

Volume 4 No 1 2004

ISSN 1473-6691

Journal of the ICRU

ICRU REPORT 71

**Prescribing, Recording, and Reporting
Electron Beam Therapy**

OXFORD
UNIVERSITY PRESS



OXFORD UNIVERSITY PRESS

INTERNATIONAL COMMISSION ON
RADIATION UNITS AND
MEASUREMENTS

Journal of the ICRU

ISSN 1473-6691

Commission Membership

A. Wambersie (Chairman)
P. M. DeLuca (Vice Chairman)
S. M. Seltzer (Secretary)
P. Dawson
K. Doi
L. E. Feinendegen
R. A. Gahbauer
M. Inokuti
D. T. L. Jones
W. Kalender
H.-G. Menzel
B. D. Michael
H. G. Paretzke
G. F. Whitmore

L. S. Taylor (Honorary Chairman and Member Emeritus)

A. Allisy (Honorary Chairman)

Executive Secretary
T. G. Hobbs

Managing Editor ICRU News
H. G. Ebert

Honorary Counsel
W. R. Ney

Journal of the ICRU Scientific Editor
M. Inokuti

Executive Editor
E. P. Goldfinch

SUBSCRIPTIONS

A subscription to Journal of the ICRU comprises 2 issues (Reports). All prices include postage, and for subscribers outside the UK delivery is by Standard Air.

Annual Subscription Rate (Volume 4, 2 issues, 2004)

Institutional

Print edition and site-wide online access: £165/US\$271

Print edition only: £157/US\$257

Site-wide online access only: £149/US\$243

Personal

Print only: £85/US\$135

Please note: £ Sterling rates apply in Europe, US\$ elsewhere

There may be other subscription rates available, for a complete listing please visit www.jicru.oupjournals.org/subinfo.

Full prepayment, in the correct currency, is required for all orders. Orders are regarded as firm and payments are not refundable. Subscriptions are accepted and entered on a complete volume basis. Claims cannot be considered more than FOUR months after publication or date of order, whichever is later. All subscriptions in Canada are subject to GST. Subscriptions in the EU may be subject to European VAT. If registered, please supply details to avoid unnecessary charges. For subscriptions that include online versions, a proportion of the subscription price may be subject to UK VAT. Personal rate subscriptions are only available if payment is made by personal cheque or credit card and delivery is to a private address.

Visit www.jicru.oupjournals.org for complete listing of previous reports available from Oxford University Press.

For further information, please contact: Journals Customer Service Department, Oxford University Press, Great Clarendon Street, Oxford OX2 6DP, UK. Email: jnl.cust.serv@oupjournals.org. Tel (and answerphone outside normal working hours): +44 (0)1865 353907. Fax: +44 (0)1865 353485. **In the US, please contact:** Journals Customer Service Department, Oxford University Press, 2001 Evans Road, Cary, NC 27513, USA. Email: jnlorders@oupjournals.org. Tel (and answerphone outside normal working hours): 800 852 7323 (toll-free in USA/Canada). Fax: 919 677 1714. **In Japan, please contact:** Journals Customer Services, Oxford University Press, 1-1-17-5F, Mukogawa, Bunkyo-ku, Tokyo, 113-0023, Japan. Email: okudaoup@po.ijinet.or.jp. Tel: (03) 3813 1461. Fax: (03) 3818 1522.

Methods of payment. Payment may be made by cheque (payable to Oxford University Press) in £ sterling drawn on a UK bank or in US\$ drawn on a US bank, bank transfer (£ sterling - Barclays Bank Plc, Oxford City Office, PO Box 333, Oxford, OX1 3HS, UK. Bank sort code: 20-65-18, Account No. 70299332, IBAN number GB89BARC20651870299332, Swift code BARCGB22), or by credit card (Mastercard, Visa, Switch or American Express).

Journal of the ICRU is published twice a year by Oxford University Press, Oxford, UK. Annual subscription price is £165/US\$271. Journal of the ICRU is distributed by Mercury International, 365 Blair Road, Avenel, NJ 07001, USA. Periodicals postage paid at Rahway, NJ and at additional entry points.

US Postmaster: send address changes to Journal of the ICRU, c/o Mercury International, 365 Blair Road, Avenel, NJ 07001, USA.

Permissions

For information on how to request permissions to reproduce articles/information from this journal, please visit www.oupjournals.org/permissions.

Dosage disclaimer

The mention of trade names, commercial products or organizations, and the inclusion of advertisements in the journal does not imply endorsement by the ICRU, the editors, the editorial board, Oxford University Press or the organization to which the authors are affiliated. The editors and publishers have taken all reasonable precautions to verify dosage, the results of experimental work and clinical findings published in the journal. The ultimate responsibility for the use and dosage of drugs mentioned in the Journal and in interpretation of published material lies with the medical practitioner, and the editors and publishers cannot accept liability for damages arising from any errors or omissions in the journal. Please inform the editors of any errors.

Legal Notice

This report was prepared by the International Commission on Radiation Units and Measurements, Inc. (ICRU). The Commission strives to provide accurate, complete and useful information in its reports. However, neither the ICRU, the members of the ICRU, Oxford University Press, other persons contributing to or assisting in the preparation of this report, nor any person acting on behalf of any of these parties: (a) makes any warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, method or process disclosed in this report may not infringe on privately owned rights; or (b) assumes any liability with respect to the use of, or for damages resulting from the use of any information, method or process disclosed in this report.

© International Commission on Radiation Units and Measurements 2004

All rights reserved; no part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise without prior written permission of the Publishers, or a licence permitting restricted copying issued in the UK by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1P 9HE, or in the USA by the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. For those in the USA or Canada not registered with CCC, articles can be obtained by fax in 48 hours by calling: WISE for Medicine™ 1-800-667-WISE.

Printed by Latimer Trend, UK

ICRU REPORT No. 71

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

**THE INTERNATIONAL COMMISSION ON
RADIATION UNITS AND
MEASUREMENTS**
June 2004

Journal of the ICRU Volume 4 No 1 2004
ISBN 0198566786
Published by Oxford University Press

PREScribing, RECORDing, AND REPORTING ELECTRON BEAM THERAPY

Report Committee

- R. Gahbauer (Co-Chairman), A. James Cancer Hospital, Ohio State University, Columbus, Ohio, USA
T. Landberg (Co-Chairman), Finsen Center, Copenhagen, Denmark
J. Chavaudra, Institut Gustave-Roussy, Villejuif, France
J. Dobbs, Guy's and St Thomas Cancer Center, London, UK
N. Gupta, A. James Cancer Hospital, Ohio State University, Columbus, Ohio, USA
G. Hanks, Fox Chase Cancer Center, University of Pennsylvania, Philadelphia, Pennsylvania, USA
J.-C. Horiot, Centre G.-F. Leclerc, Dijon, France
K.-A. Johansson, Radiofysiska Institutionen, Göteborg, Sweden
T. Möller, Regionala Tumörregistret, Lund, Sweden
S. Naudy, Centre G.-F. Leclerc, Dijon, France
J. Purdy, Mallinckrodt Institute of Radiology, Washington University, St Louis, Missouri, USA
I. Santenac, Centre Hospitalier Lyon Sud, Lyon, France
N. Suntharalingam, Thomas Jefferson University Hospital, Philadelphia, Pennsylvania, USA
H. Svensson, Radiofysiska Institutionen, Umeå, Sweden

Commission Sponsors

- P. M. DeLuca, University of Wisconsin, Madison, Wisconsin, USA
A. Wambersie, Université Catholique de Louvain, Brussels, Belgium
G. F. Whitmore, Ontario Cancer Institute—Princess Margaret Hospital, Toronto, Canada

Consultants to the Report Committee

- A. Akanuma, Chiba Minami Hospital, Chiba, Japan
A. Brahme, Karolinska Institutet, Stockholm, Sweden
W. De Neve, Ghent University Hospital, Ghent, Belgium
D. Georg, AKH-University Hospital, Vienna, Austria
V. Grégoire, Université Catholique de Louvain, Brussels, Belgium
R. Pötter, AKH-University Hospital, Vienna, Austria

The Commission wishes to express its appreciation to the individuals involved in the preparation of this report, for the time and efforts which they devoted to this task and to express its appreciation to the organisations with which they are affiliated.

All rights reserved. No part of this book may be reproduced, stored in a retrieval systems or transmitted in any form by any means, electronic, electrostatic, magnetic, mechanical photocopying, recording or otherwise, without the permission in writing from the publishers.

British Library Cataloguing in Publication Data. A Catalogue record of this book is available at the British Library.

ISBN 0198566786

THE INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

INTRODUCTION

The International Commission on Radiation Units and Measurements (ICRU), since its inception in 1925, has had as its principal objective the development of internationally acceptable recommendations regarding:

- (1) quantities and units of radiation and radioactivity,
- (2) procedures suitable for the measurement and application of these quantities in clinical radiology and radiobiology, and
- (3) physical data needed in the application of these procedures, the use of which tends to assure uniformity in reporting.

The Commission also considers and makes similar types of recommendations for the radiation protection field. In this connection, its work is carried out in close cooperation with the International Commission on Radiological Protection (ICRP).

POLICY

The ICRU endeavors to collect and evaluate the latest data and information pertinent to the problems of radiation measurement and dosimetry and to recommend the most acceptable values and techniques for current use.

The Commission's recommendations are kept under continual review in order to keep abreast of the rapidly expanding uses of radiation.

The ICRU feels that it is the responsibility of national organizations to introduce their own detailed technical procedures for the development and maintenance of standards. However, it urges that all countries adhere as closely as possible to the internationally recommended basic concepts of radiation quantities and units.

The Commission feels that its responsibility lies in developing a system of quantities and units having the widest possible range of applicability. Situations may arise from time to time when an expedient solution of a current problem may seem advisable. Generally speaking, however, the Commission

feels that action based on expediency is inadvisable from a long-term viewpoint; it endeavors to base its decisions on the long-range advantages to be expected.

The ICRU invites and welcomes constructive comments and suggestions regarding its recommendations and reports. These may be transmitted to the Chairman.

CURRENT PROGRAM

The Commission recognizes its obligation to provide guidance and recommendations in the areas of radiation therapy, radiation protection, and the compilation of data important to these fields, and to scientific research and industrial applications of radiation. Increasingly, the Commission is focusing on the problems of protection of the patient and evaluation of image quality in diagnostic radiology. These activities do not diminish the ICRU's commitment to the provision of a rigorously defined set of quantities and units useful in a very broad range of scientific endeavors.

The Commission is currently engaged in the formulation of ICRU reports treating the following subjects:

- Approaches to the Dosimetry of Low-Dose Exposures to Ionizing Radiation*
Assessment of Image Quality in Nuclear Medicine
Beta Rays for Therapeutic Applications
Bone Densitometry
Doses for Cosmic Ray Exposure for Aircrew
Dose and Volume Specifications for Reporting Intracavitary Therapy in Gynecology
Dosimetric Procedures in Diagnostic Radiology
Dosimetry Systems for Radiation Protection
Elastic Scattering of Electrons and Positrons
Image Quality and Patient Exposure in CT
Mammography—Assessment of Image Quality
Measurement Quality Assurance for Ionizing Radiation
Prescribing, Recording, and Reporting Conformal Photon Beam Therapy
Prescribing, Recording, and Reporting Proton Beam Therapy

PREScribing, RECORDing, AND REPORTING ELECTRON BEAM THERAPY

*Requirements for Radiological Sampling
ROC Analysis
Stopping Power for Heavy Ions*

In addition, the ICRU is evaluating the possibility of expanding its program to encompass non-ionizing radiation, particularly the quantities and units aspects.

The Commission continually reviews radiation science with the aim of identifying areas where the development of guidance and recommendations can make an important contribution.

THE ICRU'S RELATIONSHIP WITH OTHER ORGANIZATIONS

In addition to its close relationship with the ICRP, the ICRU has developed relationships with other organizations interested in the problems of radiation quantities, units, and measurements. Since 1955, the ICRU has had an official relationship with the World Health Organization (WHO), whereby the ICRU is looked to for primary guidance in matters of radiation units and measurements and, in turn, the WHO assists in the worldwide dissemination of the Commission's recommendations. In 1960, the ICRU entered into consultative status with the International Atomic Energy Agency (IAEA). The Commission has a formal relationship with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), whereby ICRU observers are invited to attend annual UNSCEAR meetings. The Commission and the International Organization for Standardization (ISO) informally exchange notifications of meetings, and the ICRU is formally designated for liaison with two of the ISO technical committees. The ICRU also corresponds and exchanges final reports with the following organizations:

Bureau International de Métrologie Légale
Bureau International des Poids et Mesures
European Commission
Council for International Organizations of Medical Sciences
Food and Agriculture Organization of the United Nations
International Committee of Photobiology
International Council of Scientific Unions
International Electrotechnical Commission
International Labor Office
International Organization for Medical Physics
International Radiation Protection Association
International Union of Pure and Applied Physics
United Nations Educational, Scientific and Cultural Organization

The Commission has found its relationship with all of these organizations fruitful and of substantial benefit to the ICRU program. Relations with these other international bodies do not affect the basic affiliation of the ICRU with the International Society of Radiology.

OPERATING FUNDS

In recent years, principal financial support has been provided by the European Commission, the National Cancer Institute of the U.S. Department of Health and Human Services and the International Atomic Energy Agency. In addition, during the last 10 years, financial support has been received from the following organizations:

American Society for Therapeutic Radiology and Oncology
Belgian Nuclear Research Centre
Canadian Nuclear Safety Commission
Eastman Kodak Company
Électricité de France
Fuji Medical Systems
Hitachi, Ltd.
International Radiation Protection Association
International Society of Radiology
Ion Beam Applications
Italian Radiological Association
Japan Industries Association of Radiological Systems
Japanese Society of Radiological Technology
MDS Nordin
National Electrical Manufacturers Association
Nederlandse Vereniging voor Radiologie
Philips Medical Systems, Incorporated
Radiation Research Society
Siemens
Sumitomo Heavy Industries, Ltd.
Varian

In addition to the direct monetary support provided by these organizations, many organizations provide indirect support for the Commission's program. This support is provided in many forms, including, among others, subsidies for (1) the time of individuals participating in ICRU activities, (2) travel costs involved in ICRU meetings, and (3) meeting facilities and services.

In recognition of the fact that its work is made possible by the generous support provided by all of the organizations supporting its program, the Commission expresses its deep appreciation.

**André Wambersie
Chairman, ICRU
Brussels, Belgium**

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

CONTENTS

THE INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS	3
CONTENTS	5
PREFACE	11
LIST OF ABBREVIATIONS	15
ABSTRACT	17
EXECUTIVE SUMMARY	19
1 INTRODUCTION	21
1.1 Aim of the report	21
1.2 Relation with other ICRU reports	22
1.3 From prescribing to recording and reporting	22
1.3.1 Treatment prescription	22
1.3.2 Recording the radiation treatment	22
1.3.3 Reporting the treatment	23
1.4 The three levels of dose and volume evaluation for reporting	23
1.4.1 Level 1	23
1.4.2 Level 2	23
1.4.3 Level 3	23
1.5 Reporting doses in a series of patients	24
1.6 Clinical examples	24
2 VOLUMES	25
2.1 Introduction	25
2.2 Gross Tumor Volume (GTV)	25
2.3 Clinical Target Volume (CTV)	25
2.3.1 The concept of CTV	25
2.3.2 Treatment of subclinical extensions surrounding a GTV	27
2.3.3 Treatment of subclinical extensions at a distance from a GTV	28
2.3.4 Reporting the CTV	28
2.3.5 The CTV and GTV: oncological concepts	28
2.4 Planning Target Volume (PTV)	28
2.4.1 The concept of PTV	28

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

2.4.2 Margins for the different types of variations and uncertainties	28
2.4.2.1 Internal Margin (IM)	28
2.4.2.2 Set-up Margin (SM)	30
2.4.3 Delineating the PTV	30
2.5 Treated Volume	32
2.5.1 Definition	32
2.5.2 Conformity index	33
2.6 Irradiated Volume	33
2.7 Organs at Risk (OARs)	33
2.8 Planning Organ at Risk Volume (PRV)	34
2.9 Reference Points and coordinate systems	34
2.9.1 Reference Points	34
2.9.2 Coordinate systems	34
2.9.2.1 The patient coordinate system "p"	35
2.9.2.2 Coordinate systems related to the treatment machine ("t") and the imaging units ("i")	35
2.10 Recommendations for recording and reporting volumes	36
2.10.1 Summary of the recommendations	36
2.10.2 Graphics	36
3 PHYSICAL CHARACTERISTICS OF ELECTRON BEAMS	39
3.1 Introduction	39
3.2 Electron energy	39
3.3 Practical range, R_p	39
3.4 Therapeutic range	41
3.5 X-ray background	42
3.6 Dose gradient	42
3.7 Oblique beam incidence	43
3.8 Collimation	44
3.9 Effects of heterogeneities	44
3.10 Developments in electron beam therapy	45
3.10.1 Overview	45
3.10.2 Electron beam energy	45
3.10.3 Collimation	46
3.10.4 Three-dimensional dose computation and treatment planning	47
4 GENERAL RECOMMENDATIONS FOR PRESCRIBING, RECORDING, AND REPORTING EXTERNAL-BEAM THERAPY	49
4.1 From prescribing to recording and reporting	49
4.1.1 Prescribing the treatment	49
4.1.1.1 Approach based on central Reference Point	49
4.1.1.2 Approach based on specification of a dose range within the PTV	49
4.1.1.3 Approach based on minimum dose to the PTV	49
4.1.2 Reporting the treatment	50
4.1.3 Recording the treatment parameters	50
4.2 The three levels of dose and volume evaluation for reporting	50
4.2.1 Level 1	50
4.2.2 Level 2	50
4.2.3 Level 3	50
4.3 General recommendations for reporting electron beam therapy	51
4.3.1 Principles	51
4.3.2 The ICRU reference point	51
4.3.3 Reporting dose distributions in the CTV and PTV	51

CONTENTS

4.3.3.1 <i>Dose homogeneity required in the PTV</i>	51
4.3.3.2 <i>Reporting dose distribution at Levels 1, 2, and 3</i>	51
4.3.3.3 <i>Evaluation of PTV 95 (PTV 90) for reporting</i>	52
4.3.4 <i>Dose (and dose distribution) to the Organs at Risk</i>	52
4.3.5 <i>Doses at Reference Points, dose distributions in volumes, and developments related to dose-volume histograms</i>	52
4.3.5.1 <i>Doses at Reference Points</i>	52
4.3.5.2 <i>Dose distributions in volumes</i>	52
4.3.5.3 <i>Developments related to DVHs</i>	53
4.4 Reporting a series of patients	53
4.4.1 <i>Introduction</i>	53
4.4.2 <i>Reporting prescription of treatment (protocol)</i>	53
4.4.3 <i>Description of actual treatment in a series of patients</i>	53
5 RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY FOR DIFFERENT CLINICAL SITUATIONS	57
5.1 Introduction	57
5.2 Reporting doses for a single electron beam	57
5.2.1 <i>Reference conditions</i>	57
5.2.1.1 <i>Reporting at Level 1</i>	58
5.2.1.2 <i>Reporting at Level 2 or 3</i>	59
5.2.2 <i>Small and irregularly shaped beams</i>	59
5.2.2.1 <i>Reporting at Level 1</i>	59
5.2.2.2 <i>Reporting at Level 2 or 3</i>	59
5.2.3 <i>Extended SSD-air gaps</i>	59
5.2.3.1 <i>Reporting at Level 1</i>	59
5.2.3.2 <i>Reporting at Level 2 or 3</i>	59
5.2.4 <i>Oblique electron beam incidence</i>	59
5.2.4.1 <i>Reporting at Level 1</i>	60
5.2.4.2 <i>Reporting at Level 2 or 3</i>	61
5.2.5 <i>Heterogeneities</i>	62
5.2.5.1 <i>Reporting at Level 1</i>	63
5.2.5.2 <i>Reporting at Level 2 or 3</i>	63
5.2.6 <i>Bolus</i>	64
5.3 Combination of electron and photon beams	64
5.3.1 <i>One high-energy photon beam and one electron beam (coaxial beams, same field size)</i>	64
5.3.2 <i>Adjacent electron and photon beams</i>	65
5.4 Combinations of electron beams	66
5.4.1 <i>Adjacent-parallel electron beams</i>	66
5.4.2 <i>Parallel-opposed electron beams</i>	66
5.5 Electron-beam arc therapy	68
6 SPECIAL TECHNIQUES	69
6.1 Intra-operative radiation therapy (IORT)	69
6.1.1 <i>Introduction</i>	69
6.1.2 <i>Beam requirements</i>	69
6.1.3 <i>Recommendations for reporting</i>	70
6.1.3.1 <i>Treatment technique</i>	70
6.1.3.2 <i>The ICRU Reference Point</i>	70
6.1.3.3 <i>Reporting of dose</i>	70
6.2. Total skin irradiation (TSI)	71
6.2.1 <i>Introduction</i>	71

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

<i>6.2.2 Beam requirements</i>	71
<i>6.2.3 Recommendations for reporting</i>	72
<i>6.2.3.1 Treatment technique</i>	72
<i>6.2.3.2 The ICRU Reference Dose</i>	72
<i>6.2.3.3 Reporting of dose</i>	73
7. QUALITY ASSURANCE	75
7.1 Imaging	75
7.2 Patient data	75
<i>7.2.1 Level 1</i>	75
<i>7.2.2 Levels 2 and 3</i>	75
7.3 Quality control of the electron accelerator	75
7.4 Beam data acquisition	76
<i>7.4.1 Level 1: basic techniques</i>	76
<i>7.4.2 Levels 2 and 3: advanced techniques</i>	76
7.5 Treatment-planning system	76
<i>7.5.1 Level 1</i>	76
<i>7.5.2 Level 2</i>	76
<i>7.5.3 Level 3</i>	77
7.6 Patient set-up	77
7.7 In vivo dosimetry	77
8. QUANTITIES, REFERENCE POINTS, AND VOLUMES RECOMMENDED FOR REPORTING ELECTRON BEAM THERAPY: SUMMARY	79
APPENDIX: CLINICAL EXAMPLES	81
Case number A1: medulloblastoma in a child	81
<i>Clinical situation</i>	81
<i>Treatment protocol</i>	81
<i>Patient positioning and immobilization</i>	81
<i>GTV</i>	81
<i>CTV</i>	81
<i>PTV</i>	81
<i>Organs at Risk (OARs)</i>	81
<i>Treatment prescription</i>	81
<i>Treatment technique</i>	82
<i>Quality assurance</i>	82
<i>Reporting</i>	82
<i>PTV-1: Whole brain, posterior fossa, and CTV-cervical</i>	82
<i>PTV-1B: posterior fossa</i>	82
<i>PTV-2: spine</i>	83
Case number A2: breast cancer—treatment of internal mammary chain	86
<i>Clinical situation</i>	86
<i>Treatment protocol</i>	86
<i>Patient positioning</i>	86
<i>GTV</i>	86
<i>CTV</i>	86
<i>PTV</i>	86
<i>Organs at Risk (OARs)</i>	86
<i>Dose prescription</i>	86
<i>Technique</i>	86

CONTENTS

<i>(1) Electron beam only</i>	86
<i>(2) Electron and photon beam</i>	87
<i>Dose calculation</i>	87
<i>Section for dose planning</i>	87
<i>For the electron beam</i>	87
<i>For the photon and electron beams</i>	87
<i>Quality assurance</i>	88
<i>Reporting</i>	88
 Case number A3: cancer of the parotid gland, after surgery	 88
<i>Clinical situation</i>	88
<i>Treatment protocol</i>	88
<i>Patient positioning and immobilization</i>	88
<i>GTV</i>	88
<i>CTV</i>	88
<i>PTV</i>	88
<i>Organs at Risk (OARs)</i>	88
<i>PRV</i>	88
<i>Dose prescription</i>	89
<i>Treatment technique</i>	89
<i>Quality assurance</i>	89
<i>Reporting</i>	89
 Case number A4: cancer of the tonsil (with electron irradiation of the posterior left and right neck)	 90
<i>Clinical situation: GTVs</i>	90
<i>Treatment protocol</i>	90
<i>The CTVs and PTVs</i>	90
<i>CTV-TN-70</i>	90
<i>PTV-TN-70</i>	91
<i>CTV-N-50</i>	92
<i>PTV-N-50</i>	92
<i>Organs at Risk (OARs)</i>	92
<i>Treatment technique and dose calculation</i>	93
<i>Quality assurance</i>	94
<i>Reporting</i>	94
<i>PTV-TN-70 (“boost”)</i>	94
<i>PTV-N-50 (lymph node areas)</i>	94
<i>Organs at Risk</i>	94
 REFERENCES	 95

PREFACE

For several decades, the ICRU has been involved in an effort to improve harmonization in reporting radiation treatments. The use of the same language and definitions of terms and concepts is indeed needed for an accurate, effective, and safe exchange of information, and is a prerequisite for progress in the development of radiation therapy.

The first Report in this series, ICRU Report 29, *Dose Specification for Reporting External Beam Therapy with Photons and Electrons*, was published in 1978. In Report 29, the ICRU was the first to clearly define and distinguish the Tumor Volume and the Target Volume. For reporting treatments, Report 29 recommended specification of the dose at the point of intersection of the beam axes (when possible) but always in the center (or central part) of the Target Volume, in an area where the dose is in general homogeneous and representative of the dose distribution in the Target Volume.

Fifteen years later, in Report 50 (1993) and its Supplement Report 62 (1999), *Prescribing, Recording and Reporting Photon Beam Therapy*, the ICRU again approached the problem of harmonization in describing and reporting. In the meantime, radiation therapy techniques had significantly changed and improved. At that time, two-dimensional treatment planning was the standard and three-dimensional dose computation and planning was being developed and used in leading centers. Simultaneously, the dramatic improvement of imaging techniques focused interest on the different volume concepts.

Several volumes were defined (or their definition refined) in Reports 50 and 62. For the Gross Tumor Volume (GTV), the need to specify the method used for its delineation was stressed. Around the GTV, two types of safety margin were identified. A first safety margin was added around the GTV to take into account subclinical malignant involvement, leading to the concept of Clinical Target Volume (CTV). A second type of safety margin was introduced to take into account all types of geometrical uncertainties in patient-beam positioning, leading to the concept of Planning Target Volume (PTV). This second type of safety margin compensates for

the variations in size, shape, and position of the CTV, but also for all uncertainties, and possible errors, in positioning.

The Organs at Risk (OARs) were identified and, as in the case of the PTV, a safety margin was applied to compensate for the movements of the OARs and the uncertainties in positioning. This led to the concept of Planning Organ at Risk Volume (PRV).

For reporting the treatments, Reports 50 and 62 recommended the selection of an ICRU Reference Point which should fulfill the following requirements:

- The dose at that point should be clinically relevant and representative of the dose distribution throughout the PTV.
- The point should be easy to define in a clear and unambiguous way.
- The point should be selected where the dose can be accurately determined.
- The point should be in a region where there is no large dose gradient.

A point located at the center (or central part) of the PTV generally fulfills these requirements and is recommended as the ICRU Reference Point.

In addition, the maximum and the minimum dose to the PTV should also be reported. Reporting only the minimum dose to the PTV (*i.e.*, the isodose surface encompassing the PTV) represents only part of the ICRU recommendations. Furthermore, the dose gradient at the border of the PTV is usually large and difficult to determine accurately. Reporting only the minimum dose to the PTV, instead of the dose at the center, introduces a systematic difference of 10, 15, and sometimes 20 percent in the dose to the patient, with erroneous interpretations and damaging consequences when comparing the treatment outcomes.

The present Report was originally planned to be part of ICRU Report 62 on *Prescribing, Recording, and Reporting Photon Beam Therapy*, since the general recommendations for prescribing, recording, and reporting electron beam therapy should be consistent with, and similar to, the recommendations for photon beam therapy. However, the dose

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

distributions of electron beams are so different from those of photon beams that they imply different selection of clinical indications, and require different beam arrangements and often a combination with photon beams. Therefore, the ICRU believed that it was worthwhile to devote a special report to Electron Beam Therapy.

This Report extends the concepts and recommendations of ICRU Reports 50 and 62 from photons to electrons. Today most of modern linear accelerators offer the possibility to apply electron beam therapy. The finite range of the electron beams in tissues provides a significant advantage in some clinical situations and for some series of patients. It is, however, recognized that electron beam therapy may raise complex technical and dosimetric problems and is often difficult to use efficiently and safely.

The recommendations for electrons should, in principle, follow the same logic used for photons whenever possible.

Selecting the ICRU Reference Point for prescribing and reporting on the beam axis at the maximum of the depth-dose curve ("peak dose") appears to be a reasonable choice:

- The electron energy is usually selected in such a way that the maximum of the depth-dose curve is located at (or close to) the center of the PTV.
- The maximum of the depth-dose curve is, in general, situated on a rather homogeneous plateau, with most energies and beam delivery systems.
- This approach agrees with the general approach recommended for photons.

In contrast, at the level of the 90, 85, or 80 percent isodose, the dose gradient is so great as to make selection of the ICRU Reference Point at that level impossible. However, the minimum dose to the PTV (*i.e.*, the isodose encompassing the PTV) should be reported in addition to the dose at the Reference Point at the maximum (peak dose).

At present, the situation of radiation oncology is changing dramatically. Novel and complex irradiation techniques are now rapidly developing and being implemented, *e.g.*, intensity-modulated radiation therapy (IMRT) and other techniques such as gamma knife, tomotherapy, Cyberknife®, and proton beam therapy. Their aim is to achieve more tightly any prescribed dose distribution, in particular to match as closely as possible the Treated Volume to the PTV even for complex shapes.

This also applies to electron beam therapy. One section of the present Report is devoted to developments in electron beam therapy.

These novel and complex irradiation techniques require, in turn, novel and complex approaches in

treatment planning such as inverse dose planning. Dose computation must be fast, safe, and reliable.

As a consequence of this evolution, the clinical indications of the different radiation therapy modalities have to be reconsidered continuously, as well as the methods for reporting the treatments. In particular, the recommendations contained in ICRU Reports 50 and 62 need to be adapted. With the novel and complex irradiation techniques, the dose distribution in the central part of the PTV does not always exhibit a homogeneous plateau where an ICRU Reference Point could be selected according to the requirements mentioned above.

In addition, owing to the dramatic progress in imaging, the volume concepts tend to overwhelm the traditional approach of dose specification at defined point(s). Presently, there are trends to specify the isodose encompassing a certain percentage of the PTV (*e.g.*, 90 percent) instead of the whole PTV and to consider the volume that receives a certain percentage (*e.g.*, 90 percent) of the prescribed dose. These approaches and their rationales need to be discussed and evaluated.

To deal with these new issues, the ICRU has established a Reporting Committee on "Prescribing, recording, and reporting conformal photon beam therapy". Two other reporting committees, newly established, have similar goals for proton beam therapy and intracavitary brachytherapy, respectively. These three committees have in common that they have to deal with techniques achieving dose distributions which are sometimes inhomogeneous throughout the PTV. This inhomogeneity may result from the technique or may even be intentional and based on very accurate diagnostic or functional imaging.

The ultimate goal is to develop recommendations and agreement on methods of reporting that would be, on the one hand, specific and accurate but, on the other hand, broad enough to be applied to the different techniques. For safe exchange of information and correct interpretation of the clinical results, it is indeed essential to keep, whenever possible, a common language and a common definition of terms and concepts between teams involved with different radiation therapy techniques.

ACKNOWLEDGMENTS

The ICRU expresses thanks and appreciation to Mr. David Carpenter, Division of Radiation Therapy, A. James Cancer Hospital and R. Solove Research Institute at the Ohio State University Medical Center, for reviewing and editing the manuscript and illustrations. Our appreciation also to

PREFACE

Mr. Ron McLean and Ms. Marga Garcia-Hunter, Graphic Design Services, Ohio State University for their work on the graphics. The ICRU also expresses gratitude and appreciation to Mr. Macy Block, who most generously supported work on this Report.

This Report was made possible, in part, by the support of the National Cancer Institute (NCI, Grant Number R24 CA74296-05), the European Commission (EC, Grant Number FIRI-CT-2000-20037), the International Atomic Energy Agency (IAEA, Division of Human Health and Radiation

and Waste Safety), the Ohio State University Comprehensive Cancer Center (Grant P30 CA 16058). The contents of this Report are the sole responsibility of the ICRU and do not necessarily represent the official views of the above Commissions or Agencies.

André Wambersie
Paul DeLuca
Gordon Whitmore
June 1, 2004

LIST OF ABBREVIATIONS

CI	Conformity Index
CT	Computed Tomography
CTV	Clinical Target Volume
DVH	Dose-Volume Histogram
FSU	Functional Subunit
GTV	Gross Tumor Volume
IM	Internal Margin
IMRT	Intensity Modulated Radiation Therapy
IORT	Intraoperative Radiation Therapy
MLC	Multileaf Collimator
MRI	Magnetic Resonance Imaging
OAR	Organs at Risk
PET	Positron-Emission Tomography
PMMA	Polymethylmethacrylate
PRV	Planning Organ at Risk Volume
PTV	Planning Target Volume
RBE	Relative Biological Effectiveness
R _P	Practical range (of electron beams)
SM	Set up Margin
SSD	Source Skin Distance
TSI	Total Skin Irradiation
T/ _p T	Clinical/pathological classification for staging
TV	Treated Volume
\bar{y}_F	Frequency-mean lineal energy (microdosimetric quantity)
\bar{y}_D	Dose-mean lineal energy (microdosimetric quantity)

ABSTRACT

The Report extends the concepts and recommendations for photons contained in ICRU Reports 50 and 62 to electron beam therapy. Reflecting the similarities between electron and photon treatments, the section on volumes in the present Report is very similar to the section on volumes in Reports 50 and 62, but evolutionary clarifications applicable to both modalities are presented. The concepts of Gross Tumor Volume (GTV), Clinical Target Volume (CTV), Planning Target Volume (PTV), Organs at Risk (OARs) and Planning Organ at Risk Volume (PRV) are recalled, or refined, and new examples are given to illustrate these concepts.

Background physical and dosimetric data necessary for understanding and correct interpretation of the recommendations are provided.

In general, in electron therapy, the beam energy and the beam delivery system are adjusted so that the maximum of the depth-dose curve on the beam axis ("peak dose") is reached at the center (or in the central part) of the PTV. This point is selected as the ICRU Reference Point for reporting.

If the peak dose is not obtained in the central part of the PTV, the ICRU Reference Point for reporting should be selected at the center of the PTV but, in addition, the peak dose should also be reported. The peak dose is always available and directly related to the number of monitor units for reference conditions, *i.e.*, a beam incident perpendicularly to a homogeneous medium.

Specific recommendations for reporting are provided for non-reference conditions: small and irregularly shaped beams, oblique beam incidence, and presence of heterogeneities.

One section deals with special techniques: total skin irradiation (TSI) and intra-operative radiation therapy (IORT). Recommendations are given for reporting.

As an appendix to the Report, clinical examples from several radiation oncology centers are presented and fully discussed to illustrate how to interpret the concepts and apply the recommendations for reporting electron beam therapy.

EXECUTIVE SUMMARY

The Report extends to electron beam therapy the concepts and recommendations contained in ICRU Reports 50 and 62 for photons. As a general rule, the concepts and recommendations for reporting electron beam therapy should be similar to and consistent with those published for photons. However, the dose distributions with electron and photon beams are quite different and may require different approaches as far as beam arrangement, treatment planning and also clinical indications are concerned.

The report deals mainly with harmonisation in reporting. However, without interfering with the prescription, or with the local policy for recording the treatment parameters, all procedures would be simplified and faster and the risk of confusion and accidents would be reduced if the same definitions of terms and concepts and the same methods for specifying doses and volumes were used for prescribing, recording and reporting the treatments.

As a general requirement, and as recommended in the other ICRU Reports, the irradiation conditions should be completely reported as well as the time-dose patterns. No weighting factor for RBE difference (relative to photons) has to be applied for the currently used electron energy range.

Volume concepts

Reflecting the similarities between electron and photon treatments, Chapter 2 on Volumes in the present report is very similar to the Chapter on Volumes in Reports 50 and 62.

The concepts of Gross Tumour Volume (GTV), Clinical Target Volume (CTV), Planning Target Volume (PTV), Treated Volume, Organ At Risk (OAR) and Planning Organ at Risk Volume (PRV), as defined for photons in the previous reports, are recalled. Evolutionary clarifications applicable to both modalities are given and new examples are provided to illustrate these concepts.

Physical and dosimetric data

Background information on the characteristics of the clinical electron beams, and physical and

dosimetric data necessary for the understanding and correct interpretation of the recommendations are provided in Chapter 3.

ICRU Reference Point for reporting electron beam therapy

The general principles for reporting electron beam therapy (Chapter 4) are in agreement with the recommendations for reporting photon beam therapy (Reports 50 and 62). They are based on the selection of a reference point for reporting, which is referred to as the ICRU Reference Point. This point should always be selected at the centre (or in the central part) of the PTV and should be clearly indicated.

In general, in electron therapy, the beam energy and the beam delivery system are adjusted so that the maximum of the depth-dose curve on the beam axis ("peak dose") is reached at the centre (or in the central part) of the PTV. The peak dose is always available and directly related to the number of monitor units in reference conditions, i.e., beam incident perpendicularly to a homogeneous medium. This point should be selected as the ICRU Reference Point for reporting.

If the peak dose is not obtained in the central part of the PTV, the ICRU Reference Point for reporting should be selected at the centre of the PTV but, in addition, the peak dose should also be reported.

Following dose values should be reported for reference irradiation conditions:

- the peak absorbed dose to water;
- location of and dose value at the ICRU Reference Point if not located at the level of the peak-absorbed dose;
- the maximum and minimum dose in the PTV; and
- dose(s) to OAR(s) derived from dose distributions and/or dose-volume histograms.

Reporting dose in non-reference conditions

Specific recommendations for reporting are provided for non-reference conditions: small and

PRESCRIBING, RECORDING AND REPORTING ELECTRON BEAM THERAPY

irregularly shaped beams, oblique beam incidence and presence of heterogeneities.

When corrections for oblique incidence and heterogeneity are applied they should be reported (Chapter 5). The peak absorbed dose to water for reference conditions should also be reported.

Intra-Operative Radiation Therapy (IORT)

Chapter 6 deals with special techniques where electrons are applied: Intra-Operative Radiation Therapy (IORT) and Total Skin Irradiation (TSI).

In IORT, electrons are used to deliver a large dose in a single fraction after surgical exposure of a well-defined anatomical area. The CTV is defined as accurately as possible jointly by the surgeon and the radiation oncologist during the procedure.

The irradiation procedures specific to IORT must be reported: electron energy, IORT applicator system (type, shape, bevel angle, size of the applicator, flattening filter, etc.). The ICRU Reference Point for Reporting is always selected in the centre (or central part) of PTV and, when possible, at the level of the maximum dose on the beam axis.

Following dose values should be reported:

- peak absorbed dose to water, in reference conditions, for each individual beam (if the beam axis is perpendicular to the tissue surface);
- for oblique beam axis, the maximum absorbed dose in water on the “clinical axis” (i.e., the axis perpendicular to the surface of the tissues, at the point of intersection of the central axis of the beam with the tissue surface).
- location of, and dose value at the ICRU reference point (if different from above);
- best estimate of the maximum and minimum dose to the PTV. Usually the irradiation conditions (electron energy, field size, etc.) are selected so that at least 90 percent of the dose at the ICRU Reference Point is expected to be delivered to the entire PTV.

Total skin irradiation (TSI)

TSI is indicated to treat selected cutaneous T-cell lymphomas (*Mycosis fungoides*). The aim is to irradiate the total skin envelope as homogeneously as possible. For patients with superficial disease, TSI can be delivered with one electron energy. In other

clinical situations, the thickness of the skin disease may vary with stage, pathology and location on the body surface. Several CTVs need to be identified and different beam penetration have to be used.

TSI implies identification of several anatomical areas. For each anatomical area, an ICRU Reference Point for reporting has to be selected always at or near the center of the PTVs/CTVs. The Reference point may be at the level of the peak dose if it is located in the central part of the PTV.

In addition an ICRU Reference Point, clinically relevant and located within the PTV, can be selected for the whole PTV.

Following dose values should be reported:

- peak absorbed dose in water for each individual electron beam;
- location of, and dose value at the ICRU Reference Point for each anatomical area (the ICRU Reference point may or may not be at the level of the peak dose);
- best estimate of maximum and minimum dose to each anatomical area;
- location and absorbed dose at the ICRU point for the whole PTV, and best estimate of the maximum and minimum dose for the whole PTV;
- any other dose value considered as clinically significant.

Quality assurance

Chapter 7 is devoted to quality assurance for imaging, acquisition of patient data, quality control of the accelerator, acquisition of beam data, treatment planning system, patient set-up and *in-vivo* dosimetry.

Clinical examples

A summary is presented at the end of the Report (Chapter 8) recalling the quantities, reference points and volumes recommended for reporting electron beam therapy.

As an Appendix to the Report, clinical examples from several Radiation Oncology Centres are presented and fully discussed to illustrate how to interpret the concepts and apply the recommendations developed in the Report for reporting electron beam therapy. They should not be interpreted as ICRU recommendations for selecting a given technique, beam arrangement or dose level.

1 INTRODUCTION

1.1 AIM OF THE REPORT

Exchange of clinical information and results between radiation oncology centers requires uniformity and agreement on the methods used to specify the doses and the volumes to which these doses are delivered. To avoid confusion, agreement also has to be reached on the definition of terms and concepts necessary for reporting irradiation techniques. The present Report contains the recommendations of the International Commission on Radiation Units and Measurements (ICRU) for specifying volumes and doses when prescribing, recording, and reporting electron beam therapy (Figure 1.1).

The rationale for using electron beams, rather than conventional photon beams, is based on the fact that electron beams allow one to achieve a fairly uniform dose distribution to a certain depth, which depends on the energy. Beyond that depth there is a rapid dose fall-off. Electron beams therefore are useful for treating Planning Target Volumes (PTVs) that are superficial or located at shallow depths, while sparing normal tissues or Organs at Risk (OARs) beyond that depth.

In addition, electron beams can be easily collimated by a few millimeters of lead, which are sufficient to define a beam of complex shape with a narrow penumbra. This provides excellent protection of surrounding normal tissues (Tapley and Fletcher, 1973).

As a general rule, the recommendations for prescribing, recording, and reporting electron beam therapy should be similar to, and consistent with, the recommendations for photon beam therapy, as published in ICRU Report 50 (ICRU, 1993) and ICRU Report 62 (ICRU, 1999). In particular, the same definitions of terms and concepts should be used whenever possible.

It is recognized that electron beam therapy has some special and unique aspects. As indicated above, the dose distributions of electron beams are totally different from those of photon beams. Therefore, the beam arrangements (or combinations with other radiotherapy techniques) as well as the clinical indications may be quite different. These unique aspects have to be taken into account when making

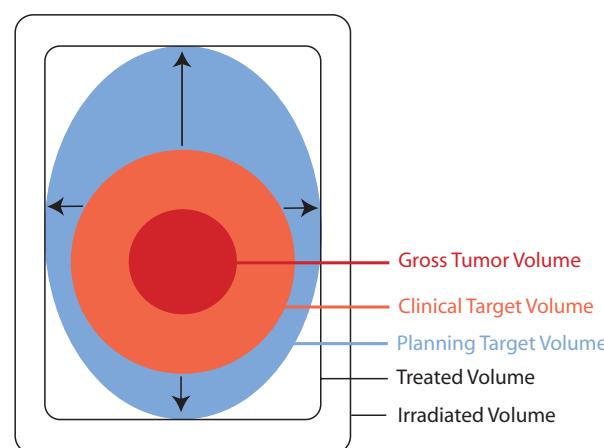


Figure 1.1. Schematic illustration of the different volumes as defined in ICRU Report 50 (1993). *Gross Tumor Volume* (GTV) denotes the demonstrated tumor. *Clinical Target Volume* (CTV) denotes the demonstrated tumor (when present) and also volumes with suspected (subclinical) tumor considered to need treatment (e.g., a margin around the GTV and regional lymph nodes not invaded clinically). The CTV is thus a purely anatomical-clinical concept. *Planning Target Volume* (PTV) consists of the CTV(s) and a margin to account for variations in size, shape, and position relative to the treatment beam(s). The PTV is thus a geometrical concept used to ensure that the CTV receives the prescribed dose, and it is defined in relation to a fixed coordinate system. Note that in the example shown the magnitude of foreseen movements of the CTV is different in different directions. *Treated Volume* is the volume that receives a dose that is considered important for local cure or palliation. *Irradiated Volume* is the tissue volume which receives a dose that is considered significant in relation to normal tissue tolerance (other than those specifically defined as Organs at Risk).

recommendations for prescribing, recording, and reporting treatments utilizing electron beams. Sufficient medical and physics expertise is required, as well as appropriate equipment and technical support for optimal and safe application of electron beam therapy.

As far as relative biological effectiveness (RBE) is concerned, for the currently used electron energy range (5–35 MeV), no significant RBE difference has been observed between electron and photon beams for a wide variety of biological systems (Alth *et al.*, 1982; Amols, 1986; Hettinger *et al.*, 1965; ICRU, 1984; Sinclair and Kohn, 1964; Wambersie, 1967; Williams and Hendry, 1978; Spadinger and

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

Palcic, 1992). In addition, no significant RBE variation as a function of depth in the electron beam has been found (Kim *et al.*, 1969; Wambersie *et al.*, 1965, 1974; Wambersie and Menzel, 1993).

Microdosimetric measurements are consistent with the radiobiological and clinical data on electron RBE. Single-event, specific-energy distributions measured in electron and photon beams were very similar (^{60}Co , 42-MV photons, 8- and 39-MeV electrons). Similar distributions were also obtained at different depths in a 15-MeV electron beam: 0.5, 2.4, and 5.7 g/cm², *i.e.*, 97, 100, and 66 percent depth-dose levels, respectively (Linborg, 1976). In addition, Booz found \bar{y}_F (frequency-mean lineal energy) and \bar{y}_D (dose-mean lineal energy) values that are nearly constant for high-energy photons and electrons (Booz, 1978).

On the basis of the above discussion it can be concluded that, in electron beam therapy applications, no weighting factor for RBE difference (relative to high-energy photons) has to be applied for the currently used energy range (ICRU, 1984). The same weighting factors for variations in fraction size should, then, be applied for electrons and photons (Wambersie *et al.*, 1990, 2002a, b).

However, some RBE differences have been reported at energies higher than 40 MeV (Åsard, 1971). For 50-MV x rays, RBEs ranging from 1.06 to 1.17 have been reported in mammalian systems *in vitro* and *in vivo* relative to 4- and 20-MV x rays. This was attributed to the presence of photonuclear processes (Zackrisson and Karlsson, 1992; Zackrisson *et al.*, 1991a, b). On the other hand, no RBE difference has been observed for 50-MeV pulsed electron beams (Zackrisson *et al.*, 1991b).

1.2 RELATION WITH OTHER ICRU REPORTS

As indicated above, exchanging clinical information and results between radiation oncology centers requires uniformity and agreement on the methods used to specify the doses and the volumes to which these doses are delivered and on reporting irradiation techniques.

