Contents

Preface *xxiii*
Preface to Second Edition *xxvii*
Preface to Third Edition *xxix*

Part 1 Basic Reactor Physics *1*

1 Neutron–Nuclear Reactions *3*
1.1 Neutron-Induced Nuclear Fission *3*
Stable Nuclides *3*
Binding Energy *3*
Threshold External Energy for Fission *5*
Neutron-Induced Fission *5*
Neutron Fission Cross Sections *5*
Products of the Fission Reaction *7*
Energy Release *9*
1.2 Neutron Capture *12*
Radiative Capture *12*
Neutron Emission *18*
1.3 Neutron Elastic Scattering *19*
1.4 Summary of Cross Section Data *23*
Low-Energy Cross Sections *23*
Spectrum-Averaged Cross Sections *24*
1.5 Evaluated Nuclear Data Files *25*
1.6 Elastic Scattering Kinematics *25*
Correlation of Scattering Angle and Energy Loss *26*
Average Energy Loss *27*

2 Neutron Chain Fission Reactors *33*
2.1 Neutron Chain Fission Reactions *33*
Capture-to-Fission Ratio *33*
Number of Fission Neutrons per Neutron Absorbed in Fuel *33*
Neutron Utilization *34*
Fast Fission *35*
Resonance Escape *36*

Bibliografische Informationen
http://d-nb.info/1140659111

digitalisiert durch DEUTSCHE NATIONAL BIBLIOTHEK

2.2 Criticality *37*
Effective Multiplication Constant *37*
Effect of Fuel Lumping *37*
Leakage Reduction *38*
2.3 Time Dependence of a Neutron Fission Chain Assembly *38*
Prompt Fission Neutron Time Dependence *38*
Source Multiplication *39*
Effect of Delayed Neutrons *39*
2.4 Classification of Nuclear Reactors *40*
Physics Classification by Neutron Spectrum *40*
Engineering Classification by Coolant *41*

3 Neutron Diffusion and Transport Theory *43*
3.1 Derivation of One-Speed Diffusion Theory *43*
Partial and Net Currents *43*
Diffusion Theory *46*
Interface Conditions *46*
Boundary Conditions *46*
Applicability of Diffusion Theory *47*
3.2 Solutions of the Neutron Diffusion Equation in Nonmultiplying Media *48*
Plane Isotropic Source in an Infinite Homogeneous Medium *48*
Plane Isotropic Source in a Finite Homogeneous Medium *48*
Line Source in an Infinite Homogeneous Medium *49*
Homogeneous Cylinder of Infinite Axial Extent with Axial Line Source *49*
Point Source in an Infinite Homogeneous Medium *49*
Point Source at the Center of a Finite Homogeneous Sphere *50*
3.3 Diffusion Kernels and Distributed Sources in a Homogeneous Medium *50*
Infinite-Medium Diffusion Kernels *50*
Finite-Slab Diffusion Kernel *51*
Finite Slab with Incident Neutron Beam *52*
3.4 Albedo Boundary Condition *52*
3.5 Neutron Diffusion and Migration Lengths *53*
Thermal Diffusion-Length Experiment *53*
Migration Length *56*
3.6 Bare Homogeneous Reactor *57*
Slab Reactor *58*
Right Circular Cylinder Reactor *59*
Interpretation of Criticality Condition *61*
Optimum Geometries *61*
3.7 Reflected Reactor *62*
Reflected Slab Reactor *63*
Reflector Savings *65*
Reflected Spherical, Cylindrical, and Rectangular Parallelepiped Cores *65*

3.8 Homogenization of a Heterogeneous Fuel–Moderator Assembly *65*
Spatial Self-Shielding and Thermal Disadvantage Factor *65*
Effective Homogeneous Cross Sections *68*
Thermal Utilization *70*
Measurement of Thermal Utilization *70*
Local Power Peaking Factor *71*
3.9 Control Rods *72*
Effective Diffusion Theory Cross Sections for Control Rods *72*
Windowshade Treatment of Control Rods *74*
3.10 Numerical Solution of Diffusion Equation *76*
Finite-Difference Equations in One Dimension *76*
Forward Elimination/Backward Substitution Spatial Solution Procedure *78*
Power Iteration on Fission Source *78*
Finite-Difference Equations in Two Dimensions *79*
Successive Relaxation Solution of Two-Dimensional Finite-Difference Equations *81*
Power Outer Iteration on Fission Source *81*
Limitations on Mesh Spacing *82*
3.11 Nodal Approximation *82*
3.12 Transport Methods *84*
Transmission and Absorption in a Purely Absorbing Slab Control Plate *86*
Escape Probability in a Slab *86*
Integral Transport Formulation *86*
Collision Probability Method *88*
Differential Transport Formulation *89*
Spherical Harmonics Methods *89*
Boundary and Interface Conditions *91*
P_1 Equations and Diffusion Theory *92*
Discrete Ordinates Method *93*

