

CONTENTS

For the detailed contents of any section consult the first page of that section.

Contributors	v
Preface	xi
Section 1. Mathematical Data and General Tables	1-1
Section 1-1. Selected Data and Formulas and Guide to the Handbook	1-2
Section 1-2. Mathematical Tables	1-75
Section 1-3. Units and Conversion Tables	1-134
Section 2. Nuclear Data	2-1
Section 3. Mathematics	3-1
Section 3-1. Algebra and Geometry	3-2
Section 3-2. Analysis	3-64
Section 3-3. Computers	3-142
Section 4. Nuclear Physics	4-1
Section 5. Experimental Techniques	5-1
Section 5-1. Instruments for Measuring Radiation	5-2
Section 5-2. Experimental Neutron Physics	5-53
Section 5-3. Measurement of Reactor Constants	5-101
Section 5-4. Accelerators	5-123
Section 5-5. Engineering Testing in Reactors	5-140
Section 6. Reactor Physics	6-1
Section 6-1. Reactor Theory	6-2
Section 6-2. Reactor Calculations	6-29
Section 7. Radiation and Radiological Protection	7-1
Section 7-1. Calculation of Nuclear Radiation	7-2
Section 7-2. Health Physics	7-22
Section 7-3. Nuclear Radiation Shielding	7-60
Section 7-4. Mechanical Handling of Radioactive Materials	7-117

Section 8. Control of Reactors	8-1
Section 8-1. Physics of Control	8-2
Section 8-2. The Control System	8-21
Section 8-3. Control Instruments and Drives	8-49
Section 8-4. Reactor Safeguards	8-76
Section 8-5. Reactor System Dynamic Simulation	8-89
Section 9. Fluid and Heat Flow	9-1
Section 9-1. Physical Properties of Heat Transfer Mediums	9-2
Section 9-2. Fluid Flow in Reactor Systems	9-24
Section 9-3. Heat Removal from Nuclear Reactors	9-50
Section 9-4. Thermal Stress and Distortion	9-110
Section 10. Reactor Materials	10-1
Section 10-1. The Metallic State	10-2
Section 10-2. Properties of Reactor Materials	10-17
Section 10-3. Structural Materials in High-temperature Water Reactor Systems	10-73
Section 10-4. Radiation Damage to Solids	10-83
Section 10-5. Radiation Damage to Liquids and Organic Materials	10-126
Section 10-6. Nondestructive Testing	10-149
Section 10-7. Recent Developments in Reactor Materials	10-168
Section 11. Chemistry and Chemical Engineering	11-1
Section 12. Nuclear-power-plant Selection	12-1
Section 12-1. Selection of Reactors	12-2
Section 12-2. Economics of Nuclear Power	12-78
Section 12-3. Power Generating Equipment	12-114
Section 13. Mechanical Design and Operation of Reactors	13-1
Section 13-1. Water-cooled Reactor Systems	13-3
Section 13-2. Aqueous Homogeneous Reactor Systems	13-49
Section 13-3. Liquid-metal Reactor Systems	13-80
Section 13-4. Gas-cooled Reactor Systems	13-105
Section 13-5. Kinds of Reactors	13-123
Section 13-6. Reactor Building Design	13-160
Section 13-7. Reactor Construction	13-177
Section 14. Isotopes	14-1
Section 14-1. Isotopes and Their Use	14-2
Section 14-2. Isotope Separation by Chemical Exchange and Related Processes	14-15

CONTENTS

xv

Section 14-3. Production of Radioisotopes	14-26
Section 14-4. Gaseous-diffusion Separation Process . . .	14-38
Section 14-5. The Electromagnetic Separation of Stable Isotopes	14-44

Index follows Section 14.

SECTION 1

MATHEMATICAL DATA AND GENERAL TABLES

BY

HAROLD ETHERINGTON, ASSOC. ROY. SCH. MINES, B.Sc., Vice President,
Nuclear Products-Erco, Division of ACF Industries, Inc., formerly Director,
Naval and Reactor Engineering Divisions, Argonne National Laboratory.
ELESA R. ETHERINGTON, B.Sc., Housewife.

