

PATIENT DOSIMETRY FOR X RAYS USED IN MEDICAL IMAGING

CONTENTS

PREFACE	X
GLOSSARY	3
ABSTRACT	5
EXECUTIVE SUMMARY	7
1 INTRODUCTION	9
1.1 Evolution of radiation dosimetry in medical x-ray imaging	9
1.2 Risks for the patient in radiological imaging and relevant dosimetric quantities	11
1.2.1 Acute deterministic effects	11
1.2.2 Late effects	12
1.2.2.1 Cancer induction	12
1.2.2.2 Late effects in normal tissues	12
1.2.2.3 Impairment of mental development	12
1.2.2.4 Genetic risk	12
1.2.3 Relevant dosimetric quantities and dosimetric procedures	12
1.2.4 Required accuracy	13
1.3 Dosimetry in radiology: relevant quantities	13
1.3.1 Calibration at the Standards Laboratory	13
1.3.2 From air kerma free-in-air to absorbed dose in water inpatient or phantom	13
1.3.3 Air kerma-area product (KAP) and dose-area product (DAP)	14
1.3.4 Reporting patient irradiation in radiological imaging	14
1.3.4.1 Radiological parameters of the exposure	14
1.3.4.2 Air kerma-area product (KAP) or dose-area product (DAP)	15
1.3.4.3 Monte Carlo computation	15
1.3.4.4 Phantoms and in vivo measurements	15
1.3.5 Discussion	16
1.4 Need for harmonization of quantities and terminology	17
1.5 The two purposes of patient dosimetry	18
1.5.1 To set and check standards of good practice	18
1.5.2 To assist in assessing detriment or harm	18
1.6 Relationship between patient dose and image quality	18
1.7 Scope of the report	19

2 SPECIFICATION OF X-RAY BEAMS	21
2.1 Photon spectrum	21
2.2 Half-value layer	22
2.3 X-ray tube voltage	23
2.4 Total filtration	24
2.5 X-ray tube output	24
3 QUANTITIES AND UNITS FOR MEASUREMENT AND CALCULATION IN MEDICAL X-RAY IMAGING	25
3.1 Basic dosimetric quantities	25
3.2 Application-specific quantities	26
3.2.1 Incident air kerma and incident air kerma rate	28
3.2.2 Entrance-surface air kerma and entrance-surface air kerma rate	29
3.2.3 Air kerma-area product and air kerma-area product rate	29
3.2.4 Air kerma-length product	29
3.2.5 CT air-kerma index free-in-air	29
3.2.6 CT air-kerma index in the standard CT dosimetry phantoms	30
3.2.7 Weighted CT air-kerma index and normalized weighted CT air-kerma index	30
3.2.8 CT air kerma-length product	30
3.3 Risk-related quantities	30
3.3.1 Absorbed dose in relation to deterministic effects	31
3.3.2 Absorbed dose for assessment of stochastic effects (organ dose)	31
3.3.3 Equivalent dose and effective dose	31
3.4 Dose-conversion coefficients for assessment of organ and tissue doses	32
3.5 Quantities recommended for establishment and use of diagnostic reference levels	33
3.5.1 Incident air kerma and entrance-surface air kerma	34
3.5.1.1 Mean mammary glandular dose	34
3.5.2 Incident air kerma rate and entrance-surface air kerma rate	34
3.5.3 Air kerma-area product	34
3.5.4 CT Air kerma-length product, $P_{dl,ct}$	34
4 MEASUREMENT METHODS	35
4.1 Quality assurance of dosimeters	35
4.1.1 Calibration of dosimeters in terms of air kerma free-in-air	36
4.1.2 Calibration of air kerma-area product meters	37
4.1.3 Calibration of thermoluminescent dosimeters	38
4.2 Measurement methods for specific dosimetric quantities	39
4.2.1 Dosimeters	39
4.2.1.1 Ionization chamber dosimeters	40
4.2.1.2 Thermoluminescent dosimeters	40
4.2.1.3 Scintillation dosimeters	40

4.2.1.4 Film dosimeters	41
4.2.2 Incident air kerma	41
4.2.3 Entrance-surface air kerma	42
4.2.4 Air kerma-area product	42
4.2.5 CT air-kerma index and CT air-kerma index in the standard CT head and body dosimetry phantoms	44
4.2.5.1 Pencil ionization chamber dosimeter	44
4.2.5.2 Thermoluminescent dosimeters	47
4.3 Features of measurements on patients and measurements with physical phantoms	47
4.4 Skin dose determination	48
4.4.1 Direct measurement of the maximum skin dose	48
4.4.1.1 Skin dose measurements on patients with thermoluminescent dosimeters	48
4.4.1.2 Skin dose measurements on patients with scinillation dosimeters	50
4.4.1.3 Skin dose measurements on patients with film dosimeters	50
4.4.2 Derivation of the skin dose from the air kerma-area product P_{ka}	50
4.4.3 Derivation of the skin dose directly from the radiological parameters of the exposure	51
5 METHODS FOR DETERMINING ORGAN AND TISSUE DOSES	55
5.1 Dose measurements in physical phantoms	55
5.2 Monte Carlo radiation transport calculations	56
5.2.1 Main features of the Monte Carlo technique	56
5.2.2 Main features of the computational models of the human body	56
5.2.2.1 Mathematical phantoms	56
5.2.2.2 Special features of the active bone marrow	57
5.2.2.3 Voxel phantoms	58
5.2.3 Uncertainties in Monte Carlo organ-dose calculations	58
5.2.4 Comparison of conversion coefficients calculated at different institutes	59
5.2.5 Comparison of measured and calculated organ doses	59
5.2.5.1 Adult phantoms: organs in the x-ray field	59
5.2.5.2 Adult phantoms: organs outside the x-ray field	60
5.2.5.3 Adult phantoms: active bone marrow	60
5.2.5.4 Paediatric phantoms: head and neck	60
5.2.5.5 Paediatric phantoms: whole body	60
5.2.5.6 Adult phantoms: CT.	61
5.2.6 Sources of data on dose-conversion coefficients	61
6 CONCLUSIONS	63

APPENDIX A BACKSCATTER FACTORS	65
APPENDIX B HANDBOOKS PRODUCED BY THE CENTER FOR DEVICES AND RADIOLOGICAL HEALTH (CDRH)	69
APPENDIX C REPORTS PRODUCED BY THE GERMAN NATIONAL RESEARCH CENTER FOR ENVIRONMENT AND HEALTH (GSF)	79
APPENDIX D REPORTS PRODUCED BY THE HEALTH PROTECTION AGENCY (HPA) (FORMERLY NATIONAL RADIOLOGICAL PROTECTION BOARD) (NRPB)	87
APPENDIX E REVIEW OF MONTE CARLO CALCULATIONS FOR ASSESSMENT OF MEAN GLANDULAR DOSE IN MAMMOGRAPHY	93
APPENDIX F PCXMC – A PC-BASED MONTE CARLO PROGRAM FOR CALCULATING PATIENT DOSES IN MEDICAL X-RAY EXAMINATIONS	99
REFERENCES	103