

Contents

1	Quantities and Fundamental Units of External Dosimetry	1
1.1	Dosimetric Quantities	1
1.1.1	Total Absorbed Dose and Linear Energy Transfer	1
1.1.2	Fundamental Quantities of Microdosimetry and Definition of the Absorbed Dose	5
1.1.3	Kerma Calculation for Radiation Indirectly Ionizing	10
1.2	Biological Damage and Relative Biological Effectiveness (RBE)	13
1.2.1	Radiation Injury on DNA of the Cell	13
1.2.2	Cell Survival Rate and RBE	14
1.3	Radiometric Quantities	18
1.3.1	Radiation Field Characterization	19
1.3.2	Radiant Energy and Flux	20
1.3.3	Application to Neutron Spectrum of ^{252}Cf	23
1.3.4	Representation of Data to an Energy Distribution in an Array	23
1.3.5	Graphical Representation Distribution Energy	26
1.3.6	Fluence Definition and Interest in Dosimetry and Radiation Protection	27
1.3.7	Calculating the Fluence Induced by an Isotropic Point Source	31
1.3.8	Calculation of the Fluence Induced by a No Punctual Source	34
	References	41
2	Ionizing Radiation Interaction in Tissues: Kerma and the Absorbed Dose	43
2.1	Electrons and Heavy Charged Particles (HCP)	43
2.1.1	Physical Characteristics of Electrons and HCP During Transport in Matter	44
2.1.2	Mass Stopping Power of Charged Particles	48

2.1.3	Scattering of Electrons.	51
2.1.4	Calculation of the Absorbed Dose for the Electrons in the Tissues	52
2.1.5	Calculation of the Tissue Dose for Particles β	60
2.1.6	Calculation of the Dose in the Tissue for HCP	63
2.1.7	Measurement of the Absorbed Dose for the Electron and β Radiation.	64
2.2	Photons.	68
2.2.1	The Photoelectric Effect.	69
2.2.2	The Compton Effect	70
2.2.3	The Pair Production Effect	76
2.2.4	Effective Macroscopic Section and Transmission of Photons in Tissue	78
2.2.5	Kerma Calculation for Photons	80
2.2.6	Relationship Between the Absorbed Dose and Photon Kerma	88
2.2.7	Kerma and Absorbed Dose in Successive Light Media.	90
2.2.8	Measurement of Air Kerma and Absorbed Dose in Tissue for Photons	94
2.3	Neutron Interaction with Matter and Calculating the First Collision Kerma	104
2.3.1	Elastic Collision (n,n)	105
2.3.2	Inelastic Scattering (n,n')	107
2.3.3	Radiative Capture (n, γ)	108
2.3.4	(n,p) and (n, α) Capture	109
2.3.5	Microscopic Cross Sections in the Chemical Constituents of Human Tissue.	110
2.3.6	Calculation of the First Collision Kerma	111
2.3.7	Calculation of Multi-collision Kerma and Mean Absorbed Dose.	116
2.3.8	Measurement of the Fluence and Neutron Spectra.	120
	References.	148
3	Protection and Operational Dosimetric Quantities and Calibration	151
3.1	Stochastic Effects	151
3.2	Deterministic Effects.	152
3.3	Protections Quantities	152
3.3.1	Organ Absorbed Dose.	152
3.3.2	Radiation Weighting Factor W_R and Equivalent Dose in an Organ or Tissue	153
3.3.3	Tissue Weighting Factor and Effective Dose.	155

