 0.15 mGy/ proced (thyroid) 0.99 mGy/proced (left hand)	Siemens Angioskop D 31 procedures	Ceiling mounted screen	Calkins 1991, Circulation

Note: staff doses are expressed in a variety of ways, each as given in the noted reference.



## ANNEX C: EXAMPLE OF CLINICAL PROTOCOL

### Clinical protocol, TIPS (transjugular intrahepatic porto-systemic shunt)

#### Indication

1. Gastroesophageal varices difficult to treat endoscopically.
2. Refractory ascites, which cannot be controlled by any procedure other than puncture.
3. Gastrointestinal haemorrhage without endoscopic evidence of varices, if melaena is definitely related to portal hypertension (hypertensive gastroenteropathy).

#### Absolute contraindications

1. Severe pulmonary hypertension.
2. Diffuse portal thrombosis.
3. Polycystic disease.
4. Severe renal impairment.
5. Severe cardiopulmonary dysfunction.

#### Relative contraindications

1. Malignant tumours in the liver.
2. Local portal thrombosis.
3. Liver cirrhosis of grade Child C (when total bilirubin is 3.0 mg/dl or more).

#### Pre-operative treatment and imaging

1. Intravenous injection of atropine sulphate and diazepam.
2. Diagnostic imaging of the portal and hepatic veins, such as DSA, 3D-CT, and 3D-MRA.

#### Procedures

1. Puncture of the jugular vein.
2. Puncture of the portal vein.
3. Catheter placement into the portal vein.
4. Shunt dilatation by a balloon catheter.
5. Stent placement.

#### Fluoroscopy

1. To minimise the time of fluoroscopy, the operator should control the fluoroscope with the foot switch.
2. The operator stands at the head of the patient during fluoroscopy, so that he or she is closer to the x-ray tube than in transfemoral angiography. Therefore, a

protective apron should be attached to the X-ray table, to minimise radiation exposure.

3. Fluoroscopy is usually done at a low dose (20 mGy/min).

### **Time of fluoroscopy**

1. Catheter placement in the hepatic vein from the jugular vein: about one minute.
2. Portal vein puncture and catheter placement: fluoroscopy time depends on the number of punctures. The mean time is about 40 minutes, 18 minutes being the shortest and 75 minutes the longest.
3. Shunt dilatation and stent deployment: about one minute.

### **Number of image acquisitions**

1. Portal venography twice, once at the time of successful puncture and once after stent placement.
2. One plain x-ray film is taken to confirm the site of stents and the degree of dilatation.

### **Records of exposure**

The cumulative skin entrance dose of the patient is recorded when it is estimated to be above 3 Gy.

### **Follow-up**

1. Hepatic function tests and urine output.
2. The patient whose estimated skin dose has exceeded 3 Gy is followed up between 10 and 14 days after the procedure to identify skin effects.
3. Imaging: after discharge, Doppler echography, CT, portal vein scintigraphy, or DSA should be done every 2 or 3 months on an out-patient basis.
4. Re-treatment: PTA should be done if there is DSA evidence of more than 50% shunt stenosis or portal pressure of 15 mmHg or more. If PTA fails to revascularise, thrombolysis should be performed. Re-TIPS is the last resort for failure of revascularisation by any other method.

## ANNEX D: DOSE QUANTITIES

### **D.1. Absorbed dose**

(D1) Absorbed dose in tissue is the energy absorbed per unit mass in a body tissue. The unit of absorbed dose is the gray (Gy); 1 gray is 1 joule per kilogram. One gray is also 1000 milligray (mGy). The mGy is often used when absorbed doses are a fraction of a Gy.

(D2) For inflammatory and cell-killing effects (*deterministic radiation effects*), such as skin injuries and cataract of the lens, the maximum cumulative absorbed dose in the tissue is the relevant quantity.

(D3) For cancer and hereditary effects (*stochastic effects*), on the assumption of a linear dose-effect relationship, the mean absorbed dose in an organ or tissue is the indicator of the increase in probability of such effects later in life.