CONTENTS

1-1 SELECTED DATA AND FORMULAS AND GUIDE TO THE HANDBOOK

BY HAROLD ETHERINGTON

	PAGE
1 Guide to Handbook Tabulated Data...	1-2
2 Units and Constants.....	1-12
3 The Elements and Nuclides.....	1-13
4 Nuclear Data Used in Reactor Calculations.....	1-19
5 Constants and Formulas Relating Power, Flux, and Fuel Consumption..	1-26
6 Numerical Integration by Simpson's Rule.....	1-28
7 Reactor Calculations.....	1-29
8 Calculation of Nuclear Radiation.....	1-36
9 Health Physics.....	1-42
10 Nuclear Radiation Shielding.....	1-43
11 Physics of Reactor Control.....	1-45
12 Fluid Properties.....	1-48
13 Fluid Flow.....	1-50
14 Heat Transfer.....	1-53
15 Thermal Stress and Distortion.....	1-61
16 Radiation Damage to Liquids and Organic Materials.....	1-62

	PAGE
17 Solution of Equations.....	1-63
18 Atomic Energy Commission Literature. References.....	1-71 1-74

1-2 MATHEMATICAL TABLES

BY HAROLD ETHERINGTON AND
ELESA R. ETHERINGTON

1 Tables of Functions.....	1-75
2 Bibliography of English-language Tables.....	1-127

1-3 UNITS AND CONVERSION FACTORS

BY HAROLD ETHERINGTON

1 Dimension and Unit Systems.....	1-134
2 Fundamental Standards and Exact Equivalents.....	1-139
3 Conversion Factors.....	1-142
4 Atomic Units, Constants, and Con- version Factors.....	1-153
References.....	1-156

SECTION 2

NUCLEAR DATA

BY

HARRY SOODAK, B.S., M.A., Ph.D., Assistant Professor of Physics, The City
College of New York.

CONTENTS

	PAGE		PAGE
1 Fission-process Data.....	2-2	6 Resonance Integral Data.....	2-24
2 Cross Sections of Fissionable and Related Heavy Atoms.....	2-5	7 Fast-neutron Data.....	2-27
3 Moderator Data.....	2-8	8 Radiations and Their Ranges.....	2-34
4 Fission-product Cross Sections.....	2-10	9 Atomic Weights.....	2-35
5 Thermal Cross Sections.....	2-12	References.....	2-36

SECTION 3

MATHEMATICS

BY

ALSTON S. HOUSEHOLDER, Ph.D., Head of Mathematics Panel, Oak Ridge National Laboratory.

WARD CONRAD SANGREN, A.B., M.A., Ph.D., Chief of Computing, General Atomic, General Dynamics Corporation; formerly Chief of Computing and Mathematics, Curtiss-Wright Research; Assistant Chief of Mathematics Panel, Oak Ridge National Laboratory.

CONTENTS

3-1 ALGEBRA AND GEOMETRY

BY ALSTON S. HOUSEHOLDER

	PAGE
1 The Algebra of Scalars, Vectors, and Matrices.....	3-2
2 Trigonometry and Complex Numbers....	3-15
3 Loci: Curves and Surfaces.....	3-24
4 Algebraic Equations.....	3-35
5 Probability and Statistics.....	3-55
References and Notes.....	3-62

3-2 ANALYSIS

BY WARD CONRAD SANGREN

1 Differential and Integral Calculus.....	3-64
2 Function Theory.....	3-75

	PAGE
3 Series and Expansions of Functions.....	3-95
4 Differential Equations.....	3-106
5 Other Topics.....	3-125
Bibliography.....	3-140

3-3 PRINCIPLES OF HIGH-SPEED COMPUTING MACHINERY

BY WARD CONRAD SANGREN AND ALSTON S. HOUSEHOLDER

1 Digital Computing Machinery.....	3-142
2 Analogue Computing Machinery.....	3-146
Bibliography.....	3-148

SECTION 4

NUCLEAR PHYSICS

BY

FRANK C. HOYT, Ph.D., Manager, Nuclear and General Physics Division, Lockheed Aircraft Corporation, formerly Alternate Division Leader, Los Alamos Scientific Laboratory.