For several decades, the ICRU has been involved in a continuous effort to improve uniformity in defining terms and concepts and in determining and specifying doses for reporting in radiation therapy. ICRU Report 29 (1978), *Dose Specification for Reporting External Beam Therapy with Photons and Electrons*, was published in 1978. It was superseded in 1993 by ICRU Report 50, *Prescribing, Recording, and Reporting Photon Beam Therapy*. A Supplement to Report 50 (ICRU Report 62) was published in 1999.

ICRU Reports 50 and 62 deal with current external photon beam irradiation techniques, including

three-dimensional conformal radiation therapy (3DCRT); another ICRU Report is being prepared to deal with complex and/or special techniques, *e.g.*, intensity-modulated radiation therapy (IMRT) and refinements needed for 3DCRT. A similar report on protons is in preparation.

For brachytherapy, ICRU Report 38, *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology*, was published in 1985 (a revision to that report is now in preparation). More recently, ICRU Report 58, *Dose and Volume Specification for Reporting Interstitial Therapy*, was published in 1997.

In principle, the same general approach to specifying and reporting doses and volumes and the same definitions of terms and concepts will be recommended whenever possible for all radiotherapy techniques, taking into account, however, the clinical and technical uniqueness of each modality. Therefore, in keeping with the generality of this approach, it should be noted that Sections 1.3–1.5 and Sections 2 and 4 in this Report are taken in large measure from previous ICRU Reports 50 (ICRU, 1993) and 62 (ICRU, 1999).

In 1984, the ICRU published Report 35, *Radiation Dosimetry: Electron Beams with Energies between 1 and 50 MeV*. The present Report contains only the physical and dosimetric information necessary for a good understanding of the recommendations presented here for prescribing, recording, and reporting electron beam therapy.

1.3 FROM PRESCRIBING TO RECORDING AND REPORTING

1.3.1 Treatment prescription

The prescription of a treatment is the responsibility of the radiation oncologist (or the radiation oncology team) in charge of the patient. It is not the purpose of this Report (nor the task of the ICRU) to make recommendations about treatment prescription, *i.e.*, about general approaches to prescription, dose level, beam arrangement, or other technical aspects of the treatment.

1.3.2 Recording the radiation treatment

Accurate and complete recording of the treatment parameters is necessary for several reasons:

- to ensure further care and follow-up of patients;
- to keep the treatment conditions reproducible, safe, and constant;
- to continuously develop clinical experience in the department and systematically improve the techniques;

INTRODUCTION

- to be able to exchange information on treatment conditions with other centers (the amount of information depends on the purpose, e.g., participation in clinical trials, follow-up of a patient, etc.); and
- to be able to “reconstruct” the treatment conditions when needed: interpretation of the treatment outcome(s), compliance with a quality assurance program or a research and development program, etc.

It is important that adequate information exchange occurs between the medical, physics, and radiography/radiotherapy staff and that there is agreement on the methods of recording the treatment parameters. The terms and concepts to be used should be clearly defined.

The amount of information that needs to be recorded depends on the technique, the complexity, and the purpose of the treatment (cure or palliation). It also depends, of course, on departmental resources.

1.3.3 Reporting the treatment

In contrast to prescribing (which is the responsibility of the radiation oncology team in charge of the patient, see Section 1.3.1) and recording the treatment (which is the responsibility of the department, see Section 1.3.2), it is mandatory to *harmonize reporting* for a reliable exchange of information between centers.

Harmonization in reporting implies an agreement on (1) a certain number of concepts and definitions of terms, and (2) a general approach on how to report a treatment. One must also agree on the (minimum) information to be contained in the report. On the other hand, because of the huge amount of information now available in some situations, part of this information has to be evaluated and selected as relevant to reporting.

Recommendations to improve harmonization in reporting electron beam therapy are presented in this Report. However, for the future, without interfering with the prescription or with the local policy for recording the treatment parameters, it is obvious that all procedures would be simplified and faster, and the risk of confusion and accidents would be reduced, if the same definitions of terms and concepts and the same methods for specifying the doses and the volumes were used for prescribing, recording, and reporting. This would also facilitate multi-center research and cooperative clinical trials.

1.4 THE THREE LEVELS OF DOSE AND VOLUME EVALUATION FOR REPORTING

Different levels of completeness and accuracy can be identified for reporting. Three levels were identified for external photon beam therapy in ICRU Report 62 (ICRU, 1999) and are proposed similarly in the present Report for electron beam therapy.

1.4.1 Level 1

Reporting at Level 1 implies reporting the minimum of data required to perform electron beam therapy effectively and safely. This implies the best possible description of the relevant volumes and dose distribution, as discussed in Sections 4 and 5.

These data should be available *in any centers contemplating electron therapy*, whatever their staffing and equipment situation. In well staffed and equipped centers, reporting at Level 1 may be sufficient for *simple treatment techniques* (palliative treatment, irradiation of metastases, etc.).

1.4.2 Level 2

Reporting at Level 2 must include all information given at Level 1.

In addition, reporting at Level 2 requires the information necessary to perform a treatment in a state-of-the-art manner. It allows the exchange of more complete and relevant information between different centers. The conditions for reporting at Level 2 usually include a well equipped and well staffed center.

Reporting at Level 2 implies the use of modern imaging techniques under reliable conditions (typically a series of CT or MRI examinations) to define the relevant volumes (see Section 2) and the Organs at Risk (see Sections 2.7 and 2.8). Other imaging techniques, such as PET or ultrasound, may add relevant information. At Level 2, it is also assumed that three-dimensional dose distributions are available, with heterogeneity corrections when appropriate. Dose-volume histograms (DVH) should also be available.

1.4.3 Level 3

Reporting at Level 3 is characterized by individualized, usually very complex, and often evolving techniques (intensity-modulated radiation therapy for electrons, etc.).

Reporting at Level 3 incorporates all information given at Levels 1 and 2. No additional reporting requirements are established yet, but comprehensive information should be given.

All radiation therapy techniques are continuously evolving, and more sophisticated equipment and

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

software become commercially available. Therefore, with time, the boundaries between the three levels, as defined above, may be altered.

1.5 REPORTING DOSES IN A SERIES OF PATIENTS

The recommendations for external photon beam therapy can be followed for electron beam therapy (see ICRU Report 62, Section 3.6, page 22) (ICRU, 1999).

1.6 CLINICAL EXAMPLES

Some clinical examples are given at the end of the present Report in order to illustrate how the recommendations can be applied in practice (see Appendix). These examples, obtained from different radiation oncology centers are solely intended to illustrate how to apply the present recommendations. They should not be considered as ICRU recommendations for choosing given treatment techniques and/or dose levels.

2 VOLUMES

2.1 INTRODUCTION

When prescribing, recording, and reporting treatment the different tissues/organs to which a dose will be delivered, as well as the dose levels, need to be specified. This implies the definition and delineation of different volumes, some of them related to the tumor others to the normal tissues. These volumes are:

- Gross Tumor Volume (GTV),
- Clinical Target Volume (CTV),
- Planning Target Volume (PTV),
- Treated Volume,
- Irradiated Volume,
- Organ at Risk (OAR), and
- Planning Organ at Risk Volume (PRV).

Each of these volumes is discussed below. The GTV and CTV are purely oncological concepts and are independent of any therapeutic approach. They represent volumes with known or suspected tumor involvement. The OAR represents normal tissues. The PTV and PRV are purely geometric concepts which do not necessarily correspond to tissue or organ borders. The definitions of these concepts and explanations are given in ICRU Report 62 (ICRU, 1999) and can be extended and applied to electron beam therapy.

2.2 GROSS TUMOR VOLUME (GTV)

The Gross Tumor Volume (GTV) is the gross, palpable, visible or clinically demonstrable location and extent of the malignant growth.

The GTV consists of primary tumor (GTV-T) and if present metastatic lymphadenopathy (GTV-N) or other metastases (GTV-M). In the GTV the tumor cell density is always high ($\geq 10^6/\text{mm}^3$). Hence, an adequate dose must be delivered to the whole GTV for radical therapy.

There is no GTV after complete surgical resection.

The shape, size, and location of a GTV may be determined by clinical examination (e.g., inspection, palpation, endoscopy) and/or various imaging techniques, e.g., x ray, CT, digital radiography,

ultrasonography, MRI, PET, and other methods using radionuclides. The methods used to determine the GTV should meet the requirements for classifying the tumor according to the clinical TNM (UICC, 1997) and AJCC (AJCC, 1997, 2002) systems.

The GTV (primary tumor, metastatic lymphadenopathy, and other known metastases) may appear different in size and shape, sometimes significantly, depending on which examination technique is used for evaluation. Examples are given in Figures 2.1 and 2.2 for breast and thyroid tumors, respectively. The radiation oncologists should in each case indicate which technique has been used for evaluation and for the definition of the GTV.

For reporting, the GTV should be described in standard topographical or anatomical terms, e.g., "18 mm \times 12 mm \times 20 mm tumor in the left upper outer quadrant of the breast, not fixed to deep muscles and not invading the skin." In many situations, a verbal description might be too cumbersome; therefore, for the purpose of data recording and analysis, a classification system is needed. Several systems are proposed for coding the anatomical description; some of them are mentioned in ICRU Report 50 (ICRU, 1993).

There are at least four reasons to describe and report the GTV in a complete and accurate way. Firstly, as indicated above, it is required for staging, e.g., according to the TNM system. Secondly, an adequate dose must be delivered to the whole GTV in order to obtain local tumor control. Thirdly, evaluation of the GTV regression is needed when redefining the PTV during the course of treatment. Fourthly, changes of the GTV during treatment may be one of the predictive values for response to treatment.

2.3 CLINICAL TARGET VOLUME (CTV)

2.3.1 The concept of CTV

The Clinical Target Volume (CTV) is a tissue volume that contains the GTV(s) and/or sub-clinical malignant disease at a certain probability level. This volume thus has to be treated adequately.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

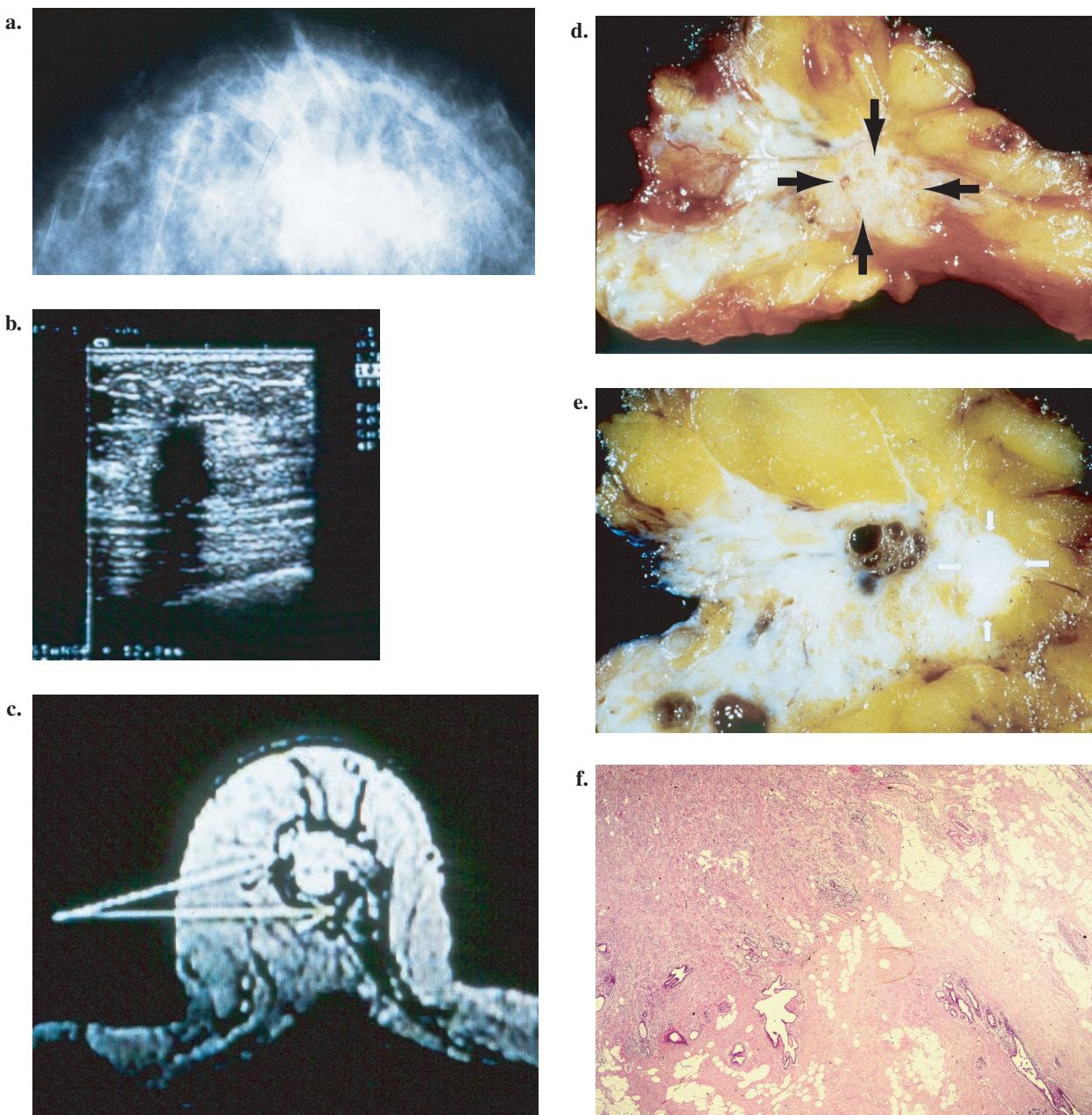


Figure 2.1. Different images of a breast cancer as obtained by different methods (note that the different figures are not reproduced to identical scales).

- (a) Mammography screening shows a tumor in the right breast. There is a 20 mm large mass on palpation.
- (b) Ultrasonography shows a 13 mm × 8 mm large hypoechogenic tumor. Fine needle aspiration biopsy shows cancer.
- (c) MRI demonstrates a 20 mm large tumor (the arrows indicate directions for core biopsies).
- (d) The fresh surgical specimen shows a 15 mm × 22 mm large tumor (marked by black arrows).
- (e) The fixed specimen shows a 14 mm × 18 mm large tumor (marked by black arrows).
- (f) Microscopy demonstrates the diffuse borders of the cancer.

Depending on which examination method is used to establish the size of the Gross Tumor Volume, one may arrive at different T/pT categories (and even different stages) in the TNM classification (AJCC, 2002). (Courtesy of the Malmö University Hospital, Sweden.)

The Clinical Target Volume, like the GTV, is a clinical-anatomical concept. Even if the cell density is as high as $10^3/\text{mm}^3$, the cells still cannot be detected clinically and thus are considered as a subclinical volume, but nevertheless part of the CTV.

Delineation of the CTV is based (1) on the available data on the probability of (subclinical) malignant cells outside the GTV and (2) on the judgment of the radiation oncologist. The relevant data to consider are the probability of microscopic extension at

VOLUMES

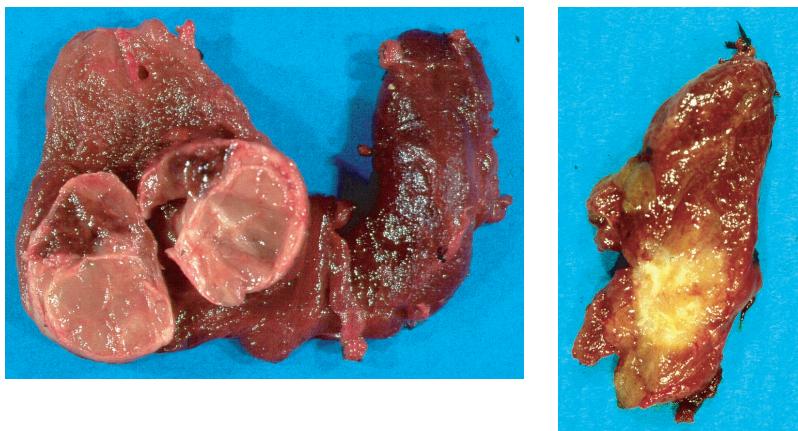


Figure 2.2. Example of two different macroscopic growth patterns for thyroid carcinomas. To the left is a differentiated follicular carcinoma. The tumor is sharply circumscribed and surrounded by a distinct fibrous capsule. To the right is a differentiated papillary carcinoma. The tumor is unencapsulated, irregularly outlined and infiltrates diffusely into the surrounding thyroid parenchyma. (Courtesy Otto Ljungberg, MD, Department of Pathology, University Hospital, Malmö, Sweden.)

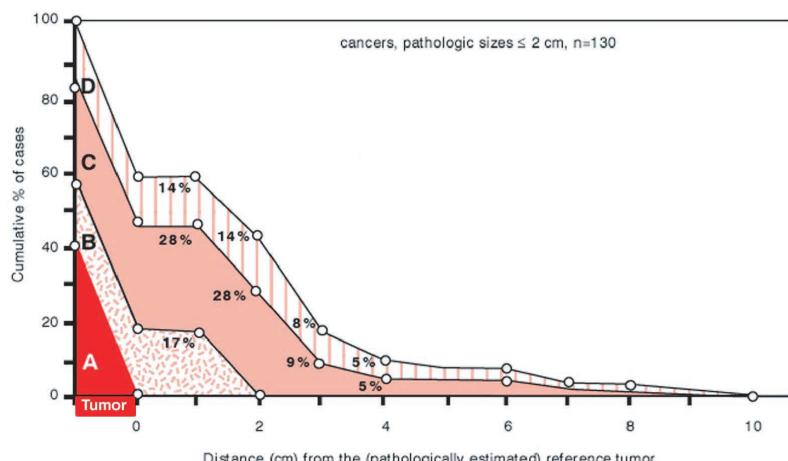


Figure 2.3. The distribution of tumor foci at different distances from the border of the Gross Tumor Volume for a sample group of patients ($n = 130$) with breast cancer. This graph shows the remaining proportion of cases with tumor foci at or beyond the specified distance from the reference tumor (the term "reference tumor" is used by the authors for the GTV). The percentages given within the groups indicate the proportion of cases with tumor foci located at or beyond the point given on the abscissa (i.e., at or beyond the specified distance from the reference tumor).

- (A) No tumor foci outside the reference tumor. These cases constitute 41 percent of all cases.
- (B) Tumor foci within 2 cm of the reference tumor. These cases constitute 17 percent of all cases. The exact distances of these foci and their invasive or noninvasive character were not specified.
- (C) Noninvasive tumor foci further than 2 cm from the reference tumor. These cases constitute 28 percent of all cases.
- (D) Invasive tumor foci further than 2 cm from the reference tumor. These cases constitute 14 percent of all cases.

(Modified from Holland *et al.*, 1985 [CANCER, 56, 1985, 979–990. Copyright © 1985 American Cancer Society. Reprinted with permission of Wiley-Liss, Inc., a subsidiary of John Wiley & Sons, Inc.].)

different distances around the GTV, and the probability of subclinical invasion of regional lymph nodes or other tissues.

The delineation of the CTV is thus part of the treatment prescription.

2.3.2 Treatment of subclinical extensions surrounding a GTV

Macroscopically, tumors may seem relatively well delineated or may have no distinct borders.

However, when microscopic examination of a cancer is performed, one often finds subclinical extensions around the GTV (Figure 2.3), *i.e.*, individual malignant cells, small cell clusters, or microextensions, which cannot be detected clinically. The GTV and the surrounding volume with suspected subclinical involvement is defined as the Clinical Target Volume, if the same dose is prescribed to both volumes. The CTV will be denoted CTV-T (designated as CTV-1 in previous Reports). If the GTV

has been removed by surgery, but radiotherapy to the tumor bed is considered necessary for the tissues close to the site of the removed GTV, the volume is also designated CTV-T.

2.3.3 Treatment of subclinical extensions at a distance from a GTV

Additional volumes with presumed subclinical spread may also be considered for therapy, *e.g.*, regional lymph nodes or metastases. They are also defined as Clinical Target Volumes, and may be designated CTV-N (and if necessary CTV-N1, CTV-N2, *etc.*). Adding the letters T, N, or M to identify the volumes may better clarify their clinical significance (compared with the identification by numbers only, as used in ICRU Reports 50 and 62).

Thus, two types of subclinical disease (adjacent to the GTV or at a distance, *e.g.*, lymph nodes) can be distinguished, as illustrated in Figure 2.4. The prescription is then based on the probability that there are cancer cells in some anatomically definable tissues/organs, even though they cannot be detected with present-day techniques: they are subclinical. For prescription of treatment, these subclinical deposits (or their probability of existence) can be described in terms of frequency of risk for later detectable manifestations if not treated adequately in the subclinical stage. The estimate of that probability is based on clinical experience from adequately documented treatment and follow-up (Grégoire *et al.*, 2000, 2003a, b; Martinez-Monge *et al.*, 1999).

Several practical situations are illustrated in Figure 2.4. In breast-sparing protocols, the CTVs containing the primary tumor and its regional lymphatics are separated anatomically. In other situations, *e.g.*, boost therapy, the “higher-dose” volume is located inside the “lower-dose” volume, which is only irradiated to eradicate subclinical disease.

2.3.4 Reporting the CTV

For reporting, the CTV must be defined in anatomical terms and/or according to a corresponding code (see, *e.g.*, Table I.2 in ICRU Report 50) in conformity with the recommendations for the GTV.

2.3.5 The CTV and GTV: oncological concepts

It must be stressed that the prescriptions for the GTV(s) and CTV(s) are based on general oncological principles, and they are independent of any therapeutic approach. In particular, they are not specific to the field of radiation therapy. For instance, in surgery, a safety margin is taken around the Gross Tumor Volume according to clinical judgment, and

this implies the same use of the Clinical Target Volume concept as in external beam radiation treatments. Also in brachytherapy, volumes to be treated are defined, and thus the concept of CTV is used. The definitions of GTV(s) and CTV(s) constitute part of the basic prescription of treatment; they are essential to the medical record. Their definition must precede the selection of the treatment modality and the subsequent treatment planning procedures.

2.4 PLANNING TARGET VOLUME (PTV)

2.4.1 The concept of PTV

The Planning Target Volume (PTV) is a geometrical concept, introduced for treatment planning. It is used to select the appropriate beam sizes and beam arrangements to ensure that the prescribed dose is actually delivered to all parts of the CTV. It surrounds the CTV with an additional margin to compensate for the different types of variations and uncertainties of the beam relative to the CTV.

Delineation of the PTV is a compromise dictated by the presence of Organs at Risk (Sections 2.7 and 2.8): it implies the judgment and experience of the radiation oncologist. In terms of probability, all (or most) parts of the CTV should receive the prescribed dose with the highest possible probability. On the other hand, a clinically acceptable probability of complications cannot be exceeded. The concept of Planning Target Volume (PTV) was introduced in ICRU Report 50 (ICRU, 1993).

The delineation of the PTV is dependent on the technique and is part of the treatment prescription.

2.4.2 Margins for the different types of variations and uncertainties

To avoid significant deviation from the prescribed dose in any part of the CTV(s), one must add margins to the CTV(s) to compensate for variations and uncertainties (1) in position, size, and shape of the CTV and (2) in patient-beam positioning, both during a given radiation treatment fraction and between successive fractions. To facilitate discussion, and in keeping with previous reports (ICRU Reports 50 and 62), these will be referred to as the Internal Margin and the Set-up Margin, respectively.

2.4.2.1 Internal Margin (IM)

A margin must be added to the CTV to compensate for expected physiological movements and variations

VOLUMES

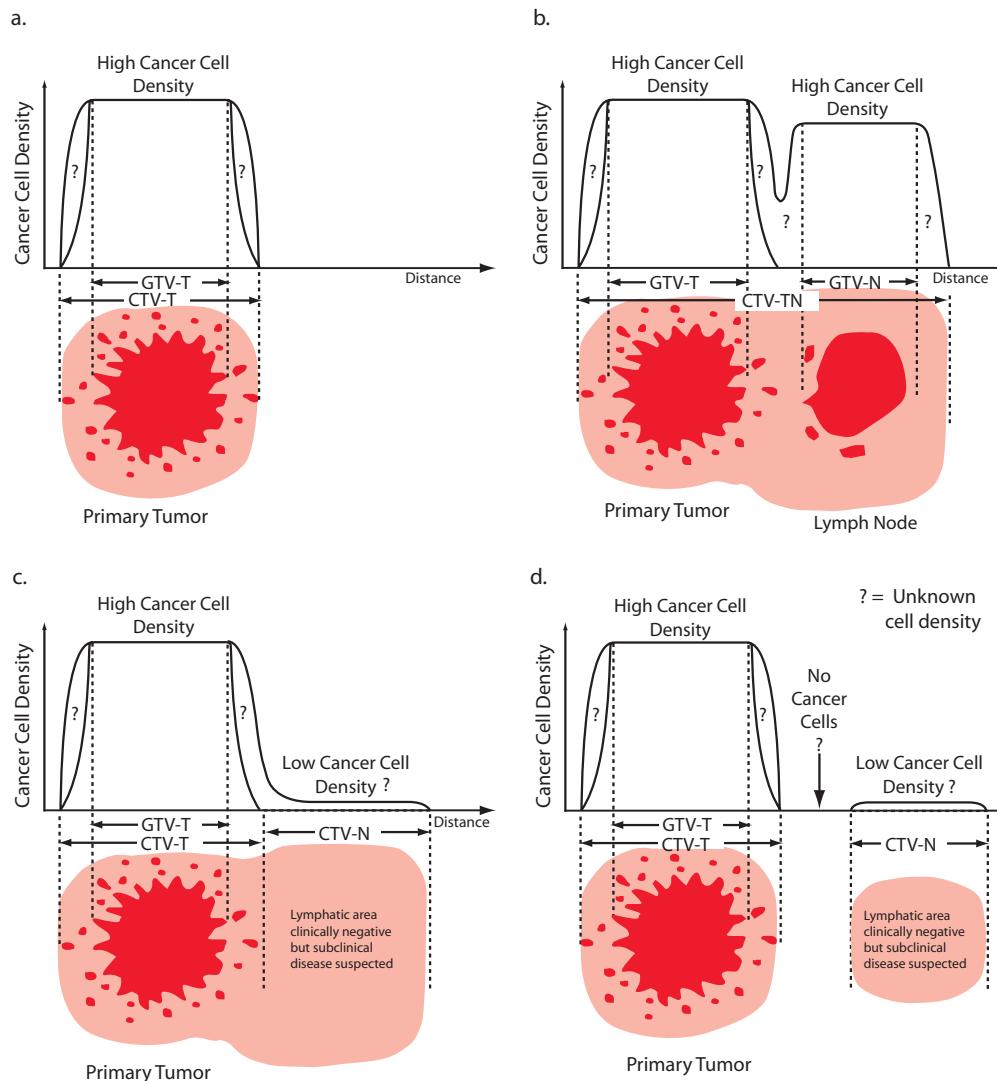


Figure 2.4. Schematic illustration of the relations between GTV(s) and CTV(s) in different clinical situations.

- Simple case with one GTV and the corresponding CTV (e.g., skin tumor). At the level of the GTV (dark red), the cellular density is the highest (as an average, about 10^6 cells/mm³), but may be heterogeneous (e.g., due to necrosis). The width of the safety margin (light red) is selected so that, in principle, no cancer cells are present outside the limits of the CTV. The cancer cell density decreases between the border of the GTV and the outer limit of the CTV, but the variation of the cell density with distance is not known ("?" in the figure) and depends on tumor type and location. In some situations a natural anatomical border may limit subclinical extension, e.g., parietal pleura in mediastinal lymphoma.
- Two GTVs are present: the primary tumor, GTV-T, and a metastatic fixed lymph node, GTV-N (e.g., a tumor of the tonsil with a homolateral cervical lymph node). A safety margin for microscopic invasion has to be taken around each GTV, which may lead to the definition of two CTVs: CTV-T corresponding to the primary tumor and its safety margin, and CTV-N for the lymph node and its safety margin. Actually, since in this example, the two CTVs are close to each other and because there are certainly malignant cells between the two GTVs, only a single CTV is selected (CTV-TN), which includes the two GTVs and a common safety margin.
- The primary tumor and its safety margin define a first CTV (CTV-T). In addition, there is a high probability of invasion of the adjacent lymph node area, which leads to the definition of a second CTV (CTV-N). It is decided to keep the two CTVs adjacent to each other as there could be cancer cells all along between them (e.g., breast cancer and adjacent lymph node area(s), or tumor of the head and neck and adjacent lymph node area(s)).
- A similar situation to that in (c), but there is a free space between the CTV containing the primary tumor and the CTVs including the lymph node areas at risk. It is the case, e.g., for a tumor of the anus and the inguinal lymphatic areas, which can be treated with electron beams.

in size, shape, and position of the CTV during therapy relative to an internal reference point and its corresponding coordinate system (see Section 2.9). It is referred to as the Internal Margin (IM).

The Internal Margin is often asymmetric around the CTV. Figure 2.5 illustrates the movements of the CTV due to respiration in the case of breast cancer.

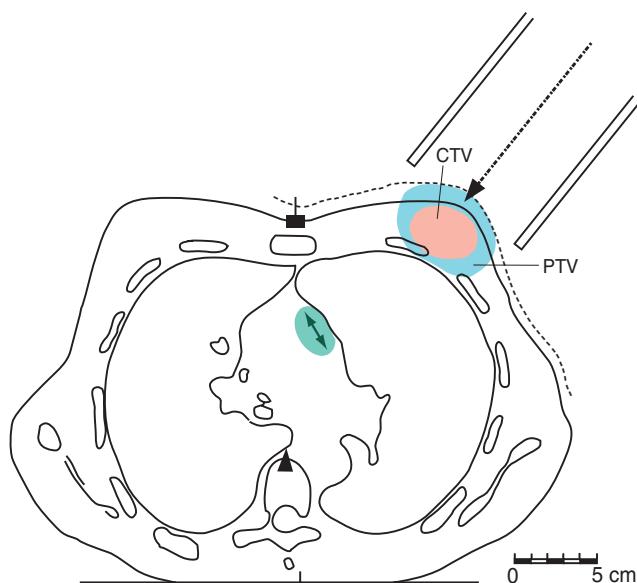


Figure 2.5. Patient with cancer of the left breast after lumpectomy and whole-breast irradiation, now planned for electron boost irradiation to the tumor bed. The relations between the different volumes and margins are shown in one planar section. The internal and external reference points are indicated. Owing to respiratory movements, the PTV extends outside the average position of the body contour.

Key:

Light red	CTV (Clinical Target Volume)
Light blue	PTV (Planning Target Volume)
↔	OAR (Organ at Risk, in this case the left anterior descending coronary artery, shown here as projected onto the section)
Light green	PRV (Planning Organ at Risk Volume)
—	Average position of the body contour
- - -	Body contour at maximum inspiration
▲	Internal Reference Point
■	External Reference Point

2.4.2.2 Set-up Margin (SM)

To account specifically for uncertainties (inaccuracies and lack of reproducibility) in patient positioning and alignment of the therapeutic beams during treatment planning and through all treatment sessions, a Set-up Margin (SM) for each beam is needed. The SM is referenced in the external coordinate system (see Section 2.9). The uncertainties vary with different anatomical directions, and thus the size of such margins depends on the selection of beam geometries. The inaccuracies depend on such factors as:

- variations in patient positioning;
- mechanical uncertainty of the equipment (*e.g.*, sagging of the gantry, collimators, and couch);
- dosimetric uncertainties, *e.g.*, penetration of the electron beam;
- transfer set-up errors from CT and simulator to the treatment unit; and
- human factors.

These factors may also vary from center to center, and within a given center from machine to machine. The use of patient immobilization devices (Hess *et al.*, 1995; Hunt *et al.*, 1993, 1995), the application of quality assurance programs, and the skill and experience of the radiographers/radiotherapists are important and must be taken into account. The use of different record and verification systems (in real time or not) may also be important and may significantly alter the size of the needed Set-up Margins.

2.4.3 Delineating the PTV

When delineating a PTV, the different types of margin identified above must be added or combined. Different scenarios are depicted in Figures 2.6 and 2.7.

The risk of missing part of the CTV must be balanced against the risk of complications due to making the PTV too large. For instance, if margins are added linearly, the resulting PTV may often be too large, with a consequent risk of exceeding patient tolerance.

Since margins are introduced to compensate for both random and systematic uncertainties, a quadratic approach similar to that recommended by the Bureau International des Poids et Mesures (BIPM, 1981) may be employed. It provides a means to combine random and systematic, as well as correlated and uncorrelated, uncertainties (Mijnheer *et al.*, 1987). Utilizing this approach, in order to find the overall margin (*i.e.*, the Internal Margin and the Set-up Margin together), the overall systematic error can be derived by adding quadratically the separate systematic errors:

$$\sum = \left(\sum_{\text{set-up}}^2 + \sum_{\text{organ motion}}^2 + \sum_{\text{delineation}}^2 \right)^{1/2}, \quad (2.1)$$

and similarly the overall random error can be derived by adding quadratically the separate random errors:

$$\sigma = \left(\sigma_{\text{set-up}}^2 + \sigma_{\text{organ motion}}^2 \right)^{1/2}. \quad (2.2)$$

Several approaches to quantifying the CTV-to-PTV margin requirements have been published (Austin-Seymour *et al.*, 1995a, b; Balter *et al.*, 1996; Crook *et al.*, 1995; Goitein, 1985; Holmberg *et al.*, 1994; Roeske *et al.*, 1995; Stroom *et al.*, 1999; van Herk *et al.*, 2000).

Stroom *et al.* (1999) presented a model which was tested for prostate, cervix, and lung cancer. A CTV-to-PTV Set-up Margin size which ensures at least 95 percent of the dose to 99 percent of the CTV is given by $2\sum + 0.7\sigma$, where \sum is the standard deviation for the systematic error (average set-up

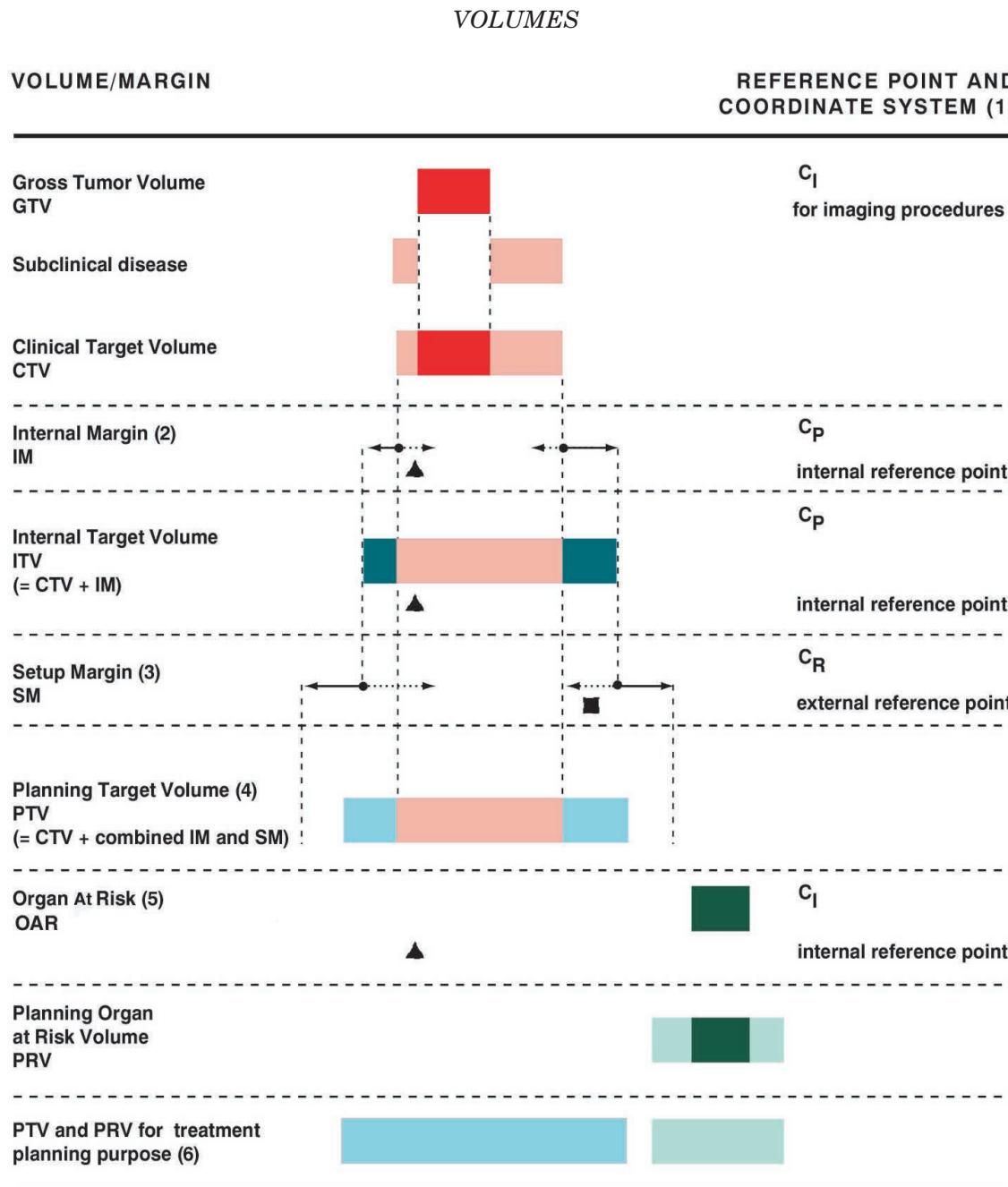


Figure 2.6. Schematic representation of the different volumes/margins. Notes: (1) For explanation, see Sections 2.2–2.9. (2) The Internal Margin may be asymmetrical. (3) Like the Internal Margin, the Set-up Margin may be asymmetrical. (4) To delineate the PTV, the IM and SM are not added linearly (since this could result in too large a PTV) but are combined (for explanation, see text). The PTV is thus smaller than it would be if the IM and SM were simply added linearly. (5) For an Organ at Risk (OAR), margins are added in the same way as for the PTV. (6) The PTV and PRV may or may not overlap.

deviations per patient in the group of patients) and σ is the standard deviation for the random error (day-to-day set-up positions). Van Herk *et al.* (2000) came to a similar conclusion that the standard deviation for the systematic errors is three times larger than that for the random errors. On the other hand, McKenzie (2000) pointed out that breathing-induced motion should be accounted for separately, with the breathing margin added linearly to the quadratic sum of the other contributing factors.

Unfortunately, this ideal approach can be applied only in situations where one can identify the causes of errors and quantify the uncertainties (e.g., by standard deviations). Currently, this is not generally possible except for a few situations (e.g., some conformal therapy protocols).

However, it should be understood that the delineation of the PTV is a matter of compromise and is not simply a mathematical concept. It requires clinical judgment, and thus is the responsibility of the

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

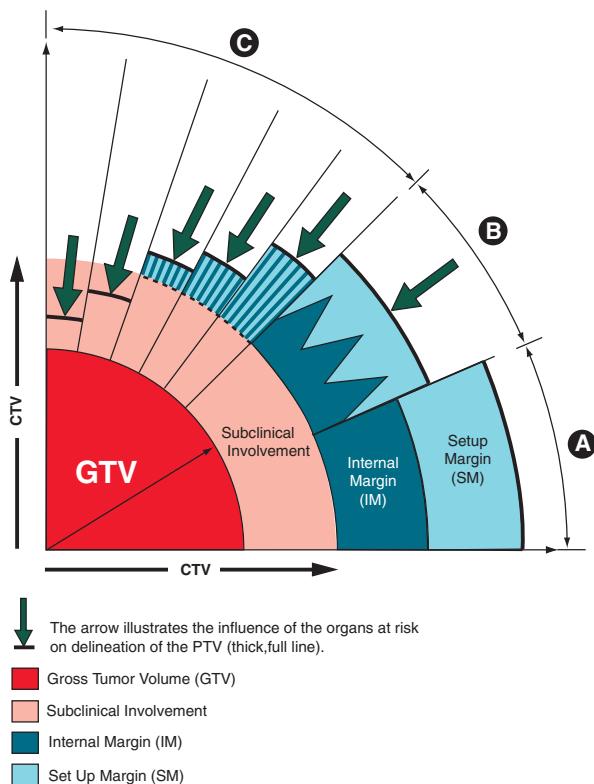


Figure 2.7. Schematic representations of the relations between the different volumes (GTV, CTV, PTV, and PRV) in different clinical scenarios.

Scenario (A) A margin is added around the Gross Tumor Volume (GTV) to take into account potential “subclinical” invasion. The GTV and this margin define the Clinical Target Volume (CTV). In external beam therapy, to ensure that all parts of the CTV receive the prescribed dose, additional margins for geometric variations and uncertainties must be considered. An Internal Margin (IM) is added for the variations in position and/or shape and size of the CTV. A Set-up Margin (SM) is added to take into account all of the variations/uncertainties in patient-beam positioning. CTV + IM + SM define the Planning Target Volume (PTV), on which the selection of beam size and arrangement is based.

Scenario (B) The simple (linear) addition of all factors of geometric uncertainty, as indicated in scenario A, often leads to an excessively large PTV, which would be incompatible with the tolerance of the surrounding normal tissues. In such instances, instead of adding linearly the Internal Margin and the Set-up Margin, compromise combinations are used (see Section 2.4.3). In practice, it may be more convenient to deal separately with systematic and random errors than to group them by origin, i.e., physiological or set-up.

Scenario (C) In the majority of clinical situations, a “global” safety margin is adopted. In some cases, the presence of an Organ at Risk dramatically reduces the width of the acceptable safety margin (e.g., presence of the spinal cord, optic nerve, etc.). In other situations, larger safety margins may be accepted. Since the incidence of subclinical invasion may decrease with distance from the GTV (see Figure 2.3), a reduction of the margin for subclinical invasion may still be compatible with chance for cure, albeit at a lower probability rate. It is important to stress that the width of the different safety margins may vary with the angle at which one looks at the PTV (e.g., bony structures or fibrotic tissue may prevent, at least temporarily, malignant cell dissemination).

(Note that if an adequate dose cannot be given to the whole GTV, the whole aim of therapy shifts from radical to palliative, unless alternative treatment strategies can be found.)

radiation oncology team. The margin due to spatial uncertainties may have to be reduced because of the proximity of OARs and consequently too high a risk of increased toxicity. It should be recorded clearly.

The possibility of quantifying margin requirements will be of increasing relevance for new techniques such as 3DCRT and IMRT. Similarly, the margin requirements around Organs at Risk (PRV) (see Sections 2.7 and 2.8) also need to be quantified and, as indicated above, in some cases will limit the desired margin width around the CTV.

The Penumbra. The penumbra of the beam(s) is not considered when delineating the PTV. However, when selecting the beam sizes, the width of the penumbra has to be taken into account and the beam size must be enlarged accordingly to ensure coverage of the PTV by the prescribed dose. The beam sizes are defined by the 50-percent isodose (ICRU, 1976).

2.5 TREATED VOLUME

2.5.1 Definition

Because of the limitations of irradiation techniques, the volume receiving the prescribed dose may not match the PTV; it may be larger (sometimes much larger) and in general more simply shaped. This leads to the concept of Treated Volume.

The Treated Volume is the tissue volume which (according to the approved treatment plan) receives at least the absorbed dose selected as the minimum dose to the PTV (or some specified percentage of the PTV) and specified by the radiation oncology team as appropriate to achieve tumor eradication or palliation, within the bounds of acceptable complications.

The Treated Volume is the volume enclosed by the isodose surface corresponding to that dose level. When reported, the value of the isodose selected to define the Treated Volume should be quoted relative to the prescribed dose (see Section 4.1) or in absolute terms.

It is important to identify the shape, size, and position of the Treated Volume in relation to the PTV for different reasons. One reason is to evaluate causes for local recurrences (inside or outside the Treated Volume). Another reason is to evaluate and interpret side-effects.

VOLUMES

2.5.2 Conformity Index (CI)

The Conformity Index (CI) is defined as the ratio of the Treated Volume to the PTV.

Ideally, the Treated Volume should totally encompass the PTV. If this is not the case, the percentage of the PTV included in the Treated Volume should be reported (see Figure 2.8).

Report 62 defines the concept of CI as the quotient of the Treated Volume and the PTV. This definition of the CI implies that the Treated Volume totally encompasses the PTV, but it is recognized that this is more an intended goal than is often times the actual case. The Treated Volume is the tissue volume that receives at least the dose selected and specified by the radiation oncology team as being appropriate to achieve the purpose of the treatment: tumor eradication or palliation.

The CI can be used as part of the optimization procedure, as was proposed by Knöös *et al.* (1998) and van't Riet *et al.* (1997). However, it is recognized that when optimizing the CI (as close as possible to unity) other optimization parameters may deteriorate, *e.g.*, the size of the Irradiated Volume or the dose homogeneity in the PTV. Again, compromises are required.

2.6 IRRADIATED VOLUME

The Irradiated Volume is the tissue volume which receives a dose that is considered significant in relation to normal tissue tolerance.

If the Irradiated Volume is reported, the significant dose must be expressed either in absolute values (Gy) or relative to the prescribed dose to the PTV. The Irradiated Volume depends on the treatment technique used.

In conformal therapy using beam shaping, *e.g.*, by Multileaf Collimator (MLC) or customized blocks, the Treated Volume may decrease and the Irradiated Volume may be reduced or may be increased.

2.7 ORGANS AT RISK (OARs)

*Organs at Risk (“critical normal structures”) are normal tissues (*e.g.*, spinal cord) whose radiation sensitivity may significantly influence treatment planning and/or prescribed dose.*

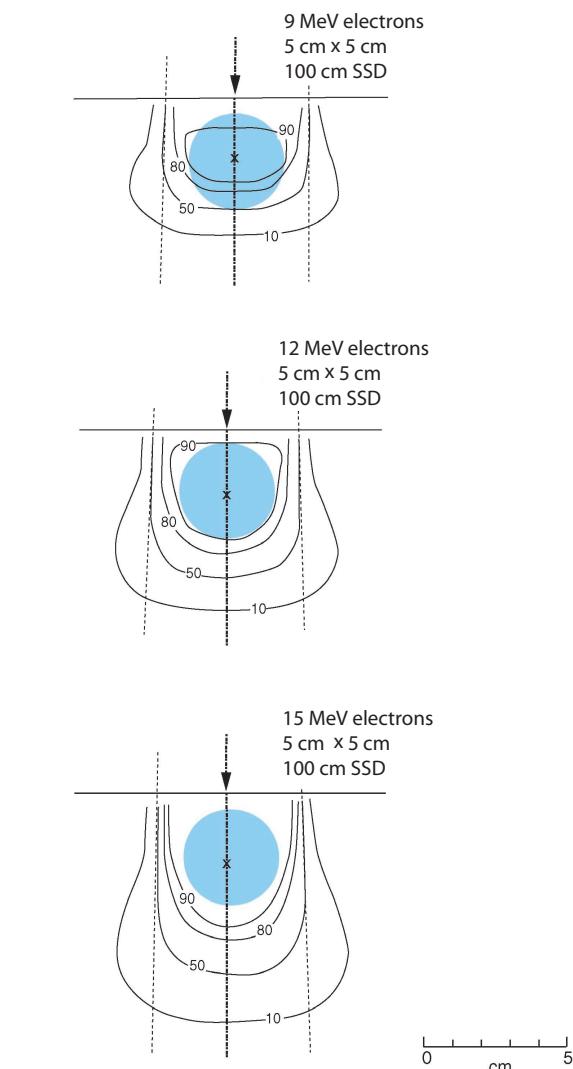


Figure 2.8. Irradiation with a single electron beam (*e.g.*, “boost”) of a PTV 3 cm in diameter, extending between 0.6 and 3.6 cm in depth. The accelerator allows the selection of electron energy in 3-MeV increments. A dose of 20 Gy is prescribed at the ICRU Reference Point indicated by “x” and located on the beam axis, at the maximum of the depth-dose curve (“peak dose”). It corresponds to the central part of the PTV. The prescribed minimum dose is 18 Gy (*i.e.*, 90 percent of the peak dose). The 90-percent isodose surface should thus encompass the whole PTV. In the present conditions, the maximum dose in the PTV is the peak dose.

