Contents

1 NUCLEAR ENGINEERING 1

2 ATOMIC AND NUCLEAR PHYSICS 5

2.1 Fundamental Particles 5
2.2 Atomic and Nuclear Structure 7
2.3 Atomic and Molecular Weight 8
2.4 Atomic and Nuclear Radii 11
2.5 Mass and Energy 11
2.6 Particle Wavelengths 14
2.7 Excited States and Radiation 15
2.8 Nuclear Stability and Radioactive Decay 18
2.9 Radioactivity Calculations 22
2.10 Nuclear Reactions 26
2.11 Binding Energy 29
2.12 Nuclear Models 33
2.13 Gases, Liquids, and Solids 37
2.14 Atom Density 40

References 44
Problems 45

3 INTERACTION OF RADIATION WITH MATTER 52

3.1 Neutron Interactions 52
3.2 Cross-Sections 54
3.3 Neutron Attenuation 57
3.4 Neutron Flux 60
3.5 Neutron Cross-Section Data 62
3.6 Energy Loss in Scattering Collisions 68
3.7 Fission 74
3.8 γ-Ray Interactions with Matter 90
3.9 Charged Particles 100
References 109
Problems 110

4 NUCLEAR REACTORS AND NUCLEAR POWER 117

4.1 The Fission Chain Reaction 117
4.2 Nuclear Reactor Fuels 119
4.3 Non-Nuclear Components of Nuclear Power Plants 129
4.4 Components of Nuclear Reactors 133
4.5 Power Reactors and Nuclear Steam Supply Systems 136
4.6 Nuclear Cycles 185
4.7 Isotope Separation 201
4.8 Fuel Reprocessing 217
4.9 Radioactive Waste Disposal 219
References 223
Problems 224

5 NEUTRON DIFFUSION AND MODERATION 230

5.1 Neutron Flux 230
5.2 Fick's Law 231
5.3 The Equation of Continuity 235
5.4 The Diffusion Equation 237
5.5 Boundary Conditions 238
5.6 Solutions of the Diffusion Equation 240
5.7 The Diffusion Length 246
5.8 The Group-Diffusion Method 248
5.9 Thermal Neutron Diffusion 252
5.10 Two-Group Calculation of Neutron Moderation 257

References 260
Problems 260

6 NUCLEAR REACTOR THEORY 266

6.1 One-Group Reactor Equation 266
6.2 The Slab Reactor 271
6.3 Other Reactor Shapes 274
6.4 The One-Group Critical Equation 282
6.5 Thermal Reactors 286
6.6 Reflected Reactors 297
6.7 Multigroup Calculations 308
6.8 Heterogeneous Reactors 309
References 320
Problems 321

7 THE TIME-DEPENDENT REACTOR 327

7.1 Classification of Time Problems 328
7.2 Reactor Kinetics 330
7.3 Control Rods and Chemical Shim 348
7.4 Temperature Effects on Reactivity 365
7.5 Fission Product Poisoning 376
7.6 Core Properties during Lifetime 389
References 397
Problems 398

8 HEAT REMOVAL FROM NUCLEAR REACTORS 403

8.1 General Thermodynamic Considerations 404
8.2 Heat Generation in Reactors 408
8.3 Heat Flow by Conduction 417
8.4 Heat Transfer to Coolants 428
8.5 Boiling Heat Transfer 441
8.6 Thermal Design of a Reactor 450
References 457
Problems 459

9 RADIATION PROTECTION 466

9.1 History of Radiation Effects 467
9.2 Radiation Units 468
9.3 Some Elementary Biology 476
9.4 The Biological Effects of Radiation 479

9.5 Quantitative Effects of Radiation on the Human Species 485
9.6 Calculations of Radiation Effects 495
9.7 Natural and Man-Made Radiation Sources 499
9.8 Standards of Radiation Protection 506
9.9 Computations of Exposure and Dose 511
9.10 Standards for Intake of Radionuclides 526
9.11 Exposure from γ-Ray Sources 535
Glossary 539
References 542
Problems 544

10 RADIATION SHIELDING ***548***

10.1 Gamma-Ray Shielding: Buildup Factors 549
10.2 Infinite Planar and Disc Sources 559
10.3 The Line Source 566
10.4 Internal Sources 571
10.5 Multilayered Shields 573
10.6 Nuclear Reactor Shielding: Principles of Reactor Shielding 576
10.7 Removal Cross-Sections 578
10.8 The Reactor Shield Design: Removal–Attenuation Calculatons 584
10.9 The Removal–Diffusion Method 588
10.10 Exact Methods 590
10.11 Shielding γ-Rays 595
10.12 Coolant Activation 599
10.13 Ducts in Shields 604
References 605
Problems 606

11 REACTOR LICENSING, SAFETY, AND THE ENVIRONMENT ***612***

11.1 Governmental Authority and Responsibility 613
11.2 Reactor Licensing 614
11.3 Principles of Nuclear Power Plant Safety 623
11.4 Dispersion of Effluents from Nuclear Facilities 631
11.5 Radiation Doses from Nuclear Plants 650
11.6 Reactor Siting 669
11.7 Reactor Accidents 681
11.8 Accident Risk Analysis 701
11.9 Environmental Radiation Doses 710
References 721
Problems 723

APPENDIXES

I Units and Conversion Factors 731
II Fundamental Constants and Data 737
III Vector Operations in Orthogonal Curvilinear Coordinates 745
IV Thermodynamic and Physical Properties 751
V Bessel Functions 757

INDEX **761**