CONTENTS

	PAGE		PAGE
1 Elements of Atomic Theory.....	4-2	4 Nuclear Reactions.....	4-65
2 Elements of Nuclear Theory.....	4-33	5 Neutron Physics.....	4-90
3 Basic Particles and Their Interaction with Matter.....	4-54	References.....	4-102

SECTION 5

EXPERIMENTAL TECHNIQUES

BY

BURTON J. MOYER, Ph.D., Professor of Physics, University of California Berkeley, and Physicist, University of California Berkeley Radiation Laboratory.

DONALD J. HUGHES, Ph.D., Senior Physicist, Brookhaven National Laboratory.

JOHN A. HARVEY, B.Sc., Ph.D., Senior Physicist, Oak Ridge National Laboratory, formerly Brookhaven National Laboratory.

HERBERT KOUTS, Ph.D., Experimental Reactor Physics Group Leader, Brookhaven National Laboratory.

G. K. GREEN, Ph.D., Senior Physicist, Brookhaven National Laboratory.

JOHN R. HUFFMAN, Ph.D., Assistant Manager, Technical, Atomic Energy Division, Phillips Petroleum Company.

F. L. McMILLAN, M.S., Assistant Superintendent, Operations Engineering Branch, Atomic Energy Division, Phillips Petroleum Company.

CONTENTS

5-1 INSTRUMENTS FOR MEASURING RADIATION

BY BURTON J. MOYER

	PAGE
1 Principles of Radiation Detection.....	5-2
2 Applications to Specific Radiations.....	5-28
References.....	5-49

5-2 EXPERIMENTAL NEUTRON PHYSICS

DONALD J. HUGHES AND JOHN A. HARVEY

1 Neutron Interactions.....	5-53
2 Fast Neutrons.....	5-57
3 Intermediate-energy Neutrons.....	5-72
4 Thermal Neutrons.....	5-83
References.....	5-99

5-3 MEASUREMENT OF REACTOR CONSTANTS

BY HERBERT KOUTS

1 Experimental Methods.....	5-102
-----------------------------	-------

	PAGE
2 Slowing-down and Diffusion Measurements.....	5-105
3 Experiments with Reproducing Assemblies.....	5-108
4 Exponential Experiments.....	5-117
5 Neutron Economy.....	5-119
References.....	5-121

5-4 ACCELERATORS

BY G. K. GREEN

1 Introduction.....	5-123
2 Straight-line Accelerators.....	5-125
3 Magnetic Accelerators.....	5-129
References.....	5-137

5-5 ENGINEERING TESTING IN REACTORS

BY JOHN R. HUFFMAN AND F. L. McMILLAN

1 Static Tests.....	5-140
2 Dynamic Tests.....	5-141

SECTION 6

REACTOR PHYSICS

BY

JOHN W. WEIL, B.S., Ph.D., Manager, Power Reactor Physics, Atomic Power Equipment Department, General Electric Company.

J. R. DIETRICH, Ph.D., Vice President, General Nuclear Engineering Corporation, formerly Associate Director, Reactor Engineering Division, Argonne National Laboratory.

CONTENTS

6-1 REACTOR THEORY		PAGE
BY JOHN W. WEIL		
	PAGE	
1	Neutron Transport.....	6-3
2	The Spherical Harmonics Method and the Diffusion Equation.....	6-10
3	Other Techniques for Transport Problems.....	6-12
4	The Treatment of Boundaries in Neutron Transport.....	6-15
5	Reactor Equations.....	6-18
6	The Four-factor Formula.....	6-21
7	Special Reactor Problems.....	6-25
	References.....	6-27
6-2 REACTOR CALCULATIONS		
BY J. R. DIETRICH		
1	Introduction.....	6-30
2	Diffusion of "Monoenergetic" Neutrons.....	6-35
3	Slowing Down of Neutrons.....	6-42
4	Energy Distribution of Thermal Neutrons.....	6-48
5	Critical Reactor Equations for Thermal and Near-thermal Reactors.....	6-51
6	Solutions of the Wave Equation for Homogeneous Bare Reactors.....	6-57
7	Reflected Reactors.....	6-60
8	Matrix Solutions for Reflected Reactors, by Otto Schulze.....	6-70
9	Evaluation of Material Constants of the Reactor, by Otto Schulze and J. R. Dietrich.....	6-75
10	Multigroup Calculations, by David Okrent.....	6-88
11	Sample Calculations.....	6-95
12	Lumped Thermal Absorbers in the Reactor.....	6-105
13	Noncritical Reactors.....	6-110
14	Perturbation Relations.....	6-117
	References.....	6-120

