

Contents

Preface	xv
About the Author	xvii

Part I Basic Concepts

Chapter 1	Energy	3
1.1	Forces and Energy	3
1.2	Thermal Energy	5
1.3	Radiant Energy	7
1.4	The Equivalence of Matter and Energy	8
1.5	Energy and the World	9
1.6	Summary	10
1.7	Exercises	10
1.8	General References	12
1.9	References	13
Chapter 2	Atoms and Nuclei	15
2.1	Atomic Theory	15
2.2	Gases	16
2.3	The Atom and Light	16
2.4	Laser Beams	20
2.5	Nuclear Structure	21
2.6	Sizes and Masses of Nuclei	23
2.7	Binding Energy	23
2.8	Summary	25
2.9	Exercises	25
2.10	References	27
Chapter 3	Radioactivity	29
3.1	Radioactive Decay	29
3.2	The Decay Law	30
3.3	Radioactive Chains	33
3.4	Measurement of Half-Life	35
3.5	Summary	36
3.6	Exercises	37
3.7	References	39
Chapter 4	Nuclear Processes	41
4.1	Transmutation of Elements	41

4.2	Energy and Momentum Conservation	43
4.3	Reaction Rates	44
4.4	Particle Attenuation	48
4.5	Neutron Cross Sections	49
4.6	Neutron Migration	51
4.7	Summary	56
4.8	Exercises	56
4.9	References	60
Chapter 5	Radiation and Materials	63
5.1	Excitation and Ionization by Electrons	63
5.2	Heavy Charged Particle Stopping by Matter	64
5.3	Gamma Ray Interactions with Matter	66
5.4	Neutron Reactions	70
5.5	Summary	70
5.6	Exercises	71
5.7	References	72
Chapter 6	Fission	73
6.1	The Fission Process	73
6.2	Energy Considerations	74
6.3	Byproducts of Fission	76
6.4	Energy from Nuclear Fuels	79
6.5	Summary	80
6.6	Exercises	80
6.7	References	81
Chapter 7	Fusion	83
7.1	Fusion Reactions	83
7.2	Electrostatic and Nuclear Forces	84
7.3	Thermonuclear Reactions in a Plasma	86
7.4	Summary	88
7.5	Exercises	88
7.6	References	89
Part II Nuclear Systems		
Chapter 8	Particle Accelerators	93
8.1	Electric and Magnetic Forces	93
8.2	High-Voltage Machines	95
8.3	Linear Accelerator	96
8.4	Cyclotron and Betatron	97
8.5	Synchrotron and Collider	99

8.6	Spallation	102
8.7	Summary	103
8.8	Exercises	104
8.9	References	106
Chapter 9	Isotope Separators	109
9.1	Mass Spectrograph	109
9.2	Gaseous Diffusion Separator	110
9.3	Gas Centrifuge	116
9.4	Laser Isotope Separation	118
9.5	Separation of Deuterium	119
9.6	Summary	119
9.7	Exercises	120
9.8	References	122
Chapter 10	Radiation Detectors	125
10.1	Gas Counters	126
10.2	Neutron Detectors	127
10.3	Scintillation Counters	129
10.4	Solid State Detectors	130
10.5	Statistics of Counting	132
10.6	Pulse Height Analysis	133
10.7	Advanced Detectors	134
10.8	Detectors and Counterterrorism	135
10.9	Summary	136
10.10	Exercises	136
10.11	References	139
Chapter 11	Neutron Chain Reactions	141
11.1	Criticality and Multiplication	141
11.2	Multiplication Factors	142
11.3	Neutron Flux and Reactor Power	147
11.4	Reactor Types	148
11.5	Reactor Operation	152
11.6	The Natural Reactor	156
11.7	Summary	156
11.8	Exercises	156
11.9	References	159
Chapter 12	Nuclear Heat Energy	161
12.1	Methods of Heat Transmission	161
12.2	Heat Generation and Removal	161

12.3	Steam Generation and Electrical Power Production	167
12.4	Waste Heat Rejection.	169
12.5	Summary	173
12.6	Exercises	174
12.7	References	176
Chapter 13	Breeder Reactors.	179
13.1	The Concept of Breeding.	179
13.2	Isotope Production and Consumption.	181
13.3	The Fast Breeder Reactor.	182
13.4	Integral Fast Reactor	186
13.5	Breeding and Uranium Resources	187
13.6	Summary	191
13.7	Exercises	191
13.8	References	192
Chapter 14	Fusion Reactors	195
14.1	Comparison of Fusion Reactions.	195
14.2	Requirements for Practical Fusion Reactors.	197
14.3	Magnetic Confinement Machines	199
14.4	Inertial Confinement Machines.	203
14.5	Other Fusion Concepts	206
14.6	Prospects for Fusion	208
14.7	Summary	211
14.8	Exercises	211
14.9	References	212
 Part III Nuclear Energy and Man		
Chapter 15	The History of Nuclear Energy	217
15.1	The Rise of Nuclear Physics.	217
15.2	The Discovery of Fission	218
15.3	The Development of Nuclear Weapons.	219
15.4	Reactor Research and Development	221
15.5	The Nuclear Controversy	223
15.6	Summary	225
15.7	Exercises	226
15.8	References	226
Chapter 16	Biological Effects of Radiation.	229
16.1	Physiological Effects	230
16.2	Radiation Dose Units	231
16.3	Basis for Limits of Exposure	234

