

## TABLE OF CONTENTS

### CHAPTER I. INTRODUCTION

1-1	Objectives . . . . .	1
1-1.1	Capital costs . . . . .	2
1-1.2	Fuel costs . . . . .	3
1-1.3	Utilization of nuclear fuel resources	5
1-2.	Methods of Approaching the Objectives . . . . .	5
1-2.1	The fast neutron reactor . . . . .	5
1-2.2	The D <sub>2</sub> O reactor . . . . .	7
1-2.3	The gas-cooled reactor . . . . .	7
1-2.4	Organic coolants and moderators . . . . .	8
1-2.5	Plutonium recycling in thermal reactors	9
1-3.	Plan of Presentation . . . . .	10

### CHAPTER 2. THE FAST NEUTRON POWER REACTOR . . . . .

2-	Introduction . . . . .	13
2-2.	Reactor Physics . . . . .	17
2-2.1	Aspects of the reactor physics problem . . . . .	17
2-2.2	Breeding ratio . . . . .	24
2-2.3	Effects of reactor size and dilution . . . . .	25
2-2.4	Effects of other fuels . . . . .	28
2-2.5	Effects of absorbing materials . . . . .	29
2-2.6	Kinetic characteristics . . . . .	31
2-2.7	Temperature effects . . . . .	33
2-3.	Reactor Safety . . . . .	36
2-3.1	Neutron lifetime . . . . .	38
2-3.2	Reactivity increases due to structural failures . . . . .	39
2-3.3	Reactivity coefficients and reactor stability . . . . .	41
2-3.4	Summary . . . . .	48
2-4.	Sodium Plant Technology . . . . .	48
2-4.1	Introduction . . . . .	48
2-4.2	Properties and characteristics of sodium and NaK . . . . .	50
2-4.3	Heat exchangers and steam generators . . . . .	61
2-4.4	Pumps . . . . .	63

## TABLE OF CONTENTS

2-4.5 Transfer and handling systems	79
2-4.6 ERB-II working model . . . . .	86
<b>CHAPTER 3. THE EXPERIMENTAL BREEDER REACTOR II</b>	<b>118</b>
<b>3-1. Introduction</b>	<b>118</b>
<b>3-2. General Plant Description</b>	<b>122</b>
<b>3-3. Reactor and Primary System . . . . .</b>	<b>130</b>
3-3.1 Reactor . . . . .	130
3-3.2 Reactor vessel assembly . . . . .	138
3-3.3 Primary cooling system . . . . .	144
3-3.4 Shutdown cooling . . . . .	148
3-3.5 Neutron shield . . . . .	148
3-3.6 Control rod and safety rod drive systems	149
3-3.7 Nuclear instrumentation . . . . .	150
3-3.8 Primary tank and biological shield . . . . .	154
3-3.9 Fuel-handling system . . . . .	158
3-3.10 Sodium cleanup system . . . . .	160
3-3.11 Inert gas system . . . . .	161
<b>3-4. Secondary Cooling System</b>	<b>161</b>
3-4.1 Introduction . . . . .	161
3-4.2 System heat exchangers	162
3-4.3 Pumping requirements.	162
3-4.4 System layout . . . . .	162
<b>3-5. Steam-Electrical System . . . . .</b>	<b>163</b>
3-5.1 Introduction . . . . .	163
3-5.2 Steam system . . . . .	164
3-5.3 Electrical svstem . . . . .	165
<b>3-6. Fuel Cycle and Reprocessing . . . . .</b>	<b>166</b>
3-6.1 Significance . . . . .	166
3-6.2 Pyrometallurgical purification	166
3-6.3 Equipment and facility design	169
3-6.4 Reprocessing operation . . . . .	176
3-6.5 Refabrication operation . . . . .	178
3-6.6 Assembly operation . . . . .	185
<b>3-7 Operation and Control . . . . .</b>	<b>188</b>
3-7.1 General control method	188
3-7.2 Power eycle startun	192