SECTION 7

RADIATION AND RADIOLOGICAL PROTECTION

BY

JOHN M. WEST, B.S., M.S., Vice President, General Nuclear Engineering Corporation, formerly Associate Director, Reactor Engineering Division, Argonne National Laboratory.

KARL ZIEGLER MORGAN, A.B., M.A., Ph.D., Director of Health Physics Division, Oak Ridge National Laboratory.

EVERITT P. BLIZARD, B.A., M.A., Director, Applied Nuclear Physics Division, Oak Ridge National Laboratory.

RAYMOND C. GOERTZ, B.S., Director, Remote Control Engineering Division, Argonne National Laboratory.

KENNETH R. FERGUSON, A.B., M.S., Associate Physicist, Argonne National Laboratory.

WILLIAM B. DOE, B.S., Associate Chemical Engineer, Argonne National Laboratory.

CONTENTS

7-1 CALCULATION OF NUCLEAR RADIATION

BY JOHN M. WEST

	PAGE
1 Nature of Radioactivity.....	7-2
2 Transmutation by Neutrons.....	7-7
3 Fission Products.....	7-14
4 Reactor Coolant Systems.....	7-17
References.....	7-21

7-2 HEALTH PHYSICS

BY KARL ZIEGLER MORGAN

1 Ionizing Radiation.....	7-22
2 Radiation Monitoring.....	7-45
3 Decontamination.....	7-48
4 Radioactive Effluents and Wastes.....	7-50
5 Shipping and Handling of Radioactive Materials.....	7-55
6 The Safe Handling of Fuel, by Thomas J. Burnett.....	7-55
7 Beryllium Toxicity, by Myron F. Fair.....	7-57
References.....	7-57

7-3 NUCLEAR RADIATION SHIELDING

BY EVERITT P. BLIZARD

	PAGE
1 γ Ray Attenuation.....	7-61
2 Sources of γ Rays and X Rays.....	7-72
3 Neutron Attenuation Principles.....	7-78
4 Neutron Sources.....	7-90
5 Geometry.....	7-93
6 Shield Materials.....	7-109
References.....	7-115

7-4 MECHANICAL HANDLING OF RADIOACTIVE MATERIALS

BY RAYMOND C. GOERTZ, KENNETH R. FERGUSON, and WILLIAM B. DOE

1 General Solutions to Handling Problems.....	7-117
2 Typical Equipment for Handling Radioactive Materials.....	7-125
References.....	7-139

SECTION 8

CONTROL OF REACTORS

BY

SIDNEY KRASIK, Ph.D., Westinghouse Electric Corporation

M. A. SCHULTZ, B.S.E.E., Project Manager, Westinghouse Testing Reactor,
Westinghouse Electric Corporation

JOSEPH M. HARRER, B.S.E.E., M.S.E.E., Head, Nuclear Reactor Control Section,
Argonne National Laboratory

C. ROGERS McCULLOUGH, Ph.D., Chairman, Advisory Committee on Reactor
Safeguards, and Deputy Director, Division of Civilian Application for Hazard
Evaluation, U.S. Atomic Energy Commission, formerly Assistant Director,
Development Department, Monsanto Chemical Company

JOHN C. MOISE, Ph.D., Assistant Principal Engineer, Liquid Rocket Plant, Aerojet-
General Corporation, formerly Assistant Project Engineer, Fox Project, Pratt and
Whitney Aircraft