(a) 9-MeV electron beam, 5 cm × 5 cm beam size (the beam size is defined on the 50-percent isodose at the depth of the peak dose), ICRU Reference Point (marked “x”) at depth 2.1 cm. The energy is too low and the Treated Volume (*i.e.*, the volume encompassed by the 90-percent isodose surface) does not encompass the whole PTV. This irradiation does not comply with the treatment prescription. The CI, in a strict sense as defined in the text, cannot be calculated.

(b) 12-MeV electron beam, 5 cm × 5 cm beam size, ICRU Reference Point (marked “x”) at depth 2.6 cm. The Treated Volume totally encompasses and matches as closely as possible the PTV. The CI is 1.2, *i.e.*, close to unity.

(c) 15-MeV electron beam, 5 cm × 5 cm beam size, ICRU Reference Point (marked “x”) at depth 2.8 cm. The Treated Volume encompasses the PTV but is much larger, and normal tissues are unnecessarily irradiated. The CI is 1.8.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

Presently, our knowledge about the sensitivity of normal tissues is derived mainly from clinical observations. However, different models and concepts have been proposed to interpret the normal-tissue complication probability (NTCP) (Källman *et al.*, 1992; Lyman, 1985; Olsen *et al.*, 1994; Withers *et al.*, 1988; Wolbarst *et al.*, 1982).

The functional-subunit concept (FSU) (Withers *et al.*, 1988) assumes that, for the purpose of evaluation of the volume-fractionation response, the tissues of an Organ at Risk can be considered to be made up of a number of functional subunits which can be organized into "serial," "parallel," or "serial-parallel" structures. For example, the spinal cord is assumed to be mostly serial, implying that a dose above tolerance limit to even a small volume of the Organ at Risk may be deleterious. In contrast, the lung is assumed to be largely parallel, meaning that the relative size of the volume irradiated above tolerance level may be the most important parameter.

Late effects on the heart and the lungs from radiation therapy for breast cancer have been reported by Gyenes *et al.* (1997) and Lind *et al.* (1997), showing that effects on the coronary arteries (structures assumed to be arranged serially) were much more serious than the effects on the myocardium and the lungs (these organs being assumed to be largely parallel). The implications of these concepts for recommendations for reporting normal tissue dose are discussed in Section 4.3.4.

2.8 PLANNING ORGAN AT RISK VOLUME (PRV)

As is the case with the Planning Target Volume, any movements of the Organ(s) at Risk during treatment, as well as uncertainties in the set-up during the whole treatment course, must be considered. An integrated margin has to be added to the OAR to compensate for these variations and uncertainties, using the same principles of Internal and Set-up Margins as for the PTV. In particular, Internal and Set-up Margins can be identified. This leads, by analogy with the PTV, to the concept of Planning Organ at Risk Volume (PRV).

For reporting, it is recommended that, as for the PTV, the PRV be described by including the size of the combined margins of the Organ(s) at Risk in different directions.

A margin around an Organ at Risk with a serial structure (*e.g.*, spinal cord) is more critical than one around Organs at Risk with parallel structure (*e.g.*, liver, lung).

Note that the margin around a CTV (*i.e.*, the PTV) and the margin around an OAR (*i.e.*, the PRV) may result in an overlap region. Therefore, they require

careful clinical judgment in the margins' specification to ensure that acceptable toxicity is not exceeded.

2.9 REFERENCE POINTS AND COORDINATE SYSTEMS

To achieve accurate radiation therapy, it must be possible to precisely relate the positions of tissues, organs, or volumes in the patient to the positions and orientations of systems used for both imaging and therapy. This requires defining a number of coordinate systems, some of them related to the patient and others to the imaging units and treatment machines.

The positions of organs, tissues, and treatment-related volumes are related to anatomical Reference Points or alignment marks and the coordinate system within the patient. The positions and orientations of the imaging and treatment machines are defined in coordinate systems related to these machines. The Reference Points serve to link the coordinate systems, since they can be defined in both patient and machine coordinates. The coordinates of the PTV can then be defined in the external coordinate system during dose planning.

2.9.1 Reference Points

Alignment of the patient in a reproducible and stable position is a prerequisite for correct definition of volumes and for the set-up of beams. Adequate patient immobilization systems are the most effective means to accomplish this. Reference Points, either internal or external, or alignment points or lines are then used to establish the patient coordinate system and for reproducible alignment of the patient for imaging or treatment.

Internal Reference Points are anatomical landmarks (*e.g.*, bony structures, gas-filled cavities, and surgical clips) which may be used for localization of the GTV, CTV, and OARs and for accurate set-up of the imaging unit, simulator, and treatment unit. Often separate Reference Points are needed for different beams and if there is more than one GTV or CTV.

External Reference Points are palpable or visible points located on or near the surface of the body or on the surface of immobilization devices that fit closely to the body contour (*e.g.*, face masks, bite blocks, and shells). One may also use skin markings or alignment tattoos that are reproducibly related to the body as a whole (*e.g.*, to skeletal structures).

2.9.2 Coordinate systems

Several types of coordinate systems are encountered in the planning and delivery of the radiation treatment.

VOLUMES

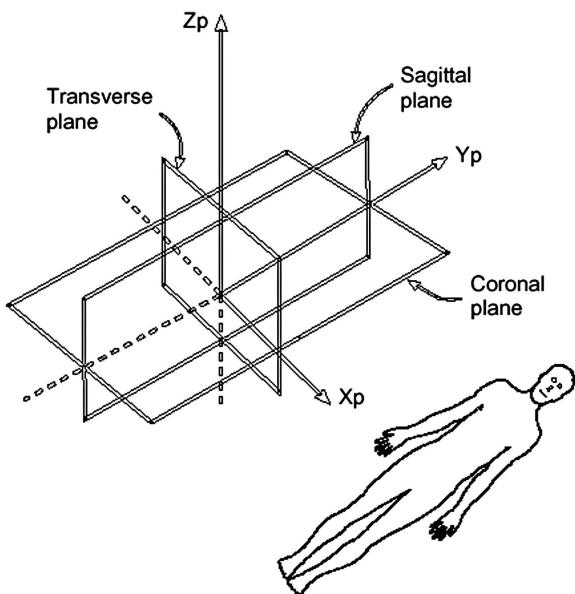


Figure 2.9. The IEC patient coordinate system (the patient is lying in supine position) (IEC, 2000).

2.9.2.1 The patient coordinate system ("p")

The patient coordinate system is defined in relation to the patient's anatomy and selected in relation to internal and/or external Reference Points (ICRU, 1987). Its origin is chosen at a suitable point for the intended treatment site and technique. This point does not need to be *in* or *on* the patient body. For example, if an immobilization device (*e.g.*, a cast) is used, it would be logical to use a point on the cast (or its base if attached to the table top).

The patient coordinate system recommended by the International Electrotechnical Commission (IEC, 2000) is given in Figure 2.9. The coordinate axis X_p is parallel to the intersection of a patient's coronal plane and a transverse plane. The coordinate axis Y_p is parallel to the intersection of a patient's sagittal and coronal planes. The coordinate axis Z_p is parallel to the intersection of a patient's sagittal plane and a transverse plane. The positive X_p axis is orientated to the patient's left, the positive Y_p axis points superiorly within the patient and the positive Z_p axis is directed anteriorly within the patient. The transverse plane is sometimes called the "axial" plane.

The DICOM system (Digital Imaging and Communications in Medicine) includes a different patient coordinate system as shown in Figure 2.10 (DICOM, 1997).

2.9.2.2 Coordinate systems related to the treatment machine ("t") and the imaging units ("i")

For therapy machines, the coordinate systems are defined with respect to the gantry, collimators,

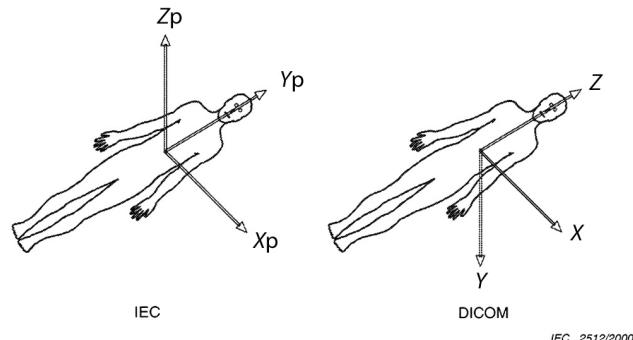


Figure 2.10. Transformation of coordinates between the IEC and DICOM patient coordinate systems (IEC, 2000).

wedges, radiation beam, beam light, laser-alignment beams, and couch-top system. Figure 2.11 shows the coordinate system recommended by IEC (1996) for a therapy machine and patient support. Figure 2.12 shows the coordinate system for an isocentric radiotherapy simulation apparatus and a CT unit. More detailed recommendations are given in IEC Report 1217, in particular concerning the rotations of the coordinate systems (IEC, 1996).

The IEC coordinate systems for the patient and for the therapy machine coincide when the patient is lying in the supine position with the head oriented toward the gantry (IEC, 1996, 2000). Transformations are necessary when the patient is lying in any other position, *e.g.*, in prone position or with the feet oriented toward the gantry arm.

With respect to imaging units, it is logical to have the coordinate system of the simulator identical to the coordinate system of the therapy unit it has to simulate. Different imaging units (CT, MRI, *etc.*) may have other coordinate systems.

Whatever the coordinate systems used for the patient, the therapy machine or the imaging unit(s), the most important issues are (1) to understand all the coordinate systems being used, and (2) to make sure that the transformations between the different coordinate systems occur correctly. All coordinate systems should be accurately related to a fixed reference system. In this respect, Figure 2.13 shows a hierarchical structure among the coordinate systems (IEC, 1996).

Advanced techniques aimed at delivering high doses to small target volumes require accurate patient-beam positioning. This implies reliable correlation between the different coordinate systems and between the patient's internal and external Reference Points. During treatment-planning procedures, displayed images of the irradiated region should be large enough to include internal and external patient Reference Points as well as patient support (table top, immobilization device(s), *etc.*) in order to show the relation to the treatment unit

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

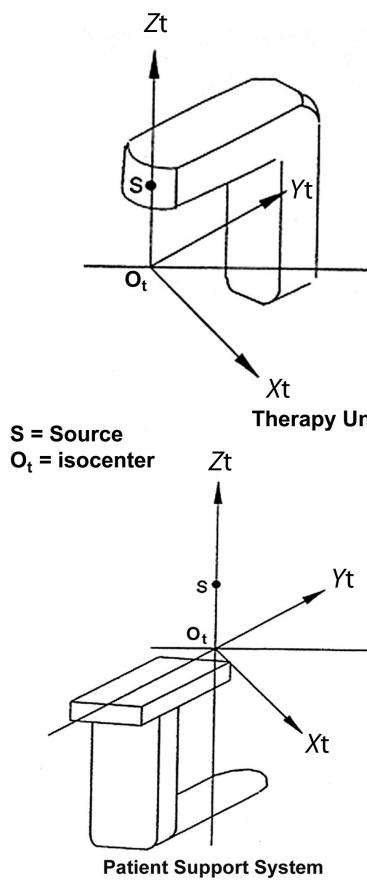


Figure 2.11. Coordinate system for a therapy machine and patient support system (IEC, 1996).

coordinate system. This is particularly important for the evaluation of organ movements in order to select the size of the Internal Margin and for the combination of Internal and Set-up Margins (Section 2.4.3). The relative positions of the internal and external Reference Points must always be traceable.

2.10 RECOMMENDATIONS FOR RECORDING AND REPORTING VOLUMES

2.10.1 Summary of the recommendations

In summary, when recording and reporting a radiation treatment, some important oncological information must be given first, *e.g.*, the description (plural, when relevant) of the:

- Gross Tumor Volume (GTV),
- Clinical Target Volume (CTV), and
- Organ at Risk (OAR).

Then, the information concerning the treatment itself must be given, in particular:

- Planning Target Volume (PTV),
- Treated Volume,

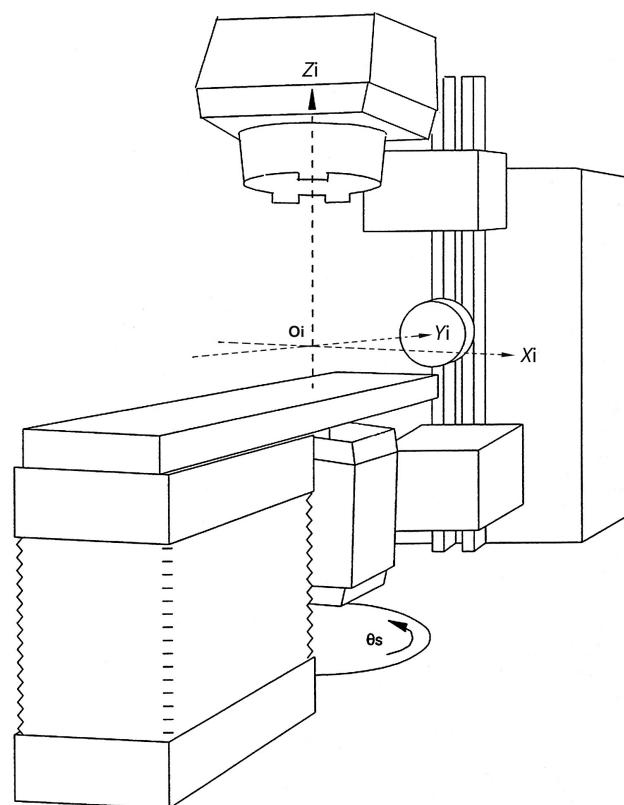


Figure 2.12. Coordinate system for an isocentric radiotherapy simulator (IEC, 1996).

- Irradiated Volume, and
- Planning Organ at Risk Volume (PRV).

The description of the Planning Target Volume is a key point in the description of the treatment. Delination of the Planning Target Volume is always a compromise, implying the judgment, the experience, and thus the responsibility of the radiation oncology team. The different margins that were added or combined as well as the Organs at Risk that were considered when defining the PTV should be clearly described so that the aim of the treatment and the doses that are reported can be understood unambiguously.

Finally, as a general recommendation, any additional relevant information should be reported.

2.10.2 Graphics

It is common practice to mark the position of anatomical structures with different colors to facilitate reading. A frequent example is to depict the tumor in red. In treatment planning, different colors will be used for anatomical structures, "regions of interest," beam geometry, and distribution of absorbed dose. The colors must be easily interpreted.

For the moment, there is no general agreement on the choice of different colors or shades for these

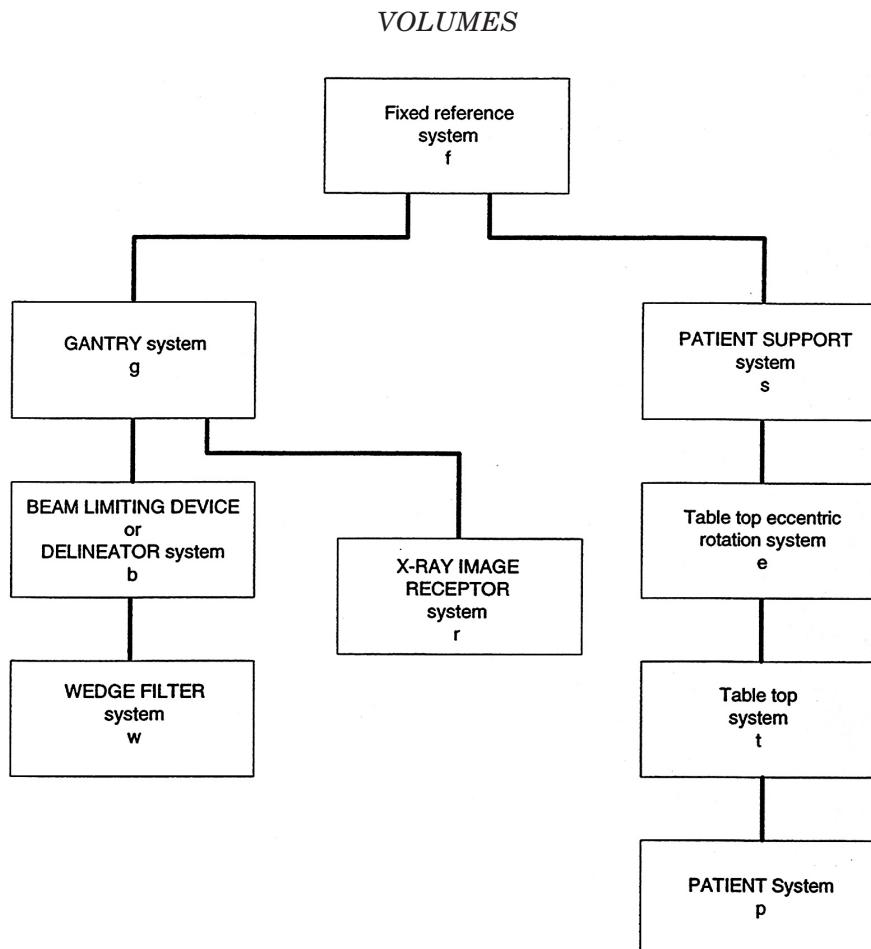


Figure 2.13. Hierarchical structure among coordinate systems (IEC, 1996).

purposes. The ICRU suggests that the following color scheme be adopted:

- GTV: Gross Tumor Volume – dark red
- CTV: Clinical Target Volume – light red
- PTV: Planning Target Volume – light blue
- OAR: Organ at Risk – dark green
- PRV: Planning Organ at Risk Volume – light green
- Landmarks – black

When further OARs are identified, to avoid confusion additional colors can be selected, *e.g.*, yellow or brown (a dark shade indicating the OAR, and the corresponding light shade indicating the PRV).

It is highly desirable that volumes be presented as color surfaces and not just as contours. The manufacturers of treatment-planning systems have an important role to play in the harmonization of volume displays.

In some clinical situations different volumes may overlap. For example, the PTV and even the CTV may overlap with the PRV(s) and even the OAR(s). Under these conditions, if priority is given to treating the whole CTV/PTV, their full dimensions should be represented with the recommended color (light red or light blue, respectively). If priority is given to sparing the OAR/PRV, their full dimensions should be represented in dark or light green, respectively. The full contours of the volumes that are not prioritized may be indicated by dotted lines. Giving priority to treating the whole CTV/PTV or to sparing the OAR is a medical decision that should be clearly stated.

When changing the existing convention in a given department to follow these recommendations, great care should be used to avoid misinterpretation or confusion.

3 PHYSICAL CHARACTERISTICS OF ELECTRON BEAMS

3.1 INTRODUCTION

The principal advantages of high-energy electron beams in radiation therapy rest on two facts. Electron beams are capable of delivering a rather uniform dose to superficial and moderately deep-seated PTVs. This plateau-like region is followed by a rapid dose fall-off. As a result deeper-seated Organs at Risk are not affected.

The depth and size of the PTVs should be accurately evaluated in order to enable the radiation oncologist and physicist team to select the appropriate beam energy to fully exploit the advantages of the electron beam.

Very different dose distributions may be obtained from different accelerators used for electron therapy for the same nominal energy, field size, and source-skin distance (SSD) owing to differences in construction (accelerator type, scattering, and collimation system). There are thus no universal beam characteristics to fully describe electron beams. In spite of this, some general characteristics of the beam can be described to give useful information on the expected dose distribution. A more comprehensive discussion of the physics of electron beams can be found in ICRU Report 35 (ICRU, 1984).

The rapid dose fall-off, and thus the sparing of normal tissues located behind the target volume, is the main advantage of electron beams. However, the slope of the steep dose fall-off is reduced with increasing energy, and the benefit of the fall-off is reduced accordingly. The steepness also depends on the accelerator type and the beam delivery system.

In the region of the depth-dose curve maximum, the dose distribution approximates a plateau. The depth and width of this plateau depend on energy, but its exact shape also varies with the beam delivery system.

Some skin sparing is observed, but its magnitude depends to a large extent on energy and on the beam delivery system. In contrast to the use of photons, the skin sparing decreases with increasing energy, but even at low energies (below about 10 MeV), it is reduced if collimation cones are used. The clinical relevance of the presence or absence of skin sparing depends on the location and extent of the target

volume. There is an obvious advantage of skin sparing when the target volume is located at depth, while less or no skin sparing is an advantage when the target volume includes the skin and subcutaneous tissues. Therefore, before prescribing a treatment and selecting energy and collimation system, a careful evaluation of the expected dose distribution should be made to fit the clinical need.

3.2 ELECTRON ENERGY

ICRU Report 35 describes different energy parameters to characterize the electron beam. The energy of the electrons is a few MeV higher when leaving the accelerator tube than when reaching the patient surface, owing to losses in scattering foils, transmission monitor chambers, air, etc. The energy of the electrons before passing the accelerator tube window has sometimes been reported. However, in radiotherapy, the electron energy at the patient (phantom) surface is of more interest because it is related to the range of the electrons in tissues.

The electrons incident on the patient have a distribution both in energy and in angle. Figure 3.1 shows the energy distribution for four different radiotherapy accelerators computed for a 10 cm × 10 cm field size at a source-skin distance (SSD) of 100 cm. The spectra are for planar fluence ϕ_p (see ICRU Report 35) averaged over the entire beam. It is obvious that for some types of accelerator the contamination by low-energy electrons is considerable (Brahme and Svensson, 1996a). Significant differences in the dose distribution may be observed when comparing either beams with the same most probable (modal) energy $E_{p,0}$ or beams with the same mean energy \bar{E}_0 at the phantom surface. Figure 3.2 compares the depth-dose distributions for two beams with the same modal energy at the phantom surface ($E_{p,0} = 20$ MeV).

3.3 PRACTICAL RANGE, R_p

The modal energy at the phantom surface ($E_{p,0}$) is related to the practical range R_p (Figure 3.2). The quantity R_p is defined as the point at which the tangent at the steepest point (the inflection point)

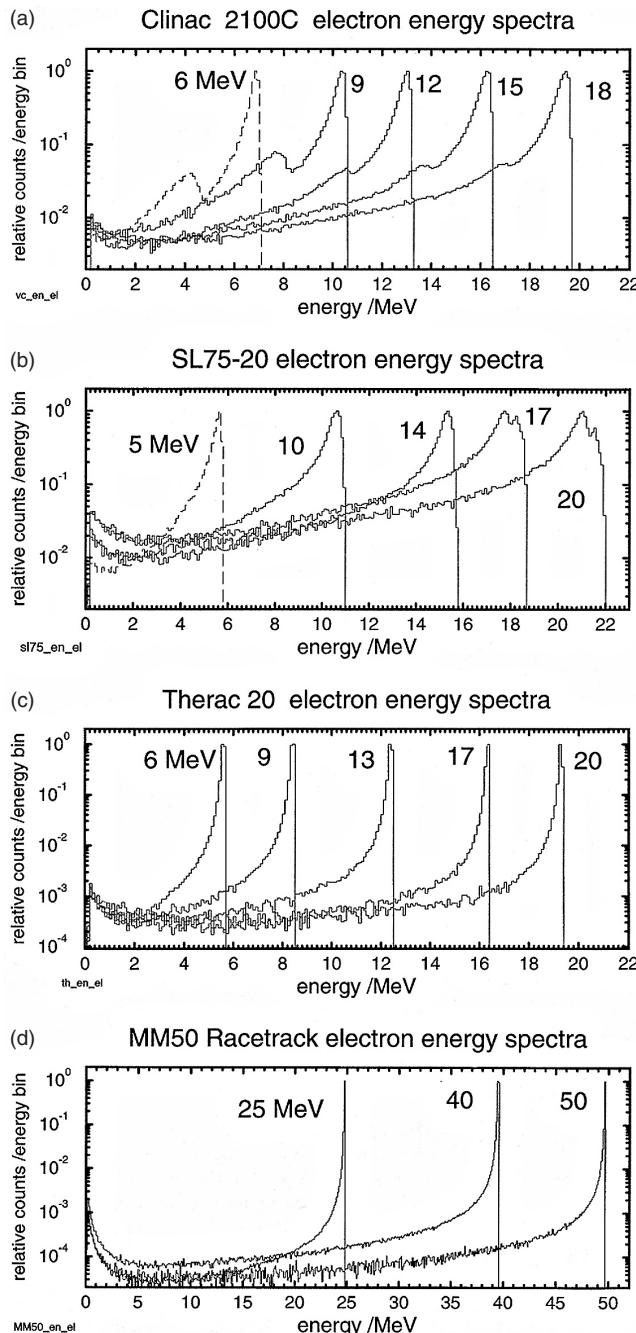


Figure 3.1. Electron energy spectra at an SSD of 100 cm and a field size of $10\text{ cm} \times 10\text{ cm}$ for four accelerators. These spectra result from a full electron transport calculation using a complete model of the devices (Rogers *et al.*, 1995). For each calculation, monoenergetic electrons were assumed to exit the accelerator and were then transported. (a) and (b) used a conventional foil scattering system to spread the beam and an applicator to help achieve uniformity. (c) and (d) used scanned beams and no foils nor applicators. In all cases, a logarithmic scale is used for the ordinate to illustrate the differences in the energy spectra.

on the almost straight descending portion of the depth-dose curve meets the extrapolated bremsstrahlung background (D_x). The dose to tissues beyond the practical range is small and generally of little

significance in radiotherapy (except in some whole-body skin irradiations).

When comparing beams with the same modal energy, differences may still be observed in the shape of the treated volume. The relationship between the practical range R_p and the modal energy $E_{p,0}$ is given by the formula

$$E_{p,0} = C_1 + C_2 R_p + C_3 R_p^2,$$

with $C_1 = 0.22\text{ MeV}$, $C_2 = 1.98\text{ MeV cm}^{-1}$, $C_3 = 0.0025\text{ MeV cm}^{-2}$.

This relationship is valid for a broad parallel beam incident perpendicularly to a water phantom and can be used in the energy range 1–50 MeV (IAEA, 1987; ICRU, 1984).

The criteria for a broad beam are reached when the central-axis depth-dose distribution can be considered independent of the field size when the field size is further increased (see Section 3.4). Therefore, it is recommended that field sizes of at least $12\text{ cm} \times 12\text{ cm}$ are used up to 15 MeV and at least $20\text{ cm} \times 20\text{ cm}$ for higher energies when determining R_p (IAEA, 1997).

For practical reasons, R_p measurements are generally carried out using an SSD of 100 cm. Neglecting corrections for divergence and also corrections for variations of water-to-air stopping-power ratios (when an ionization chamber is used as the detector) would result in only minor errors in R_p . The error in R_p increases with energy: for example, the difference between values of R_p measured including or neglecting the corrections above at $E_{p,0} = 45\text{ MeV}$ would be in the order of 2 mm (Sorcini *et al.*, 1995).

For practical applications, it is useful to note that the numerical value of $E_{p,0}$ (in MeV) is, within a few percent, twice the numerical value of R_p (in cm) in water.

Similar relations between $E_{p,0}$ and R_p are also available for other phantom materials (e.g., plastics), which might be of interest for measurements (Sorcini *et al.*, 1995).

For dosimetry purposes, the mean energy at the phantom surface, \bar{E}_0 , is more relevant than $E_{p,0}$, for instance in the choice of interaction coefficients for absorbed-dose determinations when ionization chambers are used. The quantity \bar{E}_0 is indeed related to the half-value depth in water, R_{50} , as shown in Figure 3.2. The quantity R_{50} should be measured from depth-dose distributions with a constant source–chamber distance using broad beams. When depth-ionization curves are used at a constant SSD, corrections for variations in stopping-power ratios with depth must be made (IAEA, 1997).

For electron beams produced by medical accelerators in the energy range 5–30 MeV, a ratio

PHYSICAL CHARACTERISTICS OF ELECTRON BEAMS

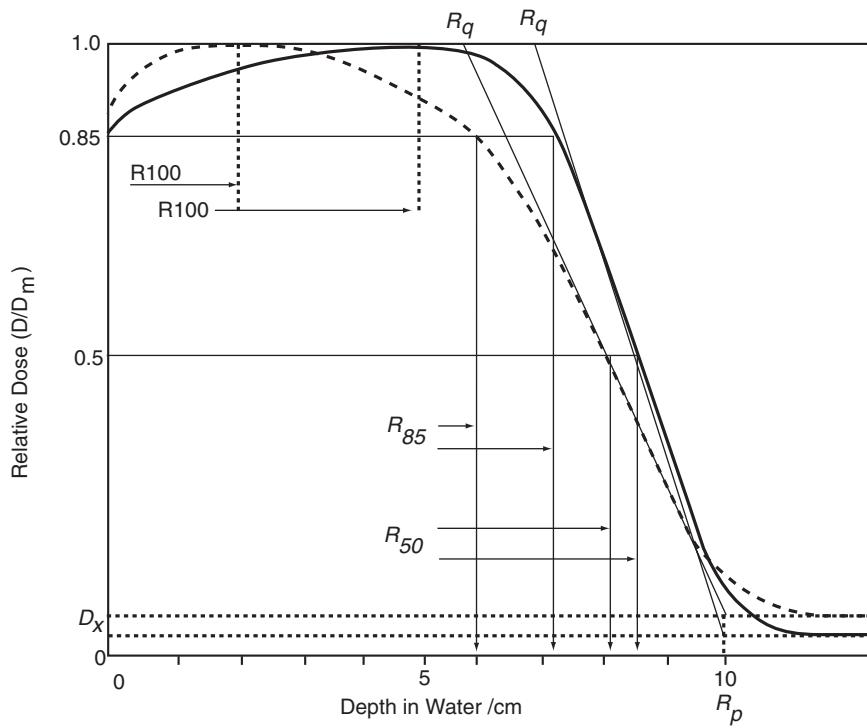


Figure 3.2. Absorbed-dose versus depth distributions for two different electron therapy accelerators with the same modal energy at the phantom surface ($E_{p,0} = 20$ MeV). Nominal SSD = 100 cm was used; the field size was 15 cm × 15 cm. Further increase in the field size does not change the central-axis depth-dose distribution, since these beams are broad by definition. The practical range R_p is the same (10 cm), but all other parameters differ. D_s is the surface dose measured at 0.5 mm depth, D_x the absorbed dose due to the bremsstrahlung background, D_m the maximum absorbed dose, R_{100} the depth of the dose maximum. R_{85} is the therapeutic range if the therapeutic dose level has been taken as 85 percent, R_{50} the half-value depth, and R_q the depth where the tangent at the steepest point intersects the dose level D_m . The depths of the R_{85} differ by 1.3 cm and the depths of the R_{50} differ by 0.5 cm. The curves are redrawn from Brahme and Svensson (1979). The broken curve is for a linear accelerator with an electron spectrum as shown in Fig. 3.1b. The solid line is a distribution for a scanning-beam linear accelerator (Fig. 3.1c). This latter curve also closely coincides with a distribution measured for a microtron using a double foil scattering system.

$C_4 = 2.33$ MeV cm⁻¹, relating the mean electron energy \bar{E}_0 and R_{50} , was measured by Brahme and Svensson (1976a). This value has been used in several dosimetry protocols (AAPM, 1991; IAEA, 1987, 1997; NACP, 1980). Recent Monte Carlo computations simulating beams from conventional accelerators show that the 2.33 approximation is adequate, at least in the most commonly used energy region below about 20 MeV (Udale-Smith, 1992).

However, a somewhat different result is obtained for monoenergetic beams. For the energy range from 5 to 50 MeV, values of C_4 between about 2.34 and 2.56 MeV cm⁻¹, with the minimum at an energy of 20 MeV, were determined using code EGS4 (Rogers and Bielajew, 1986) and ITS3 (Andreo, 1993). These data agree with experimental values for a very clean beam (Karlsson *et al.*, 1992).

The value of $C_4 = 2.33$ MeV cm⁻¹ for the ratio \bar{E}_0/R_{50} can thus be used in most practical situations in electron-beam dosimetry and is recommended in this Report.

3.4 THERAPEUTIC RANGE

Unfortunately, neither $E_{p,0}$ nor \bar{E}_0 is closely related to characteristics of the first part of the central-axis depth-dose curve. It was therefore recommended in ICRU Report 35 that a range parameter indicating the useful treatment depth should be determined. The therapeutic range R_t is the depth, on the beam axis, of a given isodose relevant for the treatment (*e.g.*, R_{95} , R_{90} , R_{85}). Isodose levels such as 95, 90, or 85 percent are usually selected.

As an example of the need for a concept such as R_t , depth-dose distributions are shown for two different commercial accelerators in Figure 3.2 (15 cm × 15 cm, SSD = 100 cm). The practical range is the same for the two beams, and they have, therefore, approximately the same most probable energy at the phantom surface. However, all other depth-dose characteristics differ, *e.g.*, R_{85} by 1.3 cm and R_{50} by 0.5 cm.

The distributions in Figure 3.2 are for broad beams. For low electron energies, central-axis

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

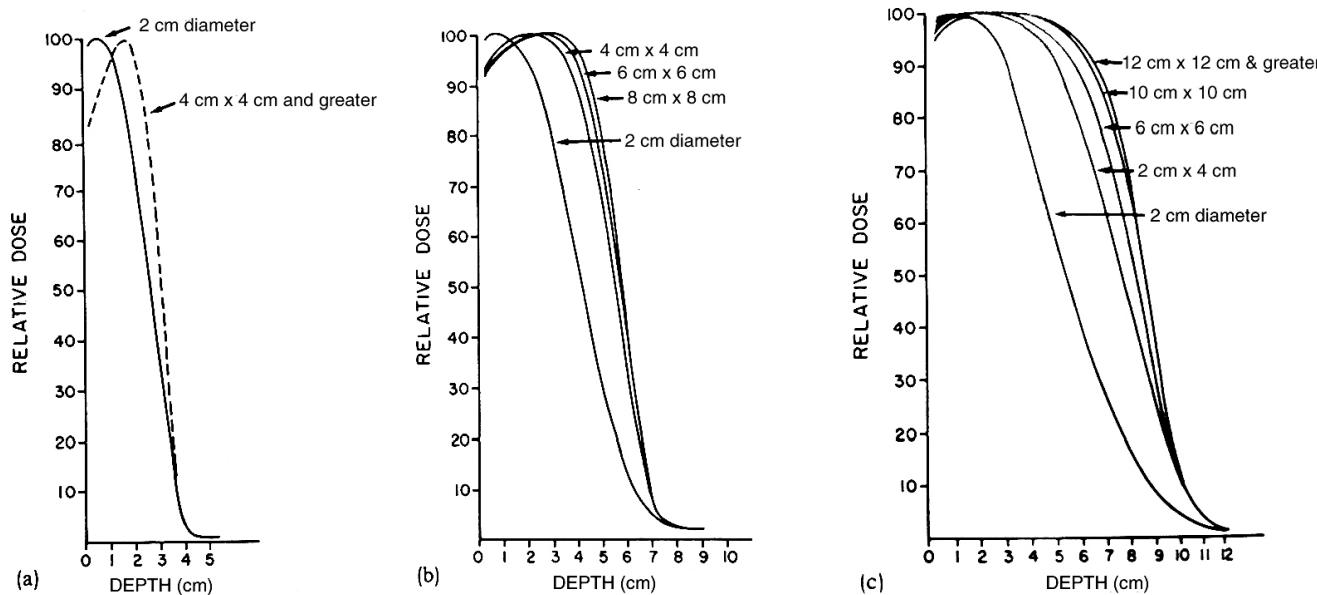


Figure 3.3. The effect of field size on central-axis depth-dose curves, measured with diodes in water, 100 cm SSD. (a) 7 MeV, (b) 13 MeV, and (c) 20 MeV (from George *et al.*, 1986).

depth-dose distributions representative for broad beams may be obtained with fairly small beam sizes. From Figure 3.3 it can be seen that at 7 MeV the same curves are obtained for $4 \text{ cm} \times 4 \text{ cm}$ field sizes or larger, and at 20 MeV for about $12 \text{ cm} \times 12 \text{ cm}$ or larger. Theoretical data by Lax and Brahme (1985) indicate that for field sizes with a diameter larger than the value of R_p the curves represent the broad-beam situation.

It must be stressed that R_t is a value determined on the central axis, but that the isodose lines are rounded and might cover a much smaller depth close to the field borders. Data on R_t should be determined as a function of the field size for each accelerator, as these data are very critically dependent on the construction of the accelerator.

The dose variation at the surface within the first millimeters has to be determined to ensure adequate coverage of the most superficial part of the PTV.

3.5 X-RAY BACKGROUND

The electron beam is always to some degree contaminated with x rays (bremsstrahlung) generated in the accelerator tube window, scattering foils, monitors, etc. In addition, x rays are generated in the water phantom or in the patient. The absorbed dose attributed to the x-ray background is indicated by D_x in Figure 3.2.

The proportion of x rays generated in the phantom increases with energy and is about 6 percent of the dose D_m at 50 MeV. For most accelerators D_x is between 1 and 6 percent of D_m for electron beams

with $E_{p,0} \leq 25 \text{ MeV}$. For most treatments this dose is far below tolerance level for Organs at Risk. However, the x-ray dose might be of significance when total-skin irradiations are performed, because the x rays give a dose to the whole body (Section 6.2).

3.6 DOSE GRADIENT

In some treatment situations it is very important to have a rapid dose fall-off. A normalized absorbed-dose gradient, G , was therefore recommended as a measure of the fall-off (Brahme and Svensson, 1976a, 1979; ICRU, 1984):

$$G = \left| \frac{dD}{dz} \right|_{\max} \cdot \frac{R_p}{D_m - D_x},$$

where $|dD/dz|_{\max}$ is the gradient at the depth of the steepest fall-off of the central-axis depth-dose distribution, R_p is the practical range, D_m the maximum absorbed dose, and D_x the x-ray background along the central axis.

The quantity G can be determined as the ratio $R_p/(R_p - R_q)$, where R_p is the practical range and R_q is the depth at which the tangent at the steepest point (the inflection point) intersects with the dose level D_m (Figure 3.2).

The normalized dose gradients for the two distributions shown in Figure 3.2 are $G = 2.5$ and 3.3 . The lower value ($G = 2.5$) is typical for most accelerators, while the higher value ($G = 3.3$) is observed for an accelerator with optimized design of the treatment head. Values for several types of accelerator have been reported by Jamshidi *et al.* (1987). A dose

PHYSICAL CHARACTERISTICS OF ELECTRON BEAMS

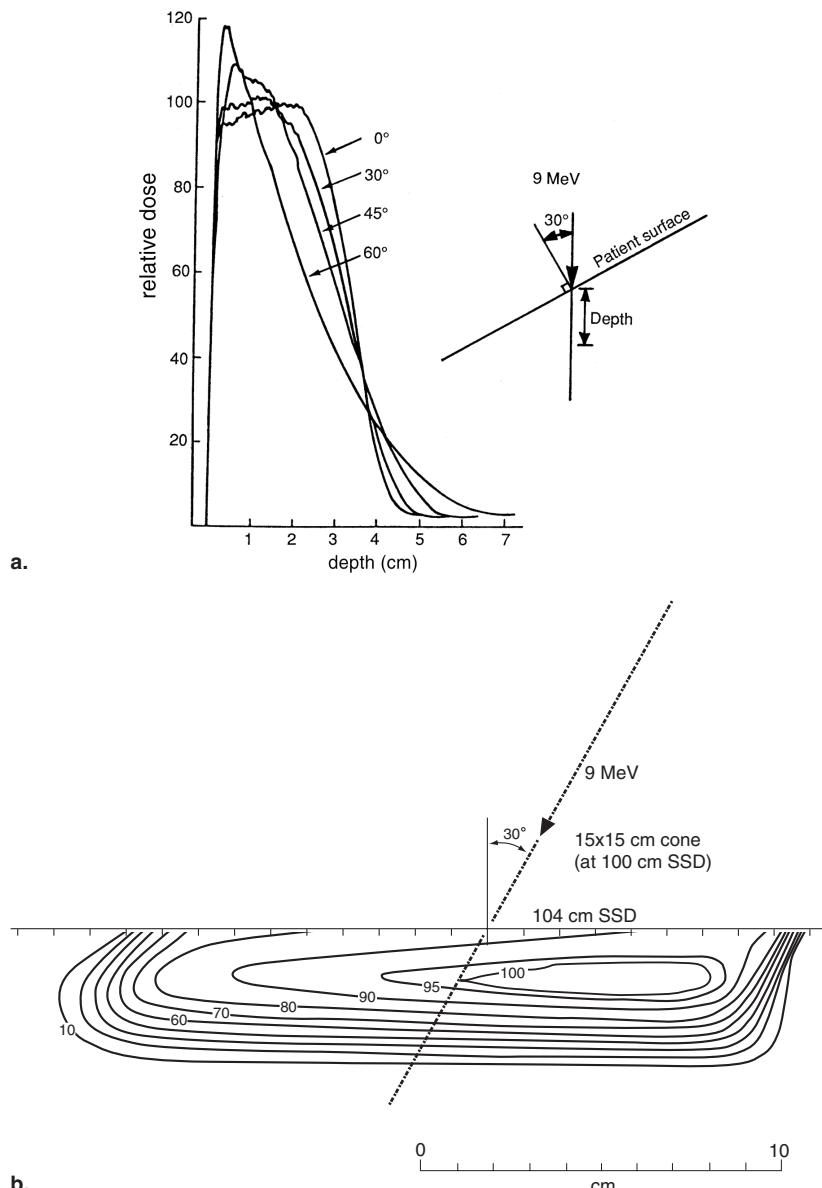


Figure 3.4. The effect of obliquity. (a) Central-axis depth-dose distributions of a 9-MeV electron beam for different angles of obliquity but at the same SSD (from Ekstrand and Dixon, 1982). (b) Isodose curves resulting from a 9-MeV electron beam, 15 cm × 15 cm. The central-axis depth dose is similar to that in Fig. 3.4a. (From Hogstrom, 1991.)

gradient below about 2.3 for broad beams in the energy range from 5 to 30 MeV indicates that the flattening and collimating system is of poor design and that unnecessarily large volumes of normal tissue are irradiated in a single-beam technique (ICRU, 1984; NACP, 1980). The dose gradient decreases for small field sizes (*i.e.*, diameters smaller than R_p), which reduces the attractiveness of such beams (Figure 3.3).

3.7 OBLIQUE BEAM INCIDENCE

When an electron beam is incident obliquely with respect to the surface, the central-axis depth dose

will change. In Figure 3.4a, it is seen that the change can be fairly large and it results can include (1) an increased surface dose, (2) an increased dose at the maximum along the beam axis, (3) a decreased penetration of the therapeutic depth dose, and (4) an increased range of penetration of a low-dose component (below about the 30 percent depth dose in Figure 3.4a) (Ekstrand and Dixon, 1982).

Figure 3.4b shows an isodose distribution for a beam with an angle of incidence of 30° (Hogstrom, 1991). The distribution has a “wedge” form, and the penumbra is much larger at the part with the largest distance to the collimator. The obliquity effect is due to scattering of electrons. It manifests itself also

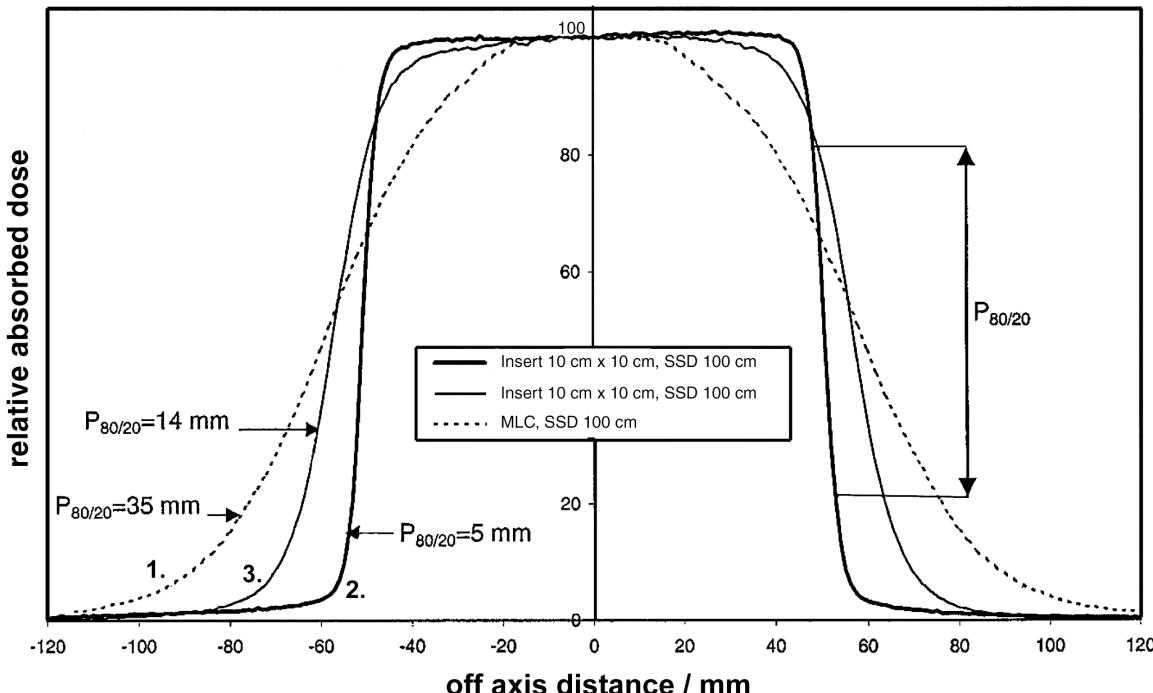


Figure 3.5. Dose distributions perpendicular to the beam axis at 15 mm depth at $E_{p,0} = 9$ MeV using a Varian Clinac 2300. Curve 1 is without the collimating cone, using the photon diaphragms as the only collimation. Curve 2 shows the distribution with the standard cone and distance to the patient, *i.e.*, 5 cm from the cone. Curve 3 shows the distribution with the cone 15 cm from the patient.

when the beam is incident on a curved surface such as the chest wall. Generally, it is a good procedure to avoid large angles of incidence for electron beams, as the depth-dose distribution in most cases is then less useful and, furthermore, is difficult to compute.

