
CONTENTS

Preface	xi
1 THE EARTH AND NUCLEAR POWER: SOURCES AND RESOURCES	1
1.1 Introduction	1
1.1.1 Forms of Energy	2
1.1.2 Units of Energy	4
1.1.3 Energy Conversion Process	5
1.2 The Earth's Internal Heat Generation	8
1.3 The Earth's Energy Flows	12
1.4 The Fission Process	13
1.5 Thermal Energy Resources	19
References	20
Examples and Problems	20
Bibliography	21
2 HOW REACTORS WORK	23
2.1 Introduction	23
2.2 The Fission Process	23
2.3 Basic Components of a Nuclear Reactor	27
2.4 Thermal Reactors	30
2.4.1 Natural Uranium Graphite-Moderated (Magnox) Reactors	30
2.4.2 Advanced Gas-Cooled Reactors	32
2.4.3 Pressurized-Water Reactors	35
	vii

2.4.4	Boiling-Water Reactors	39
2.4.5	Natural Uranium Heavy Water-Moderated and Cooled Reactors	40
2.4.6	Boiling-Water, Graphite-Moderated Direct Cycle Reactor (RBMK)	42
2.5	Fast Reactors	43
2.5.1	Liquid Metal-Cooled Fast Breeder Reactors	43
2.5.2	Gas-Cooled Fast Reactors	47
	Examples and Problems	47
	Bibliography	48
3	COOLING REACTORS	49
3.1	Introduction	49
3.2	General Features of a Reactor Coolant	49
3.3	Principles of Heat Transfer	51
3.4	Gaseous Coolants	58
3.4.1	Air	58
3.4.2	Carbon Dioxide	59
3.4.3	Helium	60
3.4.4	Steam	60
3.4.5	Oxides of Nitrogen	61
3.5	Liquid Coolants	61
3.5.1	Light Water	61
3.5.2	Heavy Water	61
3.5.3	Organic Fluids	63
3.5.4	Molten Salts	63
3.5.5	Liquid Metals	64
3.6	Boiling Coolants	65
3.6.1	Water	66
3.6.2	Liquid Metals	66
3.7	Alternative Forms of Reactor Coolant Circuits	67
3.7.1	Loop-Type Circuits	67
3.7.2	Integral-Type Circuits	68
3.7.3	Pool-Type Circuits	69
	Reference	71
	Examples and Problems	71
	Bibliography	74
4	LOSS OF COOLING	75
4.1	Introduction	75
4.2	The Electric Kettle	80
4.3	Pressurized-Water Reactor	82
4.3.1	Operating States of the PWR	82
4.3.2	Energy Balances in the PWR under Fault Conditions	86
4.3.3	The Large-Break LOCA in the PWR	89
4.3.4	The Small-Break LOCA	95
4.4	Boiling-Water Reactor	102
4.4.1	Large-Break LOCA in a BWR (the Design Basis Accident)	102
4.4.2	Small-Break LOCAs in BWRs	106

4.5	CANDU Reactor	106
4.6	Gas-Cooled Reactors	109
4.6.1	Design Base Accident for the AGR: Depressurization Fault	111
4.7	Sodium-Cooled Fast Breeder Reactor	112
	Reference	114
	Examples and Problems	114
	Bibliography	118
5	LOSS-OF-COOLING ACCIDENTS: SOME EXAMPLES	119
5.1	Introduction	119
5.2	Incidents in Light Water-Cooled Reactors	120
5.2.1	The SL-1 Accident	120
5.2.2	The Millstone 1 Accident	121
5.2.3	The Browns Ferry Fire	122
5.2.4	The Three Mile Island (TMI) Incident	122
5.2.5	The Ginna Incident	133
5.2.6	The Serious Accident at Chernobyl, Ukraine	134
5.3	Heavy Water-Moderated Reactors	135
5.3.1	The NRX Incident	135
5.3.2	The Core-Damage Incident at Lucens	137
5.4	Gas-Cooled Reactors	139
5.4.1	The Windscale Fire	139
5.4.2	The Fuel Meltdown at St. Laurent	140
5.4.3	Seawater Ingress in the Hunterston B AGR Station	142
5.4.4	Fuel Damage during Charging at the Hinkley Point B AGR	143
5.5	Liquid Metal-Cooled Fast Reactors	143
5.5.1	The EBR-1 Meltdown Accident	143
5.5.2	Fuel Melting Incident at the Enrico Fermi 1 Fast Breeder Reactor	145
	References	147
	Examples and Problems	147
	Bibliography	151
6	POSTULATED SEVERE ACCIDENTS	153
6.1	Introduction	153
6.2	Postulated Severe Accidents in the Various Reactor Types	154
6.3	Debris Beds and Their Cooling	158
6.4	Fuel-Coolant Interactions and Vapor Explosions	160
6.5	The China Syndrome: What Really Happens	162
6.6	Containment Failure	162
	References	165
	Examples and Problems	166
	Bibliography	169
7	COOLING DURING FUEL REMOVAL AND PROCESSING	171
7.1	Introduction	171
7.2	Refueling	173

7.2.1	Refueling of Gas-Cooled Reactors	173
7.2.2	Refueling of CANDU Reactors	174
7.2.3	Refueling of Light Water Reactors	177
7.2.4	Refueling of Liquid Metal-Cooled Fast Breeder Reactors	178
7.3	Spent Fuel Storage and Transport	178
7.4	Reprocessing Plant	183
	Examples and Problems	187
	Bibliography	189
8	COOLING AND DISPOSING OF THE WASTE	191
8.1	Introduction	191
8.2	Classification of Waste Products	191
8.3	Fission Products and Their Biological Significance	192
8.4	Options for Nuclear Waste Disposal	195
8.5	Long-Term Storage and Disposal of Spent Nuclear Fuel	197
	8.5.1 Undersea Disposal	198
	8.5.2 Ultimate Disposal in Salt Deposits	198
	8.5.3 Geological Storage	199
8.6	Storage and Disposal of Fission Products from Reprocessing Plants	201
8.7	Disposal of Other Materials	204
	Reference	205
	Examples and Problems	205
	Bibliography	209
9	FUSION ENERGY: PROSPECT FOR THE FUTURE	211
9.1	Introduction	211
9.2	What Do We Need to Obtain a Fusion Reaction?	212
9.3	Confinement	213
9.4	Current Technical Position	214
9.5	Fusion Reactors	218
9.6	Conclusions	220
	Reference	222
	Examples and Problems	222
	Bibliography	224
	INDEX	225