CONTENTS

8-1 PHYSICS OF CONTROL

BY SIDNEY KRASIK

	PAGE
1 Reactor Kinetics.....	8-2
2 Control-rod Effectiveness in Thermal Reactors.....	8-12
References	8-19

8-2 THE CONTROL SYSTEM

BY M. A. SCHULTZ

1 Reactor Startup and Low-power Oper- ation.....	8-21
2 Reactor Operation.....	8-32
3 Reactor Shutdown.....	8-42
References	8-46

8-3 CONTROL INSTRUMENTS AND DRIVES

BY JOSEPH M. HARRER

1 Neutron-sensitive Detectors.....	8-49
2 Control Drives.....	8-67
References	8-75

8-4 REACTOR SAFEGUARDS

BY C. ROGERS McCULLOUGH

	PAGE
1 Introduction.....	8-76
2 Nature of the Problem.....	8-77
3 Controls.....	8-81
4 Administrative Control.....	8-82
5 Containment.....	8-84
6 Location.....	8-85
7 Future Reactor Types.....	8-87
References	8-88

8-5 REACTOR-SYSTEM DYNAMIC SIMULATION

BY JOHN C. MOISE

1 Mathematical Description of System...	8-90
2 Computer Setup of Reactor-system Equations.....	8-97
References.....	8-102

SECTION 9

FLUID AND HEAT FLOW

BY

WAYNE H. JENS, B.S., M.S., Ph.D., Assistant Technical Director, Atomic Power Development Associates, formerly Senior Engineer, Nuclear Development Corporation of America.

CHARLES F. BONILLA, Ch.E., Ph.D., Professor of Chemical Engineering, Columbia University.

ROBERT DAANE, B.S., M.S., Research Engineer, Beloit Iron Works, formerly Senior Mechanical Engineer, Nuclear Development Corporation of America, and Associate Mechanical Engineer, Argonne National Laboratory.

CONTENTS

9-1 PHYSICAL PROPERTIES OF HEAT-TRANSPORT MEDIUMS

BY WAYNE H. JENS

	PAGE
Tables.....	9-2
References.....	9-22

9-2 FLUID FLOW IN REACTOR SYSTEMS

BY CHARLES F. BONILLA

1 Viscosity.....	9-25
2 Material and Mechanical Balances.....	9-27
3 Streamline Flow.....	9-29
4 Turbulent Flow in Ducts.....	9-31
5 Flow of Slurries (Bingham Bodies).....	9-40
6 Flow of Vapor-Liquid Mixtures.....	9-40
7 Flow-distribution Control.....	9-44
8 Losses in External Flow.....	9-46
9 Mechanical Pumps and Blowers.....	9-48
References.....	9-49

9-3 HEAT REMOVAL FROM NUCLEAR REACTORS

BY CHARLES F. BONILLA

	PAGE
1 The Spatial Distribution of Heat Generation in Reactors.....	9-51
2 Heat Conduction.....	9-52
3 Convection.....	9-57
4 Condensing Vapors.....	9-65
5 Boiling Liquids.....	9-66
6 Steady-state Thermal Design of Reactors.....	9-84
7 Special Steady- and Unsteady-state Calculation and Test Methods.....	9-93
References.....	9-106

9-4 THERMAL STRESS AND DISTORTION

BY ROBERT DAANE

1 Thermal Stress and Distortion by Elasticity Theory.....	9-110
2 Thermal-stress Fracture.....	9-114
References.....	9-115

SECTION 10

REACTOR MATERIALS

BY

DWAIN B. BOWEN, M.S., Group Leader, Solid State Physics, Atomics International, North American Aviation, Inc.

H. A. SALLER, B.S. (deceased), formerly Assistant Technical Director, Battelle Memorial Institute.

ROGER SUTTON, B.Ch.E., M.S., Metallurgist, International Nickel Company, formerly Senior Metallurgist, Argonne National Laboratory.

JOHN P. HOWE, B.S., Ph.D., Chief, Research, Atomics International, North American Aviation, Inc.

SIDNEY SIEGEL, A.B., Ph.D., Technical Director, Atomics International, North American Aviation, Inc.