### **D.2. Patient dosimetry for skin injuries**

(D4) Air kerma (the kinetic energy released in a mass of air) is the sum of the initial kinetic energies of all the secondary electrons released by the ionising x-ray photons per unit mass of air. For the x-ray energies utilised in interventional procedures, the air kerma is numerically equal to the absorbed dose in air. The common units for air kerma are the gray (Gy) or milligray (mGy).

(D5) The *incident dose (ID)* is the air kerma (or absorbed dose in air) on the x-ray beam axis at the focus to skin distance (FSD) without the patient present. The ID does not include back-scattered radiation from the patient. The magnitude of the ID increases as the distance from the focus of the x-ray tube to the patient surface (FSD) is reduced. The unit for ID is the Gy or mGy.

(D7) The *entrance skin dose (ESD)* is the absorbed dose in the skin at a given location on the patient. It includes the back-scattered radiation from the patient. It can be measured directly with a dosimeter on the patient or by multiplying the ID with a backscatter factor (*B*). For example, in water (which is close in radiation absorption characteristics to tissue), *B* ranges from about 1.25 to 1.40 depending on the radiation quality of the x-ray beam and the x-ray field size (see Table D.1). The magnitude of the ESD also increases as the FSD is reduced. The unit for ESD is also the Gy or mGy.

### **D.3. Other dosimetry**

(D7) The *cumulative dose-area-product (DAP)* is the sum of the products of the incident doses (*ID*) and the areas of the x-ray fields (*A*) at the FSD for all segments of an interventional procedure. It can be determined at any convenient location between the x-ray source and the patient. DAP can be helpful in dose control for stochastic effects to patients and operators, but is not a practical method for estimating maximum cumulative absorbed dose to skin or useful for predicting deterministic effects. The unit for DAP is Gy x cm<sup>2</sup>.

**Table D.1**

Backscatter factors (B) as a function of radiation quality and field size (backscatter medium: water)

Peak applied voltage in kV <sup>a</sup>	Field size in cm×cm		
	10×10	20×20	30×30
60	1.26	1.29	1.30
80	1.29	1.34	1.36
100	1.32	1.39	1.41

<sup>a</sup> Total filtration 2.5 mm Al

### D.3.1. Determination of the dose quantities

(D8) The air kerma (ID) can be determined at the appropriate reference point for interventional x-ray units; e.g. 15 cm from the centre of the isocentre of a C-arm x-ray unit on the central beam towards the focus (IEC, 2000). The ID can be determined routinely without interfering with the interventional procedure if the appropriate monitoring devices have been installed on the x-ray equipment.

(D9) The ESD can be determined using small dosimeters (e.g. TLD or semiconductor dosimeter) positioned at representative points on the skin of the patient. All dosimeters and dose calculation programs have to be calibrated regularly.

(D10) When using ID or ESD for assessment of the maximum cumulative absorbed dose in a specific area of skin, any rotation and translation of the x-ray tube relative to the patient that varies the portion of the skin exposed has to be considered. Otherwise, the maximum skin dose will be overestimated.

(D11) The DAP can be measured using specially designed ionisation chambers mounted at the collimator system or, if the x-ray unit is a modern digital system, DAP can be calculated using data for the generator and the digital recorded jaw positions. The DAP can be determined routinely without interfering with the interventional procedure if the appropriate monitoring devices have been installed on the x-ray equipment.

### D.4. Staff dosimetry for occupational dose

(D12) Dose limits for occupational exposures are expressed in equivalent doses for deterministic effects in specific tissues, and expressed as effective dose for stochastic effects throughout the body. The unit for equivalent dose and effective dose is the sievert (Sv); 1 sievert equals 1000 millisieverts (mSv). The mSv is often used when values are a fraction of a Sv.