3.3.4	Quantifying Risks for Stochastic Effects	156
3.3.5	Recommended Limits for Radiological Exposure	157
3.3.6	Calculation of Protection Quantities	158
3.4	Absorbed Dose Calculation for Deterministic Risk Evaluation	171
3.4.1	Quantifying for Deterministic Effects	171
3.4.2	Deterministic Effects for Acute Radiation	172
3.4.3	Deterministic Effects for Acute Radiation on Organ and Tissue	172
3.4.4	Absorbed Dose Calculation for a ^{18}F Contamination.	173
3.4.5	Absorbed Dose Calculation in the Case of a Proton Beam.	174
3.4.6	Absorbed Dose Calculation Using a Complex Model: Voxelized Phantom	174
3.5	The Operational Quantities	177
3.5.1	Quality Factor and Definition Dose Equivalent	177
3.5.2	Expanded and Aligned Fields	179
3.5.3	Operational Quantities for Area Monitoring	180
3.5.4	Operational Quantities for Individual Monitoring	183
3.5.5	Difference Between Strongly and Weakly Penetrating Radiation in Terms of Operational Dosimetry	188
3.5.6	“Physical Quantity—Dose Equivalent” Conversion Factors.	189
3.5.7	Conversion Factors for Electrons.	197
3.6	Comparison Between Operational Quantities and Protection Quantities	201
3.7	Calibration of Radiation Devices	203
3.7.1	Definition of Reference Fields	204
3.7.2	Transfer Dosimeters in Primary Laboratories.	204
3.7.3	Connecting Process and Transition to the Operational Quantity in a Secondary Laboratory	206
3.7.4	Calibration with a Standard Source in a Secondary Laboratory.	209
3.7.5	Area and Personal Dosimeters Responses in Energy $R(E)$, in Angular $R(\Omega)$ and Flux Rate	210
3.7.6	Realistic Spectra of Neutrons for Calibration.	222
3.8	Radiological Zoning	224
3.9	Evolution of Protection Quantities	224
	Appendix 1	229
	Appendix 2	229
	Appendix 3	230
	Appendix 4	231
	Appendix 5	232
	Appendix 6	233
	References.	234

4	Source Evaluation of the External Exposure	237
4.1	Photons Line Spectra	237
4.2	Neutrons	239
4.2.1	Nuclear Reactions	240
4.2.2	Neutrons from the Fusion	242
4.2.3	(α , n) Sources	244
4.2.4	(γ , n) Sources	247
4.3	Fission	248
4.3.1	Source Term from Prompt Fission Reactions	248
4.3.2	Source Term from the Fission Products.	251
4.4	Neutron Source from Fuel Cooling.	255
4.5	Photons from Neutron Reactions	257
4.5.1	Photons Produced by Radiative Captures	257
4.5.2	Photons Emitted During Neutron Inelastic Scattering	260
4.6	Electrons—Dark Current Effect	262
4.7	Radiation from Bremsstrahlung	263
4.7.1	Overview.	263
4.7.2	X-Ray Generators	270
4.7.3	Electron Accelerators.	274
4.7.4	Dose Equivalent Due to Photoneutrons	276
4.8	Neutrons Produced by Ion Accelerators	283
4.8.1	Neutron Yield by Light Ions	284
4.8.2	Special Case of Deuteron Accelerators: Deuteration Effect.	286
4.8.3	Neutron Spectra Caused by Light Ions	287
4.8.4	Neutron Dose Equivalent Caused by Light Ion and Low Energy Accelerators	289
4.8.5	Neutron Dose Equivalent Around Accelerators of High Energy Protons.	290
4.9	Source Term Associated with Induced Radioactivity	291
4.9.1	Radionuclides Produced by Induced Radioactivity	291
4.9.2	Activity Calculation After a Given Reaction	292
4.9.3	Radiation Protection Risk Related to the Activation	294
4.10	Emission of Radiation by “Exotic” Device.	294
4.10.1	Klystron	295
4.10.2	High-Intensity Laser Pulses	296
	Appendix 1	300
	Appendix 2	304
	References.	306