VINCENT P. CALKINS, B.S., M.S., Ph.D., Manager, Applied Materials Research, Aircraft Nuclear Propulsion Department, General Electric Company.

WARREN J. MCGONNAGLE, A.B., M.S., Ph.D., Group Leader, Nondestructive Testing, Argonne National Laboratory.

RUSSEL W. DAYTON, Ch.E., M.S., Ph.D., Assistant Technical Director, Battelle Memorial Institute.

CONTENTS

10-1 THE METALLIC STATE

BY DWAIN B. BOWEN

	PAGE
1 Structure of Metals and Alloys.....	10-2
2 Thermodynamics and Kinetics of Metals and Alloys.....	10-9
3 Deformation and Fracture.....	10-13
References and Bibliography.....	10-16

10-2 PROPERTIES OF REACTOR MATERIALS

BY H. A. SALLER

1 Fuels and Fertile Materials.....	10-17
2 Fuel Diluents and Cladding Materials..	10-38
3 Solid Moderators.....	10-54
4 Structural Materials.....	10-60
5 Control and Absorber Materials.....	10-69
References.....	10-71

10-3 STRUCTURAL MATERIALS IN HIGH-TEMPERATURE WATER REACTOR SYSTEMS

BY ROGER SUTTON

1 Corrosion.....	10-73
2 Galling and Wear.....	10-74
References.....	10-82

10-4 RADIATION DAMAGE TO SOLIDS

BY JOHN P. HOWE AND SIDNEY SIEGEL

1 Nuclear Reactors as Sources of Radiation.....	10-83
---	-------

	PAGE
2 Experiments Using Nuclear Reactors..	10-92
3 Experiments Using Cyclotrons.....	10-96
4 Elementary Processes for Damage in Solids.....	10-99
5 Changes Produced in Macroscopic Properties of Materials.....	10-105
References.....	10-124

10-5 RADIATION DAMAGE TO LIQUIDS AND ORGANIC MATERIALS

BY VINCENT P. CALKINS

1 Mechanism and Nature of Radiation Damage.....	10-126
2 Calculation of Radiation Energy Absorption.....	10-129
3 Calculation of Radiation Damage.....	10-131
References.....	10-148

10-6 NONDESTRUCTIVE TESTING

BY WARREN J. MCGONNAGLE

1 Types of Nondestructive Tests.....	10-150
2 Physical and Chemical Properties.....	10-161
3 Thickness Measurements.....	10-162
References.....	10-166

10-7 RECENT DEVELOPMENTS IN REACTOR MATERIALS

BY RUSSEL W. DAYTON

1 Fuel and Fertile Materials.....	10-168
2 Cladding Materials.....	10-185
3 Control Materials.....	10-190
References.....	10-191

SECTION 11

CHEMISTRY AND CHEMICAL ENGINEERING

BY

STEPHEN LAWROSKI, B.S., M.S., Ph.D., Director, Chemical Engineering Division,
Argonne National Laboratory.

LESLIE BURRIS, JR., B.S., M.S., Associate Chemical Engineer, Argonne National
Laboratory.

WALTON A. RODGER, B.S.Ch.E., B.S.Met.E., M.S.Ch.E., Ph.D., Associate
Director, Chemical Engineering Division, Argonne National Laboratory.

CONTENTS

	PAGE		PAGE
1 Introduction.....	11-2	7 Auxiliary Operations.....	11-106
2 Nuclear Reactor Dependence.....	11-3	8 Special Problems.....	11-114
3 Chemistry of Important Elements...	11-34	9 Special Design Problems Raised by Radioactivity.....	11-133
4 Analytical Chemistry.....	11-50	10 Waste Disposal.....	11-140
5 Basic Methods of Separations.....	11-57	References.....	11-146
6 Filtration, Centrifugation, and Evapo- ration.....	11-103		

SECTION 12

NUCLEAR-POWER-PLANT SELECTION

BY

ALFRED AMOROSI, B.S.M.E., B.S.Ch., Technical Director, Atomic Power Development Associates, Inc. (on loan from Detroit Edison Company, formerly Associate Director, Reactor Engineering Division, Argonne National Laboratory).

