

Contents

Preface	xvii
Authors	xix
1 The structure of matter	1
1.1 Introduction	1
1.2 The atom	1
1.3 The structure of the atom	1
1.4 Elements and atomic number	2
1.5 Isotopes and mass number	3
1.6 Ancient and modern theories	4
Summary of key points	5
Revision questions	5
2 Radioactivity and radiation	7
2.1 Introduction	7
2.2 Alpha, beta and gamma radiation	8
2.3 Electronvolt	8
2.4 The mechanism of radioactive decay	9
2.5 Natural radioactive series	10
2.6 Induced radioactivity	11
2.7 The unit of radioactivity	11
2.8 Nuclide chart	13
2.9 Interaction of radiation with matter	13
2.9.1 Charged particles	13
2.9.2 X and γ radiations	14
2.9.3 Neutrons	14
2.10 Penetrating powers of nuclear radiations	14
Summary of key points	15
Revision questions	16
3 Radiation units	17
3.1 Absorption of energy	17
3.2 Ionization	17
3.3 Absorbed dose	18
3.4 Equivalent dose	19
3.5 Effective dose	19
3.6 Submultiples	20
3.7 Dose rate	20
3.8 Flux	20
3.9 Relationship of units	21

3.10	International radiation symbols	21
	Summary of key points	22
	Revision questions	23
4	Biological effects of radiation	25
4.1	Introduction	25
4.2	Basic human physiology	27
4.2.1	Circulatory system	27
4.2.2	Respiratory system	28
4.2.3	Digestive system	28
4.3	Cell biology	28
4.4	Interaction of radiation with cells	29
4.5	Harmful tissue reactions	30
4.5.1	Acute radiation effects	30
4.5.2	Late tissue reactions	31
4.6	Stochastic effects: cancer induction	31
4.7	Stochastic effects: heritable	32
4.8	Detriment	33
	Summary of key points	34
	Revision questions	35
5	Natural and man-made radiation	37
5.1	Introduction	37
5.2	Cosmic radiation	37
5.3	Radiation from terrestrial sources	37
5.4	Naturally Occurring Radioactive Material (NORM)	38
5.5	Radioactivity in the body	38
5.5.1	Radon	38
5.6	Summary of doses from natural radiation	40
5.7	Man-made radiation exposure	40
5.7.1	Diagnostic radiology	40
5.7.2	Radiotherapy	41
5.7.3	Nuclear medicine	41
5.7.4	Radioactive waste	41
5.7.5	Atmospheric fallout	41
5.7.6	Occupational exposure	41
5.8	Summary of current sources of radiation	42
	Summary of key points	42
	Revision questions	42
6	The system of radiological protection	43
6.1	The role of the International Commission on Radiological Protection (ICRP)	43
6.2	The 2007 recommendations of the International Commission on Radiological Protection (<i>Publication 103</i>)	43
6.3	Recommended dose limits	44
6.3.1	Basis of dose limits	44
6.3.2	Recommended dose limits for workers	45
6.3.3	Notes on the dose limits for workers	46
6.3.4	Recommended dose limits for individual members of the public	47
6.4	Planned exposure situations	47

6.5	Emergency exposure situations	48
6.6	Existing exposure situations	49
	Summary of key points	49
	Revision questions	50
7	Radiation detection and measurement	51
7.1	General principles	51
7.2	Ionization of a gas	51
7.2.1	Ionization chamber	51
7.2.2	Proportional counter	52
7.2.3	Geiger–Müller counter	52
7.3	Solid-state detectors	53
7.3.1	Mechanism	53
7.3.2	Semiconductor detectors	54
7.3.3	Scintillation detectors	54
7.3.4	Luminescence detectors	54
7.4	Activation effect	55
7.5	Pulse counting systems	55
7.5.1	Basic counting systems	55
7.5.2	Pulse Height Analyzer (PHA)	56
7.5.3	Ratemeter	57
7.6	Maintenance, testing and calibration of radiation-monitoring instrumentation	57
7.6.1	Initial testing	57
7.6.2	Operator pre-use checks	57
7.6.3	Periodic examination and testing (including calibration)	58
	Summary of key points	58
	Revision questions	59
8	The external radiation hazard	61
8.1	Source of the hazard	61
8.2	Time	61
8.3	Distance	62
8.3.1	A point source	62
8.3.2	A line source	63
8.3.3	A disc source	64
8.4	Shielding	64
8.4.1	Half-value layer	65
8.5	Neutron sources	67
8.6	Personal dose control	67
8.7	Survey monitoring	68
8.7.1	Radiation survey monitoring	68
8.7.2	X and γ radiation monitors	68
8.7.3	Neutron monitors	69
8.8	Personnel monitoring equipment	70
8.8.1	Personal dosimetry	70
8.8.2	Thermoluminescent dosimeters	70
8.8.3	Optically stimulated luminescence dosimeters	71
8.8.4	Personal electronic dosimeter	71