3.8 COLLIMATION

The electron beam is generally collimated with external applicators. These need to be placed either directly on the skin or close to the skin to achieve acceptable flatness of the beams. Figure 3.5 shows that the collimator often is an essential part of the scattering system, which influences the flatness. Thus, without the collimating cone, using the photon diaphragms as the only collimation results in a very large penumbra; 35 mm in Figure 3.5, curve 1. The penumbra ($P_{80/20}$) is defined in accordance with ICRU Report 35 (ICRU, 1984), *i.e.*, as the distance between the 80 percent and the 20 percent isodose lines, here determined at the depth of dose maximum. Curve 2 shows the distribution with the standard cone 5 cm from the phantom: $P_{80/20} = 5$ mm. From a practical point of view, a larger distance between the collimator and the patient is often preferable; otherwise the collimator (applicator) might collide with the shoulder of the patient when tumors in the neck region are to be treated. Unfortunately, the penumbra increases rapidly with the distance

between the applicator and the patient. This is due to the broad angular distribution of electrons leaving the exit of the accelerator head. Curve 3 shows the distribution with the cone 15 cm from the phantom: $P_{80/20} = 14$ mm.

A large set of cone sizes or applicators are needed with conventional accelerators to make the different rectangular and circular fields required in treatments. Some accelerators are equipped with variable electron collimators. Special moulding techniques are also in use to create irregular field sizes. The flatness of the dose distribution and the penumbra will be very much influenced by the collimating technique in use (Brahme and Svensson, 1976b).

3.9 EFFECTS OF HETEROGENEITIES

In routine radiation therapy, information on dose distributions for complicated irradiation geometries such as oblique incidence, irregular field shapes, presence of irregular surfaces, and internal heterogeneities is often needed. Dose-planning systems involve programs that make it possible to compute such distributions based on input from measurements in some reference geometries. The accuracy of the computed distributions is generally dependent on the complexity of the irradiation geometry. Figure 3.6 shows a comparison between computed and measured distributions in a realistic phantom

PHYSICAL CHARACTERISTICS OF ELECTRON BEAMS

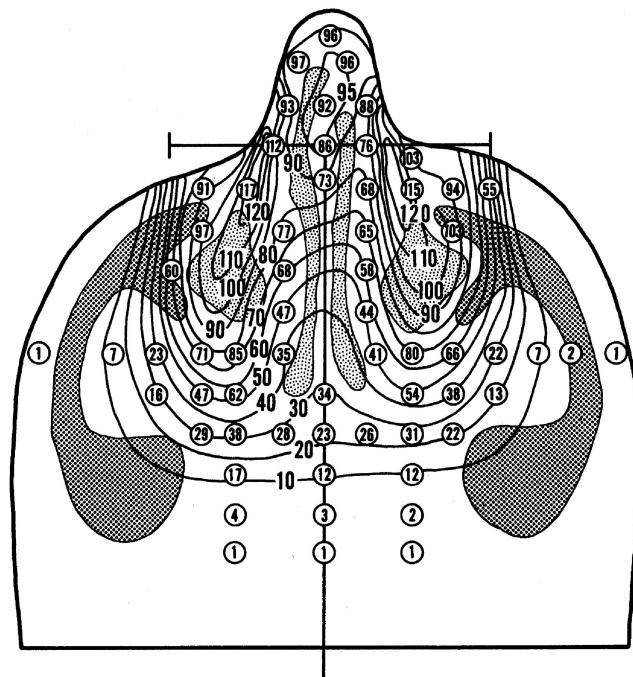


Figure 3.6. Dose distribution measured in a phantom fabricated from tissue-substitute materials having a cross-section designed from a CT scan. Numbers encircled denote doses measured by thermoluminescence dosimetry to an accuracy of approximately 2 percent. Solid lines represent dose calculations using a pencil beam algorithm. In the nasal septum, note the dose of 86 percent, which is 13 percent lower than that expected based upon its depth. The difference is due to lack of materials lateral to the nose and air passages in the nasal septum lacking material to scatter the electrons back into the septum. (From Hogstrom, 1991.)

including both surface irregularities and inhomogeneities. The agreement is quite satisfactory. The dose value in this phantom at the depth corresponding to dose maximum in a uniform water phantom is 86 percent, *i.e.*, 13 percent lower than would be calculated without considering inhomogeneities.

Using modern planning systems, it is possible to compute the dose distribution with acceptable accuracy. However, a different issue is the clinical acceptability of the perturbation in the dose distribution due to heterogeneity. In Figure 3.7, a method is shown to decrease such dose variations by using several angles of incidence for the electron beam (Zackrisson and Karlsson, 1996).

3.10 DEVELOPMENTS IN ELECTRON BEAM THERAPY

3.10.1 Overview

In today's practice, electrons are mainly used for treatment of tumors extending from or just below the tissue surface to generally no more than 5–8 cm in depth. The reason for the use of electrons is the

pattern of dose distribution: a fairly uniform dose to a certain depth followed by a rapid fall-off. There are a number of clinical situations in which this is a definite advantage.

Despite this, electrons are generally used in only a small percentage of all radiation treatment courses: $\leq 10\text{--}15$ percent of the total number of treatments. Several technical limitations could explain this:

- Irregular field shapes are laborious to set up, since special applicators, tubes, or molding devices must be used and dose distributions must be determined for these special irradiation geometries.
- There are difficulties in using adjacent electron and photon beams, or adjacent electron beams of different energies, as the applicators have to be changed and the patient has to be repositioned between the different irradiations.
- Dose determination and computation could be a problem, especially when heterogeneities are present and when different tissues are irradiated and inhomogeneous dose distributions are produced by differences in scattering.

At least some of these limitations may be overcome with further development of electron therapy units and treatment-planning systems.

Intensity-modulated radiation therapy (IMRT) with photon beams is developing rapidly. IMRT with multiple electron beams directed toward the target did not lead to improvements of the same magnitude as did photon IMRT (Korevaar, 2000). However, in applications where the tumor is irradiated from one direction, significantly improved dose distributions can be achieved. Further, the penumbra could be sharpened by combining a photon and an electron beam. A steep dose fall-off could also be achieved with a flat beam profile (Korevaar *et al.*, 1998, 1999).

3.10.2 Electron beam energy

For conventional treatment units, the depth of R_{80} (in cm) is equal to roughly one third of the value $E_{p,0}$ (in MeV) (Hogstrom, 1991). Improved construction of the treatment unit, in particular of the scattering systems and collimators, may result in a large uniform dose plateau and in an increase of the depth of R_{90} to one third of the value of $E_{p,0}$, (Figure 3.8) (Zackrisson and Karlsson, 1996). These approximations can be used for large fields up to $E_{p,0} = 25$ MeV. A further increase in the energy only modestly increases the depth of the plateau. Most manufacturers of electron accelerators therefore do not provide accelerators with energies higher than $E_{p,0} = 25$ MeV. Fairly compact linear accelerators can be

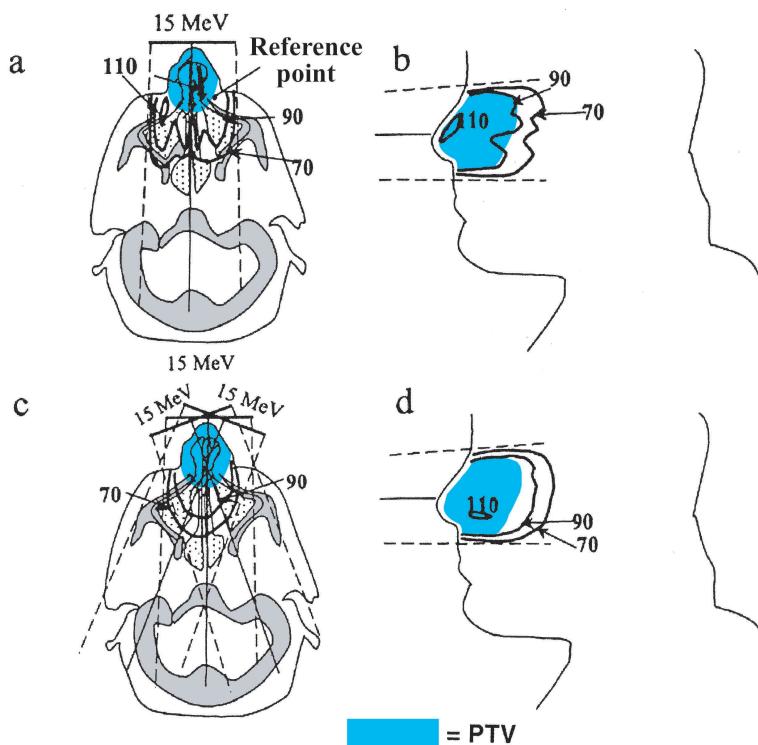


Figure 3.7. Electron treatment for carcinoma of the nasal antrum. (a,b) Absorbed-dose distribution of 15 MeV electrons from a single anterior portal in the nose region. Two hot spots are seen. (c,d) The same case with two additional portals with 20° angles from the vertical plane. The dose at the ICRU Reference Point is taken as 100 percent. The isodoses for 110, 90, and 70 percent are displayed. (Redrawn from Zackrisson and Karlsson, 1996.)

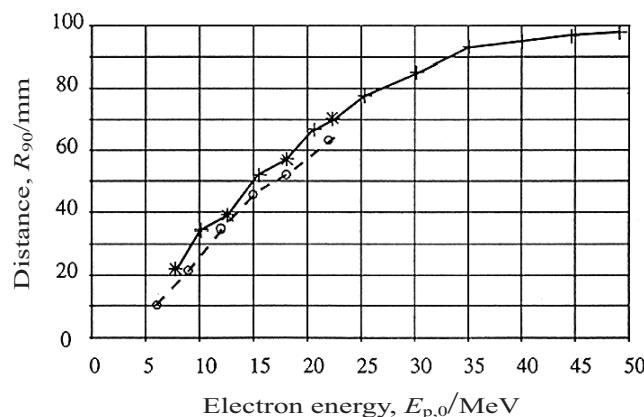


Figure 3.8. The R_{90} , as a function of electron energy, compared for an almost monoenergetic electron beam (—) and for a more conventional therapy beam (---) (modified from Zackrisson and Karlsson, 1996).

designed for this maximum energy, but their complexity would be significantly increased at higher energies.

Energies higher than $E_{p,0} = 25$ MeV, up to 40–45 MeV, were obtained with betatrons in the 1960s and 1970s. More deeply seated tumors were then irradiated, sometimes with opposed electron beams. However, these beams were generally not very uniform (Svensson and Hettinger, 1971), and dose computation and measurements were at that time less

certain. In addition, collimation for these electron energies becomes more challenging.

High-energy electrons with energies up to 50 MeV or above may, however, again be of interest, since very uniform electron beams can be obtained using a scanning-beam system and leaf collimators to define the field shape. Such beams, alone or mixed with photon beams, could then in some cases replace pure photon beams for treatment of medium- or deep-seated tumors (Karlsson *et al.*, 1988, 1992).

3.10.3 Collimation

Collimation and flattening of electron beams raise difficult problems. Improved beams can be obtained, but at the price of rather sophisticated technical solutions. Actually, manufacturers have often chosen a compromise. The main types of flattening and collimating systems are compared in Figure 3.9.

- (a) *A single flattening foil is used.* The scattering in the photon collimator, in the tube walls, etc., is considerable, resulting in large energy and angular spread of the electrons at the treatment distance.
- (b) *Two separate scattering foils are used and an applicator is constructed to trap the electrons with large scattering angles.* The field size and

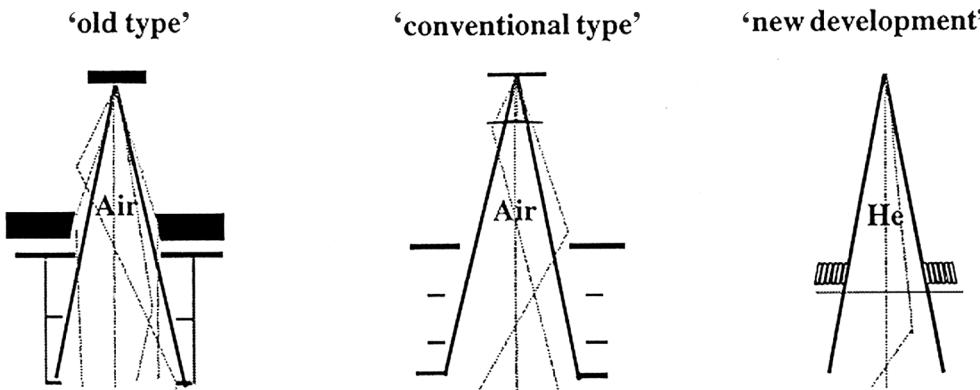


Figure 3.9. Different types of collimating and scattering systems in use for electron beams. The “old type” uses one scattering foil, often of different thickness and material for various energies, and a tube collimator which must be set close to the patient. The “conventional type” uses two scattering foils. Each of them could be changed, and they are optimized for different energies. The applicator close to the patient traps large-angle electrons. The “new development” uses a scanning beam and a leaf collimator for shaping both electron and photon beams. Air is replaced with helium to reduce the scattering material to a minimum. SSD = 100 cm is used both for photon and electron beams, which simplifies patient set-up. (Zackrisson and Karlsson, 1996.)

shape is determined by the size and shape of the distal part of the applicator, close to the patient. The energy and angular spread is reduced somewhat compared with (a). The patient must, in these two cases, be close to the collimating devices.

- (c) A *multi-leaf collimator (also in use for photon beams) combined with scanning beams defines the field shape at some distance from the patient.* In this case, a minimum of scattering material in the treatment head is a prerequisite to obtain a uniform beam. This is achieved by using a scanning-beam system instead of scattering foils, replacing the air in the accelerator with helium, and reducing to a minimum the amount of materials in the transmission chambers.

It has been shown that replacement of air with helium only, at least for one type of accelerator, reduced the penumbra $P_{80/20}$ by about 40 percent, e.g., from 14 to 8 mm for a 20 MeV beam at 1 cm in depth. This penumbra width is the same as for most photon beams (Karlsson *et al.*, 1992).

A further advantage of collimation system (c) is that the same SSD and multi-leaf collimator could therefore be used for both electron and photon beams, and it is possible to irradiate one part of the field with electrons and another part of the field with photons or with electrons of different energies. During the whole irradiation procedure the patient is not moved. An example is shown in Figure 3.10.

Electron beams produced according to method (c) have a depth-distribution shape similar to that calculated for monoenergetic and nearly monodirectional beams. The relative surface dose for such

beams is fairly low and decreases when energy decreases (e.g., about 80 percent at 20 MeV and 70 percent at 10 MeV) (ICRU, 1984). This might sometimes be an advantage, but is a disadvantage if one intends to irradiate superficial targets. In such cases, the problem can be avoided by choosing a higher energy with bolus.

3.10.4 Three-dimensional dose computation and treatment planning

Calculation of an electron dose in a patient is a difficult problem due to scatter in the different tissues, surface irregularities, and inhomogeneities. As will be seen in what follows the uncertainty in dose calculation with electron beams has been one reason for preferring photon beams in cases in which electrons could have given favorable dose distributions. In the mid-1970s Kawachi (1975) presented a pencil beam algorithm based on the age-diffusion equation, and a few years later Hogstrom *et al.* (1981) and Werner *et al.* (1982) independently developed a pencil beam model based on the Fermi-Eyges small-angle scattering theory. This algorithm has come to be called the “Hogstrom Algorithm.”

The model was originally implemented two-dimensionally. Variations in tissue density outside the plane of calculation (the CT slice) were assumed to be the same as in the plane of calculation. Therefore, the accuracy was reduced near local heterogeneities (Lax, 1987). The major reason for inaccuracies was therefore the two-dimensional approach where only one CT slice was used as input data.

Improved results have been obtained with the three-dimensional implementation of the Hogstrom

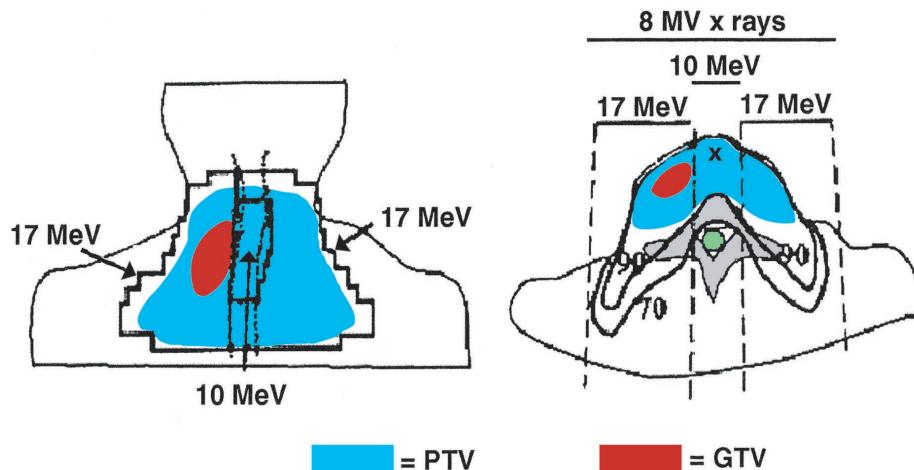


Figure 3.10. Field arrangement for multi-segmented treatment of a patient with thyroid carcinoma using a multi-leaf collimator. The central part of the PTV was treated with one 10-MeV electron beam, and the other parts of the PTV with two 17-MeV electron beams. An additional field with 8-MV x rays covering the same volume improves skin sparing. Note that the patient is not moved because the multi-leaf collimator is used for both the photon and the electron beams. (Redrawn from Zackrisson and Karlsson, 1996.)

Algorithm, which takes into account electron scattering between slices. There were, however, many approximations in the algorithm. For example, it was generally assumed that the central ray of each pencil beam passed through materials of infinite lateral extent; this assumption is called the semi-infinite slab approximation. However, methods using concepts other than the slab approximation have also been developed (Huizenga and Storchi, 1989; Yu *et al.*, 1988).

The manufacturers of dose-planning systems generally need several years to implement new algorithms in commercial systems. Commercial systems in use today therefore include different versions of

algorithms, but continuous improvements are made. Parameters used in these algorithms are often obtained or checked by Monte Carlo calculations (Lax and Brahme, 1985).

All approximations made in these systems are generally not known by the user. Several different checks of the local system based on dose measurements in tissue-equivalent phantoms, simulating typical radiotherapy cases, are therefore needed (AAPM, 1998). Such tests performed with the most advanced three-dimensional systems presently available often reveal deviations, at least when extreme heterogeneities are introduced (Blomquist *et al.*, 1996).

4 GENERAL RECOMMENDATIONS FOR PRESCRIBING, RECORDING, AND REPORTING EXTERNAL-BEAM THERAPY

Before presenting the specific recommendations for prescribing, recording, and reporting electron-beam therapy in Section 5, some general recommendations for prescribing, recording, and reporting external beam therapy are presented in this Section.

In order to emphasize the consistency of the ICRU recommendations for reporting external-beam therapy, some of the material previously published in ICRU Report 62 is repeated here. For some items, useful clarification is added.

4.1 FROM PRESCRIBING TO RECORDING AND REPORTING

4.1.1 Prescribing the treatment

The prescription of a treatment is the responsibility of the radiation oncology team in charge of the patient. It is not the purpose of this Report (nor the role of the ICRU) to make recommendations about treatment prescription, *i.e.*, about general approaches for prescription, dose level, beam arrangement, or other technical aspects of the treatment.

Historically, radiation treatments have been prescribed in different ways, and indeed different approaches are currently in use in different centers, as described in Sections 4.1.1.1–4.1.1.3.

4.1.1.1 Approach based on central Reference Point

- (1) In this approach, the dose is prescribed at a selected Reference Point, located in the center (or in the central part) of the PTV. It is the ICRU Reference Point (see Section 4.3.2).
- (2) In addition, limits for dose variation within the PTV are prescribed. For photons it is recommended that they should not exceed +7–5 percent of the dose at the Reference Point (in some cases ±10 percent must be accepted). For electrons a dose variation smaller than ±10 percent is generally acceptable.

The accepted dose variations are sometimes not formally stated, but it is then implicitly assumed

that the best possible homogeneity in the PTV should be aimed at. However, the accepted dose variation throughout the PTV should be stated. If this is not the case, the treated volume cannot be defined and thus the conformity index (CI) cannot be evaluated.

- (3) Specification of the Time Dose Pattern is part of the treatment prescription.
- (4) The accepted dose limits to the Organs at Risk are also part of the treatment prescription.

All information required to report the treatment according to the ICRU recommendations is thus available.

4.1.1.2 Approach based on specification of a dose range within the PTV

This second approach for prescribing the treatment is to specify that all points within the PTV should receive a dose within stated limits.

The difference from the first approach is that there is no selected (Reference) Point where the dose is prescribed. The other aspects of the prescription, *i.e.*, dose limits to the Organs at Risk, as well as time-dose pattern, are taken into account in the same way as in approach 4.1.1.1.

4.1.1.3 Approach based on minimum dose to the PTV

A third approach for prescribing the treatment is to prescribe the minimum dose to the PTV. It is often taken as the dose on the envelope surface encompassing the PTV. However, this may overlook the presence of cold spots within the PTV, *e.g.*, in AP/PA photon treatments. This approach has several shortcomings.

- (1) Most of the tissues enclosed in the envelope surface receive higher doses (often +10 percent or even +20 percent higher) than the prescribed dose. One has to keep this fact in mind when deriving dose-effect relations, because it could lead to inaccurate conclusions.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

- (2) There could be some critical normal structures enclosed in the envelope surface that would receive doses higher than the prescribed dose. This could lead to inadvertent overdosage.
- (3) Not all information required for reporting is available.

4.1.2 Reporting the treatment

In contrast to the prescription, the reporting of treatments must be done in an uniform way, for all patients within each department and in all centers, using uniform approaches and agreed definitions of terms and concepts. If this rule is not followed, any useful exchange of scientific or clinical information between centers becomes difficult or even impossible.

Without modifying the treatment techniques and the dose levels currently delivered in the different centers, adopting the same concepts and definitions for both prescribing and reporting makes the procedures easier and reduces the risks of confusion.

4.1.3 Recording the treatment parameters

It is recommended that the same concepts and definitions used for reporting the treatments should also be used for recording the treatment parameters within each institution (keeping the relevant clinical information for further care and follow-up, exchange of information among the medical, physics, and radiography staff, implementation of a quality assurance program, *etc.*). This would make all tasks easier and would reduce the risk of confusion. Thus, fewer errors should be expected.

4.2 THE THREE LEVELS OF DOSE AND VOLUME EVALUATION FOR REPORTING

The level of completeness and accuracy for reporting a therapeutic irradiation depends to a large extent on the equipment and staffing in a department and on the aim of the treatment (curative or palliative).

Three levels for reporting were identified for photon beam therapy in ICRU Report 62 (ICRU, 1999), but it is recognized that intermediate levels could also be identified. These three levels are also proposed in the present Report for electron beam therapy.

As with photons, for optimal and safe application of electron beam therapy, sufficient medical and physics expertise is necessary, as well as appropriate equipment and technical support.

As for any radiotherapy modality, the techniques are continuously evolving and more sophisticated software and equipment continue to become

commercially available. With time, this may alter the limits between the three levels defined below (see Section 1.4).

4.2.1 Level 1

The requirements for clinical and physics expertise at Level 1 constitute the minimum below which accurate electron beam therapy cannot be performed. These requirements should be followed in all centers and for all patients.

At this level, it is assumed that the maximum dose rate on the electron beam axis and the depth-dose curve have been measured in a homogeneous water phantom with a calibrated dosimeter for the field sizes and collimation conditions used. This information should be derived from direct checks and measurements performed at the accelerator itself.

It is important that the radiation oncology team be aware of the accuracy and limits of validity of their current evaluations and dosimetry. This is especially true when obliquity and heterogeneity corrections have to be applied (see Sections 5.2.4 and 5.2.5) and when small and/or irregular fields are used (see Section 5.2.2).

Even when reporting at Level 1, the irradiation parameters should be recorded as carefully and as completely as possible. This would later allow the re-evaluation of dose distributions in a more precise and complete way, either with the help of another better equipped center or in the department itself if the situation would have been improved by the acquisition of new expertise or equipment.

4.2.2 Level 2

Level 2 corresponds to the state of the art in well staffed and equipped departments; it allows the exchange of more complete and relevant information between different centers.

At Level 2 it is assumed that the GTV, CTV, OAR, PTV, and PRV can be defined using reliable patient data acquisition tools and/or modern imaging techniques (*e.g.*, a series of CT and/or MRI sections). It is also assumed that complete dose distributions are available, with heterogeneity corrections when appropriate. It is recommended that dose-volume histograms (DVHs) be available, preferably in absolute volume values and not only in relative values.

4.2.3 Level 3

Level 3 includes special techniques and developments for which reporting criteria may not yet be established. Some procedures, which are now at Level 3, may become Level 2 with the development of techniques, equipment, and standards.

GENERAL RECOMMENDATIONS FOR PRESCRIBING, RECORDING, AND REPORTING

At all levels, there must be a full quality assurance program covering the whole procedure, including regular internal procedures and external audits.

4.3 GENERAL RECOMMENDATIONS FOR REPORTING ELECTRON BEAM THERAPY

4.3.1 Principles

The general principles for reporting electron beam therapy contained in the present document follow as closely as possible the recommendations for reporting photon beam therapy in ICRU Report 50 (ICRU, 1993) and ICRU Report 62 (ICRU, 1999). This implies the same general approach and the use of the same definitions of terms and concepts whenever possible.

The recommendations for reporting are based on the selection of a Reference Point, in the central part of the PTV, which is referred to as the ICRU Reference Point. The dose at the ICRU Reference Point should always be reported and complemented by information on the dose distribution in the PTV. Therefore, the best available estimate of the maximum and minimum doses in the PTV should also be reported.

This set of three values constitutes the minimum information to be reported. Additional relevant information, such as dose-volume histograms for different volumes, should also be reported (see Section 4.3.5).

Finally, reporting the doses (reporting at Level 2: dose-volume histograms) to the Organs at Risk is also recommended.

4.3.2 The ICRU Reference Point

The ICRU recommendations for reporting dose are based on the definition of a Reference Point (ICRU Reference Point), which is to be selected according to the following general criteria:

- (1) the dose at the point should be clinically relevant,
- (2) the point should be easy to define in a clear and unambiguous way,
- (3) the point should be selected where the dose can be accurately determined, and
- (4) the point should be selected in a region where there is no steep dose gradient.

To fulfill these criteria, it is recommended that the ICRU Reference Point should be selected:

- (1) always at the center (or in the central part) of the PTV and
- (2) if one beam is used in electron beam therapy, whenever possible, on the beam axis, at the level of the peak dose, as defined in Section 5.2.

The dose that is to be reported is the dose at the ICRU Reference Point, which is the ICRU Reference Dose.

4.3.3 Reporting dose distributions in the CTV and PTV

4.3.3.1 Dose homogeneity required in the PTV

The dose distribution in the CTV is the relevant information to which the outcome of the treatment is directly related. However, owing to various uncertainties the dose distribution in the CTV cannot be directly determined, but it is estimated from the dose distribution in the PTV.

A certain degree of inhomogeneity of the absorbed dose throughout the PTV is always present. A dose variation may even be desirable in some instances.

The dose variation in the CTV is, in principle, smaller than the dose variation in the PTV. The maximum doses to the CTV and the PTV are in general close to each other, *i.e.*, the dose at (or near) their centers. In contrast, the minimum dose to the PTV may be much smaller than that of the minimum dose to the CTV.

A dose variation of less than +7 percent or -5 percent from the ICRU Reference Dose is generally accepted in conventional photon beam therapy. In electron beam therapy (see Section 4.1.1), it is not possible in general to enclose the whole PTV in the 95 percent isodose envelope (the ICRU Reference Dose being taken as 100 percent). Lower isodoses have to be selected sometimes to encompass the PTV, in order to avoid excessive doses to some organs at risk, *e.g.*, the 90 percent or even 85 percent envelope.

However, since the dose at the ICRU Reference Point is often the maximum (or close to the maximum) dose to the PTV, the overall dose heterogeneity in the PTV is in general similar to that usually achieved in conventional photon beam therapy.

4.3.3.2 Reporting dose distribution at Levels 1, 2, and 3

Reporting at Level 1: When reporting at Level 1, the best estimate of the maximum and minimum doses in the PTV should be reported in addition to the dose at the ICRU Reference Point. In practice, reasonable estimates of the maximum and minimum doses can be derived from measurements on the beam axis.

Reporting at Levels 2 and 3: As indicated earlier (Section 4.2), reporting at Levels 2 and 3 implies more accurate diagnostic information and sophisticated dosimetry. Therefore, at Level 2 or 3, a more accurate estimate of the maximum and the minimum dose to the PTV can be achieved than at Level 1. In addition, dose distributions and dose-volume

histograms for the PTV and in some instances for the CTV, GTV, and PRV should be reported.

In agreement with ICRU Reports 50 and 62 (ICRU, 1993, 1999), it is recommended to report the following set of dose values as minimum information:

- (1) the dose at the ICRU Reference Point,
- (2) the maximum dose to the PTV, and
- (3) the minimum dose to the PTV.

4.3.3.3 Evaluation of PTV 95 (PTV 90) for reporting

Ideally, the PTV should be totally encompassed by the Treated Volume (or by the prescribed minimum dose). Should this not be the case, for particular clinical reasons, when reporting at Level 2 or 3, the proportion of the PTV enclosed by the Treated Volume should be reported.

Development of three-dimensional treatment planning, and thus increasing availability of dose-volume histograms, facilitates the evaluation of the proportions of the PTV receiving 95, 90, 85 percent, etc. of the ICRU Reference Dose. These will be referred to as PTV 95, PTV 90, and PTV 85.

The proportion of the PTV included in the Treated Volume, e.g., PTV 95 or PTV 90, should be reported when available. However, its clinical relevance and predictive value are still to be proven.

Note that a low dose value may be found not only at the periphery, but also in more central parts of the PTV.

From the DVH, different mean values can be computed between given limits of doses or volumes. The clinical significance or predictive value of these mean values also needs to be evaluated further either for tumor control or for normal tissue complications (Wachter *et al.*, 2001).

4.3.4 Dose (and dose distribution) to the Organs at Risk

As for the other radiation therapy modalities, the Organs at Risk have to be identified. To calculate the probability of late effects in normal tissues, one must consider not only the dose level and fractionation, but also the absolute volume and/or fraction of the OAR irradiated.

For each Organ at Risk, when part of the organ or the whole organ is irradiated above some stated tolerance limit, the maximum dose should be reported.

The stated tolerance dose limit is specified by the radiation oncologist based on the current available literature and/or fixed as part of a clinical trial protocol.

In addition, the volume receiving more than the stated tolerance dose limit should be reported (see

ICRU Report 62, Section 3.5). Additional information can be derived from dose-volume histograms.

4.3.5 Doses at Reference Points, dose distributions in volumes, and developments related to dose-volume histograms

4.3.5.1 Doses at Reference Points

Reporting the dose at a Reference Point is the first and necessary step to take when performing inter-comparisons between centers. The relevance of the dose at the Reference Point depends on the criteria used for the selection of the point. Also the physical uncertainty of the reported dose and the possible ambiguity in the location of the Reference Point depend on the selection criteria. These criteria were discussed above (see Section 4.3.2).

Two issues have to be considered when discussing the relevance of the dose at the Reference Point: the first is related to geometrical factors, and the second to the dose-computation technique.

When the Reference Point is selected in the center, or in the central part, of the PTV there is generally no steep dose gradient and the dose is relatively homogeneous around the Reference Point. In addition, the dose at the Reference Point is equal or close to the dose delivered to a large proportion of the PTV; it can thus be considered as representative of the dose to the PTV. Finally, the dose can be determined with a high accuracy at the Reference Point, if it is centrally located or close to the beam axes.

However, accurate computation of the dose at the Reference Points requires some care. In particular, when the Monte Carlo technique is used, there could be a significant statistical fluctuation in the dose value obtained at a Reference Point depending both on the algorithms and on the size of the voxels used for computational purposes. Therefore, in such cases, an average dose value within a sphere centered on the Reference Point may have to be calculated and reported. The sphere diameter should be large enough that dose fluctuations remain small; it depends on the computation tool and technique used. In normal situations there is little probability that important heterogeneity would be encountered within a 1-cm diameter sphere, if the Reference Point has been adequately selected (at the center of the PTV).

4.3.5.2 Dose distributions in volumes

Reporting the dose at the Reference Point is obviously not sufficient to describe the treatment. Reporting the maximum and minimum doses to the PTV is also required.

Dose-volume histograms in the different volumes of interest (PTV, CTV, and/or GTV) and in the

GENERAL RECOMMENDATIONS FOR PRESCRIBING, RECORDING, AND REPORTING

different Organs at Risk give additional important and relevant information and are recommended for reporting at Level 2. However, reporting DVHs brings additional uncertainties with regard to the dose-computation system and also ambiguities due to the definition and position of the volumes of interest.

4.3.5.3 Developments related to DVHs

The use of DVHs allows the calculation of a variety of derived quantities such as mean doses to different volumes and to different Organs at Risk and biologically weighted doses (Wambersie *et al.*, 2002a, b). Calculation of mean doses could be restricted to doses above a stated dose level or to volumes in excess of stated volumes.

Although some of these derived quantities are claimed to be clinically relevant, they need to be further evaluated. They should be reported only in addition to, and not instead of, the doses at the Reference Points or dose distributions. For all the reported derived mean doses, the methods used for their calculation and the numerical values of any chosen parameters should be specified.

4.4 REPORTING A SERIES OF PATIENTS

4.4.1 Introduction

A large part of the present Report deals with reporting volume and dose in a single individual patient. A different situation is encountered when

reporting the results of treatment in a series of patients. This has been dealt with in ICRU Report 62 (ICRU, 1999).

For a series of patients, the principles for reporting volumes and doses should follow the general recommendations applicable to individual patients. The following additional rules are recommended for reporting treatments in a series of patients.

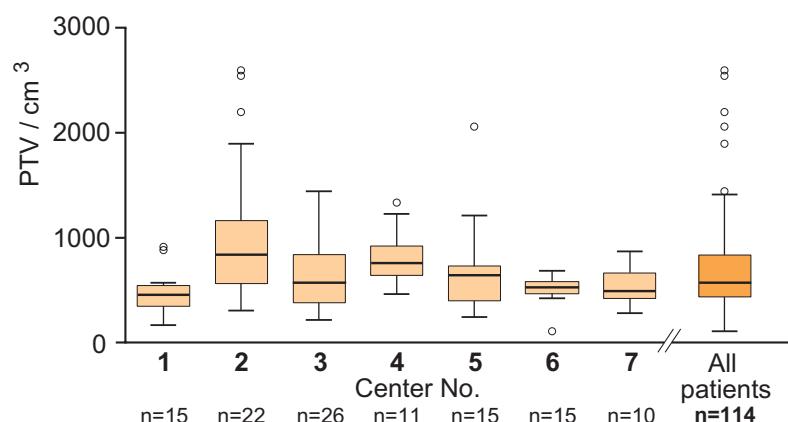
4.4.2 Reporting prescription of treatment

The description of *volumes* must be consistent with the definitions used in this Report. The prescribed *dose* to the PTVs and the *fractionation* must be reported.

4.4.3 Description of actual treatment in a series of patients

Even in prospective randomized trials where the GTVs and the PTVs are well defined in a protocol in accordance with the ICRU recommendations, variations in shape and size of the PTV among patients and centers are unavoidable and may be considerable. This is due to the topography of the individual patient, patient-selection bias, the radiation oncologist's evaluation of the clinical situation, and the chosen treatment technique. Thus, it is of value to analyze and illustrate the variation in PTV size for the whole series of patients (Fig. 4.1).

Furthermore, in clinical practice, it is not always possible to deliver the prescribed dose and dose distribution within the PTV for each patient. When



Figures 4.1–4.5 illustrate the ICRU recommendations for reporting a series of patients. Data are obtained from a multicenter, randomized clinical trial of radiotherapy with or without a radiosensitizer for non-small-cell lung cancer stage III. Radiation quality 6–10-MV photons. Data were collected for 125 patients from 7 centers, but a full data set was not available for all patients. (Courtesy of Ann-Margret Engström, RN, Oncological Center, Lund, Sweden.)

Figure 4.1 Box plot illustrating the variation in PTV size in 114 patients. The box contains the middle half of all data points, and the "whiskers" are intended to give an impression of the range of points. Data from the seven collaborating centers as well as for all patients are given. As can be seen, there is a clear systematic difference between centers, presumably due to patient selection bias and different interpretation of the definition of the PTV by the radiation oncologists. The box includes all data points between the 25th and 75th percentile. The line in the box indicates the median value. The upper "whisker" extends from the upper value of the 75th percentile incremented with 1.5 times the height of the box. Analogously, the lower "whisker" extends to the smallest value no lower than the 25th percentile minus 1.5 times the height of the box. Observations outside these limits are referred to as "outside values" and are individually plotted.

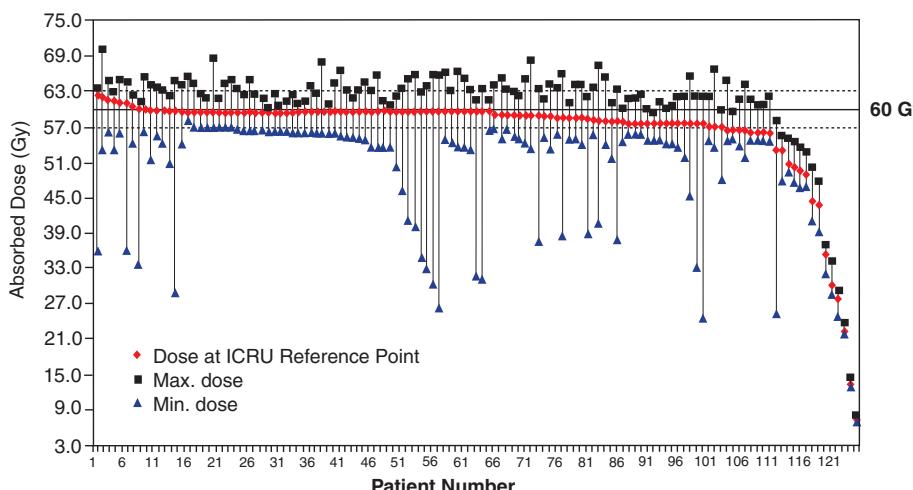


Figure 4.2. Same study as is Figure 4.1. Diagram showing the dose delivered to the 125 patients. The prescribed dose was $60\text{ Gy} \pm 5$ percent at the ICRU Reference Point. The dotted lines indicate the permissible dose variation of ± 5 percent from the prescribed dose. The patients are sorted in the descending order of (1) dose at the ICRU Reference Point and (2) minimum dose to the PTV. As regards dose to the ICRU Reference Point, 102 patients fulfilled the criteria, whereas 23 patients received higher or lower doses (ICRU, 1999).

collecting data over a considerable time span, such as in retrospective analysis, great variation in dose and fractionation may be encountered (Fig. 4.2). There may have also been changes in the policy regarding factors, such as prescription (*e.g.*, the use of the ICRU Reference Dose rather than the minimum dose) and dose normalization. Such changes may significantly influence the doses that were actually given to the patients, even though such a change may not be easily recognized. Even within a controlled clinical trial, some variations occur.

Reasons for deviations from the prescribed dose level may arise from interruptions due to hardware breakdowns, deteriorating patient condition, or re-evaluation of the patient, resulting in a different prescription (*e.g.*, change from radical to palliative intent). Thus, the final dose variation in a series of patients may be considerable and additional information to that recommended for individual patients must be given.

Hence, the proportion of patients in whom the dose variation is less than ± 5 , $\pm 5\text{--}10$, and more than ± 10 percent, respectively, relative to the prescribed dose at the ICRU Reference Point should be reported (Fig. 4.3).

In addition to the set of three dose levels recommended in ICRU Report 62 (*i.e.*, the dose at the ICRU Reference Point, the maximum and minimum dose to the PTV), the proportion of the PTV receiving at least 95 percent of the ICRU Reference Dose (PTV 95) should be reported for the series of patients when available (Figs 4.4 and 4.5). Reporting the PTV 95 implies that DVHs can be computed for all patients (Section 4.3.3).

The reasons for not delivering the prescribed dose (protocol violation) should be clearly stated.

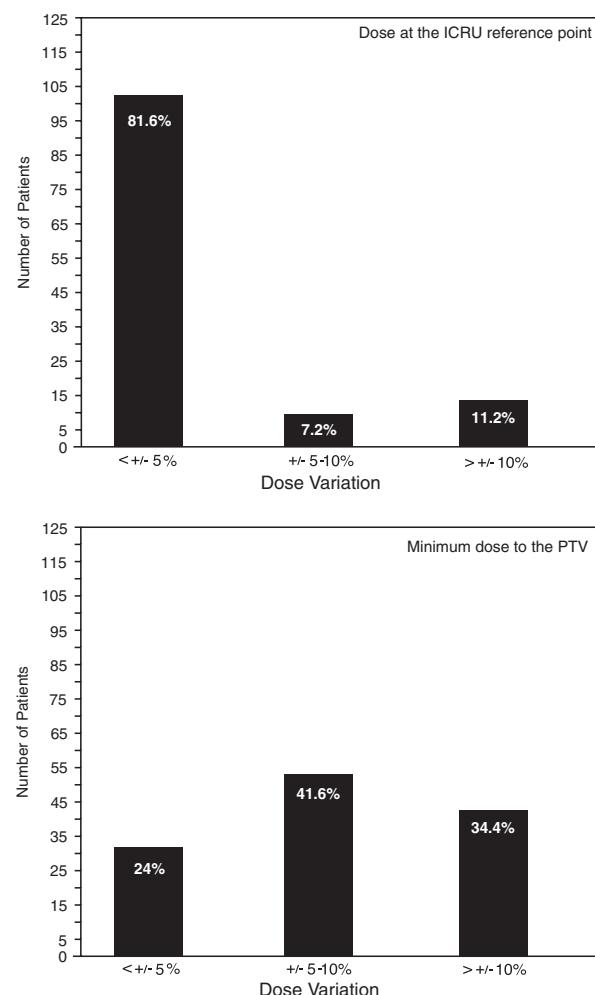


Figure 4.3. Same study as in Figure 4.1. Graph showing the proportion of patients receiving an absorbed dose within three defined deviations from the prescribed dose in the protocol (ICRU, 1999). (a) Dose at ICRU Reference Point. (b) Minimum dose to the PTV.

GENERAL RECOMMENDATIONS FOR PRESCRIBING, RECORDING, AND REPORTING

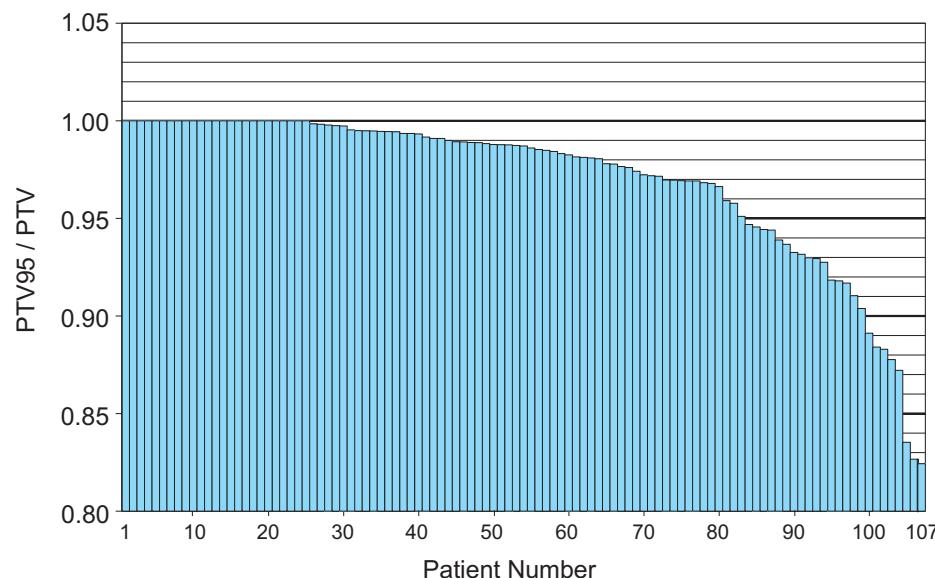


Figure 4.4. Same study as in Figure 4.1. Graphical presentation of PTV 95/PTV distribution in 107 patients. Each vertical bar represents an individual patient. In ordinate, for each patient, the proportion of the PTV that receives at least 95 percent of the dose prescribed at the ICRU Reference Point.

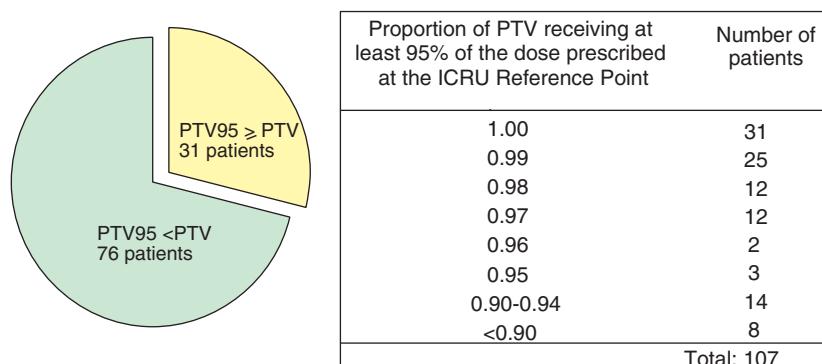


Figure 4.5. Proportion of the 107 patients, the same study as in Figure 4.1, where the PTV is totally encompassed, or not, by the 95 percent isodose (yellow sector or green sector, respectively). In 31 patients, 95 percent of the prescribed dose at the ICRU Reference Point is delivered to the whole PTV. For the other 76 patients, a small proportion of the PTV (1 percent, 2 percent, etc.) is not included in the 95 percent isodose surface. The corresponding patient numbers are indicated in the table. In 14 patients, 5–10 percent of the PTV is not included in the 95 percent isodose. In eight patients, more than 10 percent of the PTV is not included in the 95 percent isodose.

Preferably, analysis of important end points, such as survival and local tumor control, should be carried out for the entire patient series, as well as for those patients who fulfilled the prescription (per protocol analysis) and for those who did not.

When reporting treatment, *e.g.*, in a scientific journal, it is recommended that the prescribed CTV

and PTV and the corresponding doses should be illustrated in an isodose distribution chart, giving the total dose in Gy.

Reporting treatment techniques only in terms of field sizes and/or portal boundaries relative to anatomical structures is not sufficient (*e.g.*, 10 cm × 12 cm pelvic field).

5 RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY FOR DIFFERENT CLINICAL SITUATIONS

5.1 INTRODUCTION

In this section, recommendations for reporting will be presented for the following situations:

- A single electron beam (Section 5.2).
 - reference conditions (Section 5.2.1),
 - small and irregularly shaped beams (Section 5.2.2),
 - extended SSD-air gaps (Section 5.2.3),
 - oblique beam incidence (Section 5.2.4),
 - heterogeneities (Section 5.2.5), and
 - bolus (Section 5.2.6).
- Combination of electron and photon beams (Section 5.3).
- Combination of electron beams (Section 5.4).
- Electron-beam arc therapy (Section 5.5).