L. E. LINK, B.S., Associate Chemical Engineer, Argonne National Laboratory.

WALTER H. ZINN, Ph.D., President, General Nuclear Engineering Corporation, formerly Director, Argonne National Laboratory.

FRANK B. DANIELS, B.S., Assistant Manager, Research and Development, Nuclear Products-Erco, Division of ACF Industries, Inc., formerly Assistant to Director of Mechanical Engineering, Industries Group, Allis-Chalmers Manufacturing Company.

ROBERT C. ALLEN, Director of Mechanical Engineering, Industries Group, Allis-Chalmers Manufacturing Company.

CONTENTS

12-1 SELECTION OF REACTORS

BY ALFRED AMOROSI

	PAGE
1 Thermodynamics.....	12-2
2 Classification of Reactors.....	12-6
3 Factors That Influence the Design and Selection of Reactors.....	12-8
4 Principal Features of Reactor Types....	12-22
5 Coolants.....	12-56
6 Fuel Elements.....	12-59
7 Moderators.....	12-68
8 Control Rods.....	12-76
References.....	12-76

12-2 ECONOMICS OF NUCLEAR POWER

BY L. E. LINK AND WALTER H. ZINN

1 Fuel Consumption, Power, and Neutron Flux.....	12-78
--	-------

	PAGE
2 Neutron and Fuel Balance.....	12-80
3 World Fuel Resources.....	12-84
4 Conventional Plants—Power Cost.....	12-91
5 Cost of Nuclear Power Plants.....	12-95
6 Cost of Nuclear Fuels.....	12-100
7 Cost of Special Materials.....	12-106
8 Competitive Status of Nuclear Power.....	12-108
References.....	12-112

12-3 POWER-GENERATING EQUIPMENT

BY FRANK B. DANIELS AND
ROBERT C. ALLEN

1 Power Cycles.....	12-00
2 Power-generating Equipment and Auxiliaries.....	12-00
3 Operation and Maintenance.....	12-00
4 Shielding and Containment.....	12-00
References.....	12-00

SECTION 13

MECHANICAL DESIGN AND SELECTION OF REACTORS

BY

SAMUEL UNTERMYER II, B.S., Consulting Engineer on Reactor Technology, Vallecitos Atomic Laboratory, Atomic Power Equipment Department, General Electric Company.

R. B. BRIGGS, B.S.Ch.E., Director of Homogeneous Reactor Project, Oak Ridge National Laboratory.

ARTHUR H. BARNES, A.B., A.M., Ph.D. (deceased), formerly Director, Reactor Engineering Division, Argonne National Laboratory.

MILES C. LEVERETT, B.S., M.S.E., Sc.D., Manager, Development Laboratories, Aircraft Nuclear Propulsion Department, General Electric Company.

HERBERT S. ISBIN, Ph.D., Associate Professor, Department of Chemical Engineering, University of Minnesota.

ALF KOLFLAT, M.E., Senior Partner, Sargent & Lundy, Engineers.

GEORGE A. ANDERSON, B.M.E., Manager, Reactor Engineering, Nuclear Products-Erco, Division of ACF Industries, Inc., formerly Project Engineer, Argonne National Laboratory.

CONTENTS

13-1 WATER-COOLED REACTOR SYSTEMS

BY SAMUEL UNTERMYER II

	PAGE
1 Water as a Reactor Coolant.....	13-3
2 Pressure Vessel.....	13-12
3 Pressurized-tube Water-cooled Reactors*	13-18
4 Components of Water-cooled Reactor Systems.....	13-23
5 Special Features and Applications of H ₂ O-cooled Reactors.....	13-35
6 Boiling and Flashing Reactors.....	13-41
7 Other Types of Hydrogenous Coolants.....	13-48

13-2 HOMOGENEOUS AQUEOUS REACTOR SYSTEMS

BY R. B. BRIGGS

1 General Features and Reactor Types...	13-49
2 Fuels.....	13-50
3 Reactor Flow Sheets.....	13-59
4 Components of Homogeneous Aqueous Reactor Systems.....	13-62
5 Reactor Control.....	13-73
6 Maintenance.....	13-74
7 Thermodynamic Properties of Homogeneous Reactor Fuels.....	13-75
References.....	13-79

* Article 3.1 contributed by A. B. Carson.