5	Protection Against External Exposition, General Principles	309
5.1	Definitions	310
5.2	Protection Principles	311
5.2.1	Decay of a Source and Reduction of Exposure Time . . .	311
5.2.2	Dose Rate Variation with Distance	312
5.3	Shielding Against α and β Radiation	313
5.3.1	α Particle	313
5.3.2	β Particle	314
5.4	Shielding Against Photons Radiation	314
5.4.1	Calculation of Primary Shielding: Uncollided Radiation	314
5.4.2	Primary Shielding Calculation, the Case of Broad Beam	317
5.4.3	Calculation of a Secondary Shielding	336
5.4.4	Maze Calculation	342
5.4.5	Skyshine from Photon Radiation	345
5.5	Neutron Shielding	348
5.5.1	Neutrons Attenuation-Tenth Value Layer	348
5.5.2	Transmission Curves for Neutrons	350
5.5.3	Calculating a Maze for Neutrons	353
5.5.4	Neutrons Skyshine	356
5.6	Radiological Protection Around Electron Accelerators	356
5.7	Radiation Shielding at Ion Accelerators	359
5.7.1	Low Energy Ions Accelerators	359
5.7.2	High Energy Ions Accelerators	360
5.8	Accelerators and Irradiators Safety	360
5.9	Shielding Design to Avoid the Radiation Leakage	361
5.10	Shield Control	365
5.11	Toxic Gases Production: Ozone, Nitrogen Oxide, Nitrogen Dioxide	366
5.11.1	Electron Beam in Air [18]	367
5.11.2	Photon Beam	368
5.11.3	Bremsstrahlung	369
5.12	Calculation Codes Dedicated to Shielding	370
5.12.1	Point Kernel Method	371
5.12.2	Other Computer Codes	373
	Appendix 1. Material Composition	375
	Appendix 2. Neutron Transmission Indexes	376
	References	385
6	Principle of the Monte-Carlo Method Applied to Dosimetry and Radiation Protection	387
6.1	Principle of the Monte Carlo Method Applied to the Particle Transport	387
6.2	Random Number Generator	389

6.3	Sampling a Discrete Distribution, Application to Choose the Type of Collision.	390
6.4	Sampling of a Continuous Distribution, Application for Calculating Energy and Direction of a Scattering Particle. . . .	392
6.4.1	Sampling a Continuous Distribution by a Multi-group Approach.	393
6.4.2	Sampling a Continuous Distribution by the Method of Rejection.	394
6.5	Concept of Statistical Weight, Analog and Implicit Tracking	398
6.6	Definition of Geometry.	399
6.7	Emission Source.	401
6.8	Location of Collision	406
6.9	Target Nucleus Sampling	408
6.10	Sampling Charged Particle Transport: Electrons Case	409
6.10.1	“Step-by-Step” Approach for Multiple Scattering Method (Class I)	410
6.10.2	Multiple-Scattering Distribution for Energy Loss by Collision (Class I)	413
6.10.3	Sampling Bremsstrahlung Photons and Energy Loss (Class I).	414
6.10.4	Global Deflection Angle According to Multiple Scattering Theory (Class I)	416
6.10.5	From Step-by-Step to Single-Event Approach Applied to MCNP Code (Class I and II).	417
6.11	Problem Related to the Interface Between Cell for Calculating the Response of an Ionization Chamber	423
6.11.1	Response Related to the Use of the Transport Code EGS4 Code (Class I).	423
6.11.2	Improved Response with the Use of Code EGSnrc (Class II).	424
6.12	Calculated Estimators in Monte-Carlo Codes	425
6.12.1	Fluence Estimator	426
6.12.2	Kerma Estimator	433
6.12.3	Estimator “Pulse-Dose” for Indirectly Ionizing Radiation and Charged Particles	435
6.12.4	Dose Estimator for Charged Particles	436
6.13	Application to MCNP Code	437
6.13.1	Calculation of Kerma and Absorbed Dose in Crossing Media Problem, Using the Estimator Kerma with Changes in Transport Mode	439
6.13.2	Comparison of Kerma and “Dose-Pulse” Estimators for Photons in the Context of Calculating the Effective Dose	441
6.13.3	Dose Profile For a 400 MeV Protons Beam in a Water Cylinder	442

6.14	Statistical Error Associated to Estimators	443
6.14.1	Calculation of Associated Statistical Error.	443
6.14.2	Statistical Tests of Reliability	446
6.14.3	Result Finalization.	447
6.15	Complexity Levels in Dosimetric Models.	448
6.16	Application of Monte Carlo Codes for Dosimeters.	448
6.17	Application of Monte Carlo Codes for Calculations Relating to Metrology.	450
6.18	Application of Monte Carlo Codes for Scintillator Detectors	453
	References.	463
Index	467

Applied Physics of External Radiation Exposure
Dosimetry and Radiation Protection

Antoni, R.; Bourgois, L.

2017, XV, 470 p. 277 illus., 21 illus. in color., Hardcover

ISBN: 978-3-319-48658-1