8.8.5	Fast neutron dosimeter	72
8.8.6	Criticality locket	72
8.9	Radiation records	73
	Summary of key points	73
	Revision questions	74
9	The internal radiation hazard	75
9.1	Uncontained radioactivity	75
9.2	Routes of entry	75
9.3	Assessment of dose	77
9.3.1	Dose coefficient	77
9.3.2	Annual limit of intake	78
9.4	Control of the contamination hazard	78
9.4.1	Basic principles	78
9.4.2	Area classification	79
9.4.3	Protective clothing	80
9.4.4	House rules and training of personnel	80
9.5	Radiotoxicity and laboratory classifications	81
9.6	Design of areas for radioactive work	82
9.6.1	Walls, floors and ceilings	82
9.6.2	Working surfaces	83
9.6.3	Glove boxes	83
9.6.4	Fume cupboards	84
9.7	Treatment of contaminated personnel	84
9.8	Contamination monitoring	85
9.8.1	Sensitivity	85
9.8.2	Direct surface contamination monitoring	85
9.8.3	Smear surveys	85
9.8.4	Air monitoring	86
9.9	Personal monitoring	86
	Summary of key points	87
	Revision questions	88
10	The principles of risk assessment	89
10.1	Introduction	89
10.2	Hazards, scenarios and risk	89
10.2.1	Nomenclature	89
10.2.2	Risk scenarios	90
10.2.3	Likelihoods and consequences	90
10.2.4	Suitable and sufficient risk assessments	90
10.2.5	Types of risk assessments	90
10.3	The basic steps in risk assessment	91
10.4	Probabilistic risk assessments	94
10.5	Uncertainty, sensitivity and acceptability	95
10.5.1	Uncertainty and sensitivity	95
10.5.2	Acceptability of risk	96
10.6	Risk perception and communication	97
	Summary of key points	98
	Revision questions	99

11	Practical health physics techniques	101
11.1	Basic techniques	101
11.2	Analysis techniques	101
11.2.1	Identification of unknown samples	101
11.2.2	Energy determination	101
11.2.3	Determination of half-life	103
11.2.4	Gross alpha and beta counting	104
11.2.5	Corrections for resolving time	105
11.2.6	Counting statistics	106
11.3	Leak testing of radioactive sealed sources	107
	Summary of key points	108
	Revision questions	108
12	Legislation and regulations related to radiation protection	111
12.1	Introduction	111
12.2	Recommendations of the International Commission on Radiological Protection (ICRP)	111
12.3	The Euratom directive	111
12.4	Converting the EC directive into UK law	112
12.5	Regulatory framework under the Health and Safety at Work Act	112
12.5.1	Regulations	112
12.5.2	Approved code of practice and other guidance	113
12.5.3	Radiation risk assessment	114
12.6	Environmental regulatory framework in the United Kingdom	114
12.7	Transport of radioactive material	114
12.8	Summary of the UK regulatory framework	115
12.9	Brief summary of international guidance and regulations in other countries	115
12.9.1	France	116
12.9.2	Germany	116
12.9.3	Japan	116
12.9.4	United States	117
12.9.5	Australia	117
12.9.6	New Zealand	117
	Summary of key points	118
	Revision questions	118
13	Radiation protection in the nuclear industry	119
13.1	Introduction	119
13.2	Fission	119
13.2.1	The fission process	119
13.2.2	Chain reactions and criticality	120
13.2.3	Fission products	121
13.2.4	Transuranic elements	121
13.2.5	Activation products	122
13.3	Basic features of reactor systems	122
13.3.1	The core and control system	122
13.3.2	The cooling system	123
13.3.3	The biological shield	123

13.4	Different reactor systems	123
13.4.1	Power reactors	123
13.4.2	Small modular reactors	125
13.4.3	Research reactors	126
13.5	Refuelling reactors	126
13.6	Radiation hazards from reactors	127
13.6.1	General	127
13.6.2	Sources of radiation	127
13.6.2.1	Radiation from the core	127
13.6.2.2	Radiation from the coolant	128
13.6.3	Sources of radioactive contamination	128
13.6.3.1	Beta emitters	128
13.6.3.2	Coolant leaks	129
13.6.3.3	Containment	129
13.6.4	The shutdown reactor	129
13.6.4.1	Maintenance	129
13.6.4.2	External radiation	130
13.6.4.3	Contamination	130
13.7	Fuel storage ponds	130
13.7.1	Introduction	130
13.7.2	Criticality	131
13.7.3	Loss of shielding	131
13.7.4	Operational aspects	131
13.7.5	Pond instrumentation	131
13.8	The nuclear fuel cycle	132
13.8.1	Front-end operations	132
13.8.1.1	Uranium mining	132
13.8.1.2	Uranium enrichment	132
13.8.1.3	Fuel fabrication	133
13.8.2	Back-end operations	133
13.8.2.1	Fuel reprocessing	133
13.8.2.2	Long-term storage	134
13.8.2.3	Waste and decommissioning	134
13.9	Safety analysis of nuclear facilities	134
13.9.1	Deterministic safety analysis	134
13.9.2	Probabilistic safety analysis	135
13.9.3	Severe accident analysis	135
	Summary of key points	135
	Revision questions	136
14	Radioactive waste and the decommissioning of radioactive facilities	137
14.1	Introduction	137
14.2	Radioactive liquid waste	138
14.3	Radioactive gaseous waste	139
14.4	Radioactive solid waste	140
14.5	Radiological environmental impact of releases	142
14.5.1	Legal requirements	142
14.5.2	Methodology	142