13-3 LIQUID-METAL REACTOR SYSTEMS

BY ARTHUR H. BARNES

	PAGE
1 Alkali-metal Systems.....	13-80
2 Heavy-metal Systems.....	13-98
3 Homogeneous Metal Systems.....	13-99
4 Design Considerations of Liquid-metal-cooled Reactors.....	13-100
References.....	13-102

13-4 GAS-COOLED REACTOR SYSTEMS

BY MILES C. LEVERETT

1 Gas-cooled Reactors.....	13-105
2 Once-through Systems.....	13-108
3 Recirculating Systems.....	13-119
References.....	13-122

13-5 KINDS OF REACTORS

BY HERBERT S. ISBIN

1 Reactor Classification.....	13-123
2 Nuclear-reactor Catalogue.....	13-123
3 Reactor Descriptions.....	13-141
References.....	13-157

SECTION 14

ISOTOPES

BY

- PAUL C. AEBERSOLD, M.A., Ph.D.**, Assistant Director for Isotopes and Radiation, Division of Civilian Application, U.S. Atomic Energy Commission.
- CHARLES E. CROMPTON, Ph.D.**, Associate Technical Director, National Lead Company of Ohio, formerly Deputy Director, Isotopes Division, U.S. Atomic Energy Commission.
- GLENN CLEWETT, A.B.**, Group Leader, Sterling Forest Laboratory, Union Carbide Nuclear Co., formerly Director of Materials Chemistry Division, Oak Ridge National Laboratory.
- ARTHUR F. RUPP, B.S.Ch.E.**, Laboratory Services Superintendent, Oak Ridge National Laboratory.
- FRANKLIN T. BINFORD, B.S.**, Senior Development Engineer, Reactor Operations Department, Oak Ridge National Laboratory.
- GEORGE A. GARRETT, Ph.D.**, Superintendent of Operations, Analysis Division, Oak Ridge Gaseous Diffusion Plant.
- C. P. KEIM, A.B., M.Sc., Ph.D.**, Director, Technical Information Division, formerly Director, Stable Isotopes Division, Oak Ridge National Laboratory.
- C. E. NORMAND, Ph.D.**, Stable Isotope Research and Production Division, Oak Ridge National Laboratory.

CONTENTS

14-1 ISOTOPES AND THEIR USE

BY PAUL C. AEBERSOLD AND
CHARLES E. CROMPTON

	PAGE
1 Radioisotope Distribution.....	14-2
2 Industrial Applications.....	14-3
3 Other Applications.....	14-10
4 Isotope Licensing and Distribution.....	14-12
References.....	14-14

14-2 ISOTOPE SEPARATION BY CHEMICAL EXCHANGE AND RELATED PROCESSES

BY GLEN CLEWETT

1 Basic Concepts.....	14-15
2 Chemical Exchange.....	14-17
3 Other Processes.....	14-22
4 Commercially Available Isotopes.....	14-24
References.....	14-25

14-3 PRODUCTION OF RADIOISOTOPES

BY ARTHUR F. RUPP AND
FRANKLIN T. BINFORD

	PAGE
1 Irradiation.....	14-26
2 Chemical Processing.....	14-31
3 Radioisotope Separations Procedures.....	14-32
4 Radioisotope Processing Facilities.....	14-36
References.....	14-37

14-4 GASEOUS-DIFFUSION SEPARATION PROCESS

BY GEORGE A. GARRETT

1 The Cascade.....	14-38
References.....	14-43

14-5 THE ELECTROMAGNETIC SEPARATION OF STABLE ISOTOPES

BY C. P. KEIM AND C. E. NORMAND

1 The Calutron.....	14-44
2 Operation of the Calutron.....	14-50
3 Survey of Isotopes Separated in the Calutron.....	14-54
References.....	14-58