(D13) Equivalent dose is derived from the absorbed doses in specific tissues, weighted by the relative effect of the type and energy of the radiation encountered. For x rays used in interventional procedures the weighting factor is 1. When used for deterministic effects, equivalent dose is an indicator of whether the threshold for the deterministic effect is being approached.

(D14) Effective dose is derived from the absorbed doses in specific tissues, the relative effect for the type and energy of radiation encountered, and the relative radiation sensitivity for the stochastic health detriments associated with the specific tissues. It is an indicator of the increase in probability for stochastic effects later in life for a population exposed to the given levels.

(D15) Occupational dose limits are recommended by the Commission (ICRP, 1991) for stochastic effects (dose limits for effective dose) and deterministic effects (dose limits for equivalent dose to the relevant tissue); see Fig. D.2. Occupational dose limits are given in mSv (millisievert). For x-ray energies in interventional procedures, the numerical value of the absorbed dose in mGy is essentially equal to the numerical value of the equivalent dose in mSv.

(D16) The radiation source for the staff is the patient's body, which scatters radiation in all directions during fluoro- and radiography. The personal dosimeter should be worn below the lead apron (see Fig. D.2). The determined dose will be used as a substitute for the effective dose. A second dosimeter worn outside and above the apron at the neck level makes it possible to determine the effective dose more accurately (NCRP, 1995).

(D17) To monitor doses to the skin, hands and feet, and the lens of the eyes of the interventionist, special dosimeters (e.g. ring dosimeter) should be used. TLD's and new semiconductor dosimeters are available.

(D18) One of the most important radiation protection measures is to increase one's distance from the radiation source. In Fig. D.3, a typical plan view of an operating room with isodose curves is shown. No additional protective measures like shielding or lead aprons are considered. The dose rate is strongly dependent on the relative distance from the radiation entrance surface of the patient. The dose rate

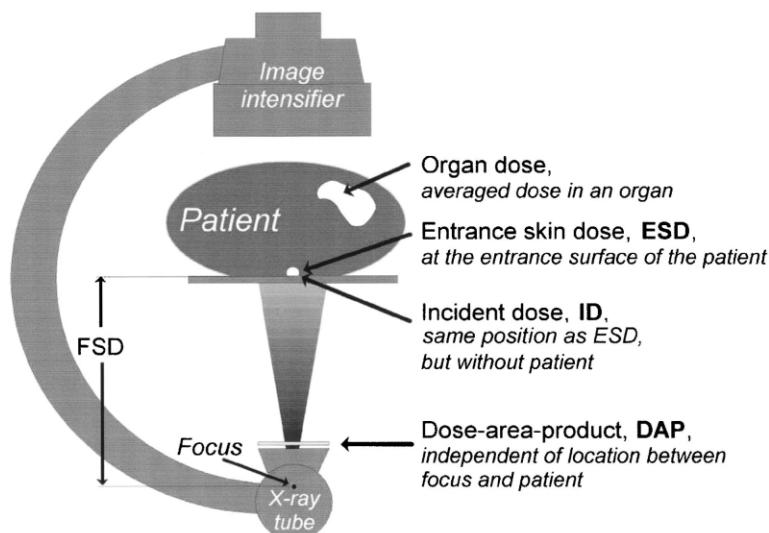


Fig. D.1. Dose quantities for describing radiation exposure (of the patient) in interventional radiology.