	14.5.2.1	Definition of source term	142
	14.5.2.2	Mode of discharge	143
	14.5.2.3	Characterization of receiving environment	143
	14.5.2.4	Identification of exposure pathways	143
	14.5.2.5	Assessment of doses and identification of reference person	145
	14.5.2.6	Criteria	145
	14.5.2.7	Operational surveys and reviews	146
	14.5.3	Application to disposals of solid waste	146
	14.5.4	Effects on non-human species	146
14.6		Decommissioning of radioactive facilities	146
	14.6.1	Planning and preparation	147
	14.6.2	Stages of decommissioning	147
	14.6.2.1	Nuclear power plants	148
	14.6.2.2	Research reactors	149
	14.6.2.3	Other facilities in the nuclear fuel cycle	149
	14.6.2.4	Minor facilities	149
	14.6.3	Risk assessment for decommissioning	150
	14.6.4	Radiological protection in decommissioning	150
	14.6.5	Site release	150
14.7		Transport of radioactive material	151
14.8		Regulations	151
		Summary of key points	152
		Revision questions	153
15		Radiation protection in the non-nuclear industry	155
	15.1	Introduction	155
	15.2	X-rays	155
	15.2.1	General	155
	15.2.2	X-ray equipment	155
	15.2.3	Quality and intensity of X-rays: the X-ray spectrum	156
	15.2.4	Protection against X-rays: general principles	157
	15.2.5	Monitoring of X-ray installations	158
	15.2.6	Protection in industrial radiography	159
	15.2.7	Protection in research applications	160
	15.2.8	X-rays in other industrial applications	160
15.3		Sealed sources	161
	15.3.1	General principles of protection	161
	15.3.2	Portable moisture/density gauges	162
	15.3.3	Industrial radiography equipment	163
	15.3.4	Well-logging devices	163
	15.3.5	Radiation risk assessment for work with a sealed source	163
15.4		Unsealed sources	164
15.5		Naturally Occurring Radioactive Materials (NORM)	164
		Summary of key points	167
		Revision questions	168
16		Radiation protection in medicine	169
	16.1	Applications	169
	16.2	General principles and organization	170

16.3	Diagnostic procedures	172
16.3.1	Diagnostic radiography	172
16.3.2	Diagnostic fluoroscopy	172
16.3.3	Computed tomography	174
16.3.4	Dose reduction techniques for diagnostic radiography	174
16.4	Radiotherapy	176
16.5	Nuclear medicine	177
16.5.1	Diagnostic radioisotope tests and nuclear medicine imaging	178
16.5.2	Radioisotope therapy	179
16.6	Control and disposal of radioactive materials	180
	Summary of key points	181
	Revision questions	182
17	Radiological incidents and emergencies	183
17.1	Introduction	183
17.2	International Nuclear and Radiological Event Scale	183
17.3	Loss of shielding	184
17.3.1	Small sealed sources	184
17.3.2	Large sealed sources	184
17.3.3	Entry into shielded cells	185
17.3.4	Reactor fuel-handling accidents	185
17.4	Loss of containment	185
17.4.1	Minor spillage of radioactivity	185
17.4.2	Major spills of radioactivity	186
17.4.3	Major releases from nuclear facilities	186
17.4.3.1	Windscale	187
17.4.3.2	Three Mile Island	188
17.4.3.3	Chernobyl	188
17.4.3.4	Fukushima	189
17.4.3.5	Other potential sources	190
17.5	Uncontrolled criticality	190
17.5.1	General	190
17.5.2	Reactors	191
17.5.3	Reactor fuel plants	191
17.6	Pre-planning for emergencies	192
17.6.1	Background	192
17.6.2	Radiological factors	193
17.6.3	Training	193
17.6.4	Dissemination of information	194
17.7	The emergency organization	194
	Summary of key points	195
	Revision questions	196
18	The organization and administration of radiation protection services	197
18.1	The overall process	197
18.2	Standards and regulations	197
18.3	Design and operation	197
18.4	Review and audit	198
18.5	The health physics organization	198

18.6 Documents and reports	199
18.7 Training	200
Summary of key points	201
Appendix A: List of elements	203
Appendix B: Relationship of units	205
Appendix C: Answers to numerical questions	207
Bibliography	209
Index	213