4 Neutron Energy Distribution *101*
4.1 Analytical Solutions in an Infinite Medium *101*
Fission Source Energy Range *102*
Slowing-Down Energy Range *102*
Moderation by Hydrogen Only *103*
Energy Self-Shielding *103*
Slowing Down by Nonhydrogenic Moderators with No Absorption *104*
Slowing-Down Density *105*
Slowing Down with Weak Absorption *106*
Fermi Age Neutron Slowing Down *107*
Neutron Energy Distribution in the Thermal Range *108*
Summary *111*

4.2 Multigroup Calculation of Neutron Energy Distribution in an Infinite Medium *112*
Derivation of Multigroup Equations *112*
Mathematical Properties of the Multigroup Equations *114*
Solution of Multigroup Equations *115*
Preparation of Multigroup Cross-Section Sets *116*
4.3 Resonance Absorption *118*
Resonance Cross Sections *118*
Doppler Broadening *120*
Resonance Integral *122*
Resonance Escape Probability *122*
Multigroup Resonance Cross Section *122*
Practical Width *122*
Neutron Flux in Resonance *123*
Narrow Resonance Approximation *123*
Wide Resonance Approximation *124*
Resonance Absorption Calculations *126*
Temperature Dependence of Resonance Absorption *126*
4.4 Multigroup Diffusion Theory *127*
Multigroup Diffusion Equations *127*
Two-Group Theory *128*
Two-Group Bare Reactor *128*
One-and-One-Half-Group Theory *129*
Two-Group Theory of Two-Region Reactors *130*
Two-Group Theory of Reflected Reactors *133*
Numerical Solutions for Multigroup Diffusion Theory *135*

5 Nuclear Reactor Dynamics *141*
5.1 Delayed Fission Neutrons *141*
Neutrons Emitted in Fission Product Decay *141*
Effective Delayed Neutron Parameters for Composite Mixtures *143*
Photoneutrons *144*
5.2 Point Kinetics Equations *145*
5.3 Period–Reactivity Relations *146*
5.4 Approximate Solutions of the Point Neutron Kinetics Equations *148*
One-Delayed Neutron Group Approximation *148*
Prompt-Jump Approximation *151*
Reactor Shutdown *153*
5.5 Delayed Neutron Kernel and Zero-Power Transfer Function *153*
Delayed Neutron Kernel *153*
Zero-Power Transfer Function *154*
5.6 Experimental Determination of Neutron Kinetics Parameters *155*
Asymptotic Period Measurement *155*
Rod Drop Method *155*
Source Jerk Method *156*
Pulsed Neutron Methods *156*
Rod Oscillator Measurements *157*