16.4	Sources of Radiation Dosage.	238
16.5	Radiation and Terrorism.	239
16.6	Summary	240
16.7	Exercises	240
16.8	References	241
Chapter 17	Information from Isotopes	245
17.1	Stable and Radioactive Isotopes	246
17.2	Tracer Techniques	246
17.3	Radiopharmaceuticals	248
17.4	Medical Imaging	249
17.5	Radioimmunoassay	250
17.6	Dating	252
17.7	Neutron Activation Analysis	253
17.8	Radiography	257
17.9	Radiation Gauges.	259
17.10	Summary	261
17.11	Exercises	262
17.12	References	264
Chapter 18	Useful Radiation Effects	269
18.1	Medical Treatment. ⁴	269
18.2	Radiation Preservation of Food.	271
18.3	Sterilization of Medical Supplies	276
18.4	Pathogen Reduction.	277
18.5	Crop Mutations	277
18.6	Insect Control.	278
18.7	Applications in Chemistry	279
18.8	Transmutation Doping of Semiconductors.	279
18.9	Neutrons in Fundamental Physics.	280
18.10	Neutrons in Biological Studies	282
18.11	Research with Synchrotron X-rays.	283
18.12	Summary	284
18.13	Exercises	284
18.14	References	285
Chapter 19	Reactor Safety and Security	289
19.1	Neutron Population Growth.	289
19.2	Assurance of Safety	293
19.3	Emergency Core Cooling and Containment	300
19.4	Probabilistic Risk Assessment	303
19.5	The Three Mile Island Accident and Lessons Learned.	306

19.6	The Chernobyl Accident	309
19.7	Philosophy of Safety	311
19.8	Nuclear Security	312
19.9	Summary	313
19.10	Exercises	314
19.11	References	318
Chapter 20	Nuclear Propulsion	323
20.1	Reactors for Naval Propulsion	323
20.2	Space Reactors	325
20.3	Space Isotopic Power	327
20.4	Future Nuclear Space Applications	331
20.5	Summary	334
20.6	Exercises	334
20.7	References	335
Chapter 21	Radiation Protection	339
21.1	Protective Measures	339
21.2	Calculation of Dose	341
21.3	Effects of Distance and Shielding	342
21.4	Internal Exposure	348
21.5	The Radon Problem	349
21.6	Environmental Radiological Assessment	350
21.7	Newer Radiation Standards	352
21.8	Summary	355
21.9	Exercises	355
21.10	References	358
Chapter 22	Radioactive Waste Disposal	361
22.1	The Nuclear Fuel Cycle	361
22.2	Waste Classification	363
22.3	Spent Fuel Storage	365
22.4	Transportation	366
22.5	Reprocessing	369
22.6	High-Level Waste Disposal	372
22.7	Low-Level Waste Generation, Treatment, and Disposal	378
22.8	Environmental Restoration of Defense Sites	385
22.9	Nuclear Power Plant Decommissioning	386
22.10	Summary	387
22.11	Exercises	388
22.12	References	391

Chapter 23	Laws, Regulations, and Organizations	395
23.1	The Atomic Energy Acts	395
23.2	The Environmental Protection Agency	396
23.3	The Nuclear Regulatory Commission	397
23.4	The Department of Energy	399
23.5	International Atomic Energy Agency	400
23.6	Institute of Nuclear Power Operations	401
23.7	Department of Homeland Security	404
23.8	Other Organizations	404
23.9	Energy Policy Acts	408
23.10	Summary	409
23.11	References	410
Chapter 24	Energy Economics	415
24.1	Components of Electrical Power Cost	415
24.2	Forecasts and Reality	418
24.3	Technical and Institutional Improvements	423
24.4	Effect of Deregulation and Restructuring	425
24.5	Advanced Reactors	427
24.6	Nuclear Power Renaissance	429
24.7	Summary	433
24.8	Exercises	433
24.9	References	434
Chapter 25	International Nuclear Power	437
25.1	Reactor Distribution	438
25.2	Western Europe	441
25.3	Eastern Europe and the CIS	443
25.4	The Far East	445
25.5	Other Countries	446
25.6	Summary	448
25.7	References	449
Chapter 26	Nuclear Explosions	453
26.1	Nuclear Power Versus Nuclear Weapons	453
26.2	Nuclear Explosives	454
26.3	The Prevention of Nuclear War	460
26.4	Nonproliferation and Safeguards	463
26.5	IAEA Inspections	465
26.6	Production of Tritium	466
26.7	Management of Weapons Uranium and Plutonium	467

26.8	Summary	469
26.9	Exercises	469
26.10	References	470
Chapter 27	The Future	473
27.1	Dimensions	474
27.2	World Energy Use	475
27.3	Nuclear Energy and Sustainable Development	478
27.4	Greenhouse Effect and Global Climate Change	480
27.5	Perspectives	483
27.6	Desalination	487
27.7	Recycling and Breeding	488
27.8	The Hydrogen Economy	489
27.9	Next Generation Nuclear Plant	491
27.10	Summary	493
27.11	Exercises	493
27.12	References	494
Appendix		499
	Conversion Factors	499
	Atomic and Nuclear Data	500
	Answers to Exercises	504
	Comments	509
	Original Computer Programs	510
Index		513