5.2 REPORTING DOSES FOR A SINGLE ELECTRON BEAM

5.2.1 Reference conditions

The reference conditions refer to an electron beam incident perpendicularly to a plane surface of a homogeneous medium (*i.e.*, water phantom, flat skin surface, and homogeneous tissue).

5.2.1.1 Reporting at Level 1

The following dose values should be reported:

- (1) *The peak absorbed dose.* The peak absorbed dose is defined as the maximum dose on the beam axis (Section 3). The monitor units are calibrated in terms of the peak absorbed dose to water; this quantity is thus always available and should always be reported in electron beam therapy.
- (2) *The dose at the ICRU Reference Point.*
 - (a) When the maximum dose on the beam axis (peak dose) is located at a clinically relevant point, at or near the center of the PTV, this point should be selected as the ICRU Reference Point (Fig. 5.1). This recommendation is justified by the fact that, if the electron energy is adequately selected to

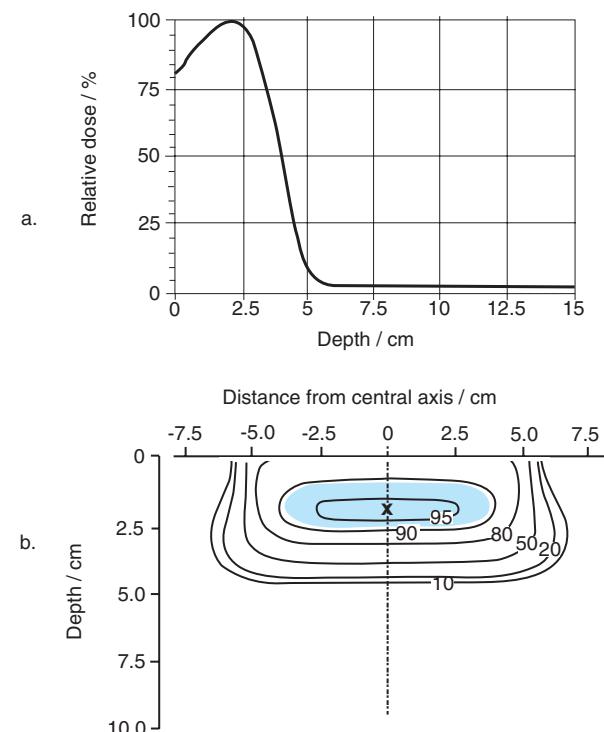


Figure 5.1. The depth-dose curve and the dose distribution for a 10-MeV electron beam incident perpendicularly on a flat surface for the treatment of a superficial tumor. The PTV is indicated by the light blue area. The ICRU Reference Point is selected at the level of the maximum of the depth-dose curve ("x") ("peak dose" = 100 percent). This point is closer to the center of the PTV. The maximum dose to the PTV is 100 percent and the minimum dose to the PTV is 90 percent.

cover the PTV, the maximum of the depth-dose curve lies at, or close to, the center of the PTV.¹ The dose distribution is then often homogeneous in that area. This is the

¹In most cases and when the electron beam energy is selected in an appropriate way, there should not be a large difference between the peak absorbed dose and the dose at the ICRU Reference Point. If large differences ever appear, the choice of the electron energy and even the use of electrons may have to be reconsidered. This remark also applies when electrons are combined with photon beams (see Section 5.3).

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

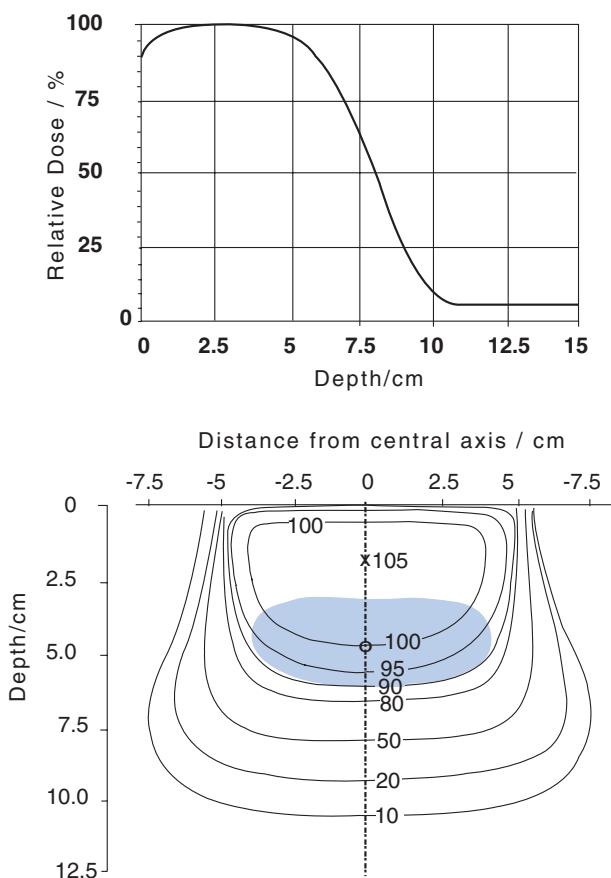


Figure 5.2. Depth-dose curve and dose distribution for a 20 MeV electron beam incident perpendicularly on a flat surface for the treatment of a PTV located between 3 and 6 cm in depth (light blue area). The ICRU Reference Point (taken as 100 percent) is selected at the center of the PTV, i.e., at 4.5 cm in depth ("o"). The maximum dose to the PTV is 104 percent and the minimum dose to the PTV is 90 percent. In this particular example, the ICRU Reference Point cannot be selected at the level of the peak dose because the peak dose lies outside the PTV. The peak dose is 105 percent of the dose at the ICRU Reference Point.

case when electrons are used to treat, e.g., skin tumors, thoracic wall recurrences, or fixed cervical lymph nodes.

- (b) When the peak absorbed dose is obtained at a point which cannot be selected as the ICRU Reference Point (because it is located outside or near the border of the PTV), the radiation oncologist should select a clinically more relevant, easily defined point at the center (or near the center) of the PTV, if possible on the beam axis (Fig. 5.2). For example, this recommendation may apply for the irradiation of the internal mammary nodes, where the PTV is located in-depth behind a rather thick layer of normal tissues, depending on the anatomy of the patient. The peak absorbed dose is then

located outside the PTV and thus cannot be used as the ICRU Reference Dose.

- (3) *Maximum and minimum dose to the PTV.* Although in some instances high-quality and complete diagnostic and dosimetric information may not be available, the best estimate of the maximum and minimum dose to the PTV should be reported together with the location and value of the ICRU Reference Dose. In these cases, only the maximum and the minimum doses on the beam axis may be available. It is, however, always encouraged to report additional relevant information that could be obtained.

Organs at Risk should be identified and the best estimate of the maximum dose to the Planning Organ at Risk Volume (PRV) should be reported.

In summary, at Level 1, the following dose values should be reported:

- *peak absorbed dose to water;*
- *location of, and dose value at, the ICRU Reference Point (the ICRU Reference Point may or may not be at the Level of the peak absorbed dose);*
- *maximum dose on the beam axis, in the PTV*;*
- *minimum dose on the beam axis, in the PTV*; and*
- *estimate of the dose(s) to the Organ(s) at Risk (PRV).*

**In some instances, at this level, only dose variations on the beam axis may be available.*

5.2.1.2 Reporting at Level 2 or 3

As indicated previously, reporting at Level 2 implies the use of modern imaging techniques under reliable conditions (typically a series of CT or MRI examinations) to define the relevant volumes (see Section 2) and the Organs at Risk (see Sections 2.7 and 2.8). Other imaging techniques, such as PET or ultrasound, may add relevant information. At Level 2, it is also assumed that three-dimensional dose distributions are available, with heterogeneity corrections when appropriate. Dose-volume histograms should also be available.

This information allows the radiation oncologist to select an ICRU Reference Point at a clinically more relevant point at (or near) the center of the PTV. In this situation, the ICRU Reference Point may be different from the point of the peak absorbed dose and may even be located off-axis. The doses to the

RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY

Organ(s) at Risk should be reported following the recommendations of Section 4.3.4. The concept of PRVs can be applied.

In summary, at Level 2 (or 3), the following dose values should be reported:

- peak absorbed dose to water;
- location of, and dose value at, the ICRU Reference Point (the ICRU Reference Point may or may not be at the Level of the peak absorbed dose; see footnote 1);
- maximum dose in the PTV*;
- minimum dose in the PTV*; and
- dose(s) to Organ(s) at Risk (PRV).*

*Determined from dose distributions and/or dose-volume histograms.

5.2.2 Small and irregularly shaped beams

The central-axis dose distribution in irregularly shaped fields, where a large proportion of the original field is blocked, may deviate significantly from that observed for unblocked fields.

However, so long as the field dimension is large enough for lateral equilibrium, the introduction of inserts into electron collimators will cause only a small change in depth-dose distribution (AAPM, 1991) (see Sections 3.3 and 3.4).

As a general rule, when the beam size decreases and the shape is modified, the following effects are observed (Fig. 3.3):

- the depth of the maximum dose moves toward the surface,
- the depth of the therapeutic range becomes smaller,
- the relative surface dose increases,
- the dose fall-off becomes more shallow, and
- the dose rate is reduced.

The magnitude of these changes increases with decreasing energy. These changes should be kept in mind when selecting beam energy in cases where additional collimation is used.

Additional measurements should be performed:

- In elongated or small fields, as the dose distribution depends primarily on the side-scatter equilibrium (Niroumand-Rad, 1989; Niroumand-Rad *et al.*, 1986; Rashid *et al.*, 1990).
- In irregularly shaped fields, as the absorbed dose at a point depends strongly on the shape of the surrounding field (AAPM, 1991; Bruinvis *et al.*, 1983).

5.2.2.1 Reporting at Level 1

At Level 1, interpolation over the measured data should be used to provide information for irregular fields. Dose reporting should follow the recommendations of Section 5.2.1.

The peak absorbed dose to water should always be reported, as this quantity is directly related to the number of monitor units and is thus always available.

5.2.2.2 Reporting at Level 2 or 3

Measurements over the range of inserts used clinically should be performed to verify computation algorithms before reporting at Level 2 (or 3) can be considered.

Reporting of dose at Levels 2 and 3 should follow the recommendations of Section 5.2.1.

5.2.3 Extended SSD-air gaps

The beam divergence is energy dependent and related to the scattering power of the medium. Because of electron scattering in air, the beam characteristics at extended SSD may significantly deviate from those measured at the standard treatment distance (AAPM, 1991; Das *et al.*, 1995).

A moderate increase in SSD causes:

- a decrease in the surface dose;
- a moderate change in the depth-dose distribution, except in the build-up region;
- a loss in beam flatness at extended SSD; and
- a wider penumbra due to air scattering.

5.2.3.1 Reporting at Level 1

At Level 1, interpolation between the measured data at the regular SSD and at some available extended SSD should be used.

Dose reporting should follow the recommendations of Section 5.2.1. The peak absorbed dose to water should be reported, as this quantity is directly related to the number of monitor units and is thus always available.

5.2.3.2 Reporting at Level 2 or 3

Dose distributions for non-standard SSD should be measured for selected field sizes to verify computational algorithms.

Reporting of dose at Level 2 or 3 should follow the recommendations of Section 5.2.1.

5.2.4 Oblique electron beam incidence

With oblique beam incidence (and also for curved or irregular surfaces), the actual dose distribution

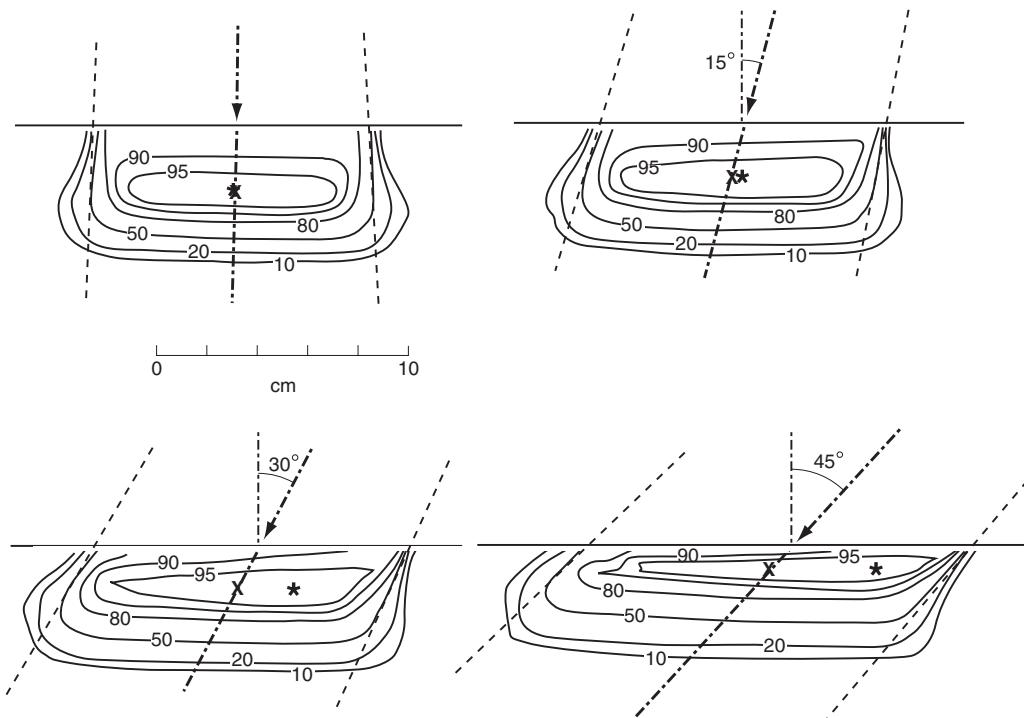


Figure 5.3. The dose distribution for the electron beams with oblique incidence: 0°, 15°, 30°, 45°. Electron energy: 9 MeV. Field size: 10 cm × 10 cm. The isodoses are expressed as percentages of the peak absorbed dose located on the beam axis ("×"). The position of the maximum dose is indicated by asterisks. For 0°, 15°, 30°, and 45° the peak doses are located at 2.3, 1.9, 1.4, and 0.9 cm in depth, measured perpendicularly to the surface, and the maximum doses are 100 percent, 100 percent, 101 percent, and 102 percent of the peak dose, respectively.

may significantly deviate from that observed for a perpendicular open beam (Fig. 5.3).

The radiation oncology team must be aware of these alterations and carefully evaluate whether the resulting dose distribution still allows adequate coverage of the PTV and sparing of normal tissues, or if different electron energies, angles, or beam combinations are needed, or even if other irradiation modalities need to be considered.

For oblique incidence, the peak absorbed dose per monitor unit in a water phantom is different from the peak absorbed dose for a perpendicularly incident beam. The magnitude of this perturbation depends on the angle of incidence, beam energy, type of accelerator, etc.; it is influenced by in-scattering of electrons.

The depth d of the peak absorbed dose has to be reported on the beam axis, i.e., oblique to the skin surface. The depth d' of the peak absorbed dose on an axis perpendicular to the skin surface is shorter (Fig. 5.4). Similarly all isodoses shift toward the surface. This fact has to be kept in mind when selecting the electron beam energy to treat a given tissue thickness as it may require an increase in electron energy.

In the case of oblique incidence, the maximum dose is off-axis and in some irradiation geometries

it may be considerably higher than the peak absorbed dose, which is defined on the beam axis (see Section 3).

5.2.4.1 Reporting at Level 1

When only dose evaluation for reporting at Level 1 is available, the use of electron beams should sometimes be reconsidered since the deviation from reported reference conditions to the actual dose distribution may be significant.

It is left to the judgement of the radiation oncology team in charge of the patient to decide if electron beam therapy can be safely applied. The beam obliquity (angle), the curvature or irregularity of the skin surface, as well as the available dosimetric information, have to be taken into account. If the angle of obliquity or the surface irregularity is small, one may neglect the resulting alterations in the dose distribution.

Dose reporting should follow the recommendations of Section 5.2.1. The peak absorbed dose to water should be specified, assuming the dose distribution for an incident perpendicular beam. As mentioned above, this quantity is directly related to the number of monitor units and is always available.

RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY

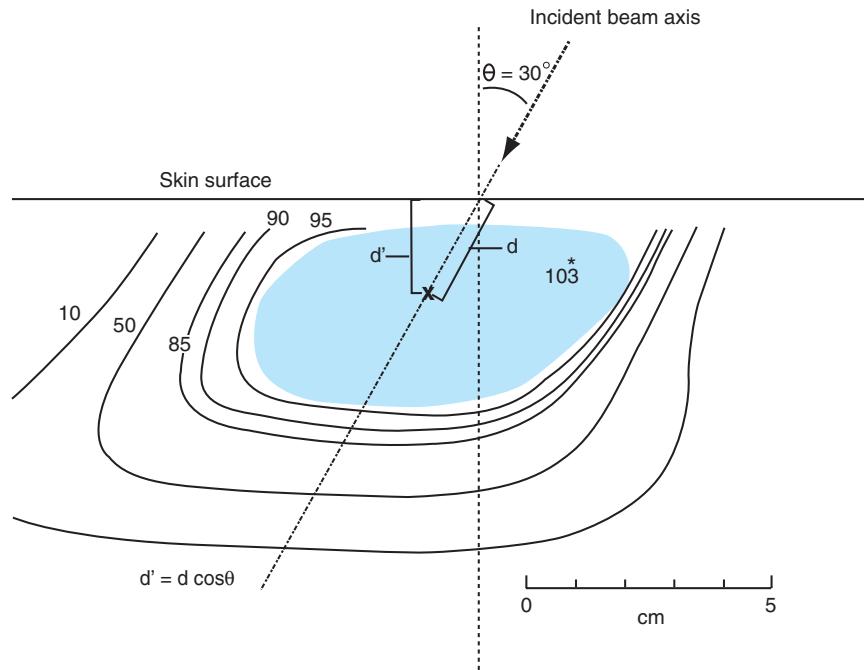


Figure 5.4. The dose distribution for an obliquely incident 19-MeV electron beam ($\theta = 30^\circ$, collimated by diaphragm, $8 \text{ cm} \times 10 \text{ cm}$, SSD = 100 cm, distance from diaphragm to patient = 20 cm). Although the dose distribution is asymmetrical, the PTV (light blue area) is encompassed by the 95 percent isodose surface and is irradiated in a homogeneous way. The ICRU Reference Point (100 percent) is located at the depth of the peak absorbed dose on the beam axis. The maximum dose is 103 percent and the minimum dose to the PTV is 95 percent. The depth of the peak absorbed dose measured perpendicularly to the surface ($d' = 1.9 \text{ cm}$), is smaller than the depth along the beam axis ($d = 2.25 \text{ cm}$).

5.2.4.2 Reporting at Level 2 or 3

Reporting of dose at Level 2 or 3 should follow the general recommendations of Section 5.2.1.

At Level 2 (or 3), the following dose values should be reported:

- peak absorbed dose to water as if the beam incidence was perpendicular;
- location of, and dose value at, the ICRU Reference Point;
- maximum dose in the PTV*;
- minimum dose in the PTV*; and
- dose to the Organs at Risk (PRV).*

**Determined from dose distributions and/or dose-volume histograms.*

The ICRU Reference Point should be selected on the beam axis at the maximum of the depth-dose curve, if that maximum is near or at the center of the PTV. Otherwise, another clinically more relevant point should be selected at or near the center of the PTV. Even at Level 2 or 3, it is recommended to report the peak absorbed dose to water assuming the dose distribution for an incident perpendicular beam (as recommended for reporting at Level 1).

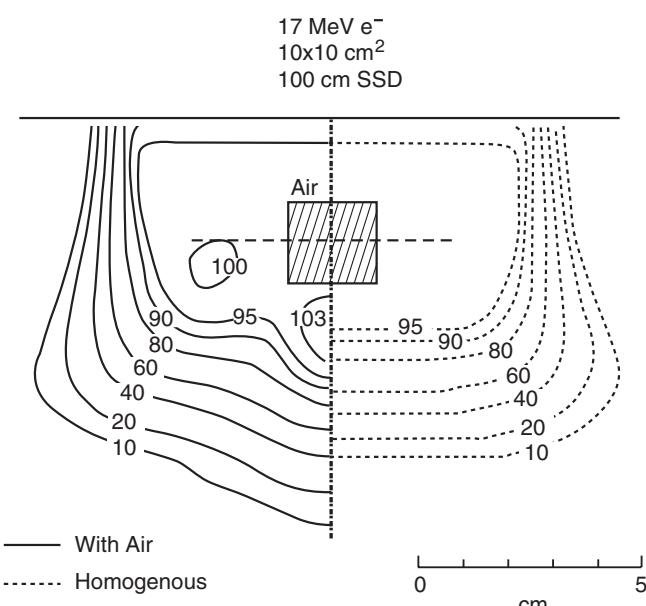


Figure 5.5. The figure illustrates the perturbation of the dose distribution due to the introduction of a heterogeneity. On the right-hand side, dose distribution in a homogeneous water phantom. On the left-hand side, the dose distribution after introduction of an air cavity ($2 \text{ cm} \times 2 \text{ cm}$). The shape of the isodoses is altered and the maximum dose is 103 percent of the maximum dose in the homogeneous phantom. (Modified from Hogstrom and Almond, 1983.)

5.2.5 Heterogeneities

With electron beams, more than with photon beams, heterogeneities influence the dose distribution in such a way that the actual dose distribution may in some cases differ significantly from that expected in a homogeneous phantom (see Section 3). When heterogeneities are present, computation of the dose distribution is particularly difficult and requires advanced computational

resources and suitable programs (e.g., pencil-beam algorithms).

Modification of the dose distribution due to the heterogeneities may result in a need to adjust the electron energy. Moreover, the difficulty of achieving an adequate dose distribution in the PTV when important heterogeneities are present may sometimes require reconsideration of the suitability of electron therapy for a given patient (Figs 5.5 and 5.6).

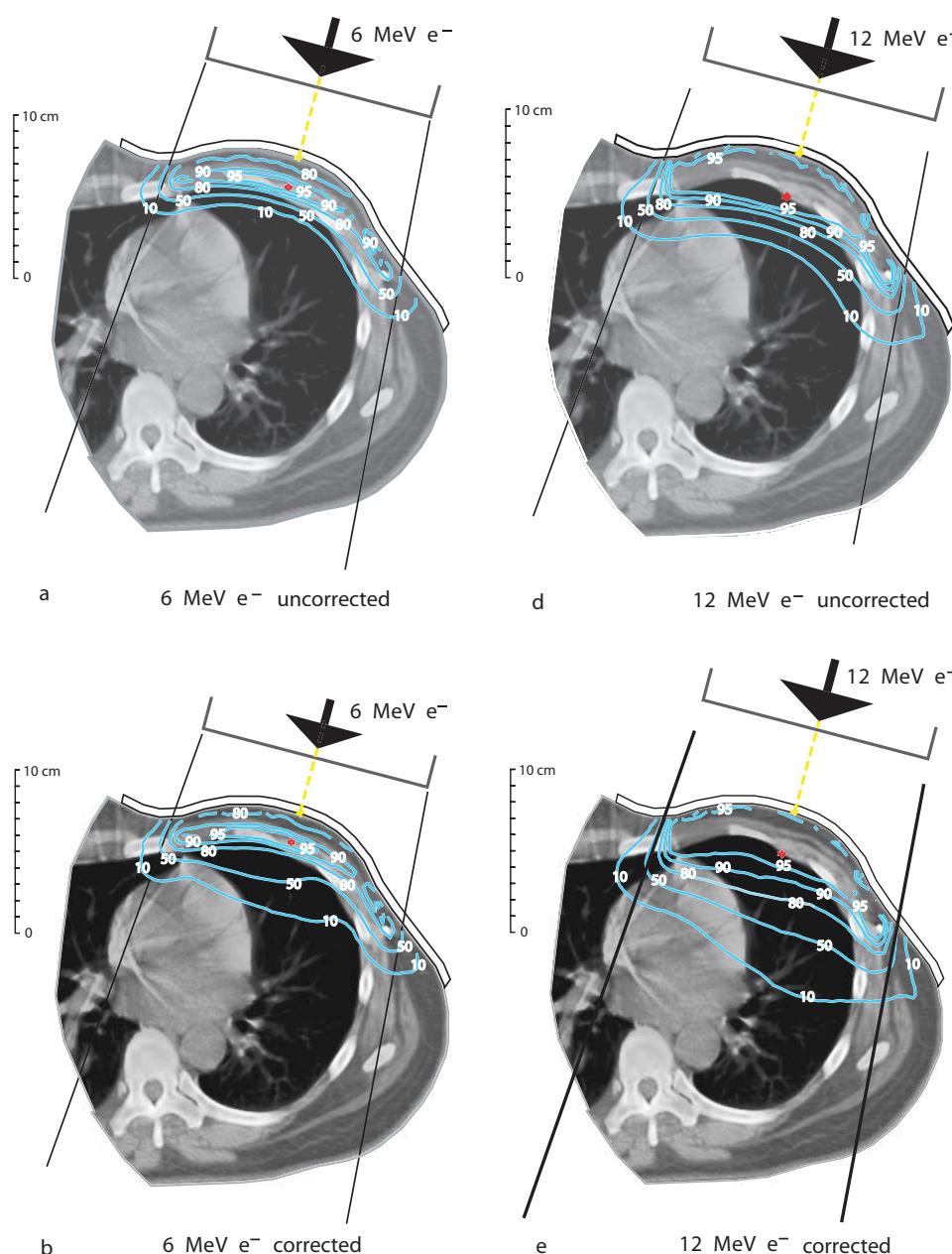


Figure 5.6. Effect of heterogeneity corrections on the dose distribution in the treatment of the chestwall. The dose distributions are compared for beams of electrons of 6 and 12 MeV (beam size: 15 cm × 15 cm). The isodose curves are expressed relative to the dose at the ICRU Reference Point (indicated in red), which is selected at the maximum of the central-axis depth-dose curve. A bolus increases the dose at the level of the skin (yellow asterisk); the set-up distance is measured at the level of the skin (not at the level of the bolus). The effect of heterogeneity corrections for evaluating the dose to the lung is clearly illustrated (a,b for 6 MeV and d,e for 12 MeV). This is also reflected in the dose-volume histograms (c,f; opposite).

RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY

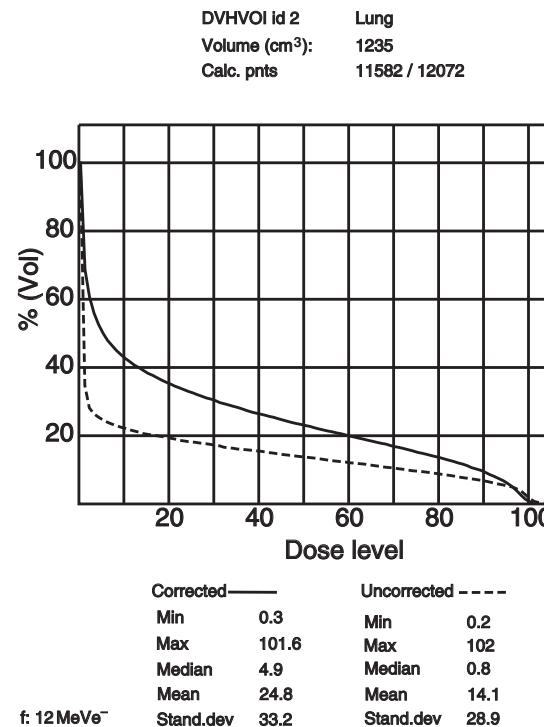
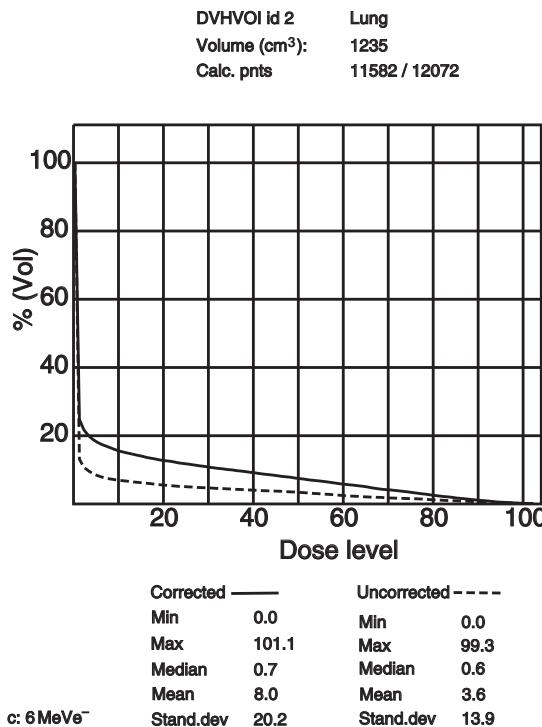


Figure 5.6. Continued

The recommendations of Sections 5.2.1 and 5.2.2 may be applied when the heterogeneities are not too important (e.g., thin trabecular bones such as the ribs).

5.2.5.1 Reporting at Level 1

When large heterogeneities are present and when dose evaluation for reporting at Level 1 only is available, the use of electron beams should sometimes be reconsidered.

It is then left to the judgment of the radiation oncology team in charge of the patient to decide if electron beam therapy is useful. The importance of the heterogeneities, as well as the available dosimetric information, has to be taken into account.

Dose reporting should follow the recommendations of Section 5.2.1. The peak absorbed dose to water should be specified assuming the dose distribution for an incident perpendicular beam in a homogeneous phantom (as mentioned above, this quantity is directly related to the number of monitor units and is thus always available).

5.2.5.2 Reporting at Level 2 or 3

Reporting of dose at Level 2 or 3 should follow the recommendations of Sections 5.2.1 and 5.2.2.

It is recommended that the dose distribution should be computed first for a homogeneous water

phantom, and then taking into account the actual heterogeneities.

Firstly (as recommended for reporting at Level 1), the peak absorbed dose in water should be determined for an incident perpendicular beam in a homogeneous phantom.

This recommendation is particularly important when comparing dose delivered in different centers (e.g., in randomized trials), as it would avoid any discrepancy or uncertainty related to differences in the methods used (algorithms) to correct for the heterogeneities.

Secondly, an accurate description of the actual dose distribution (corrected for heterogeneities) in the PTV should be obtained to allow the radiation oncologist to select the ICRU Reference Point, at or near the center of the PTV, on the beam axis or at a clinically more relevant point. In particular, the ICRU Reference Point should be selected where the dose distribution is homogeneous and where the dose can be determined accurately, *i.e.*, at a distance from the edge of the heterogeneities. The dose to the ICRU Reference Point before and after heterogeneity corrections should always be reported.

In agreement with the general recommendations of the present Report, the best estimates of the maximum and the minimum doses to the PTV, before and after correction for heterogeneities, should be reported with dose-volume histograms.

PREScribing, RECORDing, AND REPORTING ELECTRON BEAM THERAPY

The Organs at Risk should be identified. The doses, dose distributions, and dose-volume histograms, before and after correction for heterogeneities, should be reported.

In summary, when important heterogeneities are present, reporting at Level 2 or 3 is recommended, and the following dose values should be reported:

- peak absorbed dose to water, in a homogeneous water phantom;
- location of, and dose value at, the ICRU Reference Point (the ICRU Reference Point may or may not be at the Level of the peak absorbed dose) before and after heterogeneity corrections;
- maximum dose in the PTV*;
- minimum dose in the PTV*; and
- dose to Organs at Risk (PRV).*

*Determined from the dose distribution and/or dose-volume histograms before and after heterogeneity corrections.

5.2.6 Bolus

A bolus (usually tissue-equivalent material) is placed directly into contact with the irradiated tissues in order to provide build-up, attenuation, or sometimes additional scattering of the electron beam (ICRU, 1976).

A bolus is used:

- (1) to increase the skin dose, mainly for low-energy electron beams;
- (2) to compensate for surface irregularities or oblique beam incidence; and
- (3) to match the beam penetration with the shape of the PTV, especially when different parts of the PTV reach different depths.

The shape, thickness, composition, density, and position of the bolus material will influence the dose distribution and alter the therapeutic range of the electron beam in the tissues. Therefore, complete information on the bolus should be reported. In particular, it should be clearly stated whether the distance ("SSD") is taken from the electron source to the bolus surface or to the skin surface.

For reporting the location of, and the dose value at, the ICRU Reference Point and other dose values, the recommendations of Section 5.2.1 should be followed.

However, the ICRU Reference Point should be selected in the tissues and not in the bolus material. In general, all reported dose values and dose-volume

histograms should be related to volumes of tissues and not to bolus material.

The peak absorbed dose to water should always be reported, since it is directly related to the number of monitor units, and is thus always available.

5.3 COMBINATION OF ELECTRON AND PHOTON BEAMS

Such combinations are used in order to take advantage of the specific characteristics of the two types of beams.

5.3.1 One high-energy photon beam and one electron beam (coaxial beams, same field size)

This combination is used in order to achieve a more homogeneous irradiation of the PTV and a better sparing of the skin and/or surrounding normal tissues (Fig. 5.7). High-energy photons (a few MV or above) improve the skin sparing effect, while the dose fall-off of the electrons reduces the irradiation of deeply underlying tissues (Karlsson and Zackrisson, 1993). This technique is used, e.g., for the irradiation of the internal mammary nodes in breast cancer. The electron energy should be selected taking into account the total photon and electron depth-dose curve and not only the electron depth-dose curve. The peak absorbed dose to water for the electron beam should always be reported. When the electron beam energy has been selected in such a way that the maximum of the electron depth-dose curve (peak absorbed dose) lies at, or close to, the center of the PTV, this point should be selected as the ICRU Reference Point.

When the peak absorbed dose for the electron beam is obtained at a point which cannot be selected as the ICRU Reference Point (e.g., located outside or near the border of the PTV), another point which is clinically more relevant has to be selected as the ICRU Reference Point. It should be near the center of the PTV and when possible on the beam axis.

The dose at the ICRU Reference Point for each beam and for the beam combination should always be reported. It must also be stated whether or not both the electron and the photon beams were used daily and simultaneously.

When reporting at Level 1, the best available estimate of the maximum and minimum dose to the PTV, or at least the maximum and minimum dose on the beam axis, should be reported.

When reporting at Level 2 or 3, the maximum and minimum dose to the PTV, as well as the dose distribution and dose-volume histograms when clinically relevant, should be reported.

RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY

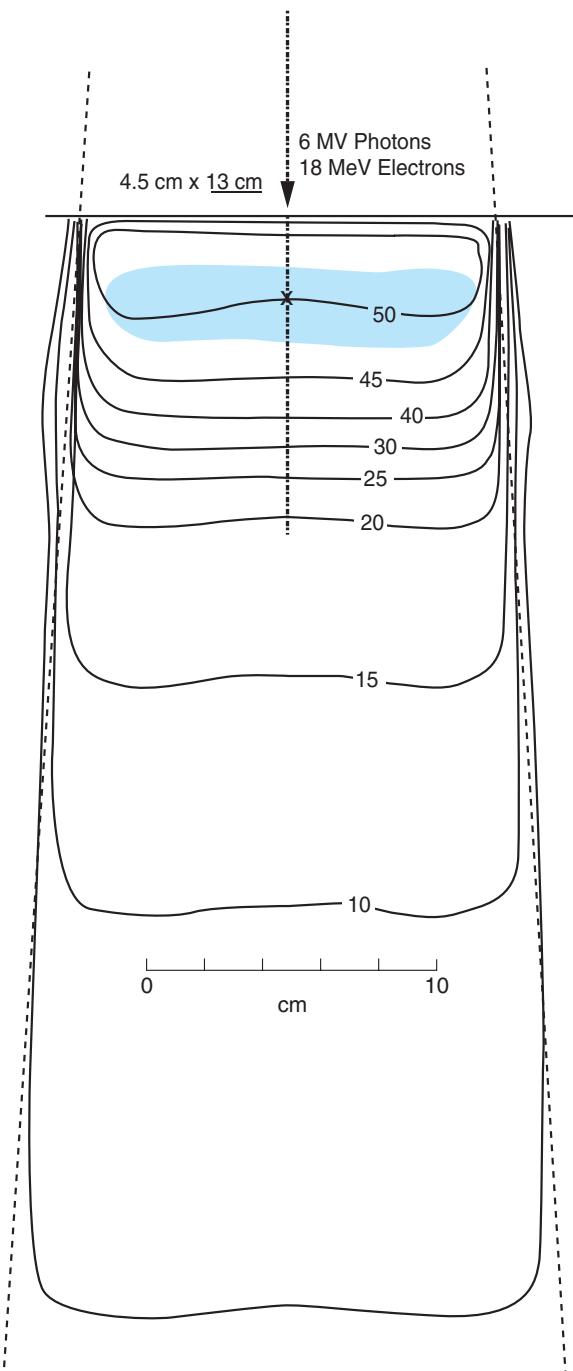


Figure 5.7. The dose distribution resulting from the combination of an 18-MeV electron beam and a 6-MV photon beam, using the same portal (coaxial beams, same field size: 4.5 cm in width, and 13 cm in height). This combination is used in the treatment of internal mammary nodes in breast cancer. Selection of the electron energy depends on the patient's dimensions. The dose distribution is presented in the sagittal plane containing the beam axes. The doses are indicated in absolute values. The PTV (light blue area) is located between 16 and 40 mm in depth. The ICRU Reference Point is selected on the beam axis at the center of the PTV, *i.e.*, at 28 mm in depth. The dose contribution at the ICRU Reference Point is 25 Gy for each beam. The maximum and the minimum doses to the PTV are 104 percent and 96 percent, respectively, relative to the dose at the ICRU Reference Point.

The dose(s) and dose distribution(s) at the Organs at Risk should be reported according to the recommendations of Section 4.2.4.

In summary, the following dose values should be reported:

- peak absorbed dose to water for the electron beam;
- location of, and total dose value at, the ICRU Reference Point (the ICRU Reference Point may or may not be at the Level of the peak absorbed dose);
- contribution to the dose at the ICRU Reference Point from the electron and the photon beams and their combination;
- maximum dose in the PTV*;
- minimum dose in the PTV*;
- dose(s) to the Organ(s) at Risk (PRV).

*Best estimate, depending on the level of reporting; at Levels 2 and 3, dose distributions, and dose-volume histograms, when relevant.

5.3.2 Adjacent electron and photon beams

Adjacent electron and photon beams are used when different parts of the PTV reach significantly different depths (*e.g.*, cervical lymph nodes in the head and neck area). These parts are then to be irradiated with radiation beams with different penetration depths. The presence of Organs at Risk may also justify the use of beams with different penetration depths.

A CTV may then have to be covered by several PTVs, depending on the technical approach to treatment (*i.e.*, beam arrangements, type of radiation, or technique). An initially large PTV may also have to be divided into several PTVs.

For each PTV and/or anatomical area, an ICRU Reference Point has to be defined; it should be clinically relevant and located in the central part of the PTV (see, *e.g.*, Section 6.2 “Total skin irradiation” and Appendix).

For reporting, the doses at the ICRU Reference Points of each PTV have to be reported, as well as the corresponding maximum and minimum doses. Recommendations of Section 5.2 have to be followed for the electron beams, while the recommendations of ICRU Reports 50 and 62 have to be followed for the photon beams.

Doses at the Organs at Risk should be reported according to the recommendations of Section 4.4 (for the photon and electron beams).

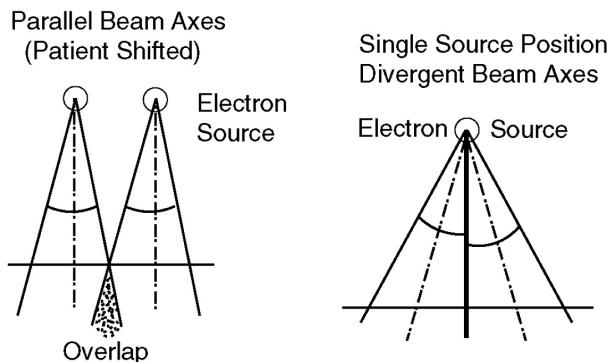


Figure 5.8. Adjacent electron beams. On the left-hand side is a conventional set-up where the beam axes are parallel and some overlap is unavoidable (Fig. 5.9). On the right-hand side, the beam axes are inclined toward one another to avoid overlap due to the divergence of the beam.

Special care should be taken to check the dose variation at the beam junctions. The precautions taken in order to avoid overlapping and/or cold spots have to be reported. The possibility of scattered radiation from the other beams should be evaluated and taken into account.

5.4 COMBINATION OF ELECTRON BEAMS

5.4.1 Adjacent-parallel electron beams

Adjacent-parallel electron beams are used when the PTV is too large to be included in one electron beam (Figs 5.8 and 5.9). They can also be used in situations where different parts of the PTV reach different depths (Fig. 5.10). These parts are then to be irradiated with electron beams of different energies (*e.g.*, chest wall and internal mammary nodes in breast cancer).

When using adjacent electron beams, one faces the same situation as described above in Section 5.3.2 for adjacent electron and photon beams. The doses at the ICRU Reference Points of each PTV have to be reported, as well as the corresponding maximum and minimum doses. Recommendations of Section 5.2 should be followed. Comparison of the doses at the Reference Points of the different PTVs may provide an evaluation of the homogeneity of the dose distribution of the whole treatment. Doses at the Organs at Risk should be reported according to the recommendations of Section 4.4.

Special care should be taken to check the dose variation at the beam junctions, especially when different beam energies are used. The precautions taken in order to avoid overlapping and/or cold spots have to be reported (Fig. 5.9).

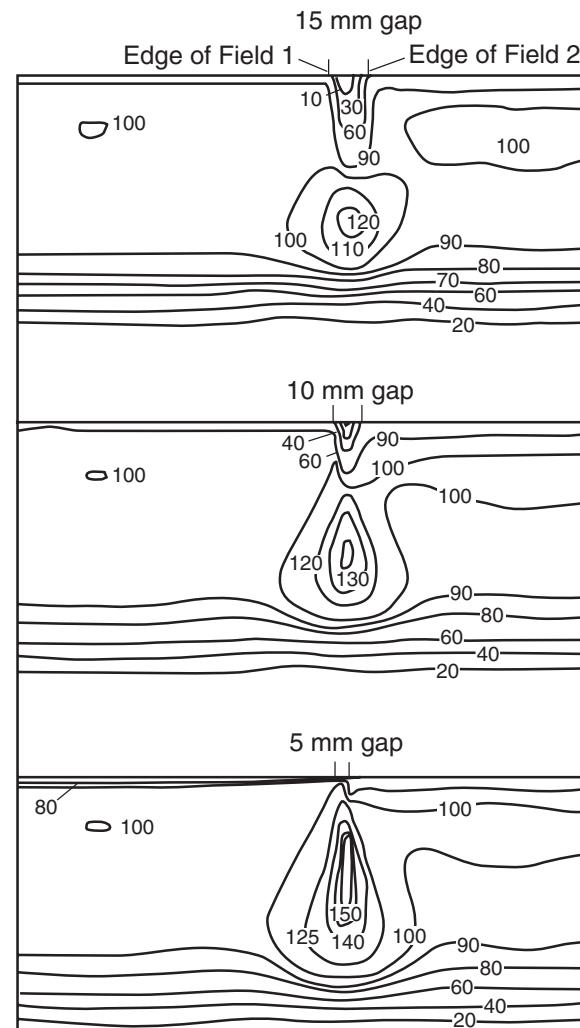


Figure 5.9. The dose distribution for two adjacent 19-MeV electron beams. The beam axes are parallel, (left-hand side part of Fig. 5.8). The influence of different gaps between the edges of the fields is illustrated: 15, 10, and 5 mm. (Redrawn from Almond, 1976.)

5.4.2 Parallel-opposed electron beams

Parallel-opposed electron beams are less frequently used than parallel-opposed photon beams. However, to treat deep-seated tumors, parallel opposed electron beams of high energy (*i.e.*, 40 MeV or more) can in some cases achieve more advantageous dose distributions than conventional photon beams (Fig. 5.11).

At these very high energies, the dose gradient in the fall-off region of the beam is smaller. As a result, when combining two parallel-opposed beams, rather homogeneous dose distributions can be obtained for deep-seated PTVs. High-energy electrons, above 40 MeV, are used only in a few centers today, but developments can be expected in the future (see Section 3.10).

RECOMMENDATIONS FOR REPORTING DOSES IN ELECTRON BEAM THERAPY

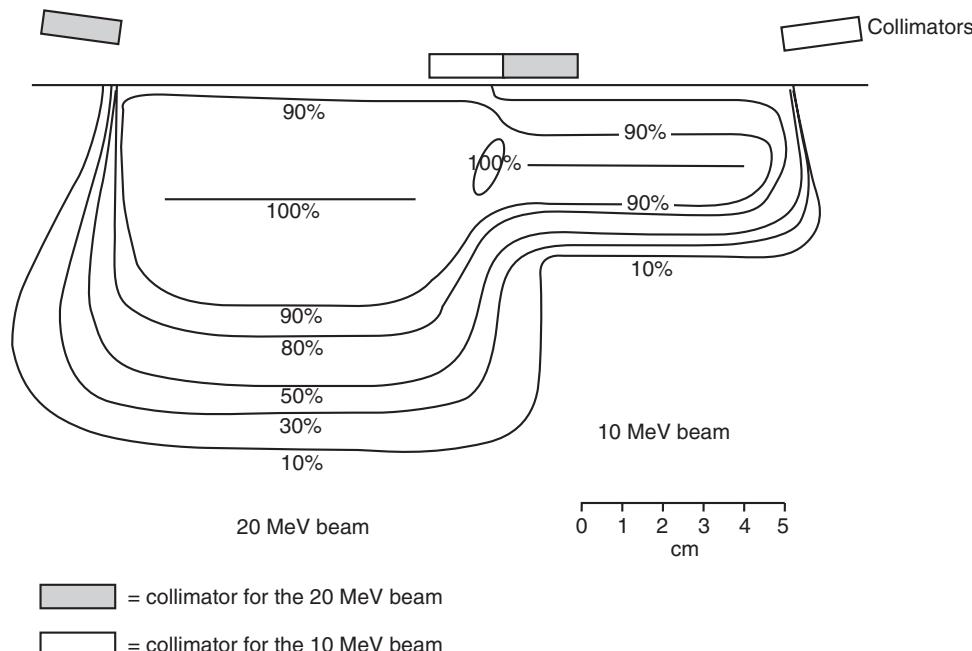


Figure 5.10. Example of two adjacent nearly parallel electron beams of different energies (20 and 10 MeV), used to treat different parts of the PTV, reaching different depths. The dose distribution is obtained with the beam edges inclined to one another to avoid overlap due to the divergence of each beam. (Modified from Zackrisson and Karlsson, 1996.)

