

Contents

List of figures	xiii
Acronyms	xv
1. Introduction and Prelude	1
1.1 Global Warming	1
1.2 Capacity Factors	3
1.3 Welcome to the Nuclear Age	5
1.4 The First Electricity Producing Reactors	6
1.5 The Prelude	8
2. Fundamental Nuclear Physics	11
2.1 The Pauli Exclusion Principle	11
2.2 Nuclear Forces	11
2.3 Nuclear Reactions	12
2.4 Energy and Mass Units	14
2.5 Photons	14
2.6 Antimatter, Pair Production, and Annihilation	16
2.7 Mass Defects, Q Values, and Cross-sections	17
2.8 Cross-sections	18
2.9 The Discovery of Radioactivity	20
2.10 The General Characteristics of Radioactivity	22
2.11 Gamma Decay	23
2.12 Spontaneous Fission	23
3. Basic Quantum Theory	24
3.1 Skip This Chapter If You Wish	24
3.2 The Uncertainty Principle	24
3.3 The Theoretical Treatment of Nuclear Physics	25
3.4 Atomic Spectra and Quantum Numbers	27
3.5 Sommerfeld's Contribution	28
3.6 Pauli's Contribution	28
3.7 Spin and Parity	29
3.8 Alpha Decay	30
3.9 Beta Decay and the Story of the Neutrino	31
3.10 The Discovery of the Neutron	32
3.11 Quantum Theory and Beyond	33
4. The Story of $E = mc^2$ and Relativity	36
4.1 The Unification of Electricity and Magnetism	36
4.2 Relative Motion	37
4.3 Einstein's Theory	38
4.4 Standards of Mass, Length, and Time	40

5. The Fission Process and the Characteristics of Fission	41
5.1 The Discovery of Fission	41
5.2 Niels Bohr and Copenhagen	42
5.3 The Fission Process	43
5.4 Neutron Interactions	46
5.5 The Fate of Gamma Rays	47
5.6 Fission Fragments	48
5.7 Delayed Neutrons	48
5.8 The Energy of Fission	49
5.9 Decay Heat	50
5.10 The Chain Reaction	50
6. Nuclear Reactors in General	52
6.1 Nuclear Reactor Calculations	52
6.2 The Growth of the Neutron Population	52
6.3 The Six Factor Formula	55
6.4 The Effect of Delayed Neutrons on Reactor Control	56
6.5 Reactivity	56
6.6 Monte Carlo Models	57
6.7 Nuclear Reactor Operations	58
6.8 Fuel	59
6.9 Moderators	60
6.10 Coolants	61
6.11 Poisons	62
6.12 Control Poisons	62
6.13 Unavoidable Poisons	63
6.14 Burnable Poisons	65
6.15 Engineering Materials	65
6.16 The Fast Reactor	66
6.17 Hybrid Reactors	68
7. Reactor Operations and Control	69
7.1 Controlling Reactors to Keep Them Safe	69
7.2 The First Reactors	69
7.3 Reactor CP1	70
7.4 Controlling Commercial Reactors	71
7.5 The Reactor Pressure Vessel	72
7.6 The Reactor Coolant Pump	73
7.7 The Pressurizer	73
7.8 The Steam Generator	73
7.9 The Boron Loading Loop	74
7.10 Power Measurement	75
7.11 The Fuel Temperature Coefficient (FTC)	76
7.12 The Moderator Temperature Coefficient (MTC)	77
7.13 The Void Coefficient (VC)	78
7.14 Changes in Steam Demand	78
7.15 Control Room Operations	78
8. Safety	81
8.1 Safety, Risk, and Consequences	81
8.2 The Regulators	82

8.3	Decay Heat Removal	82
8.4	Loss of Coolant	83
8.5	Passive Safety Measures	84
8.6	The Windscale Fire	84
8.7	Brown's Ferry	85
8.8	Three Mile Island	87
8.9	Chernobyl 1986	88
8.10	Problems in the Fukushima Region of Japan	89
8.11	Safety Overview	90
8.12	Understanding the Health Hazard of Radiation	92
9.	The Nuclear Fuel Cycle	97
9.1	The Nuclear Fuel Cycle Definition	97
9.2	Mining	98
9.3	Enrichment	98
9.4	Fuel Fabrication	99
9.5	Spent Fuel Management	100
9.6	Spent Fuel Ponds	102
9.7	Cherenkov Radiation	102
9.8	Reprocessing	102
9.9	Nuclear Waste	105
10.	International Treaties and Obligations	107
10.1	Euratom	107
10.2	Treaty on the Non-Proliferation of Nuclear Weapons (NPT)	108
10.3	The International Atomic Energy Agency (IAEA)	108
10.4	Nuclear Safeguards	108
10.5	Obligations	110
11.	The Future of Fission Reactors	111
11.1	The Alternatives to Fossil Fuel	111
11.2	Generation IV Technology	111
11.3	The Move to Higher Temperatures	112
11.4	The Move to Fast Reactors	112
11.5	The Move to Modular Reactors, SMRs, and AMRs	113
11.6	Plutonium Breeding	114
11.7	Thorium Breeding	115
11.8	New Coolants	116
11.9	Molten Salts	116
11.10	New Types of Fuel	118
11.11	Burning Waste and Using the Minor Actinides as Fuel	118
11.12	New Reprocessing Technology	118
11.13	The Economics and Politics of Electricity Generation	119
11.14	The Utilization of $E = mc^2$	121
12.	Nuclear Fusion	122
12.1	The Fusion Process	122
12.2	Producing Fusion in the Laboratory	123
12.3	ITER	125
12.4	MAST and STEP	125
12.5	The Fuel for Fusion	126

12.6	The Tritium Breeding Ratio (TBR)	127
12.7	Venture Capital	129
12.8	The Conclusion on Fusion	129
13.	The Hydrogen Strategy	131
13.1	The Basic Properties of Hydrogen	131
13.2	The Production of Hydrogen	132
13.3	Carbon Capture	135
13.4	Energy Storage	136
13.5	New Markets for Hydrogen	136
13.6	Hydrogen in the Colours of the Rainbow	138
13.7	The Race to Deliver Net Zero	138

Further Reading

Index

Further Reading	140
Index	146