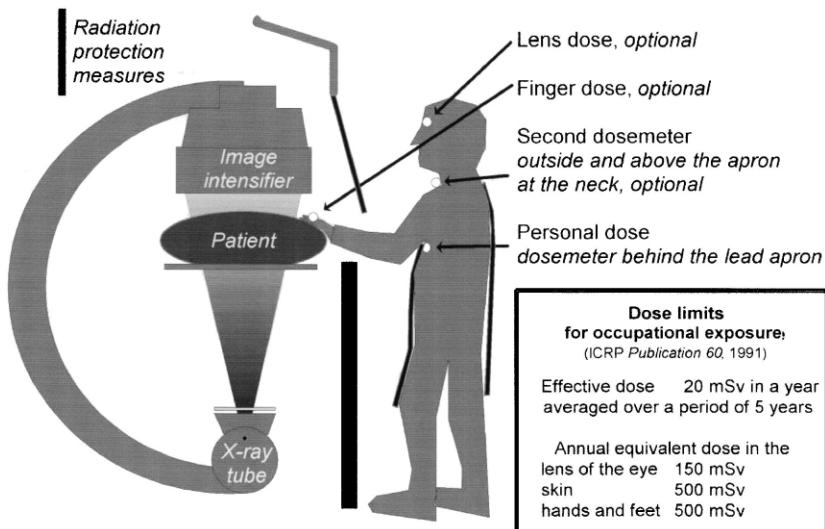


Fig. D.2. Dose quantities for describing radiation exposure of the staff in interventional radiology. The personal dosimeter behind the apron should be worn at the upper part of the body directed towards the radiation source (irradiated volume of the patient). The second dosimeter is worn outside of and above the apron at the neck level.

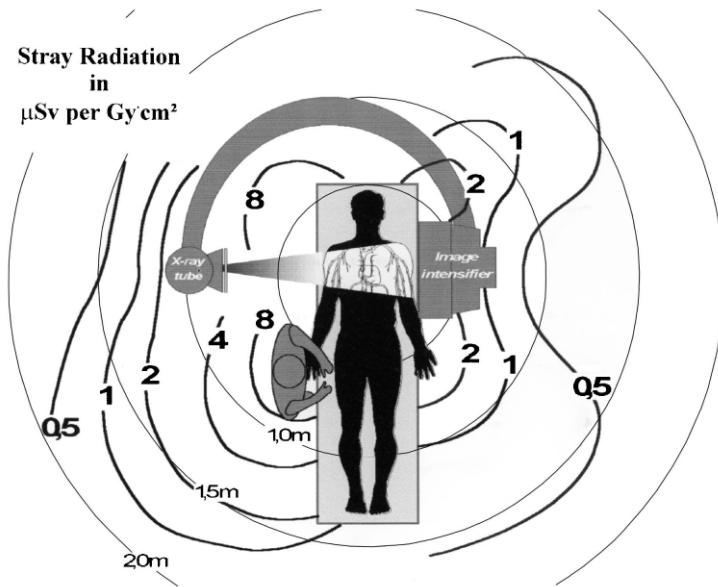


Fig. D.3. Plan view of an interventional operating x-ray unit with isodose curves. The dose values in mSv are normalised to a DAP of 1 Gy·cm<sup>2</sup>. The height above the ground is 150 cm. In the case of fluoroscopy using the High Dose Rate Mode, the dose rates at the same positions are in the range of mSv/h using the same numbers at the isodose curves. (Isodose curves changed from Marx and Balter, 1995).

also depends on other parameters like the dose rate at the image intensifier entrance, the field size, and the tube voltage and orientation of the incident x-ray beam. In Fig. D.3 typical isodose curves of a fluoroscopic x-ray system with horizontal beam direction are shown. If the beam direction is vertical (e.g. under-couch tube), the dose rate varies greatly with height above the floor.

### D.5. References for Annex D

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## ANNEX E: PROCUREMENT CHECKLIST

<b>Analysis of clinical need</b>	Workload
<b>Equipment specification</b>	General requirements Major equipment components Functional requirements Specific equipment requirements
<b>Computer capabilities</b>	Image display matrix Processing times Memory/image storage PACS linkages CIS linkages
<b>Systems performance</b>	Image quality Patient dose Dose control measures
<b>User manuals</b>	Technical training Operational training
<b>Compliance with national and international standards</b>	Electrical safety Mechanical safety Radiation safety Room design/shielding
<b>Service and warranty</b>	Maintenance programme Quality control programmes Access to service software protocols/rationale for service schedules
<b>Operation Costs</b>	Cost of consumables - projected over 5 years