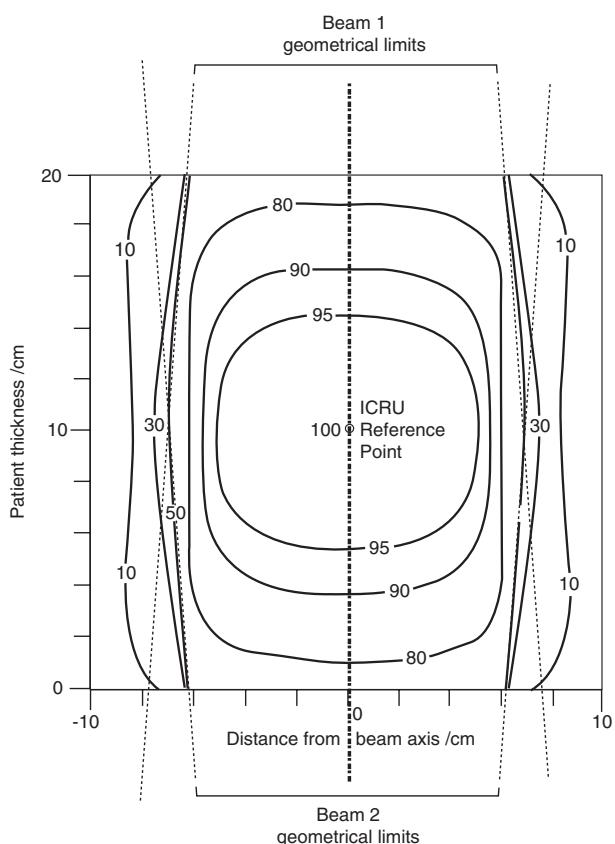


Figure 5.11. Isodose contours for two parallel-opposed 50-MeV electron beams, for a field size of 14 cm × 14 cm and a patient thickness of 20 cm. The doses are expressed as a percentage of the dose to the ICRU Reference Point selected on the beam axis at midplane. (Modified from Brahme *et al.*, 1980.)

Compared with photons, more accurate determination of relevant anatomical data (tissue thickness, density, and heterogeneity) is required. Therefore, safe application of high-energy electron beams requires dose evaluation and reporting at Level 3. The possibility of RBE changes at high energies has to be considered (see Section 1.1).

For reporting, the ICRU Reference Point should be selected at the center of the PTV, if possible on the beam axes. Selection of parallel-opposed, equally weighted electron beams implies that the PTV is located at (or close) to the mid-depth. Therefore, the dose at mid-depth on the beam axes is close to the dose at the center of the PTV (except of course if boluses or beam absorbers are used). The same approach is followed for two parallel-opposed, equally weighted photon beams (ICRU, 1993).

In addition to the dose at the ICRU Reference Point, the maximum and the minimum dose to the PTV, the doses at the Organs at Risk and the dose-volume histograms should be reported.

At energies below 30 MeV, because of the steep dose fall-off, the use of parallel-opposed electron beams could lead to the significant over- or underdosage if the patient thickness and tissue densities, and/or the beam energies, are not carefully matched or if the beam energies are not stable. In addition, patient thickness and tissue density may vary from one part of the beam to another, or from one session to another during the several weeks of the treatment (Fig. 5.12). Therefore, the use of two

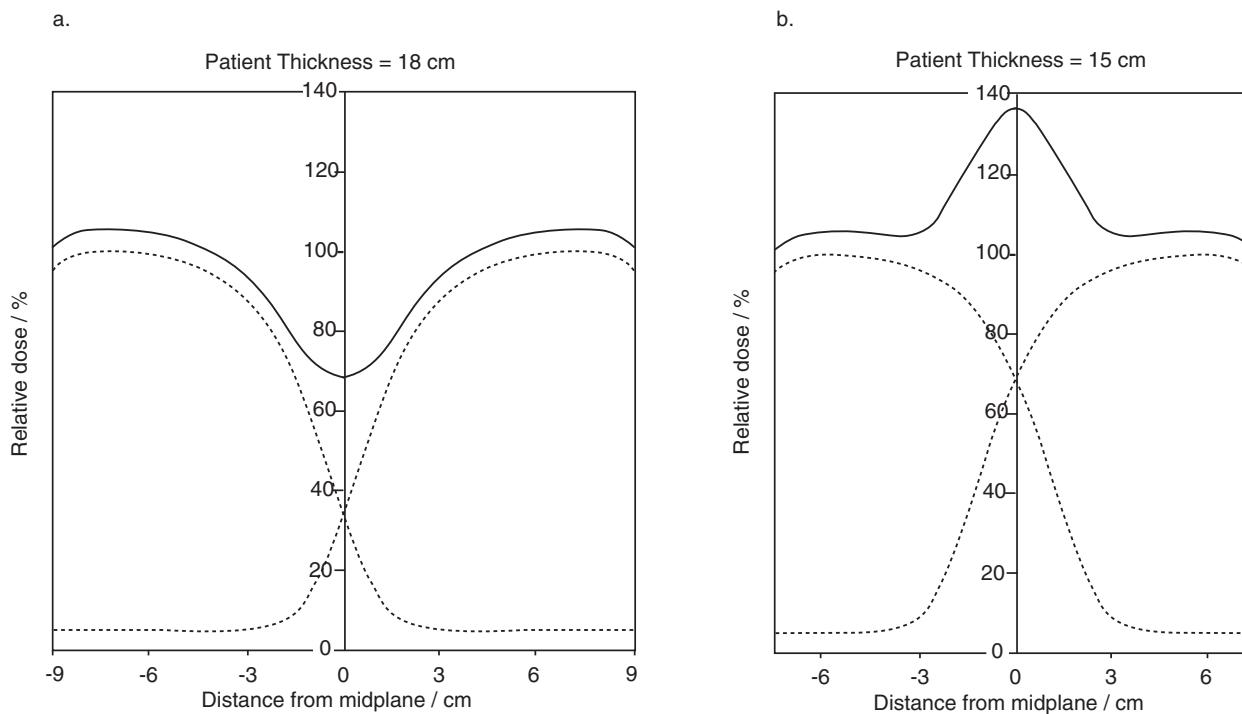


Figure 5.12. Dose variation along the beam axes for two parallel-opposed electron beams of 20 MeV (solid line). The depth-dose curves for the individual beams are shown as dotted lines. When the patient's thickness varies from 18 cm (a) to 15 cm (b), the dose at midplane varies from –32 percent to +37 percent (the peak dose for each beam being taken as 100 percent).

parallel-opposed electron beams in the energy range between 15 and 30 MeV has few clinical indications, if any.

When two superficial PTVs separated by Organs at Risk have to be treated, parallel-opposed electron beams of low energy can be used. Typical examples are tumors of the head and neck, where the posterior parts of the lymph node regions, in both sides of the neck, are treated with electron beams (e.g., from 6 to 10 MeV), in order to spare the spinal cord. However, the bremsstrahlung from the two beams contributes a certain dose to the spinal cord. Many clinical protocols and the accumulated clinical experience do not account for bremsstrahlung.

At low energies (<10 MeV), provided there is a sufficient thickness of tissues between the two skin surfaces, there is in general no great interaction between the two beams (in fact, the beams are independent of each other). However, the thickness of the tissues between the skin surfaces has to be checked carefully. Occasionally, the thickness reduces during treatment (tumor reduction or poor nutrition) and therefore may require attention during treatment.

For reporting, the two electron beams can be considered separately, except for the contribution of the bremsstrahlung. When photon and electron beams are combined, the scattered radiation from both

beams has to be taken into account when evaluating the dose to the PTVs and Organs at Risk.

5.5 ELECTRON-BEAM ARC THERAPY

Arc therapy using electron beams may be, and is sometimes, used to treat PTVs of complex shapes or extended PTVs. The optimal and safe use of this technique is difficult and carries specific problems. Accurate determination of the dose distribution requires sophisticated computational resources and elaborate methods for anatomical data acquisition. Therefore, dose evaluation and reporting at Level 2 (or 3) are absolutely required. Patient positioning also requires special care.

The ICRU Reference Point for reporting should be at the center (or near the center) of the PTV. However, depending on the technique and dose distribution, several PTVs and corresponding ICRU Reference Points may have to be identified.

Comparison of the doses at these Reference Points may provide an evaluation of the homogeneity of the dose distribution of the whole treatment. In addition to the dose delivered at the ICRU Reference Point(s), the maximum and the minimum doses within each PTV, the dose distributions and the dose-volume histograms should be reported.

6 SPECIAL TECHNIQUES

6.1 INTRA-OPERATIVE RADIATION THERAPY (IORT)

6.1.1 Introduction

In intra-operative radiation therapy (IORT), electron beams are used to deliver a large single-dose fraction after surgical exposure of a well-defined anatomical area (Abe, 1984; Abe *et al.*, 1980).

The CTV is defined as accurately as possible by the surgeon and the radiation oncologist during the procedure.

The purpose of this procedure is the curative treatment of a presumed subclinical disease after a macroscopically complete resection. Sometimes, an unresectable gross tumor or residual tumor after an incomplete resection may receive palliative IORT (Gunderson *et al.*, 1983; Tepper *et al.*, 1986).

The exact shape, size, and location of the CTV can thus only be defined during surgical exploration. During the procedure, mobile sensitive tissues are displaced out of the beam using applicators, in order to decrease normal tissue toxicity.

IORT is often used as a boost to additional external photon beam therapy (Calvo *et al.*, 1990; Goldson, 1981).

6.1.2 Beam requirements

Different types of IORT applicator systems have been described, according to the local radiation-treatment equipment and facilities. The dose distribution depends strongly on the design of such applicators, and other accessories, as well as on patient-beam positioning accuracy (AAPM, 1995). Most irradiation techniques use special lucite (PMMA) or brass applicators linked physically to the head of the treatment machine ("docking system") as shown in Figure 6.1. Some systems have also been designed to use laser beams or an optical set-up for alignment ("non-docking systems") (Palta and Suntharalingam, 1989).

Depending on the location and depth of the CTV and surrounding organs/tissues, the approach and positioning of the applicator may be easier when using an oblique beam incidence. The distal end of the applicator, which should be parallel to the tissue

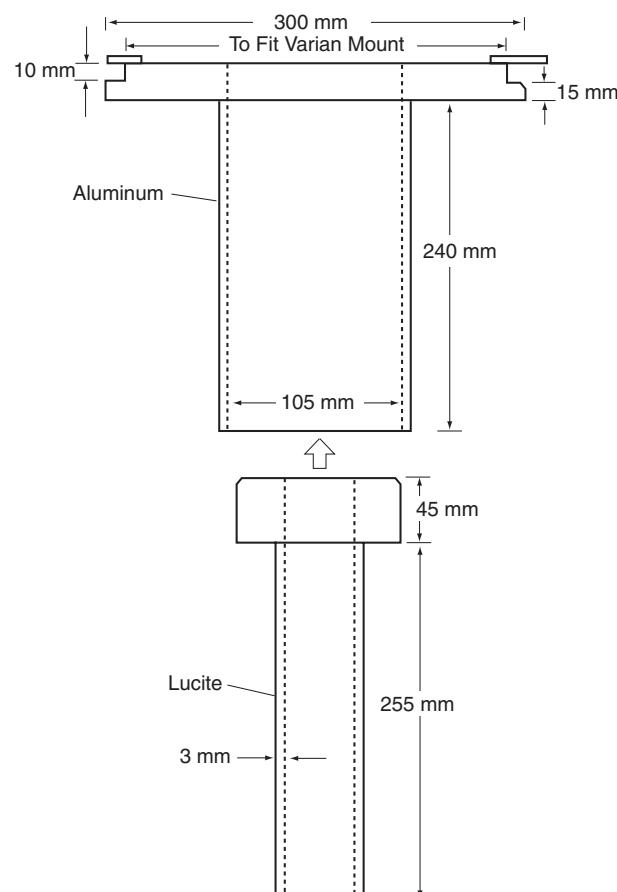


Figure 6.1. Basic features of the intra-operative electron applicator system developed at the Mayo Clinic. Lucite (PMMA) applicators "dock" into an aluminum jacket that attaches to the head of the accelerator using the standard wedge-tray attachment geometry. (Modified from McCullough and Anderson, 1982.)

surface, then often needs to be oblique relative to the beam axis ("bevel angle") (Dahl and McCullough, 1989). Depending on the clinical conditions, an air gap may or may not be left between the distal end of the collimator and the tissues (Figs 6.2 and 6.3).

In general, the nominal incident electron beam energy (beam energy at the exit window) used in IORT treatment ranges from 6 to 22 MeV giving energies between 3 and 18 MeV at the surface of the CTV/PTV. Such energy losses are due to scattering of the electrons in the head of the treatment machine, and on the walls of the applicators and

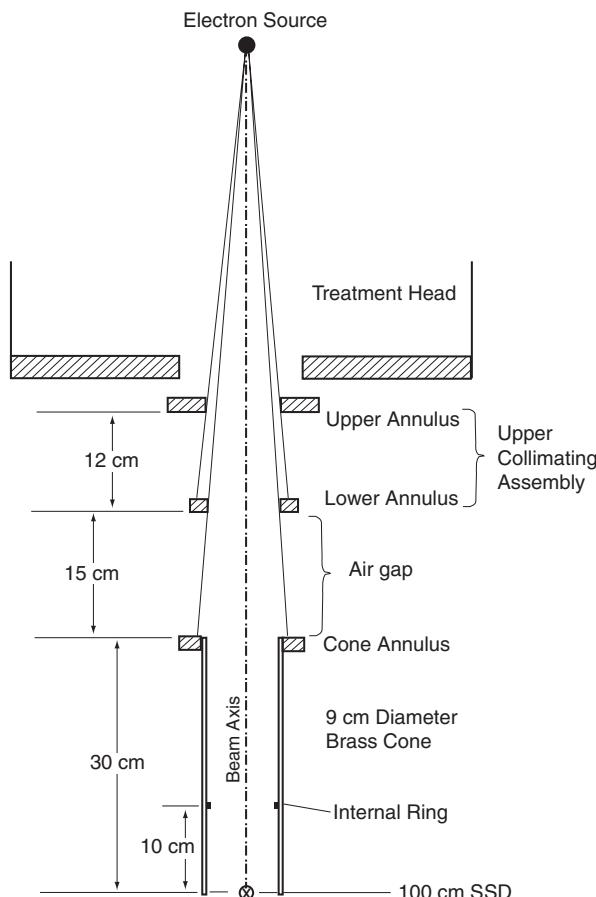


Figure 6.2. Schematic picture of a “non-docking” intraoperative collimation system developed at M. D. Anderson Hospital. The two annuli are attached to the treatment head and provide electron collimation. A 15-cm air gap is maintained between the lower annulus and the IORT applicator (redrawn from Hogstrom *et al.*, 1990).

the other accessories between the exit window and the region to be treated (Hogstrom *et al.*, 1990). If special flattening filters are used to provide dose homogeneity within the geometrical limits of the field, these also act as scattering foils, leading to an additional decrease in the beam energy at the target level. Thus, in addition to the nominal energy, the beam quality used in delivering IORT treatments should be described using depth-dose penetration curves specific to the applicator system.

With the use of flattening filters, the need for bolus is reduced or eliminated.

6.1.3 Recommendations for reporting

6.1.3.1 Treatment technique

The irradiation procedure specific to the IORT facility must be reported:

- machine;
- nominal beam energy;
- IORT applicator system;

- type, shape, bevel angle, and external size of the IORT applicator;
- type, shape, and size of additional collimation;
- flattening filters; and
- accessories such as bolus and shielding blocks.

6.1.3.2 The ICRU Reference Point

Usually, a single PTV is prescribed. In some cases, combinations of adjacent beams have to be used to treat a PTV larger than the available applicators. Rarely is a second PTV included within the first PTV.

When the beam axis is perpendicular to the tissue surface, the ICRU Reference Point for reporting dose is selected on the beam axis, at the maximum of the depth-dose curve (peak dose). The dose at this point is the ICRU Reference Dose and should always be reported.

The recommendations of Section 5.2.1 (“Reference conditions”) are applicable. The beam energy is usually selected in such a way that the peak absorbed dose is located at, or in the central part of, the PTV. If this is not the case, the best estimate of the dose at the center of the PTV should also be reported.

When the beam axis is oblique relative to the tissue surface (applicator, bevel angle), the ICRU Reference Point for reporting dose is selected on the “clinical axis,” at the level of the maximum of the depth-dose curve.

The clinical axis (Fig. 6.3) is defined as the axis perpendicular to the surface of the tissues, at the point of intersection of the central axis of the beam with the tissue surface (Nyerick *et al.*, 1991).

The depths of the 100 percent dose and of the different isodoses in the tissues are shorter along the *clinical axis* (perpendicular to the surface), than along the *oblique electron beam axis*. As stressed previously (Section 5.2.4) this has to be kept in mind when selecting the beam energy.

Usually, the irradiation conditions (e.g., electron energy, field size, etc.) are selected so that a dose of at least 90 percent of the ICRU Reference Dose is expected to be delivered to the entire PTV.

6.1.3.3 Reporting of dose

It is assumed that the central-axis depth-dose and the dose distributions on the two major axes of any applicator at the depth of the dose maximum (*i.e.*, central-axis depth-dose, as well as cross beam profile data, assuming a homogeneous tissue-equivalent medium) are available.

Firstly, all of the technical procedures have to be reported as well as the peak absorbed dose under standard conditions for each applicator.

SPECIAL TECHNIQUES

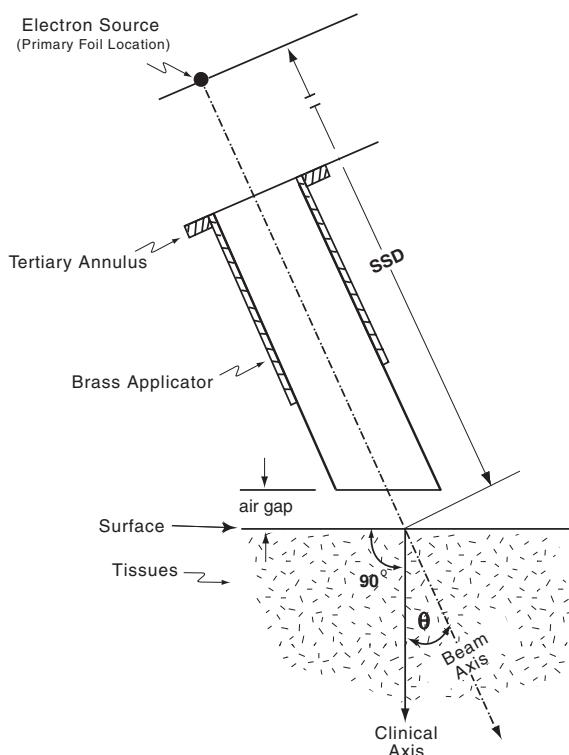


Figure 6.3. Definition of "clinical axis" for IORT electron application with oblique incidence of the beam axis (angle θ). (Redrawn from Nyerick *et al.*, 1991.)

Secondly, when reporting the dose, the three major dimensions of the 90 percent isodose curve should be reported.

When using adjacent beams, any overlap or gap that has been observed should be reported.

Unfortunately, surgical procedures do not allow for accurate acquisition of different target volume data (contour and volumes). Thus full three-dimensional dosimetry is presently not realistic.

In summary, the following dose values should be reported:

- peak absorbed dose to water, in reference conditions, for each individual beam (if beam axis is perpendicular to the tissue surface);
- for oblique beam axis, the maximum absorbed dose in water on the "clinical axis";
- location of, and dose value at, the ICRU Reference Point (if different from above);
- maximum dose to the PTV*; and
- minimum dose to the PTV.*

*Best estimate from the available dose distributions for the applied irradiation conditions.

6.2 TOTAL SKIN IRRADIATION (TSI)

Total skin irradiation (TSI) is indicated to treat selected cutaneous T-cell lymphomas (previously called Mycosis fungoides).

6.2.1 Introduction

The basic aim of the TSI treatment is to irradiate the total skin envelope as homogeneously as possible. In patients presenting with superficial disease, TSI is delivered with one beam energy.

In other clinical situations the thickness of the skin may vary with stage, pathology, and location on the body surface. This results in the identification of several CTVs and the need to use beams of different penetration. This is also the case when skin tumors are present and may require additional boost irradiation.

6.2.2 Beam requirements

Different technical approaches for the delivery of TSI treatments have been developed using multiple fields, arc therapy, patient rotation, patient translation, and dual energies according to the available local equipment and facilities (AAPM, 1987; Cox *et al.*, 1990; Horiot *et al.*, 1988; Karzmark, 1968; Karzmark *et al.*, 1960; Kim *et al.*, 1984; Podgorsak *et al.*, 1983; Sewchand *et al.*, 1979; Williams *et al.*, 1979). Most irradiation techniques involve several large fields at a large treatment distance.

In most clinical presentations with localized and even generalized plaques, the CTV is located within the first 5 mm. Infiltrated plaques, ulcerations, and skin tumors require an individual estimate of the thickness of the lesions.

Figure 6.4 shows the depth-dose curve for a degraded electron beam with a mean energy of 2 MeV on the skin of the patient. Usually, the incident electron beam energy on the patient's skin ranges from 2 to 7 MeV, with nominal energy ranging from about 4 to 10 MeV (energy at the exit window of the accelerator). Such energy losses are due to the material in the treatment head, the large air gap between the exit window and the patient, and the use of scattering screens. The use of a scatter energy-degrader (typically a 1 g/cm^2 lucite panel) close to the patient improves dose uniformity, particularly on oblique body surfaces. It also results in a higher surface-dose and shallower depth-dose distribution because of the decreased energy and increased angular spread of the original electron beam (Fig. 6.5) (LeBourgeois *et al.*, 1992).

Whatever the technique used, the final dose distribution is the result of the inhomogeneous dose distribution in each beam. The aim is to obtain

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

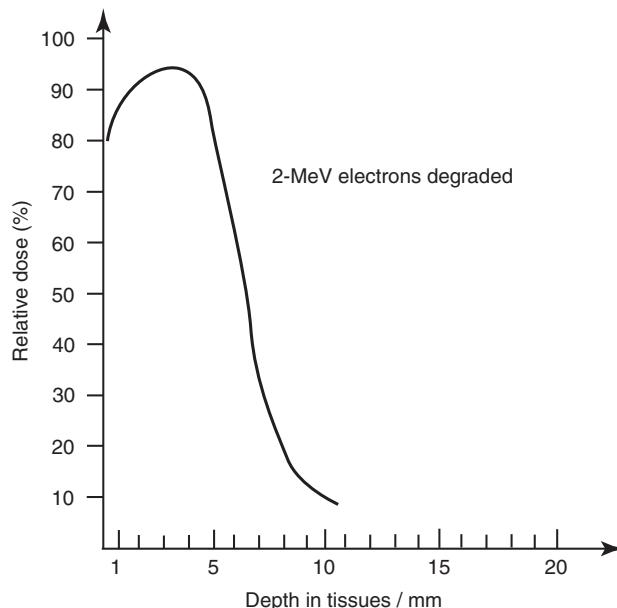


Figure 6.4. Depth-dose curve for a 2-MeV degraded electron beam for total skin irradiation (see text). (Modified from LeBourgeois *et al.*, 1977.)

a rather homogeneous dose distribution after completion of the whole treatment sequence. As a general rule, the integral dose should be kept as low as possible (Karzmark, 1964; Karzmark *et al.*, 1960).

Total skin irradiation is generally performed in several fractions. However, for obvious radiobiological reasons, the complete sequence needed to obtain a homogeneous skin irradiation should be performed in a single treatment session. All beams should thus be applied on the same day.

Total skin irradiation is usually followed by localized boost fields, for two reasons:

- (1) to compensate for the unavoidable inhomogeneities in the body surfaces hit tangentially by the beam (e.g., skull, sole of the feet, perineum, inner upper arms, thighs) and
- (2) to increase the total dose on specific areas (infiltrating plaques, nodules).

All these additional fields should be documented and reported by drawings and/or photographs.

6.2.3 Recommendations for reporting

6.2.3.1 Treatment technique

The irradiation procedure established in the department must be reported: machine and patient set-up, use of beam modifiers, number of fields, angle, and direction of each beam. In addition, technical devices and methods aiming to improve daily reproducibility of patient positioning and to monitor variations in the dose distribution should be reported.

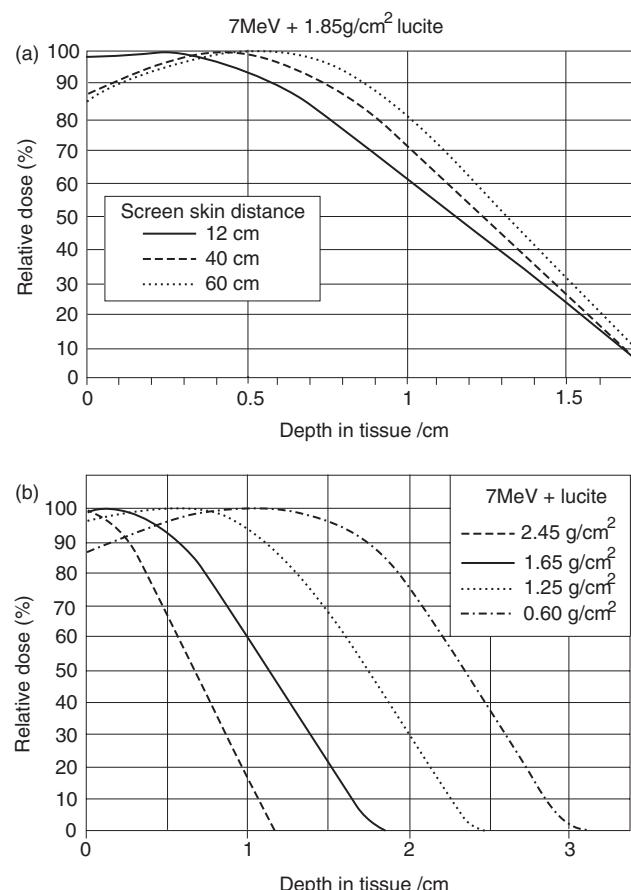


Figure 6.5. Total skin irradiation with electrons. For a 7-MeV electron beam, the depth-dose distribution varies with the *lucite* scatterer thickness (b) and the position of this screen relative to the patient's skin (a). (From LeBourgeois *et al.*, 1992.)

Clinical information about the patient, including a mapping representation of the locations and estimated thickness of the skin disease, should be reported.

Patient contours and individualized radiation-field arrangements result in complex dose variations to different anatomical areas. Thus, there is no simple way to adequately describe the TSI treatment. It is necessary to measure the dose at several clinically relevant points using *in vivo* dosimeters.

The following section deals only with situations where the depth of the PTV can be considered constant over the whole-body surface. In other clinical situations additional techniques are needed and should be reported separately.

6.2.3.2 The ICRU Reference Dose

Total skin irradiation implies the identification of several anatomical areas. For each anatomical area an ICRU Reference Point for reporting dose has to be

SPECIAL TECHNIQUES

selected at, or near, the center of the anatomical area. The dose at this point is the ICRU Reference Dose for the anatomical area. The maximum and minimum doses to the anatomical area provide an estimation of the dose variation throughout the anatomical area. Anatomical areas where dose deficiencies are identified must be documented.

In addition, an appropriate point, clinically relevant, located within the PTV can be chosen as the ICRU Reference Point for the whole PTV. The dose at that point is quoted as the ICRU Reference Dose for the whole PTV. This dose should be reported, as well as the best estimate of the maximum and minimum doses to the whole PTV.

6.2.3.3 Reporting of dose

It is assumed that, in addition to the central depth-dose curve, the dose distribution in selected planes is available.

Firstly, the technical procedures have to be reported as well as the peak absorbed doses for each electron beam.

Secondly, the doses resulting from the overlap of all beams should be considered.

The electron energies and technical procedures are often chosen in such a way that the peak absorbed doses are at, or near, the center of the anatomical areas. The points where the peak absorbed doses are observed can then be chosen as the ICRU Reference Points for the different anatomical areas. If this is not the case, other clinically relevant points have to be selected and the doses at these points have to be reported as well as the different peak doses.

In summary, the following dose values should be reported for TSI:

- *peak absorbed dose in water for each individual electron beam;*
- *location of, and absorbed dose value at, the ICRU Reference Point for each anatomical area (the ICRU Reference Points may or may not be at the level of the peak absorbed dose);*
- *best estimate of maximum dose to each anatomical area;*
- *best estimate of the minimum dose to each anatomical area;*
- *location of absorbed dose at the ICRU Reference Point for the whole PTV;*
- *best estimate for the maximum dose for the whole PTV; and*
- *best estimate for the minimum dose for the whole PTV, and any other dose value that is available and considered to be significant.*

Furthermore, according to the general ICRU recommendations for reporting, information should be given on the dose per fraction, the number of fractions per week, the total number of fractions, and the overall treatment time.

Owing to the complex procedures needed for total skin irradiation, an evaluation of the full three-dimensional dose distribution is highly desirable. Unfortunately, at present reliable three-dimensional reconstructions and dose computations are not widely available.

7 QUALITY ASSURANCE

The goal of a quality assurance (QA) program is to evaluate the complete chain of procedures involved in electron beam therapy, from diagnostic imaging to treatment delivery. Most importantly, the stated dose values must be validated.

7.1 IMAGING

Since the overall precision of the treatment can be no better than the accuracy of the diagnostic imaging, QA must begin with the diagnostic procedure. This is especially true in the case of electron beam therapy, where accurate determination of the CTV and PTV is very critical for the choice of the beam energy. An insufficient estimate of the depth of the PTV will result in under-dosage of part of the PTV. Conversely, an overly generous estimate will lead to inclusion in the Treated Volume of normal tissues that should be either excluded or at least located in an area of a large dose gradient.

The following steps should be checked and subjected to quality-control procedures wherever applicable:

- clinical examination and documentation in the patient's chart and
- imaging procedures (CT, MRI, ultrasound, *etc.*).

When three-dimensional treatment planning is used, the imaging equipment must be checked to ensure good diagnostic quality to allow a reliable estimate of the different volumes of interest such as GTV, CTV, PTV, OAR, and PRV.

Reproducible patient positioning and immobilization is mandatory and can only be obtained by using the same locating devices on the imaging and accelerator tables.

7.2 PATIENT DATA

7.2.1 Level 1

At this level, determination of the dimensions and of the proximal and distal depths of the PTV may be sufficient. However, this implies the assumption

that the entire PTV has the same shape and configuration over the entire irradiated region. This assumption should always be made with caution, particularly in the head and neck area.

7.2.2 Levels 2 and 3

At these levels, it is assumed that the GTV, CTV, PTV, OAR, and PRV can be defined in one or more planes using reliable tools (*e.g.*, a series of CT or MRI sections).

Comprehensive quality control of imaging equipment must be maintained. In any digital-imaging tool, signals produced from the radiation source are first detected and captured, then processed and finally displayed. Each stage of the imaging system should be evaluated in terms of its capability of performing a particular task (AAPM, 1993; ICRU, 1987). As these digital images are entered directly into the treatment-planning system, one should also check that neither loss nor distortion of information occurs because of poor data transmission.

Tools for automatic definition and recognition of anatomical structures are now available on treatment-planning systems. However, as some of these anatomical structures may be very complicated in shape, adequate information about the system should be provided by the manufacturer to the radiation oncologist, who must always define and validate the GTV, CTV, and OAR contours.

At Level 3, full three-dimensional patient anatomy is available. Because volume information is derived from a series of two-dimensional body sections, a sufficient number of closely spaced sections must be obtained.

7.3 QUALITY CONTROL OF THE ELECTRON ACCELERATOR

Quality control includes all the procedures used to:

- verify that the equipment meets minimum specifications and
- maintain the equipment within these specifications.

Mechanical and radiation characteristics in reference conditions should be assessed and checked periodically. Mechanical stability of the equipment is even more critical in electron mode than in photon mode. Indeed, the average energy and angular spread of electrons greatly depends on the components within the treatment head and their relative position, including beam-shaping devices.

Particular attention should be paid to the electron applicators, often designed as removable accessories and therefore subject to frequent mechanical stress. Misalignment may strongly affect beam flatness and symmetry.

Acceptance tests and routine control procedures can be found in various reports (AAPM, 1991; IEC, 1989a, b, 1990; Marinello *et al.*, 1989, 1993).

7.4 BEAM DATA ACQUISITION

The type of beam generation (scattering, scanning), accelerator type, and treatment-head geometry all have a large impact on the dose distribution. Therefore, it is necessary that the actual beam characteristics are determined for each accelerator on site. For the same reason, the use of standard isodose charts (actually seldom published) should be avoided.

Determination of the local beam characteristics requires a minimum set of dosimetry equipment and computing facilities. An expert and trained staff is needed. The following sections describe the minimal requirements for the type of technique and for the level of expected accuracy.

7.4.1 Level 1: basic techniques

The peak absorbed dose, depth-dose curves, flatness, and symmetry should be measured for the standard treatment conditions.

Phantom: These basic measurements should preferably be made in water; however, for practical reasons, plastic phantoms could be considered, using appropriate correction factors (IAEA, 1987, 1997; ICRU, 1992).

Ionization chamber: Cylindrical ionization chambers, commonly used for photon beams, are also used for high-energy electron beams to acquire ionization curves and beam profiles. Parallel-plane chambers are preferred for energies below 10 MeV.

Electrometer: Dual voltage and opposite polarities should be available on the associated electrometer in order to assess recombination and polarity effects.

Calibration of both ionization chamber and electrometer at a primary or secondary standards

dosimetry laboratory should be performed at regular intervals.

7.4.2 Levels 2 and 3: advanced techniques

At these levels, dose-distribution data acquired in the relevant planes are correlated with the patient's anatomy, taking into account obliquity and heterogeneity when appropriate. Resulting dose-distribution data depend on the treatment-planning system and the algorithms used. Therefore, measurement of a large set of dose distributions for different beam configurations is highly recommended to provide verification of the treatment-planning system (see Section 7.5).

Phantom: Connecting the ionization chambers or the electrometer set to an automated field scanner in a water tank will save time in building the beam library. However, particular attention should be paid to the reconstruction algorithm of the computer software.

Film dosimetry can also be considered with solid phantoms. Again, when a computer is connected to the densitometer, particular attention should be paid to the reconstruction algorithm.

7.5 TREATMENT-PLANNING SYSTEM

7.5.1 Level 1

At this level, manual calculation will suffice to provide the peak absorbed dose. The estimate of the dose distribution may be derived using a tabular or matrix format to represent the electron beam data. It is important to be aware of the limited accuracy of such a method, particularly when obliquity and heterogeneities are present.

7.5.2 Level 2

At this level, the scattering of electrons in tissues, and in particular different types of scattering in different tissues, must be considered. Dose distributions are therefore determined by using planning systems that use algorithms including models for multiple scattering. The user of a planning system is generally not familiar with details of these models. Verification of the accuracy of the dose-distributions obtained when using such a system is therefore needed. Dose-accuracy tests of electron beam calculation algorithms implemented in treatment-planning systems have been reported (Blomquist *et al.*, 1996; Cheng *et al.*, 1996; McShan *et al.*, 1994; Müller-Runkel and Cho, 1997).

QUALITY ASSURANCE

The complete verification of a planning system is a comprehensive task and must be performed by the manufacturer. The procedure used and the results must be documented by the manufacturer. The user can use published data on dose distributions for validation of the system. A collaborative group (Shiu *et al.*, 1992) of the National Cancer Institute has published measured distributions using irregular fields, inhomogeneities in phantoms, oblique incidence, and so on. The measurements have been carried out on one type of linear accelerator. Similar measurements were performed by Samuelsson *et al.* (1998).

An acceptance test of the treatment-planning system should be performed before the system is commissioned by the user. The AAPM (1998) recommends that, in the acceptance-testing procedure, a set of dose calculations should be carried out for a set of standard electron beam configurations. In these tests, at least the following should be included: open fields, different SSDs, shaped fields, inhomogeneity test cases, and surface irregularity test cases.

It is the responsibility of the center to verify that certain criteria for acceptability are maintained in its daily work. Van-Dyk *et al.* (1993) have presented a detailed description of the limits of acceptability for electron dose calculations. After the acceptance test, the user should set up test geometries to compare some computed and measured distributions. It is important to repeat these tests regularly and of course especially with any new or upgraded computer software or accelerator. At this level, the gross influence of heterogeneities in the patient may be

estimated using a simple two-dimensional correction algorithm.

7.5.3 Level 3

At this level, three-dimensional dose calculation would involve an integration over the entire scattering volume for each grid point used in the display. Such algorithms are still under development and not yet widely available (Purdy, 1996; Purdy *et al.*, 1996).

7.6 PATIENT SET-UP

One must ensure reproducible positioning of the patient during the whole treatment process from data acquisition to the last session.

7.7 IN VIVO DOSIMETRY

The overall uncertainty in the dose delivered to the patient may be estimated on the basis of the probability of random and systematic errors (type A and B uncertainties) (BIPM, 1981). However, in daily practice it is recommended that the dose accuracy be verified with *in vivo* measurements.

Thermoluminescence dosimetry or silicon detectors, calibrated under appropriate conditions, easily provide an acceptable estimate of the dose delivered to different points on the patient's skin. However, one has to be aware of uncertainties introduced by the detector positioning. When performed, *in vivo* dosimetry should be reported.

8 QUANTITIES, REFERENCE POINTS, AND VOLUMES RECOMMENDED FOR REPORTING ELECTRON BEAM THERAPY: SUMMARY

(1) Complete description^a of:

- (1.1) The clinical conditions (see Sections 2 and 7.2).
- (1.2) The technique^b (see Sections 3, 5, and 7).
- (1.3) Time-dose pattern (see Section 1.1).
- (1.4) Treatment prescription (see Section 1).

^aThe clinical conditions, treatment technique, time-dose pattern, and treatment prescription should be reported as fully as possible consistent with the level of reporting (Level 1, 2, or 3).

^bDescription of the accelerator, nominal energy, scattering foil, and any feature that could affect the beam quality, such as collimation system, scattering foil/scanning beam, monitor, etc. (see Sections 3 and 7).

(2) Description of beam parameters for all electron beams:

- (2.1) R_p in water (see Section 3.3).
- (2.2) R_q in water (see Section 3.6).
- (2.3) R_t in water (see Section 3.4).
- (2.4) Peak absorbed dose, in water, per monitor unit, and dose distribution when available.

(3) Volumes^c for reporting (location and dimensions):

- (3.1) GTV (see Section 2.2).
- (3.2) CTV (see Section 2.3).
- (3.3) PTV (see Section 2.4).
- (3.4) Treated Volume (see Section 2.5).
- (3.5) Irradiated Volume (see Section 2.6).
- (3.7) Organs at Risk (see Section 2.7).
- (3.8) PRV (Section 2.8).

^cThe techniques used to determine the volumes (CT, MRI, etc.) should be described. The location of all volumes with respect to fixed anatomical points should be reported as well as actual volumes where

available (as a minimum, three major axes should be reported).

(4) Location of and absorbed dose to ICRU Reference Point (see Section 4.3.2).

(5) Maximum and minimum doses to the PTV^d.

^dAt Level 1, estimated from the best available data; at Level 2, determined from dose distributions and/or dose-volume histograms.

(6) Dose(s) to the Organs at Risk^e.

^eAs minimum information, the maximum dose to any part of the Organ(s) at Risk should be reported. In addition, at Level 2, the volume of the Organ(s) at Risk receiving a dose higher than some chosen and specified tolerance dose limit should be reported.

(7) Dose-volume histograms (DVHs) for PTV and PRV if available.

(8) Quantities derived from DVHs such as biologically weighted doses together with an indication of the method of derivation including numerical values of any selected parameter.

(9) Description of any correction applied for small or irregular beam, oblique incidence, and tissue heterogeneity (see Section 5).

(10) For special techniques such as intra-operative radiation therapy (IORT) or total skin irradiation (TSI), additional information is required as indicated in Sections 6.1 and 6.2, respectively.

GENERAL REMARK

Reporting at Level 2 (and 3) should always include all data that are recommended to be reported at Level 1.

APPENDIX: CLINICAL EXAMPLES

As in ICRU Reports 50 and 62, clinical examples are presented with the aim of illustrating how the recommendations contained in the present Report can be applied in practice. The four examples were obtained from different radiation oncology centers and different countries. They should not be considered as ICRU recommendations for choosing given treatment techniques, volumes, or dose levels.

In the following clinical examples, the anatomical sites of the different volumes (such as GTV, CTV, and OAR) are described according to WHO (1990) and UICC (1997). The WHO document is cited in

ICRU Report 50 (pp. 41–43). The anatomical levels of section(s) for treatment planning follow the “code for sections” presented in Table I.3 (p. 44) in ICRU Report 50.

The same definitions of terms, the same concepts and the same methods of describing the volumes and specifying the doses are used for prescribing, recording, and reporting the treatment, as recommended in Section 1.3 of the present Report.

The color code recommended in Section 2.10 of the present Report is used whenever possible in the figures.

CASE NUMBER A1: MEDULLOBLASTOMA IN A CHILD

Clinical situation

A five-year-old boy presented with a gross tumor located in the cerebellum, 3 cm × 2 cm × 3 cm in size (GTV), as determined by MRI examination. Macroscopically complete surgery was followed by chemotherapy. Six months later, a local recurrence was removed by surgery again. This was followed by further chemotherapy including bone marrow transplant.

Treatment protocol

Radiation therapy was prescribed with curative intent.

Patient positioning and immobilization

Patient is prone, with head and shoulder immobilized in fixed mold.

GTV

After surgical resection, no GTV is defined.

CTV

The whole cerebro-spinal space is to be treated to two dose levels, depending on the suspected tumor cell density. Several CTVs are defined:

CTV-1: whole brain,
CTV-1B: boost to posterior fossa (cerebellum),

CTV-cervical: upper part of the spine (4.5 cm), and
CTV-2: spine (whole spine except the upper part).

CTV-cervical and CTV-2 include the whole spinal cavity as delineated from the spinal bony structures.

PTV

PTV-1 includes CTV-1 (whole brain), CTV-1B (posterior fossa), CTV-cervical, and a 5 mm safety margin.

PTV-1B (boost) includes CTV-1B (posterior fossa) and a 5 mm safety margin.

PTV-2 includes CTV-2 (spine) and a 5 mm safety margin. It is irradiated with electrons, using posterior portals. Because of the height of PTV-2, two adjacent electron beams need to be used, and therefore two PTVs are identified: PTV-2A and PTV-2B.

Organs at Risk (OARs)

Whole brain: maximum dose 30 Gy;
Optical nerve, pituitary: maximum dose 30 Gy; and
Spinal cord: maximum dose 30 Gy at any point of the spinal cord.

Treatment prescription

PTV-1: total dose 25.2 Gy at ICRU Reference Point.
Dose per fraction: 1.8 Gy, five fractions a week.

PTV-1B (boost to posterior fossa): up to 54 Gy, at ICRU Reference Point. Dose per fraction: 1.8 Gy, five fractions a week.

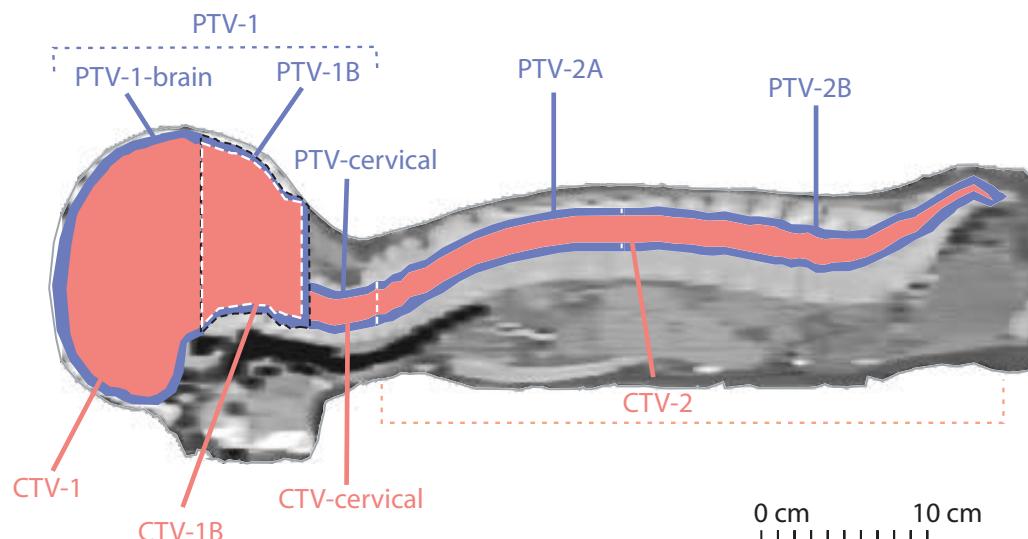


Figure A1.1. Treatment of medulloblastoma in a child. Sagittal reconstructed view of the cerebro-spinal space illustrating the volumes: CTVs (light red) and PTVs (light blue).

PTV-2A and PTV-2B (spine): total dose 25.2 Gy, at the ICRU Reference Point(s). Dose per fraction: 1.8 Gy, five fractions a week.

The CTVs and PTVs are illustrated in Figure A1.1.

Note that the cranial CTVs and PTVs are not defined with individual beam's-eye view, but are drawn schematically only to illustrate the concepts and the treatment technique.

Treatment technique

PTV-1 (whole brain, posterior fossa, and cervical spine) is irradiated using two lateral parallel opposed fields, 20 cm × 21.5 cm in size, using 6-MV photons.

The boost to the posterior fossa (PTV-1B) is given using two lateral parallel opposed fields, 15.5 cm × 8.5 cm in size, using 6-MV photons.

The spine (PTV-2A and PTV-2B) is irradiated with two adjacent electron beams, using posterior portals. The energy of the electron beams is 15 MeV.

In order to reduce the dosimetric consequences of overlaps and/or gaps between the two electron beams, the “moving-junction technique” is adopted. The junction is moved 1 cm upwards and 1 cm downwards relative to the nominal position. The extreme dimensions of the upper electron beam are 15–17.5 cm in height; the extreme dimensions of the lower electron beam are 21.3–23.8 cm in height (at the skin). The width of the beams is 7 cm at the skin.

The moving-junction technique is also used between the photon beams and the upper electron beam; the junction is moved 0.5 cm upwards and downwards.

The treatment technique is illustrated in Figure A1.2 and A1.3.

Dosimetry and treatment delivery are performed assuming a homogeneous water medium. The influence of the heterogeneity corrections is illustrated and discussed in Figure A1.5.

Quality assurance

Portal films are taken weekly for all photon-treated fields. Photographic images are taken initially, and with every move of the photon and electron junctions.

Reporting

PTV-1: whole brain, posterior fossa, and CTV-cervical

A dose of 25.2 Gy is delivered, in 14 fractions over 19 days.

The dose is specified at the ICRU Reference Point (ICRU-1) selected on the beam axes, at mid-plane, i.e., 7.8 cm in depth.

The DVHs are calculated separately for the brain and the cervical spine and shown in Figure A1.4.

PTV-1B: posterior fossa

A total dose of 54 Gy is delivered, in 30 fractions over 40 days. Of this, 26.8 Gy is delivered as a part of the treatment of PTV-1, and 27.2 Gy is delivered to PTV-1B as a boost.

The dose is specified at the ICRU Reference Point (ICRU-1B) selected on the beam axes, at mid-plane, i.e., 6.8 cm in depth.