## TABLE OF CONTENTS

xi

3-7.3 Power cycle shutdown . . . . .	193
3-7.4 Fuel loading and unloading . . . . .	195
<b>3-8. Performance . . . . .</b>	<b>195</b>
3-8.1 Neutron physics . . . . .	195
3-8.2 Thermal performance . . . . .	206
3-8.3 Fuel performance . . . . .	210
3-8.4 Safety . . . . .	229
 <b>CHAPTER 4. THE ENRICO FERMI ATOMIC POWER PLANT</b>	 <b>239</b>
4-1. Introduction . . . . .	239
4-2. General Description of the Plant . . . . .	243
4-2.1 Core and blanket . . . . .	243
4-2.2 Fuel-handling mechanisms . . . . .	243
4-2.3 Heat transport system . . . . .	243
4-2.4 Shielding and containment . . . . .	246
4-2.5 General design consideration . . . . .	248
4-3. Core and Blanket . . . . .	248
4-3.1 General considerations . . . . .	248
4-3.2 Description of core and blanket . . . . .	254
4-3.3 Performance . . . . .	259
4-4. Physics . . . . .	271
4-4.1 Reactor statics . . . . .	271
4-4.2 Reactor kinetic relationships . . . . .	283
4-4.3 Dynamic response of the reactor . . . . .	289
4-4.4 Reactor stability . . . . .	295
4-4.5 Critical experiment . . . . .	297
4-4.6 Fuel reloading cycle . . . . .	297
4-4.7 Choice of control elements . . . . .	301
4-5. Control Rods and Safety Rods . . . . .	304
4-5.1 General description . . . . .	304
4-5.2 Safety rods . . . . .	304
4-5.3 Operating control rods . . . . .	307
4-5.4 Safety rod actuators . . . . .	307
4-5.5 Control rod physics . . . . .	310
4-5.6 Oscillator rod . . . . .	312
4-6. Reactor Compartment . . . . .	314
4-6.1 General description . . . . .	314

## TABLE OF CONTENTS

4-6.2	Lower reactor vessel . . . . .	317
4-6.3	Meltdown section . . . . .	317
4-6.4	Coolant flow . . . . .	318
4-6.5	Hold-down device . . . . .	318
4-6.6	Rotating shield plug . . . . .	318
4-6.7	Reactor vessel shielding . . . . .	320
4-6.8	Mechanical integrity and thermal stresses . . . . .	320
4-7.	Mechanical Handling . . . . .	321
4-7.1	General description . . . . .	321
4-7.2	Offset handling mechanism . . . . .	323
4-7.3	Transfer rotor assembly . . . . .	325
4-7.4	Cask car . . . . .	327
4-7.5	Hold-down actuator . . . . .	328
4-7.6	Loading and unloading procedure . . . . .	330
4-7.7	Maintenance of radioactive equipment . . . . .	331
	Liquid Metal and Steam Systems . . . . .	334
4-8.1	General description . . . . .	334
4-8.2	Primary coolant system . . . . .	335
4-8.3	Secondary coolant system . . . . .	343
4-8.4	Inert gas system . . . . .	345
4-8.5	Primary sodium service system . . . . .	348
4-8.6	Secondary sodium service system . . . . .	351
4-8.7	Overflow tanks . . . . .	352
	Reactor Building . . . . .	352
4-9.1	General description . . . . .	352
4-9.2	Building design criteria for an assumed sodium-air reaction . . . . .	353
4-9.3	Building internals . . . . .	355
4-9.4	Reactor building ventilation, heating, and cooling systems . . . . .	356
4-10.	Reactor Plant Shield System . . . . .	357
4-10.1	Design criteria . . . . .	357
4-10.2	Shield design . . . . .	358
	Materials . . . . .	363
4-11.1	Coolant and structural materials . . . . .	363
4-11.2	Shielding materials . . . . .	366
4-11.3	Fuel and blanket materials . . . . .	366
4-12.	Control and Instrumentation . . . . .	371
4-12.1	General description . . . . .	371
4-12.2	The operating control system . . . . .	372

## TABLE OF CONTENTS

xiii

4-12.3	The reactor safety system . . . . .	377
4-12.4	Primary and secondary inert gas control systems . . . . .	380
4-12.5	Primary and secondary sodium service control systems . . . . .	380
4-12.6	Neutron source and nuclear detectors . . . . .	380
4-12.7	Non-nuclear detectors . . . . .	384
4-12.8	Centralized control concept . . . . .	387
4-12.9	Cost of reactor construction . . . . .	388
 CHAPTER 5. HEAVY-WATER POWER REACTORS		 398
5-1	Introduction	398
Design of a 100-Mw Electrical Power Plant Using Heavy Water as Reactor Moderator . . . . .		400
5-2.1	General considerations . . . . .	400
5-2.2	Experience with D <sub>2</sub> O at the Savannah River Plant . . . . .	402
5-2.3	Design of the 100-Mw (electrical) reactor . . . . .	404
5-2.4	Alternative design possibilities . . . . .	423
5-2.5	Cost considerations . . . . .	426
5-2.6	Design of a test reactor (HWCTR) . . . . .	428
The Physics of Natural Uranium, Heavy-Water Reactors.		432
5-3.1	Introduction . . . . .	432
5-3.2	Lattice parameters . . . . .	433
5-3.3	Reactor design . . . . .	448
5-4.	Physics Data Relating to ThO <sub>2</sub> -UO <sub>2</sub> Fueled Boiling Reactors	459
5-4.1	Introduction . . . . .	459
5-4.2	Experimental results . . . . .	459
5-4.3	Characteristics of a 60-Mw (thermal) heavy-water thoria converter . . . . .	463
 CHAPTER 6. GAS-COOLED REACTORS		 475
6-	Introduction	475
6-2.	Heat Transfer and Choice of Coolant . . . . .	480
6-2.1	Heat removal from a single channel . . . . .	480
6-2.2	Relative performance of different gases . . . . .	484
6-2.3	Heat removal from many channels . . . . .	490
6-2.4	Choice of coolant . . . . .	492
6-3.	Fuels and Fuel-Element Materials	495
6-3.1	Uranium metal . . . . .	495