# International Commission on Radiological Protection: History, policies, procedures

*A free booklet describing ICRP*

The International Commission on Radiological Protection (ICRP) recently issued this document as a straightforward review of its history, mode of operations, concepts, and current policies. After an Introduction, it presents the History and affiliation and The structure and mode of operation of the Commission. The objectives of the Commission's recommendations are laid out; Quantities, The biological basis of the Commission's policy, Concepts, and The quantitative basis for risk estimates are briefly explained. The structure of the system of protection, Problems of interpretation and application in the system of protection, and The need for stability, consistency, and clarity are all briefly discussed.

This booklet is not part of the *Annals of the ICRP*, and is not automatically distributed to subscribers.

Individual copies, in English or French, may be requested free of charge from  
The Scientific Secretary, Dr J Valentin  
ICRP  
SE-171 16 Stockholm  
Sweden.

Bulk deliveries (5 or more copies) can be arranged through the ICRP Scientific Secretary, Dr Valentin, at £ 1.00 per copy.

# The International Commission on Radiological Protection

## ***Our Mission Statement***

**The International Commission on Radiological Protection, ICRP,  
is an independent Registered Charity,  
established to advance for the public benefit  
the science of radiological protection,  
in particular by providing recommendations and guidance  
on all aspects of protection against ionising radiation.**

The primary body in radiological protection is ICRP. It was formed in 1928 as the ‘International X-ray and Radium Committee’, but adopted its present name in 1950 to reflect its growing involvement in areas outside that of occupational exposure in medicine, where it originated.

ICRP consists of the Main Commission, Committee 1 (Radiation Effects), Committee 2 (Doses from Radiation Exposure), Committee 3 (Protection in Medicine), Committee 4 (Application of ICRP Recommendations), *ad hoc* Task Groups and Working Parties, and the Scientific Secretariat.

The Main Commission consists of 12 members and a Chairman, while the Committees contain between 15 and 20 members each. The Commission and its Committees run for four-year periods, from 1 July. On each occasion of a new period, at least three, and not more

than five, members of the Commission must be changed. A similar rate of renewal is sought for the Committees. Such a new period began 1 July 1997.

The Commission meets once or twice a year. Each Committee meets once a year. Twice in each four-year period, the annual meeting of the Committees is conducted jointly and together with the Commission. These meetings are funded as necessary from monies available to ICRP.

The activities of ICRP are financed mainly by voluntary contributions from national and international bodies with an interest in radiological protection. Some additional funds accrue from royalties on ICRP *Publications*. Members’ institutions also provide support to ICRP by making the members’ time available without charge and, in many cases, contributing to their costs of attending meetings.

The Commission uses Task Groups and Working Parties to deal with specific areas. Task Groups are formally appointed by the Commission to perform a defined task, usually the preparation of a draft report. A Task Group usually contains a majority of specialists from outside the Commission's structure. It is funded as necessary from monies available to ICRP.

Working Parties are set up by Committees to develop ideas, sometimes leading to the establishment of a Task Group. The membership of a Working Party is usually limited to Committee members. Working Parties receive no funding of their own, *i.e.* they operate primarily by correspondence and by meetings in direct conjunction with meetings of the Committee concerned.

These activities are co-ordinated with a minimum of bureaucracy by a Scientific Secretary, ensuring that ICRP recommendations are promulgated.

Thus, ICRP is an independent international network of specialists in various fields of radiological protection. At any one time, about 100 eminent scientists are actively involved in the work of ICRP. The four-tier structure described provides a rigorous Quality Management system of peer review for the production of ICRP Publications.