The large variations of dose within PTV-1 and PTV-1B are caused by the PTV extending up to the

APPENDIX

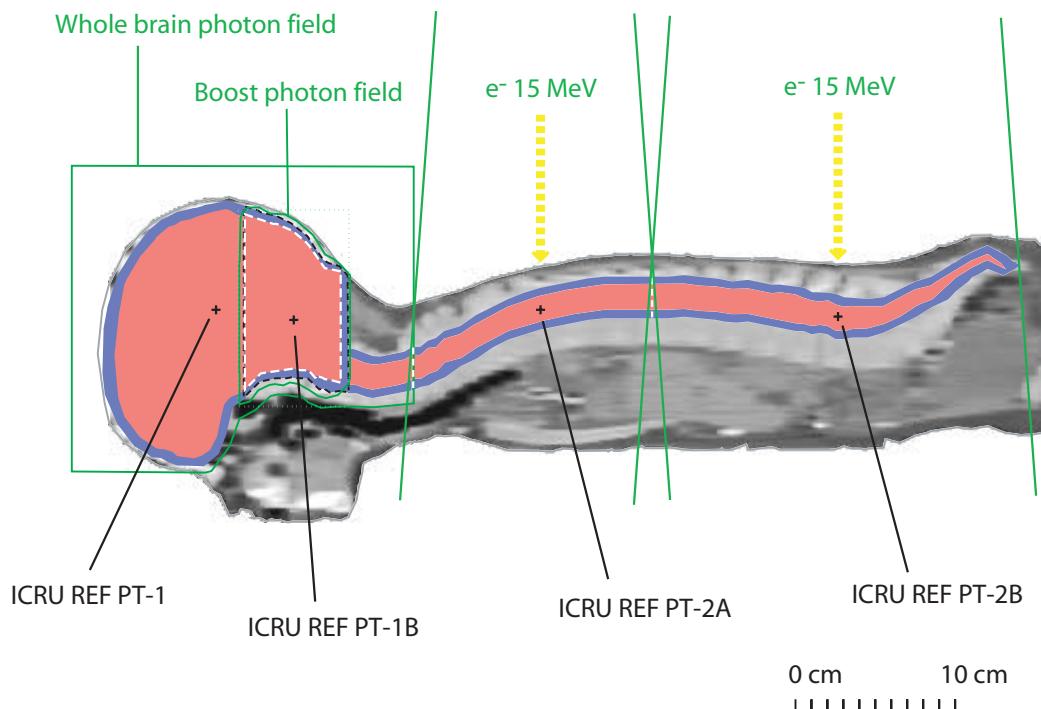


Figure A1.2. Sagittal reconstructed view illustrating the treatment technique: the lateral photon beams irradiating PTV-1; the lateral photon beams irradiating PTV-1B (boost to the posterior fossa); the posterior upper and lower 15-MeV electron beams irradiating the spine, PTV-2A, and PTV-2B.

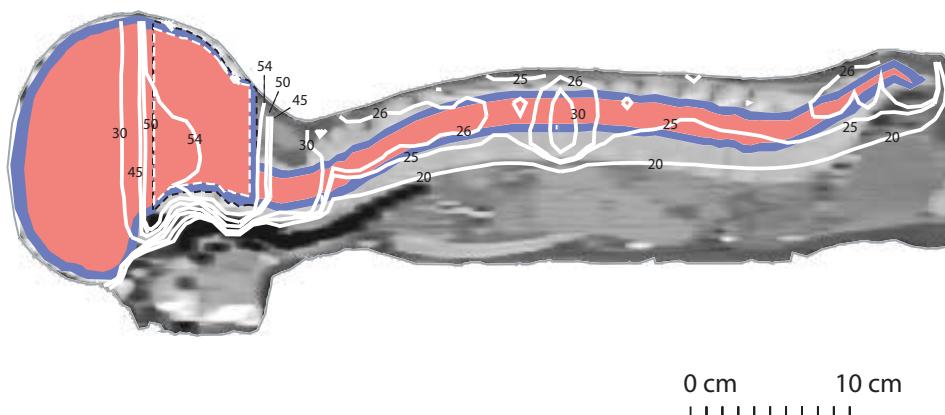


Figure A1.3. The dose distribution computed in the sagittal mid-plane assuming a homogeneous water phantom: the isodoses are superimposed on the anatomical contours. The absorbed doses are expressed in Gy. The doses are prescribed and reported at the ICRU Reference Points selected for the different PTVs, as indicated in the text.

skin surface of the patient, in the dose build-up region. In addition, the tangent incidence of the parallel opposed beams causes some hot spots in the dose distribution.

After 14 fractions to PTV-1, the dose at the ICRU Reference Point for PTV-1 is 25.2 Gy, but 26.8 Gy at the ICRU Reference Point for PTV-1B.

PTV-2: spine

Homogeneous water medium

A dose of 25.2 Gy is delivered, in 14 fractions over 19 days, to PTV-2A and PTV-2B.

The doses are specified at the ICRU Reference Points selected on the electron beam axes at the center of PTV-2A and of PTV-2B, respectively.

The maximum and the minimum doses to PTV-2A are 36.3 and 19.9 Gy, respectively. The maximum and the minimum doses to PTV-2B are 36.3 and 24.1 Gy, respectively. The maximum dose levels are delivered to a small part of the spinal cord as a result of beam overlap at the junction of the photon/electron and electron/electron beams (see Fig. A1.4). Note that the results of the “moving-junction technique” are not taken into account in the computation.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

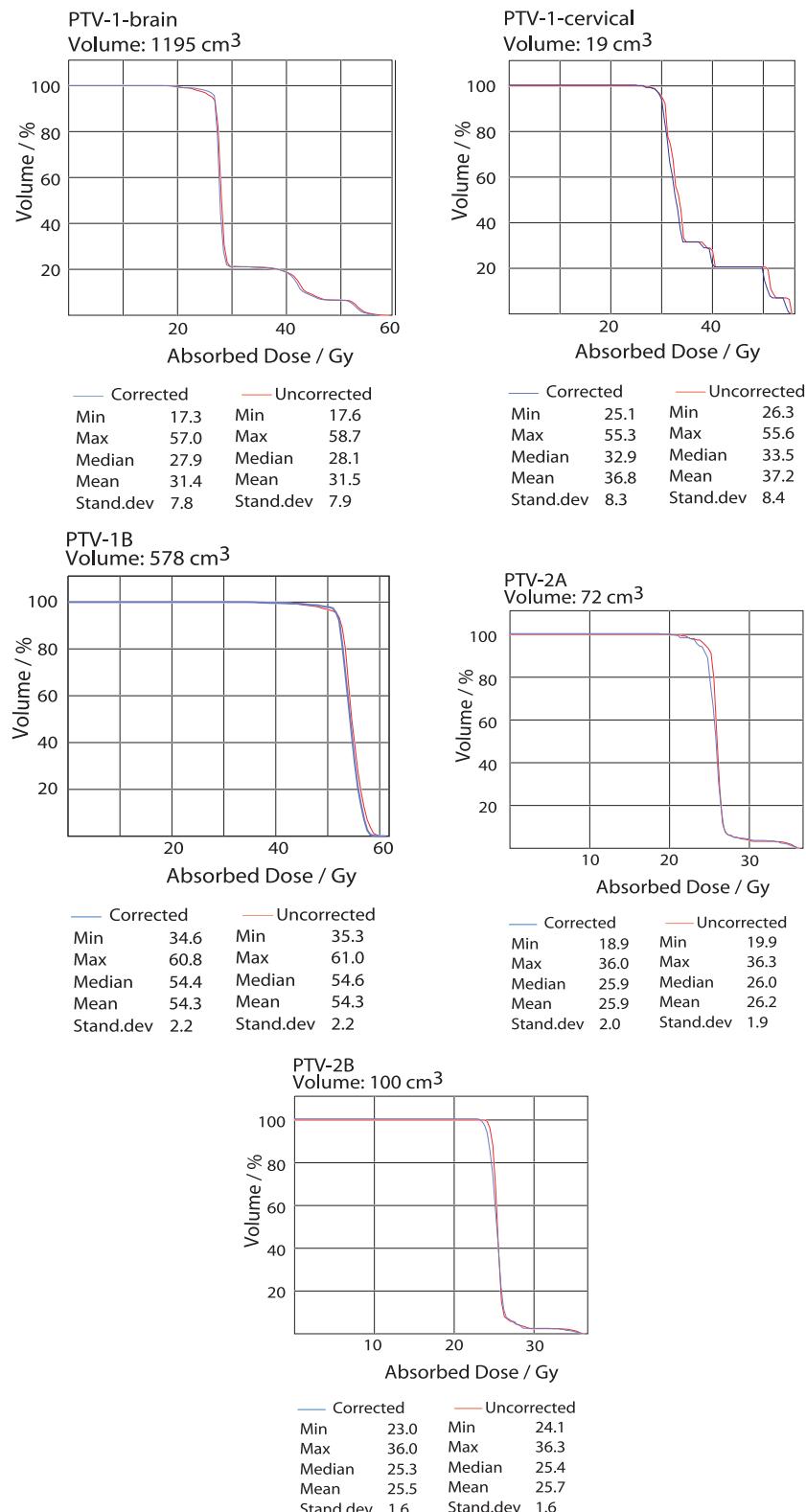


Figure A1.4. Comparison of dose-volume histograms computed for the different PTVs with and without heterogeneity corrections. (a,b) For PTV-1, DVHs are computed separately for different parts: PTV-1-brain and PTV-1-cervical. For PTV-1-cervical, a large dose gradient from 54 to 25 Gy is prescribed because of the proximity of PTV-1B (indeed, it cannot be avoided). The same comment applies to PTV-1-brain. (c) DVH for PTV-1B. (d,e) For the spine (PTV-2A and B), the doses after applying the heterogeneity corrections are slightly lower than the doses computed for a homogeneous medium (see text on PTV-2, heterogeneity corrections). For the spinal cord, the high doses found for a small proportion of PTV-2A and B result from the overlap between the electron beams, since the beam junctions are adjusted at the level of the skin (see text on treatment technique). In the DVH, computed in Fig. A1.4., the effect of the moving junction is not taken into account.

APPENDIX

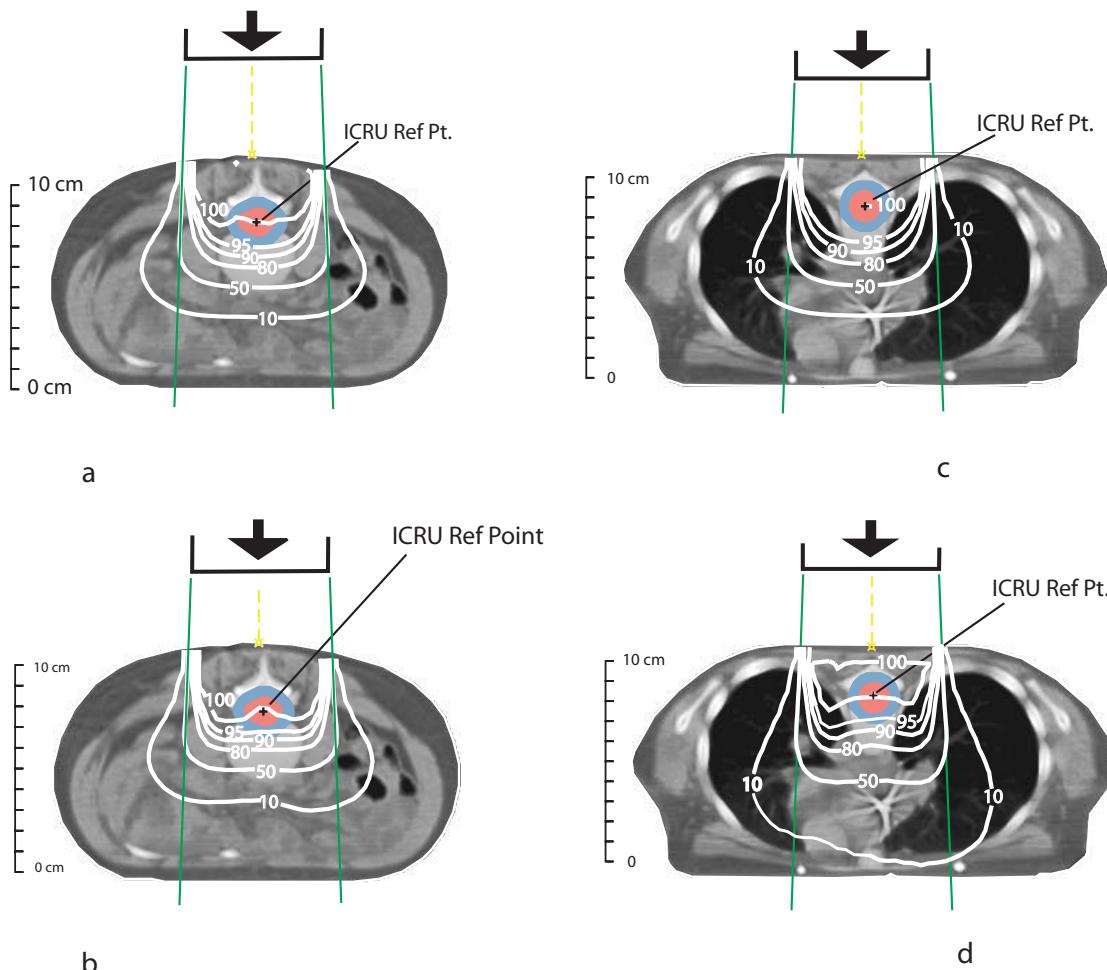


Figure A1.5. (a,b) Compare the dose distributions in a transverse section, through the abdomen, containing the center of PTV-2B and the beam axis, with and without heterogeneity corrections. (c,d) Same presentation, but for a section through the thorax, containing the center of PTV-2A. For PTV-2A and B, the doses computed with heterogeneity corrections are only slightly lower than those computed in a homogeneous medium. At the level of the abdomen (a,b), behind the spine, the isodoses computed using the heterogeneity corrections are shifted toward the surface (mainly the isodoses located closely behind the spine, due to bone attenuation). In contrast, at the level of the thorax (c, d), only the isodoses at the level of—or immediately behind—the vertebral body are slightly shifted toward the surface. Laterally to the vertebrae and further in depth, due to the presence of lung, the bone attenuation in the vertebra is balanced by electron scattering, which tends to shift the isodoses towards depth (see discussion on heterogeneities in PTV-2).

Heterogeneity correction

After application of the heterogeneity corrections, the dose at the ICRU Reference Point for PTV-2A and for PTV-2B is 24.9 Gy.

Figure A1.4 shows a comparison of the dose-volume histograms (DVHs) for the brain, cervical spine, PTV-1B, and PTV-2A, and PTV-2B, with and without heterogeneity corrections.

As illustrated in Figure A1.5, the heterogeneity corrections do not affect significantly the dose to the spinal cord, because the spinal cord is located close (depending on the level of the transverse section) to the plateau region of the electron depth-dose curve. Behind the spine, at the level of the abdomen, the isodoses, computed using heterogeneity corrections, are shifted toward the surface due to bone

attenuation (mainly the isodoses located closely behind the vertebrae, Fig. A1.5a and b). In contrast, at the level of the thorax, only the isodoses at the level of the vertebral body, or immediately behind it, are slightly shifted toward the surface. However, deeper in, bone attenuation in the vertebra is balanced by electron scattering, which tends to increase the doses behind the vertebral body compared with the doses computed in a homogeneous medium (Fig. A1.5c and d).

Evaluation of the effects of heterogeneity was performed using the pencil-beam algorithm of the current Helax program. It is, however, recognized that a more accurate evaluation of the heterogeneity corrections requires a complex computation facility (such as Monte Carlo methods).

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

CASE NUMBER A2: BREAST CANCER—TREATMENT OF INTERNAL MAMMARY CHAIN

Clinical situation

A 48-year-old female presented with a 5 mm × 10 mm, hard, mobile lump in the upper inner quadrant of the left breast. There was no fixation to skin or underlying muscle and no palpable regional lymphadenopathy. Mammography showed a mass suspicious of malignancy. Clinical diagnosis: T1b N0 M0 mammary carcinoma. Wide local excision was performed. Histology showed a completely excised ductal carcinoma. The patient did not accept further treatment at the level of the breast. Because of the localization of the tumor, the internal mammary node chain only was considered to be at risk, and was planned for radiotherapy.

Treatment protocol

Radical radiotherapy after radical surgery. No systemic therapy.

Two different techniques are compared:

1. a single electron beam and
2. a combination of one photon beam and one electron beam.

Patient positioning

Supine with arms raised. Chest and head immobilized in a plastic cast. Arm poles and foot board. A Styrofoam wedge under the patient to make the surface over the sternum horizontal.

GTV

No GTV to be defined because of radical surgery.

CTV

The homolateral internal mammary lymph nodes [C77.1D-2].

The CTV is defined from CT scans: its diameter is 12 mm in the transverse section, and its crano-caudal length 100 mm.

PTV

To define the diameter of the PTV, a margin of 9 mm is added to the CTV (diameter 12 mm); the diameter of the PTV is thus 30 mm.

A margin of 9 mm is taken in the direction perpendicular to the skin to compensate for the movements of the CTV and in the antero-posterior direction to compensate for the uncertainties in beam penetration due to, e.g., uncertainties in electron energy and tissue densities. The crano-caudal length of the PTV is taken equal to 110 mm.

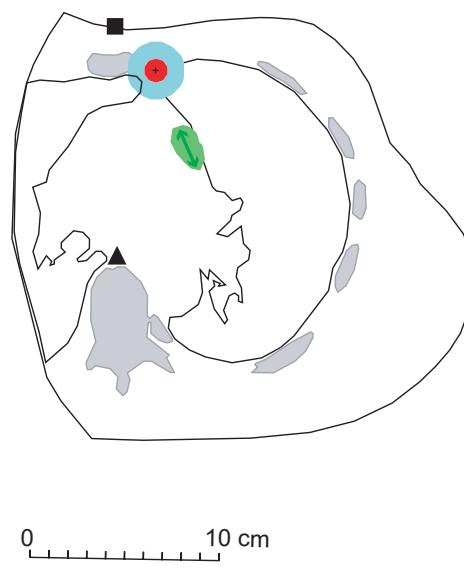


Figure A2.1. The CTV, PTV, and PRV in a transverse section through the center of the internal mammary nodes (=central plane, containing the beam axes).

Light red: CTV (Clinical Target Volume).

Light blue: PTV (Planning Target Volume).

Light green: PRV (Planning Organ at Risk Volume).

←→: Projection onto the central plane of the left anterior descending coronary artery (LADCA). The tops of the arrows (posterior and anterior) correspond to the projection of the upper and lower part of the descending coronary artery (*i.e.*, in the beam), respectively.

Organs at Risk (OARs)

(1) Lung tissue (parallel structure) [C34.9-2]: for treatment planning purposes, the dose should not exceed 20 Gy in more than 25 percent of the total lung volume.

(2) Myocardium [C38.0], left anterior descending coronary artery, LADCA (serial structure): for treatment planning purposes, the maximum dose to LADCA should not exceed 30 Gy.

Figure A2.1 shows the position of the CTV and the PTV and the projection of LADCA (dark green arrow surrounded by the corresponding PRV in light green) in the transverse section through the center of the internal mammary lymph node area (about the level of the nipple).

Dose prescription

50 Gy in 25 fractions over 5 weeks.

Technique

(1) *Electron beam only* (Fig. A2.2)

Electron beam 12 MeV.

Beam perpendicular to skin.

Beam direction 0°.

APPENDIX

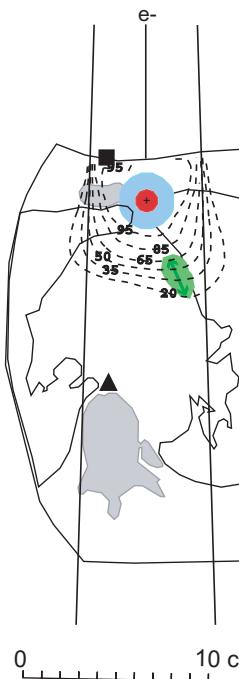


Figure A2.2. A single 12-MeV electron beam. Dose distribution in the transverse central plane. Doses are corrected for tissue heterogeneity. Dose specification for reporting at Level 2:

- Dose at the center of the PTV = peak absorbed dose = dose at the ICRU Reference Point (+) = 100%.
- Maximum dose in the PTV = 103%
- Minimum dose in the PTV = 94%
- Dose to the LADCA (PRV) ranges from 69% to 20%.
- Dose to the lung: only 62 cm^3 receive a dose greater than 20 Gy.
- The average dose to the PTV is 99% with a standard deviation of 1.6, and the median dose 98%.

SSD 100 cm.

Field width 60 mm.

Field length 130 mm.

Selection of the electron energy depends on the dimensions of the patient. The width of the beam is increased in order to improve the shape of the isodose curves.

The beam sizes are defined by the 50 percent isodoses (thus including half of the penumbra).

(2) Electron and photon beam (Fig. A2.3)

A combination of one electron beam and one photon beam is chosen, each of them contributing half of the prescribed dose.

(a) Photon beam 6 MV.

Beam perpendicular to skin.
Beam direction 0° .

SSD 100 cm.
Field width 45 mm.

Field length 130 mm.

(b) Electron beam 12 MeV.

Same technique as for electron beam only.

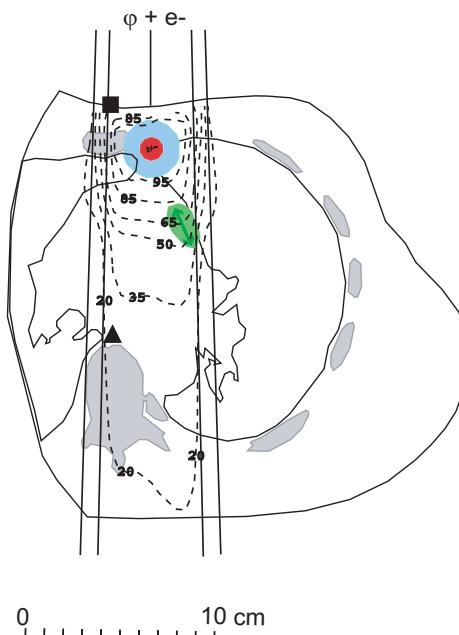


Figure A2.3. Dose distribution in the transverse central plane for one anterior 12-MeV electron beam and one anterior 6-MV photon beam. Each beam gives the same dose contribution at the ICRU Reference Point. Doses are corrected for tissue heterogeneity. Dose specification for reporting at Level 2:

- Dose at the center of the PTV = dose at the ICRU Reference Point (+) = 100%.
- Maximum dose in the PTV = 102%.
- Minimum dose in the PTV = 92%.
- Dose to the LADCA (PRV) ranges from 79% to 35%.
- Dose to the lung: only 49 cm^3 receive a dose greater than 20 Gy.
- The average dose to the PTV is 99% with a standard deviation of 1.6, and the median dose is 98%.

Dose calculation

Section for dose planning

Transverse section through the center of the CTV, *i.e.*, section [24] (according to ICRU 50, p. 44).

The dose distributions displayed in Figures A2.2–3 are obtained as follows.

For the electron beam

Multiple-plane dose calculations are performed using three-dimensional pencil beam electron algorithms (Level 2).

For the photon and electron beams

Multiple-plane dose calculations are performed using photon beam generating functions. Corrections for tissue inhomogeneity and for loss of side-scatter in 3D are applied. Because of the use of styrofoam to make the chest horizontal, the beam obliquity does not need to be considered.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

The dose-volume histograms are compared in Figure A2.4: they are very close to each other.

Quality assurance

Simulator port films.

Verification films of photon beams once a week.

Diode measurements of entrance dose twice.

Reporting

When electrons only are used, the dose is prescribed and reported at the ICRU Reference Point, *i.e.*, on the central beam axis, at the depth of the center of the CTV. The dose at the maximum of the electron depth-dose curve is also reported.

When a combination of electrons and photons is chosen, the dose is prescribed and reported at the ICRU Reference Point, on the central axes of the two (coaxial) beams, at the depth of the center of the CTV (see captions to Figs A2.2–3).

CASE NUMBER A3: CANCER OF THE PAROTID GLAND, AFTER SURGERY

Clinical situation

A 44-year-old female presented with a right-sided facial palsy and a tumor in the right cheek. Cytology showed malignant tumor of salivary gland type, and CT showed a tumor measuring 35 mm × 35 mm × 30 mm at the position of the parotid gland. There was some extension in the dorsal direction around the external auditory meatus. The skin was not infiltrated (T2 N0 M0, Stage II). A radical excision was made, and pathology revealed acinic-cell carcinoma of the parotid gland with free resection margins.

Treatment protocol

Radical, postoperative radiotherapy after radical surgery. No systemic therapy.

Patient positioning and immobilization

Supine with arms at sides. Head immobilized in plastic cast.

GTV

No GTV to be defined after radical surgery.

CTV

The region corresponding to the right parotid gland [C07.9-1] and a margin up to 2 cm to account for subclinical spread. The skin was intentionally excluded from the CTV. The CTV excludes the mandibula, which does not show any radiological or pathological sign of infiltration.

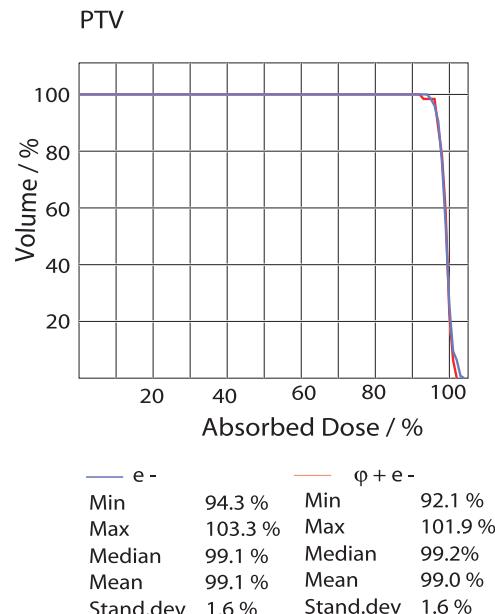


Figure A2.4. The dose-volume histograms of the PTV are presented for both treatment techniques.

PTV

A margin of 5 mm is added to the CTV in antero-posterior and crano-caudal directions to compensate for variations in patient-beam positioning. The same 5-mm margin is added in the direction of the beam axis to compensate for uncertainties in beam penetration (due, *e.g.*, to electron energy and/or tissue density).

The CTV and PTV are shown in Figure A3.1 in a transverse section through the center of the PTV and CTV, at the level of the third cervical vertebral body.

Organs at Risk (OARs)

Cervical spinal cord [C72.0A]: the dose should not exceed 44 Gy at any point of the cervical spinal cord (serial structure).

Contralateral salivary gland [C07.9-2,C08]: the dose should not exceed 25 Gy.

PRV

A PRV margin of 5 mm surrounds the spinal cord and the contralateral salivary gland, as shown in Figure A3.1.

Dose prescription

60 Gy in 30 fractions over 6 weeks at the ICRU Reference Point selected in the central part of the PTV.

Two thirds of the dose (40 Gy) are given with a 17-MeV electron beam, one third is given by photons to spare the skin.

APPENDIX

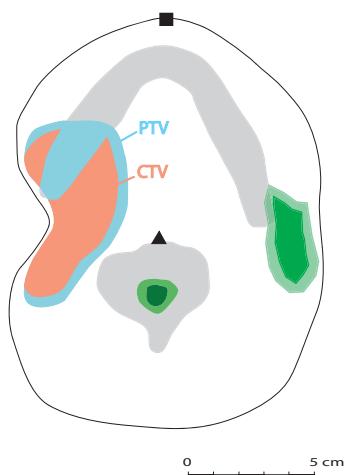


Figure A3.1. Transverse section through the center of the PTV (and CTV), *i.e.*, at the center of the third cervical vertebra.

- Square: External Reference Point.
- Triangle: Internal Reference Point.
- Light red: Clinical Target Volume (CTV).
- Light blue: Planning Target Volume (PTV).
- Dark green: Organs at Risk (OARs).
- Light green: Planning Organ at Risk Volumes (PRVs).

The following applies to the electron part of the treatment only.

Treatment technique

Electron beam 17 MeV.

Beam perpendicular to skin, direction 270°. A bolus is added in the middle and posterior part of the beam to increase the dose at the superficial part of the CTV and to reduce the dose to the spinal cord.

SSD 100 cm at the level of the skin (not at the level of the bolus).

Field size 10 cm (antero-posterior) × 10 cm (craniocaudal).

The dimensions of the beam are derived as follows:

- parotid region: diameter 3.5 cm,
- 2 cm × 2 cm for CTV,
- 2 cm × 0.5 cm for PTV, and
- 2 cm × 0.75 cm for penumbra.

The dose-volume histogram for the PTV is given in Figure A3.3.

Quality assurance

Simulator port films.

Diode measurements of the entrance dose are performed twice during the six weeks of treatment.

Reporting

The ICRU Reference Point is selected on the beam axis at the maximum of the depth-dose curve. This point is close to the center of the PTV (Fig. A3.2).

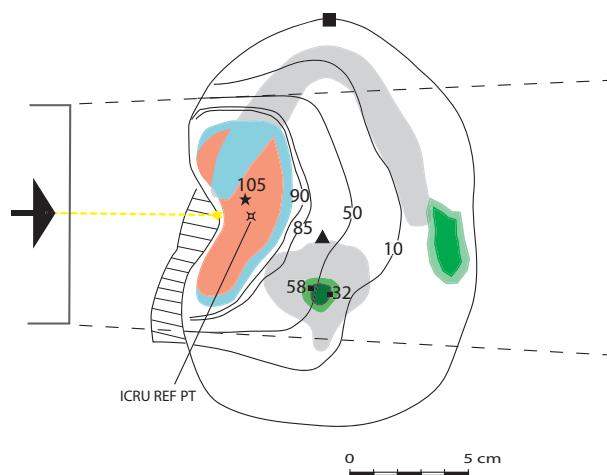
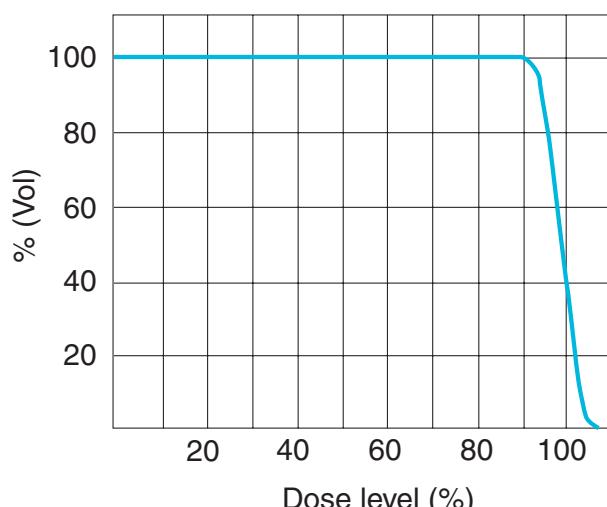


Figure A3.2. Dose distribution for the transverse section through the center of the PTV, *i.e.*, section containing beam axis. The doses are expressed as a percentage of the electron dose at the ICRU Reference Point (REF PT) and are corrected for tissue heterogeneities. Same presentation as in Fig. A3.1, in addition:

- Hatched area: bolus.
- Dose at the ICRU Reference Point (*i.e.*, peak dose and dose in the central part of the PTV) = 100%.
- Maximum dose in the PTV = 105%.
- Minimum dose in the PTV = 90%.
- Maximum dose to the spinal cord = 58%.

Note that the dose to the contralateral salivary gland does not exceed 25 Gy, even when part of the treatment is given with photons.



Dose at the ICRU ref point	100%
Maximum dose in the PTV	105%
Minimum dose in the PTV	90%
Mean dose in the PTV	98%
Standard deviation	3.6

Figure A3.3. Electron beam treatment to the parotid gland after surgery. Dose-volume histogram for the PTV. On the abscissa, the dose level is expressed in terms of the percentage of the electron dose at the ICRU Reference Point.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

CASE NUMBER A4: CANCER OF THE TONSIL (WITH ELECTRON IRRADIATION OF THE POSTERIOR LEFT AND RIGHT NECK)

Clinical situation: GTVs

Patient presented with a tumor of the left tonsil with maximum dimensions of 3.2 cm × 2.3 cm × 2.0 cm. The tumor extended to the faucial arch (GTV-T).

Within the upper jugular lymph node region (Level II), on the left, enlarged lymph nodes (with a maximum diameter of 2.5 cm) were present (GTV-N) (see Table A4.1 and Fig. A4.1).

All other lymph node areas were clinically negative. No distant metastases were detected.

Classification: T2 N2b M0 (TNM: AJCC, 1997).

Anatomical codes (see WHO, 1990; ICRU Report 50):

- Tonsillar fossa: C 09.0
- Lymph nodes in left Level II.

Treatment protocol

Radical radiotherapy. No surgery nor systemic treatment.

The CTVs and PTVs

CTV-TN-70

A dose of 70 Gy (35 fractions of 2 Gy in 7 weeks) is prescribed to the primary tumor (GTV-T) and to a surrounding tissue volume potentially invaded. This includes the adjacent parapharyngeal wall (CTV-T).

The same dose of 70 Gy is prescribed to the involved jugular lymph nodes (GTV-N) and to the

Table A4.1. Comparison between the TNM atlas terminology and the Robbins classification of the lymph nodes of the neck.

TNM atlas for lymph nodes of the neck		Robbins classification	
Group no.	Terminology	Level	Terminology
1	Submental nodes	Ia	Submental group
2	Submandibular nodes	Ib	Submandibular group
3	Cranial jugular nodes	II	Upper jugular group
4	Medial jugular nodes	III	Middle jugular group
5	Caudal jugular nodes	IV	Lower jugular group
6	Dorsal cervical nodes along spinal accessory nerve	V	Posterior triangle group
7	Supraclavicular nodes	V	Posterior triangle group
8	Prelaryngeal and paratracheal nodes	VI	Anterior compartment group
9	Retropharyngeal nodes	—	—
10	Parotid nodes	—	—
11	Buccal nodes	—	—
12	Retroauricular and occipital nodes	—	—

From Grégoire *et al.*, 2003b, p. 71.

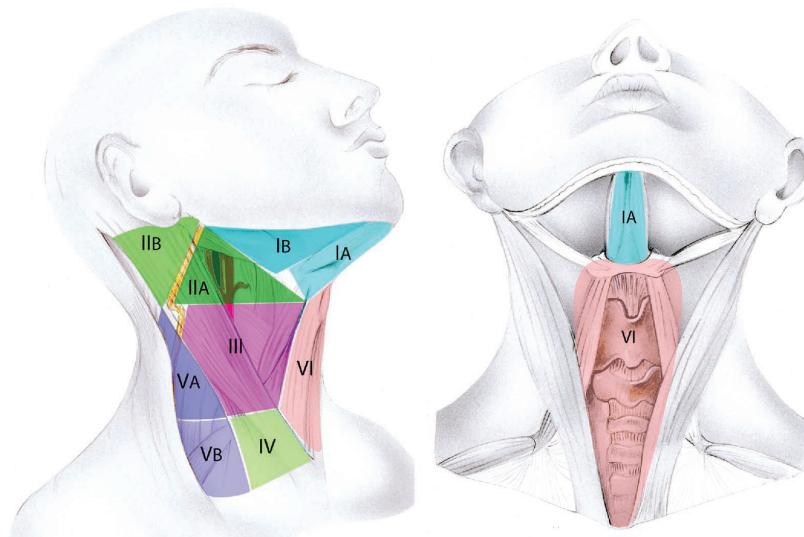


Figure A4.1. Schematic representation of the various neck node groups: submental (Ia) and submandibular (Ib); upper jugular (II); middle jugular (III); lower jugular (IV); posterior triangle (VA); and anterior compartment (VI). (From Grégoire *et al.*, 2003b, p. 71.)

APPENDIX

potentially invaded surrounding tissue volume (CTV-N).

Owing to the high probability of the presence of cancer cells between the two GTVs, and because of their proximity, only one CTV is defined, which includes the two GTVs and a common tissue margin potentially involved (CTV-TN-70).

PTV-TN-70

The PTV-TN is defined by adding a safety margin of 3 mm (in all directions) to the CTV-TN to account for patient- and set-up-related uncertainties. For patient positioning, a stereotactic head and neck immobilization device is used.

A ICRU Reference Point for prescribing and reporting dose is selected at the center of PTV-TN-70 (ICRU-REF-TN). The aim of planning is to keep the dose variation within the PTV-TN-70 between +7 and -5 percent of the prescribed dose at the ICRU Reference Point.

CTV-N-50

Outside CTV-TN-70, a dose of 50 Gy is prescribed to a CTV (CTV-N-50) which includes the retropharyngeal nodes and the nodes in Level II right, and Levels I, III, IV, and V bilaterally.

The dose within the CTV-N-50 should not be lower than 95 percent of the prescribed dose (50 Gy) at the ICRU Reference Points 1–4 for the different lymph node areas. Because of overlap with the beams needed to irradiate CTV-TN-70, doses significantly higher than 50 Gy may have to be accepted in parts of these lymph node areas. However, the doses must not exceed the tolerance doses of the Organs at Risk given below.

PTV-N-50

Inside the PTV-N-50, different lymph node areas are identified. An ICRU Reference Point is selected at the mid-point of each lymph node area.

Organs at Risk (OARs)

Spinal cord: The dose at any point of the spinal cord should not exceed 50 Gy.

Larynx: The larynx should be shielded as much as possible. Tolerance dose is 30 Gy.

Mandibula: The dose at any point of the mandibula should not exceed 70 Gy.

Salivary glands: No attempt is made to spare the function of the salivary glands. It is recognized that above a mean dose of 26–30 Gy the function of the salivary glands is impaired.

Treatment technique and dose calculation

The treatment consists of three phases:

- (1) During weeks 1–4, a dose of 40 Gy is delivered to the primary tumor site and the upper part of the neck. Two lateral opposed photon beams are used (beams 1 and 2, Fig. A4.2).
- (2) At the same time, an anterior beam (beam 3, Fig. A4.3) is used to treat the lower part of the neck and the supraclavicular lymph node areas left and right. For beam 3, central blocking allows sparing of the larynx and the spinal cord.
- (3) During week 5, the anterior lower neck field (beam 3) remains unchanged, but the large lateral opposed photon beams are reduced posteriorly to spare the spinal cord (beams 4 and 5 in Fig. A4.2). In addition during week 5, two

Table A4.2. Beam characteristics and their contribution to the ICRU Reference Points.

Beam number	Dimensions (cm)		Type and energy	Beam angle	ICRU Reference Point	Contribution to dose (Gy)	Week
	Antero-posterior	Cranio-caudal					
1	17.0	13.0	ph 6 MV	270°	1	20	1–4
2	17.0	13.0	ph 6 MV	90°	1	20	1–4
3	22.0	6.0	ph 6 MV	0°	2	50	1–5
4	13.5	13.0	ph 6 MV	270°	1	5	5
5	13.5	13.0	ph 6 MV	90°	1	5	5
6	10.0	10.0	e ⁻ 15 MeV	270°	3	10	5
7	10.0	10.0	e ⁻ 15 MeV	90°	4	10	5
8	5.5	6.0	ph 25 MV	335°	TN ^a	10	6–7
9	7.0	6.0	ph 10 MV	40°	TN	5	6–7
10	8.0	6.0	ph 6 MV	110°	TN	5	6–7

^aThe absorbed dose at Reference Point TN at the end of week 5 is 48.5 Gy.

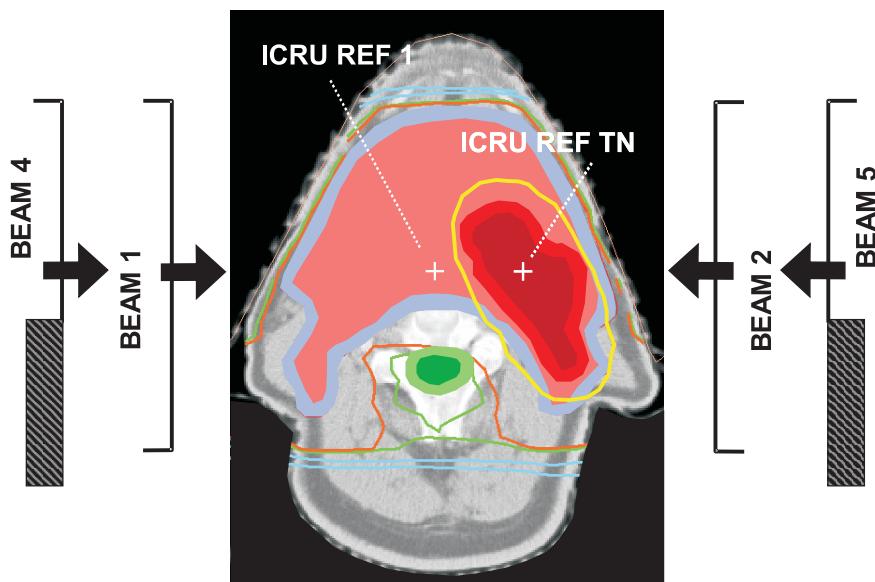


Figure A4.2. Transverse section containing the center of PTV-TN-70 and the axes of beams 1, 2, 4, 5, 8, 9, and 10. It corresponds to cervical vertebra 2 and is located 2 cm below the section of Fig. A.5. The center of PTV-TN-70 is indicated on the figure as + ICRU REF TN. For beams 1, 2, 4, and 5, the same Reference Point is selected (ICRU REF 1) for dose specification. The position of beams 1, 2, 4, and 5 is shown. For beams 4 and 5 an asymmetrical collimator is used.

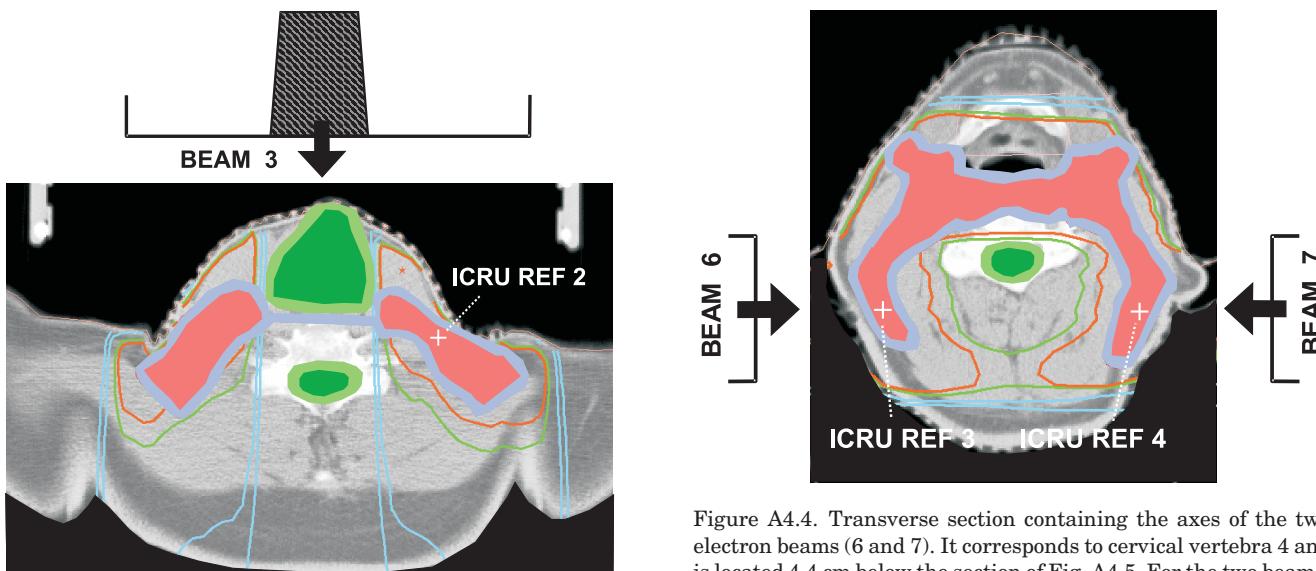


Figure A4.3. Transverse section containing the axis of beam 3. It corresponds to cervical vertebra 6 and is located 8 cm below the section of Fig. A.5. The ICRU Reference Point for the left supraclavicular lymph node area (ICRU REF 2) is indicated (+). The position of photon beam 3 with central blocking is shown.

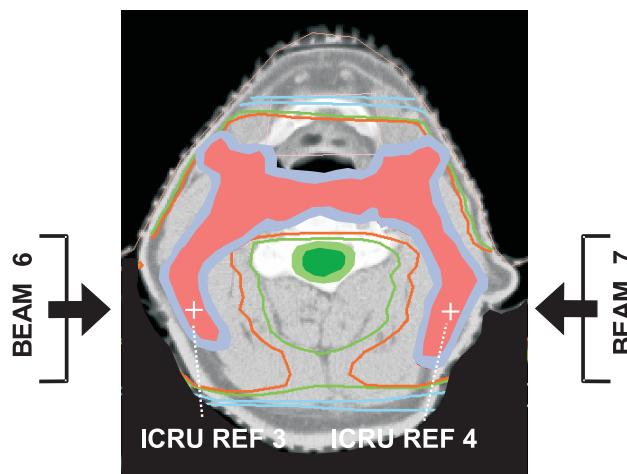


Figure A4.4. Transverse section containing the axes of the two electron beams (6 and 7). It corresponds to cervical vertebra 4 and is located 4.4 cm below the section of Fig. A4.5. For the two beams, the Reference Points for dose specification are indicated (ICRU REF 3 and 4, respectively). The electron energy of 15 MeV is selected to take into account the beam attenuation in the 2-cm thick perspex immobilization device. The position of electron beams 6 and 7 is shown.

electron beams (15 MeV) are used to irradiate the posterior part of the neck (beams 6 and 7 in Fig. A4.4). The electron energy of 15 MeV is selected because of the beam attenuation in the immobilization device (2-cm thick perspex).

- (4) During weeks 6 and 7, the field arrangement consists of three photon beams coming from a left anterior, right anterior, and right posterior direction (beams 8, 9, and 10 in Fig. A4.5, respectively).

APPENDIX

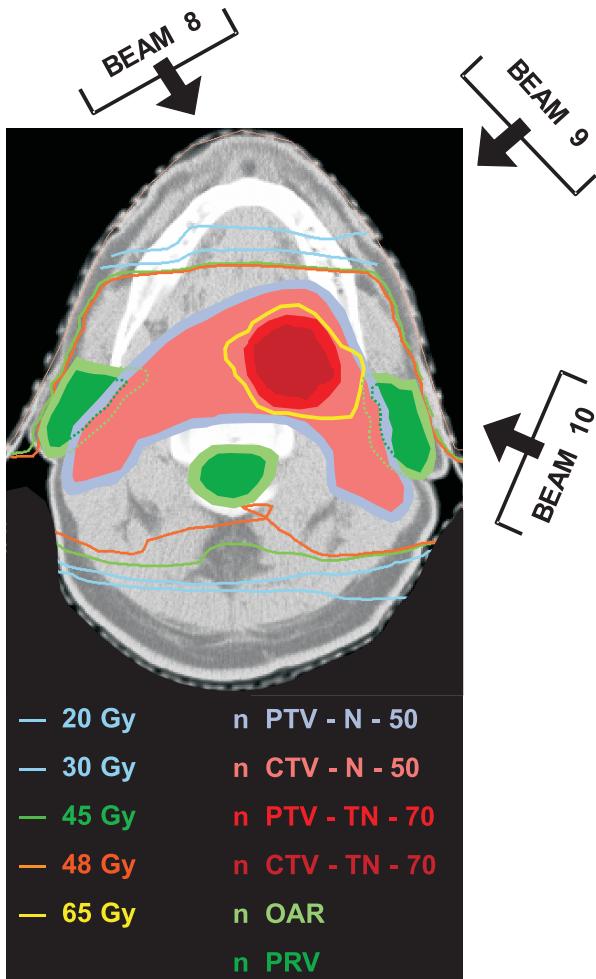


Figure A4.5. Transverse section 2 cm cranially from the center of PTV-TN-70 and from the axes of beams 8, 9, and 10. This section corresponds to cervical vertebra 1.