## TABLE OF CONTENTS

6-3.2	Uranium metal jacket materials . . . . .	517
6-3.3	Uranium dioxide . . . . .	530
<b>6-4</b>	<b>Graphite-Moderated Reactors . . . . .</b>	<b>546</b>
6-4.1	General characteristics of gas-cooled, graphite-moderated reactors . . . . .	546
6-4.2	Measured neutron physics characteristics of graphite-moderated lattices . . . . .	548
6-4.3	Neutron physics of gas-cooled, graphite-moderated reactors . . . . .	553
6-4.4	Natural uranium design studies . . . . .	574
6-4.5	Enriched-uranium design studies . . . . .	591
6-4.6	Comparison of gas-cooled graphite-moderated reactor designs . . . . .	607
<b>6-5</b>	<b>The D<sub>2</sub>O-Moderated Gas-Cooled Reactor . . . . .</b>	<b>611</b>
6-5.1	Fundamental characteristics of the concept . . . . .	611
6-5.2	Design concept . . . . .	617
6-5.3	Performance of prototype . . . . .	621
6-5.4	Performance of large reactor . . . . .	623
<b>CHAPTER 7. ORGANIC COOLED AND MODERATED REACTORS</b>		<b>667</b>
<b>7-1.</b>	<b>Introduction . . . . .</b>	<b>667</b>
<b>7-2</b>	<b>Effects of Radiation on Organic Liquids . . . . .</b>	<b>670</b>
7-2.1	Causes of radiation damage . . . . .	670
7-2.2	Effects of radiation damage to polyphenyls . . . . .	674
7-2.3	Effects of radiation damage on the properties of organic coolant materials . . . . .	674
<b>7-3.</b>	<b>Heat Transfer and Fouling Characteristics of the Polyphenyls . . . . .</b>	<b>687</b>
7-3.1	Out-of-pile study . . . . .	687
7-3.2	In-pile study . . . . .	693
<b>7-4.</b>	<b>The Organic Moderated Reactor Experiment (OMRE) . . . . .</b>	<b>696</b>
7-4.1	Objectives . . . . .	696
7-4.2	Engineering bases . . . . .	696
7-4.3	Description of the OMRE . . . . .	699
7-4.4	Construction . . . . .	710
7-4.5	Preoperational testing . . . . .	711
7-4.6	Fuel-loading and low-power tests . . . . .	717
7-4.7	Power operation . . . . .	722
7-4.8	Evaluation of results . . . . .	726
7-4.9	Future program . . . . .	727

## TABLE OF CONTENTS

xv

7-5. Power Reactors Employing Organic Liquids . . . . .	727
7-5.1 Introduction . . . . .	727
7-5.2 Electric power generating plants . . . . .	729
7-5.3 Process and space heating . . . . .	747
7-5.4 Marine propulsion . . . . .	750
CHAPTER 8. PLUTONIUM RECYCLING IN THERMAL REACTORS . . . . .	759
8-1 Introduction and Objectives . . . . .	759
8-2. Progress and Results . . . . .	762
8-2.1 Physics . . . . .	762
8-2.2 Plutonium utilization analyses . . . . .	776
8-2.3 Fuel elements for plutonium recycle reactors . . . . .	793
8-2.4 Chemical processing of fuel elements from plutonium recycle reactors . . . . .	805
8-3. Major Experimental Facilities . . . . .	813
8-3.1 The plutonium fabrication pilot plant . . . . .	813
8-3.2 The plutonium recycle test reactor . . . . .	816
INDEX . . . . .	835