In preparing its recommendations, the Commission considers the fundamental principles and quantitative bases on which appropriate radiation protection measures can be established, while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice, or regulations that are best suited to the needs of their individual countries. The aim of the recommendations of ICRP is to

*—provide an appropriate standard of protection for mankind from sources of ionising radiation, without unduly limiting beneficial practices that give rise to exposure to radiation.*

### **Composition of the International Commission on Radiological Protection and Committees, 1997–2001**

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## PAST PUBLICATIONS OF THE ANNALS OF THE ICRP

### Publications of the ICRP

Full details of all ICRP reports can be obtained from your nearest Elsevier Science office.

### ICRP CD-ROMS

The ICRP Database of Dose Coefficients: Workers and Members of the Public (Version One, 1999)

0 08 042751 0

### Published reports of the ICRP

ICRP Publication 84 (Annals of the ICRP Vol. 30 No. 1, 2000)	
ICRP Publication 83 (Annals of the ICRP Vol. 29 No. 3-4, 1999)	
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ICRP Publication 82 (Annals of the ICRP Vol. 29 No. 1-2, 1999)	
<i>Protection of the Public in Situations of Prolonged Radiation Exposure</i>	0 08 043898 9
ICRP Publication 81 (Annals of the ICRP Vol. 28 No. 4, 1998)	
<i>Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste</i>	0 08 043859 8
ICRP Publication 80 (Annals of the ICRP Vol. 28 No. 3, 1998)	
<i>Radiation Dose to Patients from Radiopharmaceuticals</i>	0 08 043573 4
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<i>Genetic Susceptibility to Cancer</i>	0 08 042752 9
ICRP Publication 78 (Annals of the ICRP Vol. 27 No. 3-4, 1997)	
<i>Individual Monitoring for Internal Exposure of Workers: Replacement of ICRP Publication 54</i>	0 08 042750 2
ICRP Publication 77 (Annals of the ICRP Vol. 27 Supplement, 1997)	
<i>Radiological Protection Policy for the Disposal of Radioactive Waste</i>	0 08 042749 9
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<i>Protection from Potential Exposures: Application to Selected Radiation Sources</i>	0 08 042744 8
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<i>General Principles for the Radiation Protection of Workers</i>	0 08 042741 3
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ICRP Publication 70 (Annals of the ICRP Vol. 25 No. 2, 1995)	
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ICRP Publication 69 (Annals of the ICRP Vol. 25 No. 1, 1995)	
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<i>Cost-Benefit Analysis in the Optimization of Radiation Protection</i>	0 08 029817 6

# Annals of the ICRP

## Aims and Scope

The International Commission on Radiological Protection was founded in 1928 to advance for the public benefit the science of radiological protection. The ICRP provides recommendations and guidance on protection against the risks associated with ionising radiation, from artificial sources as widely used in medicine, general industry and nuclear enterprises, and from naturally occurring sources. These reports and recommendations are published four times each year on behalf of the ICRP as the journal *Annals of the ICRP*. Each issue provides in-depth coverage of a specific subject area.

Subscribers to the journal receive each new report as soon as it appears so that they are kept up to date on the latest developments in this important field. While many subscribers prefer to acquire a complete set of ICRP reports and recommendations, single issues of the journal are also available separately for those individuals and organizations needing a single report covering their own field of interest. Please order through your bookseller, subscription agent, or direct from the publisher.

## Future publications of the ICRP

(Please note that these reports may be subject to late changes and alterations)

ICRP Publication 86, *Prevention of Accidents to Patients Undergoing Radiation Therapy* (2001).

ICRP Publication 87, *Managing Patient Dose in Computed Tomography* (2001).

ICRP Publication 88, *Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother* (2001).

ICRP Publication –, *Basic Anatomical and Physiological Parameters for Use in Radiological Protection, Part 2. Anatomy, Physiology, and Elemental Composition* (2002).

ICRP Publication –, *Dosimetric Model for the Gastro-Intestinal Tract* (2002).

## Further Supporting Guidance Material

*Guide for the Practical Application of the ICRP Human Respiratory Tract Model* (2001).

*The ICRP Database of Dose Coefficients: Embryo and Fetus* (2001, on CD-ROM).

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