In Figures A4.2–A4.5, the isodose lines (in Gy) represent the total doses at the end of the treatment. The color codes for the isodose lines and the volumes are given in the key above. The ICRU recommendations (Report 62) are followed for the selection of the color code for the different volumes. The position of beams 8, 9, and 10 is shown.

Table A4.3. Doses to lymph node areas: PTV-N-50.

Lymph node area	Dose at ICRU Reference Point (Gy)	Minimum dose to PTV (Gy)	Minimum dose to PTV-skin ^a (Gy)	Maximum dose to PTV (Gy)
II L	67	64	64	72
II R	54	47	52	55
III L	53	47	52	55
III L	53	47	52	55
V L	53	52	52 ^b	55
V R	53	52	52 ^b	55
IV L	53	46	51	53
IV R	53	46	51	53

^aBy expansion from the CTV, the PTV may reach inside the skin in the photon beam build-up region, or even into the air outside the patient's contour. A PTV dose minimum in these layers is not representative of the minimum dose in the CTV. Therefore, in the table, the minimum dose in the (whole) PTV is reported together with the minimum dose in the sub-volume of the PTV that is nowhere closer than 3 mm to the patient's surface (in case the skin is not invaded). This PTV sub-volume is referred to as "PTV minus skin" (PTV-skin).

^bNo build-up because of the presence of the patient immobilization device.

The characteristics of the beams are given in Table A4.2.

Quality assurance

Weekly port films and photographic images of the set-up.

Reporting

For this case reporting at Level 2 was used (Fig. A4.6).

PTV-TN-70 ("boost")

The total dose at the ICRU Reference Point TN is 68.5 Gy in 35 fractions in 7 weeks (*i.e.*, 48.5 Gy in 5 weeks and 20 Gy in 2 weeks). The maximum dose to PTV-TN-70 is 73.5 Gy. The minimum dose to PTV-TN-70 is 65.0 Gy.

The minimum dose of 65 Gy observed in PTV-TN-70 results from build-up. Because the skin at the level of PTV-TN-70 was not invaded, no bolus was used and the minimum dose of 65 Gy at the level of the skin surface was accepted.

PTV-N-50 (lymph node areas)

The DVH for PTV-N-50 is presented in Fig A4.6b. The doses at the ICRU Reference Points for the lymph node areas, and the best estimate of the maximum and minimum doses in each lymph node area are reported in Table A4.3.

Organs at Risk

Spinal cord: The maximum dose to the spinal cord is 49.5 Gy.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

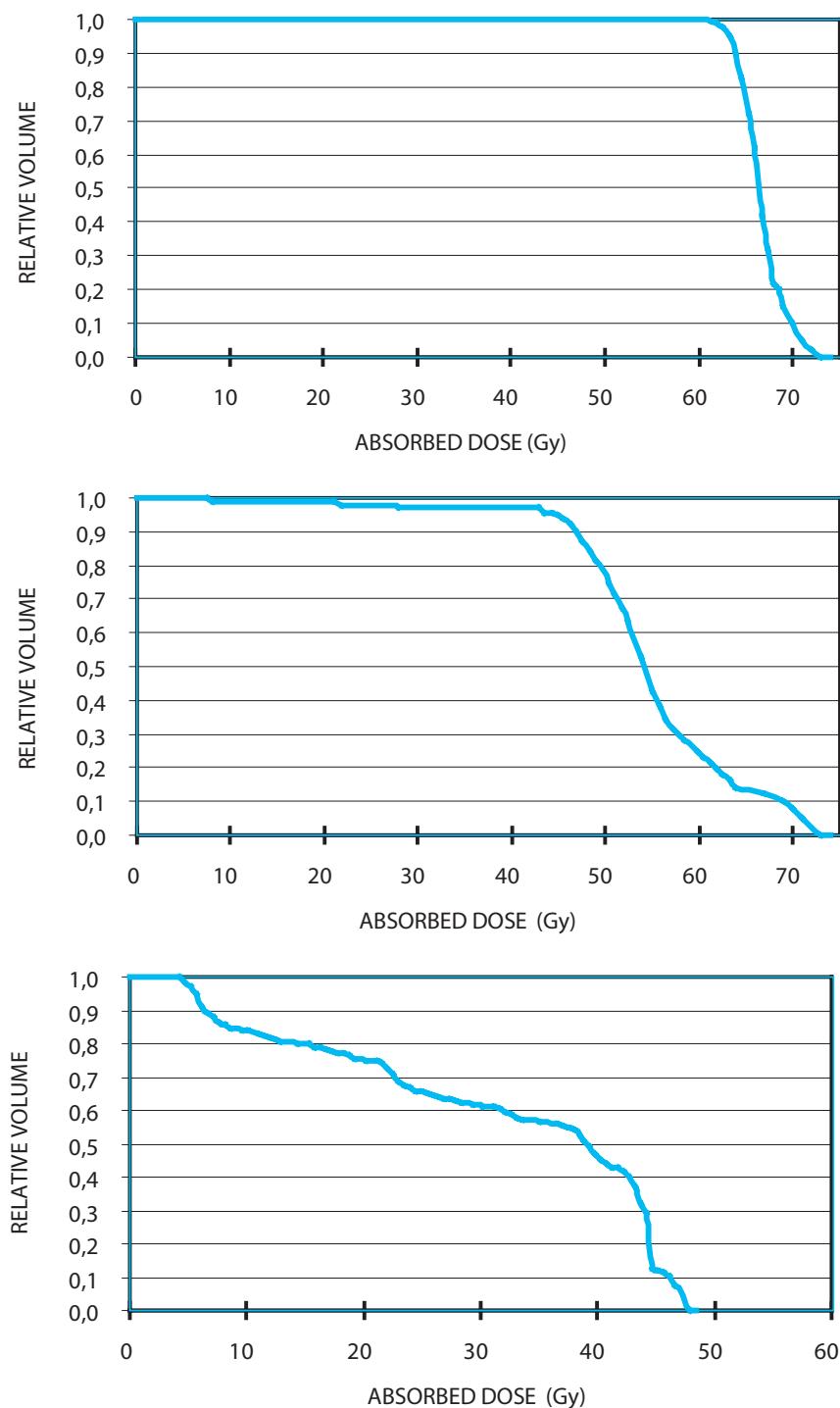


Figure A4.6. (a) DVH for PTV-TN-70. (b) DVH for PTV-N-50. (c) DVH for the spinal cord. The dose to the spinal cord is evaluated between the transverse planes C1 and Th2. No more than 50% of the part of spinal cord volume evaluated receives more than 40 Gy.

Larynx: Most of the larynx is shielded (anterior block in beam 3). The maximum dose to the larynx is 52 Gy.

Mandibula: The maximum dose to the mandibula is 65 Gy.

Parotid glands: The maximum dose to the right parotid gland is 56 Gy. The maximum dose to the left parotid gland is 65 Gy. With the present technique, the whole volume of both parotid glands receives a dose much higher than 25–30 Gy.

REFERENCES

- AAPM. (1987) American Association of Physicists in Medicine. *Total Skin Electron Therapy: Technique and Dosimetry*. AAPM Report No. 23 (American Institute of Physics: New York).
- AAPM. (1991) American Association of Physicists in Medicine. *Clinical Electron Beam Dosimetry*. AAPM Report No. 32, Task Group 25, Reprinted from *Med. Phys.* **18**, 73–109.
- AAPM. (1993) American Association of Physicists in Medicine. *Specification and Acceptance Testing of Computed Tomography Scanners*. AAPM Report No. 39 (New York: American Institute of Physics).
- AAPM. (1995) American Association of Physicists in Medicine. *Intraoperative Electron Beam Radiation Therapy—Technique, Dosimetry and Dose Specification*. Task Group 48, Radiation Therapy Committee, Int. J. Radiat. Oncol. Biol. Phys., **33**, 725–746.
- AAPM. (1998) American Association of Physicists in Medicine. *Quality Assurance for Clinical Radiotherapy Treatment Planning*. AAPM Report No. 62, Task Group 53, Reprinted from *Med. Phys.* **25**, 10.
- Abe, M. (1984) 'Intraoperative radiotherapy—past, present and future.' Int. J. Radiat. Oncol. Biol. Phys., **10**, 1987–1990.
- Abe, M., Takahashi, M., Yabumoto, E., Adachi, H., Yoshii, M. and Mori, K. (1980) 'Clinical experiences with intraoperative radiotherapy for locally advanced cancers,' *Cancer* **45**, 40–48.
- AJCC. (1997) American Joint Committee on Cancer. In: *Manual for Staging Cancer*, 5th ed. Fleming, I., Cooper, J., Earl Henson, D., Hutter, R., Kennedy, B., Murphy, G., O'Sullivan, B., Sabin, L. and Yasboro, J., Eds. (Philadelphia: J.P. Lippincott-Raven Press).
- AJCC. (2002) American Joint Committee on Cancer. In: *Manual for Staging Cancer*, 6th ed. Greene, F. L., Page, D. L., Fleming, I. D., Fritz, A. G., Balch, C. M., Haller, D. G. and Morrow, M., Eds. (New York, Berlin, Heidelberg: Springer).
- Almond, P. R. (1976) Dosimetry considerations of electron beams, p. 131. In: *High-Energy Photons and Electrons: Clinical Applications in Cancer Management*, Kramer, S., Suntharalingam, N. and Zinniger, E., Eds. (New York: John Wiley and Sons, Inc.).
- Alth, G., Weniger, P., Turtzer, K., Klein, W. and Kocsis, F. (1982) 'RBE comparison between rapid electrons of 20 MeV and 45 MeV with survival rate, DNA synthesis, DNA preparation and nucleoid sedimentation.' *Strahlentherapie* **158**, 570–572.
- Amols, H. I., Lagueux, B. and Cagna, D. (1986) 'Radio-biological effectiveness (RBE) of megavoltage X-ray and electron beams in radiotherapy.' *Radiat. Res.* **105**, 58–67.
- Andreo, P. (1993) 'The status of high-energy photon and electron beam dosimetry five years after the implementation of the IAEA Code of Practice in the Nordic countries.' *Acta Oncol.* **32**, 483–500.
- Åsard, P. E. (1971) 'RBE variations for high energy electrons.' *Acta Radiol. Suppl.* **310**, 9–28.
- Austin-Seymour, M., Chen, G. T., Rosenman, J., Michalski, J., Lindsley, K. and Goitein, M. (1995a) 'Tumor and target delineation: current research and future challenges.' *Int. J. Radiat. Oncol. Biol. Phys.* **33**, 1041–1052.
- Austin-Seymour, M., Kalet, I., McDonald, J., Kromhout-Schiro, S., Jacky, J., Hummel, S. and Unger, J. (1995b) 'Three dimensional planning target volumes: a model and a software tool.' *Int. J. Radiat. Oncol. Biol. Phys.* **33**, 1073–1080.
- Balter, J. M., Ten Haken, R. K. and Lamm, K. L. (1996) Treatment setup verification. In: *Teletherapy: Present and Future*. Mackie, T. and Palta, J., Eds. (Madison, WI: Advanced Medical Publishing) pp. 471–493.
- BIPM. (1981) Bureau International des Poids et Mesures. Recommendation R(I)-1. In: BIPM Com. Cons. Étalons Mes. Ray. Ionisants (Section I) 6. (Paris: Offilib) p. R(I) 15.
- Blomquist, M., Karlsson, M. and Karlsson, M. (1996) 'Test procedures for verification of an electron pencil beam algorithm implemented for treatment planning.' *Radiother. Oncol.* **39**, 271–286.
- Booz, J. (1978) Mapping of fast neutron radiation quality. In: *Proceedings of the Third Symposium on Neutron Dosimetry in Biology and Medicine*. Burger, G. and Ebert, H. G., Eds. EURATOM EUR 5848 (Luxembourg: Commission of the European Communities) pp. 499–514.
- Brahme, A. and Svensson, H. (1976a) 'Specification of electron beam quality from the central-axis depth absorbed-dose distribution.' *Med. Phys.* **3**, 95–102.
- Brahme, A. and Svensson, H. (1976b) 'Methods of improving dose uniformity in high energy photon and electron beams.' *Digest 4th ICMP, Phys., Canada* **32**, 283.
- Brahme, A. and Svensson, H. (1979) 'Radiation beam characteristics of a 22 MeV microtron.' *Acta Radiol. Oncol.* **18**, 244–272.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

- Brahme, A., Kraepelien, T. and Svensson, H. (1980) Electron and photon beams from a 50 MeV racetrack microtron. *Acta Radiol. Oncol.* **19**, 305–319.
- Briot, E., Dutreix, A. and Bridier, A. (1990) 'Dosimetry for total body irradiation.' *Radiother. Oncol.* **18**, Suppl. 1, 16–29.
- Bruinvis, I. A., Van Amstel, A., Eleveld, A. J. and Van der Laarse, R. (1983) 'Calculation of electron beam dose distributions of arbitrarily shaped fields.' *Phys. Med. Biol.* **28**, 667–683.
- Calvo, F. A., Ortiz de Urbina, D., Abuchaibe, O., Azinovic, I., Aristu, J., Santos, M., Escude, L., Herreros, J. and Llorens, R. (1990) 'Intraoperative radiotherapy during lung cancer surgery: technical description and early clinical results.' *Int. J. Radiat. Oncol. Biol. Phys.* **19**, 103–109.
- Cheng, A., Harms, Sr, W. B., Gerber, R. L., Wong, J. W. and Purdy, J. A. (1996) 'Systematic verification of a three-dimensional electron beam dose calculation algorithm.' *Med. Phys.* **23**, 685–693.
- Cox, R. S., Heck, R. J., Fessenden, P., Karzmark, C. J. and Rust, D. C. (1990) 'Development of total-skin electron therapy at two energies.' *Int. J. Radiat. Oncol. Biol. Phys.* **18**, 659–669.
- Crook, J. M., Raymond, Y., Salhani, D., Yang, H. and Esche, B. (1995) 'Prostate motion during standard radiotherapy as assessed by fiducial markers.' *Radiother. Oncol.* **37**, 35–42.
- Dahl, R. A. and McCullough, E. C. (1989) 'Determination of accurate dosimetric parameters for beveled intraoperative electron beam applicators.' *Med. Phys.* **16**, 130–131.
- Das, I. J., McGee, K. P. and Cheng, C. W. (1995) 'Electron-beam characteristics at extended treatment distances.' *Med. Phys.* **22**, 1667–1674.
- DICOM. (1997) Digital Imaging and Communications in Medicine, Supplement 11, Radiotherapy Objects. Available at: <http://www.dclunie.com/dicom-status/status.html>.
- Ekstrand, K. E. and Dixon, R. L. (1982) 'The problem of obliquely incident beams in electron-beam treatment planning.' *Med. Phys.* **9**, 276–278.
- George, R. E., Frost, S. V. and Hartson-Eaton, M. (1986) 'Characteristics of electron beams from a medical microtron.' *Med. Phys.* **13**, 533–538.
- Goitein, M. (1985) 'Calculations of the uncertainty in the dose delivered during radiation therapy.' *Med. Phys.* **12**, 608–612.
- Goldson, A. L. (1981) 'Past, present, and prospects of intraoperative radiotherapy (IOR).' *Semin. Oncol.* **8**, 59–64.
- Grégoire, V., Coche, E., Cosnard, G., Hamoir, M. and Reyhler, H. (2000) 'Selection and delineation of lymph node target volumes in head and neck conformal radiotherapy. Proposal for standardizing terminology and procedure based on the surgical experience.' *Radiother. Oncol.* **56**, 135–150.
- Grégoire, V., Levendag, P., Ang, K. K., Bernier, J., Braaksma, M., Budach, V., Chao, C., Coche, E., Cooper, J. S., Cosnard, G., Eisbruch, A., El-Sayed, S., Emami, B., Grau, C., Hamoir, M., Lee, N., Maingon, P., Muller, K. and Reyhler, H. (2003a) 'CT-based delineation of lymph node levels and related CTVs in the node-negative neck: DAHANCA, EORTC, GORTEC, NCIC, RTOG consensus guidelines.' *Radiother. Oncol.* **69**, 227–236.
- Grégoire, V., Scalliet, P. and Ang, K. Eds. (2003b) *Clinical Target Volumes in Conformal and Intensity Modulated Radiation Therapy*. (Berlin, Heidelberg, Germany: Springer).
- Gunderson, L. L., Cohen, A. C., Dosoretz, D. D., Shipley, W. U., Hedberg, S. E., Wood, W. C., Rodkey, G. V. and Suit, H. D. (1983) 'Residual, unresectable or recurrent colorectal cancer: external beam irradiation and intraoperative electron-beam boost +/- resection.' *Int. J. Radiat. Oncol. Biol. Phys.* **9**, 1597–1606.
- Gyenes, G., Gagliardi, G., Lax, I., Fornander, T. and Rutqvist, L. E. (1997) 'Evaluation of irradiated heart volumes in stage I breast cancer patients treated with postoperative adjuvant radiotherapy.' *J. Clin. Oncol.* **15**, 1348–1353.
- Hess, C. F., Kortmann, R. D., Jany, R., Hamberger, A. and Bamberg, M. (1995) 'Accuracy of field alignment in radiotherapy of head and neck cancer utilizing individualized face mask immobilization: a retrospective analysis of clinical practice.' *Radiother. Oncol.* **34**, 69–72.
- Hettinger G., Bergman, S. and Österberg, S. (1965) 'The relative biological efficiency (RBE) of 30-MeV electrons on haploid yeast.' *Biophysik* **2**, 276–281.
- Hogstrom, K. R. (1991) 'Treatment planning in electron beam therapy.' *Front. Radiat. Ther. Oncol.* **25**, 30–52.
- Hogstrom, K. R. and Almond, P. R. (1983) 'Comparison of experimental and calculated dose distributions. Electron beam dose planning at the M. D. Anderson Hospital.' *Acta Radiol. Suppl.* **364**, 89–99.
- Hogstrom, K. R., Mills, M. D. and Almond, P. R. (1981) 'Electron beam dose calculations.' *Phys. Med. Biol.* **26**, 445–459.
- Hogstrom, K. R., Boyer, A. L., Shiu, A. S., Ochran, T. G., Kirchner, S. M., Krispel, F. and Rich, T. (1990) 'Design of metallic electron beam cones for an intraoperative therapy linear accelerator.' *Int. J. Radiat. Oncol. Biol. Phys.* **18**, 1223–1232.
- Holland, R., Veling, S. H., Mravunac, M. and Hendriks, J. H. (1985) 'Histologic multifocality of Tis, T1-2 breast carcinomas. Implications for clinical trials of breast-conserving surgery.' *Cancer* **56**, 979–990.
- Holmberg, O., Huijzen, H., Idzes, M. H., Lebesque, J. V., Vlijbrief, R. E. and Mijnheer, B. J. (1994) 'In vivo determination of the accuracy of field matching in breast cancer irradiation using an electronic portal imaging device.' *Radiother. Oncol.* **33**, 157–166.
- Horiot, J. C., Lepinoy, D., Ibrahim, E. and Velasquez, W. S. (1988) Mycosis fungoides management of early and late disease. In: *Hodgkin's Disease and non-Hodgkin's Lymphomas in Adults and Children*. Fuller, L. M., Hagemeister, F. B., Sullivan, M. P., Velasquez, W. S., Eds. (New York: Raven Press) pp. 402–427.
- Huijzen, H. and Storchi, P. R. (1989) 'Numerical calculation of energy deposition by broad high-energy electron beams.' *Phys. Med. Biol.* **34**, 1371–1396.
- Hunt, M. A., Schultheiss, T. E., Desobry, G. E., Hakki, M. and Hanks, G. E. (1995) 'An evaluation of setup

REFERENCES

- uncertainties for patients treated to pelvic sites.' *Int. J. Radiat. Oncol. Biol. Phys.* **32**, 227–233.
- Hunt, M. A., Kutcher, G. J., Burman, C., Fass, D., Harrison, L., Leibel, S. and Fuks, Z. (1993) 'The effect of setup uncertainties on the treatment of nasopharynx cancer.' *Int. J. Radiat. Oncol. Biol. Phys.* **27**, 437–447.
- IAEA. (1987) International Atomic Energy Agency. *Absorbed Dose Determination in Photon and Electron Beams: An International Code of Practice*, 2nd ed. Technical Report Series No. 277 (Vienna, Austria: IAEA).
- IAEA. (1997) International Atomic Energy Agency. *The Use of Plane Parallel Ionization Chambers in High Energy Electron and Photon Beams: An International Code of Practice for Dosimetry*. Technical Report Series No. 381 (Vienna, Austria: IAEA).
- ICRU. (1976) International Commission on Radiation Units and Measurements. *Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures*. ICRU Report 24 (Bethesda, MD: ICRU).
- ICRU. (1978) International Commission on Radiation Units and Measurements. *Dose Specification for Reporting External Beam Therapy with Photons and Electrons*. ICRU Report 29 (Bethesda, MD: ICRU).
- ICRU. (1984) International Commission on Radiation Units and Measurements. *Radiation Dosimetry of Electron Beams with Energies Between 1 and 50 MeV*. ICRU Report 35 (Bethesda, MD: ICRU).
- ICRU. (1985) International Commission on Radiation Units and Measurements. *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology*. ICRU Report 38 (Bethesda, MD: ICRU).
- ICRU. (1987) International Commission on Radiation Units and Measurements. *Use of Computers in External Beam Radiotherapy with High-Energy Photons and Electrons*. ICRU Report 42 (Bethesda, MD: ICRU).
- ICRU. (1992) International Commission on Radiation Units and Measurements. *Phantom and Computational Models in Therapy, Diagnosis and Protection*. ICRU Report 48 (Bethesda, MD: ICRU).
- ICRU. (1993) International Commission on Radiation Units and Measurements. *Prescribing, Recording, and Reporting Photon Beam therapy*. ICRU Report 50 (Bethesda, MD: ICRU).
- ICRU. (1997) International Commission on Radiation Units and Measurements. *Dose and Volume Specification for Reporting Interstitial Therapy*. ICRU Report 58 (Bethesda, MD: ICRU).
- ICRU. (1999) International Commission on Radiation Units and Measurements. *Prescribing, Recording, and Reporting Photon Beam therapy, Supplement to ICRU Report No. 50*. ICRU Report 62 (Bethesda, MD: ICRU).
- IEC. (1989a) International Electrotechnical Commission. *Medical Electron Accelerators: Functional Performance Characteristics*. Publication 976 (Geneva, Switzerland: IEC).
- IEC. (1989b) International Electrotechnical Commission. *Medical Electron Accelerators in the Range of 1 MeV–50 MeV: Guidelines for Functional Performance Characteristics*. Publication 977 (Geneva, Switzerland: IEC).
- IEC. (1990) International Electrotechnical Commission. *Safety of Medical Electrical Equipment, Part 2: Particular Requirements for Medical Electron Accelerators in the Range of 1 MeV–50 MeV*. Publication 601-2-1 (Geneva, Switzerland: IEC).
- IEC. (1996) International Electrotechnical Commission. *International Standard IEC 1217: Radiotherapy Equipment—Coordinates, Movements and Scales*. (Geneva, Switzerland: IEC).
- IEC. (2000) International Electrotechnical Commission. *International Standard IEC 61121: Amendment 1: Radiotherapy Equipment—Coordinates, Movements and Scales*. (Geneva, Switzerland: IEC).
- Jamshidi, A., Kuchnir, F. T. and Reft, C. S. (1987) 'Characteristic parameters of 6–22 MeV electron beams from a 25-MeV linear accelerator.' *Med. Phys.* **14**, 282–288.
- Källman, P., Ågren, A. and Brahme, A. (1992) 'Tumour and normal tissue responses to fractionated nonuniform dose delivery.' *Int. J. Radiat. Oncol. Biol. Phys.* **62**, 249–262.
- Karlsson, M. and Zackrisson, B. (1993) 'Matching of electron and photon beams with a multi-leaf collimator.' *Radiother. Oncol.* **29**, 317–326.
- Karlsson, M., Nyström, H. and Svensson, H. (1992) 'Electron beam characteristics of the 50 MeV racetrack microtron.' *Med. Phys.* **19**, 307–315.
- Karlsson, M., Svensson, H., Nyström, H. and Stenberg, J. (1988) 'The 50 MeV race-track accelerator—a new approach to beam shaping and modulation.' *IAEA-SM 298*, 307–320.
- Karzmark, C. J. (1964) 'Large-field superficial electron therapy with linear accelerators.' *Br. J. Radiol.* **37**, 302–305.
- Karzmark, C. J. (1968) 'Physical aspects of whole-body superficial therapy with electrons.' *Front. Radiat. Ther. Oncol.* **2**, 36–54.
- Karzmark, C. J., Loevinger, R. and Steel, R. E. (1960) 'A technique for large field, superficial electron therapy.' *Radiology* **74**, 633–644.
- Kawachi, K. (1975) 'Calculation of electron dose distribution for radiotherapy treatment planning.' *Phys. Med. Biol.* **20**, 571–577.
- Kim, J. H., Pinkerton, A. and Laughlin, J. S. (1969) 'Dosimetry and biological parameters in studies of relative biological effectiveness of high-energy electron beams.' *Ann. N.Y. Acad. Sci.* **161**, 310–316.
- Kim, T. H., Pla, C., Pla, M. and Podgorsak, E. B. (1984) 'Clinical aspects of a rotational total skin electron irradiation.' *Br. J. Radiol.* **57**, 501–506.
- Knöös, T., Kristensen, I. and Nilsson, P. (1998) 'Volumetric and dosimetric evaluation of radiation treatment plans: radiation conformity index.' *Int. J. Radiat. Oncol. Biol. Phys.* **42**, 1169–1176.
- Korevaar, E. W. (2000) High energy electron beams in intensity modulated radiation therapy. Thesis (University Hospital Rotterdam, The Netherlands).
- Korevaar, E. W., Heijmen, B. J. M., Woudstra, E., Huizenga, H. and Brahme, A. (1999) 'Mixing intensity modulated electron and photon beams: combining a steep dose fall-off at depth with sharp and

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

- depth-independent penumbras and flat beam profiles.' *Phys. Med. Biol.* **44**, 2171–2181.
- Korevaar, E. W., van Vliet, R. J., Woudstra, E., Heijmen, B. J. and Huijzen, H. (1998) 'Sharpening the penumbra of high energy electron beams with low weight narrow photon beams.' *Radiother. Oncol.* **48**, 213–220.
- Lax, I. (1987) 'Accuracy in clinical electron beam dose planning using pencil beam algorithms.' *Radiother. Oncol.* **10**, 307–319.
- Lax, I. and Brahme, A. (1985) 'Electron beam dose planning using Gaussian beams. Energy and spatial scaling with inhomogeneities.' *Acta Radiol. Oncol.* **24**, 75–85.
- LeBourgeois, J., Chavaudra, J., and Eschwege, F. (1992) *Radiothérapie Oncologique*. (Paris: Herman).
- LeBourgeois, J. P., Bridier, A., Bounik, H. and Schlienger, M. (1977) 'Whole cutaneous irradiation in mycosis fungoïdes with 55 KV x-rays. Technical study.' *Bulletin du Cancer* **64**, 313–322.
- Linborg, L. (1976) Microdosimetric measurements in beams of high energy photons and electrons: technique and results. In: *Proceedings of the Fifth Symposium on Microdosimetry*. Booz, J., Ebert, H. G. and Smith, B. G. R., Eds. (Luxembourg, Belgium: Commission of the European Communities) pp. 347–376.
- Lind, P. A., Gagliardi, G., Wennberg, B. and Fornander, T. (1997) 'A descriptive study of pulmonary complications after postoperative radiation therapy in node-positive stage II breast cancer.' *Acta Oncol.* **36**, 509–515.
- Lyman, J. T. (1985) 'Complication probability as assessed from dose-volume histograms.' *Radiat. Res. Suppl.* **8**, S13–S19.
- Marinello, G., Bard, J. J., Barrie, A. M., Brassart, N., Briot, E., Gaboriaud, G., Noel, A. and Valinta, D. (1989) *Quality Control of Electron Accelerators for Medical Use: Equipment Task Group Report—G*. Société Française des Physiciens d' Hôpital, SFPH publication 4/1A. (Paris, France: Fondation Curie).
- Marinello, G., Brun, A., Estivalet, A., Gaboriaud, G., Hoornaert, M. T., Masok, V., Naudy, S. and Puel, G. (1993) *Quality control of Asymmetric Fields on Medical Electron Accelerators, Equipment Task Group Report—G*. Société Française des Physiciens d' Hôpital, SFPH publication 21/6A. (Paris, France: Fondation Curie).
- Martinez-Monge, R., Fernandes, P. S., Gupta, N. and Gahbauer, R. (1999) 'Cross-sectional nodal atlas: a tool for the definition of clinical target volumes in three-dimensional radiation therapy planning.' *Radiology* **211**, 815–828.
- McCullough, E. C. and Anderson, J. A. (1982) 'The dosimetric properties of an applicator system for intraoperative electron-beam therapy utilizing a Clinac-18 accelerator.' *Med. Phys.* **9**, 261–268.
- McKenzie, A. L. (2000) 'How should breathing motion be combined with other errors when drawing margins around clinical target volumes?' *Br. J. Radiol.* **73**, 973–977.
- McShan, D. L., Fraass, B. A. and Ten Haken, R. K. (1994) 'Dosimetric verification of a 3-D electron pencil beam dose calculation algorithm.' *Med. Phys.* **21**, 13–23.
- Mijnheer, B. J., Battermann, J. J. and Wambersie, A. (1987) 'What degree of accuracy is required and can be achieved in photon and neutron therapy?' *Radiother. Oncol.* **8**, 237–252.
- Müller-Runkel, R. and Cho, S. H. (1997) 'Evaluation of a commercial three-dimensional electron pencil beam algorithm.' *Med. Phys.* **24**, 91–101.
- NACP. (1980) 'Nordic Association of Clinical Physics. Procedures in external radiation therapy with electron and photon beams with maximum energies between 1 and 50 MeV. Recommendations by the Nordic Association of Clinical Physics (NACP).' *Acta Radiol. Oncol.* **19**, 55–79.
- Niroomand-Rad, A. (1989) 'Film dosimetry of small elongated electron beams for treatment planning.' *Med. Phys.* **16**, 655–662.
- Niroomand-Rad, A., Gillin, M. T., Kline, R. W. and Grimm, D. F. (1986) 'Film dosimetry of small electron beams for routine radiotherapy planning.' *Med. Phys.* **13**, 416–421.
- Nyerick, C. E., Ochran, T. G., Boyer, A. L. and Hogstrom, K. R. (1991) 'Dosimetry characteristics of metallic cones for intraoperative radiotherapy.' *Int. J. Radiat. Oncol. Biol. Phys.* **21**, 501–510.
- Olsen, D. R., Kambestad, B. K. and Kristoffersen, D. T. (1994) 'Calculation of radiation induced complication probabilities for brain, liver and kidney, and the use of a reliability model to estimate critical volume fractions.' *Br. J. Radiol.* **67**, 1218–1225.
- Palta, J. R. and Suntharalingam, N. (1989) 'A non-docking intraoperative electron beam applicator system.' *Int. J. Radiat. Oncol. Biol. Phys.* **17**, 411–417.
- Podgorsak, E. B., Pla, C., Pla, M., Lefebvre, P. Y. and Hesse, R. (1983) 'Physical aspects of a rotational total skin electron irradiation.' *Med. Phys.* **10**, 159–168.
- Purdy, J. A. (1996) Volume and dose specification, treatment evaluation, and reporting for 3D conformal radiation therapy. In: *Teletherapy: Present and Future*, Mackie, T. R. and Palta, J. R., Eds. (Madison, WI: Advanced Medical Publishing) p. 235.
- Purdy, J., Harms, W. B., Michalski, J. and Cox, J. D. (1996) 'Multi-institutional clinical trials: 3-D conformal radiotherapy quality assurance. Guidelines in an NCI/RTOG study evaluating dose escalation in prostate cancer radiotherapy.' *Front. Radiat. Ther. Oncol.* **29**, 255–263.
- Rashid, H., Islam, M. K., Gaballa, H., Rosenow, U. F. and Ting, J. Y. (1990) 'Small-field electron dosimetry for the Philips SL25 linear accelerator.' *Med. Phys.* **17**, 710–714.
- Roeske, J. C., Forman, J. D., Mesina, C. F., He, T., Pelizzari, C. A., Fontenla, E., Vijayakumar, S. and Chen, G. T. (1995) 'Evaluation of changes in the size and location of the prostate, seminal vesicles, bladder, and rectum during a course of external beam radiation therapy.' *Int. J. Radiat. Oncol. Biol. Phys.* **33**, 1321–1329.
- Rogers, D. W. and Bielajew, A. F. (1986) 'Differences in electron depth-dose calculated with EGS and ETRAN and improved energy-range relationships.' *Med. Phys.* **13**, 687–694.
- Rogers, D. W., Faddegon, B. A., Ding, G. X., Ma, C. M., We, J. and Mackie, T. R. (1995) 'BEAM: a Monte Carlo code to simulate radiotherapy treatment units.' *Med. Phys.* **22**, 503–524.
- Samuelsson, A., Hyödynmaa, S. and Johansson, K. A. (1998) 'Dose accuracy check of the 3D electron beam

REFERENCES

- algorithm in a treatment planning system.' *Phys. Med. Biol.* **43**, 1529–1544.
- Sewchand, W., Khan, F. M. and Williamson, J. (1979) 'Total-body superficial electron-beam therapy using a multiple-field pendulum-arc technique.' *Radiology* **130**, 493–498.
- Shiu, A. S., Tung, S., Hogstrom, K. R., Wong, J. W., Gerber, R. L., Harms, W. B., Purdy, J. A., Ten Haken, R. K., McShan, D. L. and Fraass, B. A. (1992) 'Verification data for electron beam algorithms.' *Med. Phys.* **19**, 623–636.
- Sinclair, W. K. and Kohn, H. I. (1964) 'The relative biological effectiveness of high energy photons and electrons.' *Radiology* **82**, 800–815.
- Sorcini, B. B., Andreo, P., Bielajew, A. F., Hyödynmaa, S. and Brahme, A. (1995) 'An improved energy-range relationship for high-energy electron beams based on multiple accurate experimental and Monte Carlo data sets.' *Phys. Med. Biol.* **40**, 1135–1159.
- Spadinger, I. and Palcic, B. (1992) 'The relative biological effectiveness of 60 Co gamma-rays, 55 kVp X-rays, 250 kVp X-rays and 11 MeV electrons at low doses.' *Int. J. Radiat. Biol.* **61**, 345–353.
- Stroom, J. C., de Boer, H. C., Huizenga, H. and Visser, A. G. (1999) 'Inclusion of geometrical uncertainties in radiotherapy treatment planning by means of coverage probability.' *Int. J. Radiat. Oncol. Biol. Phys.* **43**, 905–919.
- Svensson, H. and Hettinger, G. (1971) 'Dosimetric measurements at the nordic medical accelerators. I. Characteristics of the radiation beam.' *Acta Radiol. Ther. Phys. Biol.* **10**, 369–384.
- Tapley, N. du V. and Fletcher, G. H. (1973) 'Applications of electron beam in the treatment of cancer of the skin and lips.' *Radiology* **109**, 423–428.
- Tepper, J. E., Gunderson, L. L., Goldson, A. L., Kinsella, T. J., Shipley, W. U., Sindelar, W. F., Wood, W. C. and Martin, J. K. (1986) 'Quality control parameters of intraoperative radiation therapy.' *Int. J. Radiat. Oncol. Biol. Phys.* **12**, 1687–1695.
- Udale-Smith, M. (1992) 'Monte Carlo calculations of electron beam parameters for three Philips linear accelerators.' *Phys. Med. Biol.* **37**, 85–105.
- UICC. (1997) International Union Against Cancer. *TNM Classification of Malignant Tumors*, 5th ed., Sabin, L. H. and Wittekind, C., Eds. (New York: Wiley-Liss and Sons, Inc.).
- Van-Dyk, J., Barnett, R. B., Cygler, J. E. and Shragge, P. C. (1993) 'Commissioning and quality assurance of treatment planning computers.' *Int. J. Radiat. Oncol. Biol. Phys.* **26**, 261–273.
- van Herk, M., Remeijer, P., Rasch, C. and Lebesque, J. V. (2000) 'The probability of correct target dosage: dose-population histograms for deriving treatment margins in radiotherapy.' *Int. J. Radiat. Oncol. Biol. Phys.* **47**, 1121–1135.
- van't Riet, A., Mak, A. C., Moerland, M. A., Elders, L. H. and van der Zee, W. (1997) 'A conformation number to quantify the degree of conformality in brachytherapy and external beam irradiation: application to the prostate.' *Int. J. Radiat. Oncol. Biol. Phys.* **37**, 731–736.
- Wachter, S., Gerstner, N., Goldner, G., Potzi, R., Wambersie, A. and Potter, R. (2001) 'Rectal sequelae after conformal radiotherapy of prostate cancer: dose-volume histograms as predictive factors.' *Radiother. Oncol.* **59**, 65–70.
- Wambersie, A. (1967) Contribution à l'étude de l'Efficacité Biologique Relative des faisceaux de photons et d'électrons de 20 MeV du bétatron. Thesis, Université Catholique de Louvain, Journal Belge de Radiologie, Monographie N.1.
- Wambersie, A. and Menzel, H. G. (1993) 'RBE in fast neutron therapy and in boron neutron capture therapy. A useful concept or a misuse?' *Strahlenther. Onkol.* **169**, 57–64.
- Wambersie, A., Pihet, P. and Menzel, H. G. (1990) 'The role of microdosimetry in radiotherapy.' *Radiat. Prot. Dosim.* **31**(1–4), 421–432.
- Wambersie, A., Dutreix, A., Dutreix, J. and Tubiana, M. (1965) Depth dose curves determined by ionization, film density, ferrous sulphate and survival rate of coli bacteria and diploid yeasts using a 20 MeV electron beam. In: *Symposium on High-Energy Electrons*. Zuppinger, A. and Poretti, G., Eds. (Berlin, Germany: Springer-Verlag) p. 140.
- Wambersie, A., Zreik, H., Prignot, M. and Van Dorpe, J. C. (1974) 'Variation of RBE as a function of depth in a high energy electron beam in the first millimeters of the irradiated tissues determined by the observation of skin reactions on patients (a clinical trial).' *Strahlentherapie* **148**, 279–287.
- Wambersie, A., Menzel, H. G., Gahbauer, R. A., Jones, D. T. L., Michael, B. D. and Paretzke, H. (2002a) 'Biological weighting of absorbed dose in radiation therapy.' *Radiat. Prot. Dosim.* **99**, 445–452.
- Wambersie, A., Menzel, H. G., Gahbauer, R. A., DeLuca, P. and Whitmore, G. (2002b) RBE and harmonization in prescribing, recording and reporting hadron therapy. In: *Progress in Radio-Oncology VII*, Kogelnik, H. D., Lucas, P. and Sedlmayer, F., Eds. (Bologna, Italy: Mondadori Editore) pp. 361–371.
- Werner, B. L., Khan, F. M. and Deibel, F. C. (1982) 'A model for calculating electron beam scattering in treatment planning.' *Med. Phys.* **9**, 180–187.
- WHO. (1990) World Health Organization. *International Classification of Diseases for Oncology*. (ICD-0 10, 2nd ed. Based on 10th revision) (Geneva, Switzerland: WHO).
- Williams, P. C. and Hendry, J. H. (1978) 'The RBE of megavoltage photon and electron beams.' *Br. J. Radiol.* **51**, 220.
- Williams, P. C., Hunter, R. D. and Jackson, S. M. (1979) 'Whole body electron therapy in mycosis fungoides—a successful translational technique achieved by modification of an established linear accelerator.' *Br. J. Radiol.* **52**, 302–307.
- Withers, H. R., Taylor, J. M. and Maciejewski, B. (1988) 'Treatment volume and tissue tolerance.' *Int. J. Radiat. Oncol. Biol. Phys.* **14**, 751–759.

PRESCRIBING, RECORDING, AND REPORTING ELECTRON BEAM THERAPY

- Wolbarst, A. B., Chin, L. M. and Svensson, G. K. (1982) 'Optimization of radiation therapy: integral-response of a model biological system.' *Int. J. Radiat. Oncol. Biol. Phys.* **8**, 1761–1769.
- Yu, C. X., Ge, W. S. and Wong, J. W. (1988) 'A multiray model for calculating pencil electron beam distribution.' *Med. Phys.* **15**, 662–671.
- Zackrisson, B. and Karlsson, M. (1992) 'Relative biological effectiveness of 50-MV X rays on jejunal crypt survival in vivo.' *Radiat. Res.* **132**, 112–114. (Erratum: (1993), **133**, 141).
- Zackrisson, B. and Karlsson, M. (1996) 'Matching of electron beams for conformal therapy of target volumes of moderate depths.' *Radiother. Oncol.* **39**, 261–270.
- Zackrisson, B., Johansson, B. and Ostbergh, P. (1991a) 'Relative biological effectiveness of high-energy photons (up to 50 MV) and electrons (50 MeV).' *Radiat. Res.* **128**, 192–196.
- Zackrisson, B. U., Nystrom, U. H. and Ostbergh, P. (1991b) 'Biological response in vitro to pulsed high dose rate electrons from a clinical accelerator.' *Acta Oncol.* **30**, 747–751.



- Image Quality in Chest Radiography**
Report no. 70, 2003
- Direct Determination of the Body Content of Radionuclides**
Report no. 69, 2003
- Retrospective Assessment of Exposures to Ionising Radiation**
Report no. 68, 2002
- Absorbed Dose Specification in Nuclear Medicine**
Report no. 67, 2002
- Determination of Operational Dose Equivalent Quantities for Neutrons**
Report no. 66, 2001
- Quantities, Units and Terms in Radioecology**
Report no. 65, 2001
- Dosimetry of High Energy Photon Beams based on Standards of Absorbed Dose to Water**
Report no. 64, 2001
- Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection**
Report no. 63, 2000
- Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50)**
Report no. 62, 1999
- Tissue Substitutes, Phantoms and Computational Modelling in Medical Ultrasound**
Report no. 61, 1998
- Fundamental Quantities and Units for Ionizing Radiation**
Report no. 60, 1998
- Clinical Proton Dosimetry—Part I: Beam Production, Beam Delivery and Measurement of Absorbed Dose**
Report no. 59, 1998
- Dose and Volume Specification for Reporting Interstitial Therapy**
Report no. 58, 1997
- Conversion Coefficients for Use in Radiological Protection Against External Radiation**
Report no. 57, 1998
- Dosimetry of External Beta Rays for Radiation Protection**
Report no. 56, 1997
- Secondary Electron Spectra from Charged Particle Interactions**
Report no. 55, 1995
- Medical Imaging—The Assessment of Image Quality**
Report no. 54, 1995
- Gamma-Ray Spectrometry in the Environment**
Report no. 53, 1994
- Particle Counting in Radioactivity Measurement**
Report no. 52, 1994
- Quantities and Units in Radiation Protection Dosimetry**
Report no. 51, 1993
- Prescribing, Recording and Reporting Photon Beam Therapy**
Report no. 50, 1993
- Stopping Powers and Ranges for Protons and Alpha Particles, with Data Disk**
Report no. 49D, 1993
- Stopping Powers and Ranges for Protons and Alpha Particles**
Report no. 49, 1993
- Phantoms and Computational Models in Therapy, Diagnosis and Protection**
Report no. 48, 1992
- Measurement of Dose Equivalents from External Photon and Electron Radiations**
Report no. 47, 1992
- Photon, Electron, Proton and Neutron Interaction Data for Body Tissues, with Data Disk**
Report no. 46D, 1992
- Photon, Electron, Proton and Neutron Interaction Data for Body Tissues**
Report no. 46, 1992
- Clinical Neutron Dosimetry—Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons**
Report no. 45, 1989

- Tissue Substitutes in Radiation Dosimetry and Measurement**
Report no. 44, 1989
- Determination of Dose Equivalents from External Radiation Sources - Part 2**
Report no. 43, 1988
- Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photons and Electrons**
Report no. 42, 1987
- Modulation Transfer Function of Screen-Film Systems**
Report no. 41, 1986
- The Quality Factor in Radiation Protection**
Report no. 40, 1986
- Determination of Dose Equivalents Resulting from External Radiation Sources**
Report no. 39, 1985
- Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology**
Report no. 38, 1985
- Stopping Powers for Electrons and Positrons**
Report no. 37, 1984
- Microdosimetry**
Report no. 36, 1983
- Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV**
Report no. 35, 1984
- The Dosimetry of Pulsed Radiation**
Report no. 34, 1982
- Radiation Quantities and Units**
Report no. 33, 1980
- Methods of Assessment of Absorbed Dose in Clinical Use of Radionuclides**
Report no. 32, 1979
- Average Energy Required to Produce an Ion Pair**
Report no. 31, 1979
- Quantitative Concepts and Dosimetry in Radiobiology**
Report no. 30, 1979
- Basic Aspects of High Energy Particle Interactions and Radiation Dosimetry**
Report no. 28, 1978
- Neutron Dosimetry for Biology and Medicine**
Report no. 26, 1977
- An International Neutron Dosimetry Intercomparison**
Report no. 27, 1978
- Conceptual Basis for the Determination of Dose Equivalent**
Report no. 25, 1976
- Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures**
Report no. 24, 1976
- Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays**
Report no. 23, 1973
- Measurement of Low-Level Radioactivity**
Report no. 22, 1972
- Radiation Protection Instrumentation and Its Application**
Report no. 20, 1970
- Specification of High Activity Gamma-Ray Sources**
Report no. 18, 1970
- Radiation Dosimetry: X rays Generated at Potentials of 5 to 150 kV**
Report no. 17, 1970
- Linear Energy Transfer**
Report no. 16, 1970
- Cameras for Image Intensifier Fluorography**
Report no. 15, 1969
- Radiation Dosimetry: X Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV**
Report no. 14, 1969
- Neutron Fluence, Neutron Spectra and Kerma**
Report no. 13, 1969
- Certification of Standardized Radioactive Sources**
Report no. 12, 1968
- Physical Aspects of Irradiation**
Report no. 10b, 1964

Please visit the web site for pricing and ordering information

www.jicru.oupjournals.org