Zero-Power Transfer Function Measurements *158*
Rossi-α Measurement *158*
5.7 Reactivity Feedback *160*
Temperature Coefficients of Reactivity *161*
Doppler Effect *162*
Fuel and Moderator Expansion Effect on Resonance Escape Probability *164*
Thermal Utilization *165*
Nonleakage Probability *165*
Representative Thermal Reactor Reactivity Coefficients *166*
Startup Temperature Defect *167*
5.8 Perturbation Theory Evaluation of Reactivity Temperature Coefficients *168*
Perturbation Theory *168*
Sodium Void Effect in Fast Reactors *169*
Doppler Effect in Fast Reactors *170*
Fuel and Structure Motion in Fast Reactors *170*
Fuel Bowing *171*
Representative Fast Reactor Reactivity Coefficients *171*
5.9 Reactor Stability *171*
Reactor Transfer Function with Reactivity Feedback *171*
Stability Analysis for a Simple Feedback Model *173*
Threshold Power Level for Reactor Stability *174*
More General Stability Conditions *176*
Power Coefficients and Feedback Delay Time Constants *178*
5.10 Measurement of Reactor Transfer Functions *179*
Rod Oscillator Method *180*
Correlation Methods *180*
Reactor Noise Method *182*
5.11 Reactor Transients with Feedback *184*
Step Reactivity Insertion ($\rho_{ex} < \beta$): Prompt Jump *185*
Step Reactivity Insertion ($\rho_{ex} < \beta$): Post-Prompt-Jump Transient *186*
5.12 Reactor Fast Excursions *187*
Step Reactivity Input: Feedback Proportional to Fission Energy *187*
Ramp Reactivity Input: Feedback Proportional to Fission Energy *188*
Step Reactivity Input: Nonlinear Feedback Proportional to Cumulative Energy Release *189*
Bethe–Tait Model *190*
5.13 Numerical Methods *192*

6 Fuel Burnup *197*
6.1 Changes in Fuel Composition *197*
Fuel Transmutation–Decay Chains *198*
Fuel Depletion–Transmutation–Decay Equations *199*
Fission Products *203*
Solution of the Depletion Equations *204*

Measure of Fuel Burnup *205*
Fuel Composition Changes with Burnup *205*
Reactivity Effects of Fuel Composition Changes *206*
Compensating for Fuel-Depletion Reactivity Effects *207*
Reactivity Penalty *208*
Effects of Fuel Depletion on the Power Distribution *209*
In-Core Fuel Management *210*
6.2 Samarium and Xenon *211*
Samarium Poisoning *211*
Xenon Poisoning *213*
Peak Xenon *215*
Effect of Power-Level Changes *215*
6.3 Fertile-to-Fissile Conversion and Breeding *217*
Availability of Neutrons *217*
Conversion and Breeding Ratios *217*
6.4 Simple Model of Fuel Depletion *219*
6.5 Fuel Reprocessing and Recycling *221*
Composition of Recycled LWR Fuel *221*
Physics Differences of MOX Cores *222*
Physics Considerations with Uranium Recycle *224*
Physics Considerations with Plutonium Recycle *224*
Reactor Fueling Characteristics *225*
6.6 Radioactive Waste *225*
Radioactivity *225*
Hazard Potential *226*
Risk Factor *226*
6.7 Burning Surplus Weapons-Grade Uranium and Plutonium *232*
Composition of Weapons-Grade Uranium and Plutonium *232*
Physics Differences Between Weapons- and Reactor-Grade Plutonium-Fueled Reactors *232*
6.8 Utilization of Uranium Energy Content *234*
6.9 Transmutation of Spent Nuclear Fuel *236*
6.10 Closing the Nuclear Fuel Cycle *242*

7 Nuclear Power Reactors *247*
7.1 Pressurized Water Reactors *247*
7.2 Boiling Water Reactors *249*
7.3 Pressure Tube Heavy Water–Moderated Reactors *253*
7.4 Pressure Tube Graphite-Moderated Reactors *255*
7.5 Graphite-Moderated Gas-Cooled Reactors *258*
7.6 Liquid Metal Fast Reactors *260*
7.7 Other Power Reactors *265*
7.8 Characteristics of Power Reactors *266*
7.9 Advanced Generation-III Reactors *267*
Advanced Boiling Water Reactors (ABWR) *267*
Advanced Pressurized Water Reactors (APWR) *267*

Advanced Pressure Tube Reactor *269*
Modular High-Temperature Gas-Cooled Reactors (GT-MHR) *269*
7.10 Advanced Generation-IV Reactors *271*
Gas-Cooled Fast Reactors (GFR) *271*
Lead-Cooled Fast Reactors (LFR) *272*
Molten Salt Reactors (MSR) *273*
Supercritical Water Reactors (SCWR) *273*
Sodium-Cooled Fast Reactors (SFR) *273*
Very High Temperature Reactors (VHTR) *273*
7.11 Advanced Subcritical Reactors *274*
7.12 Nuclear Reactor Analysis *276*
Construction of Homogenized Multigroup Cross Sections *276*
Criticality and Flux Distribution Calculations *277*
Fuel Cycle Analyses *278*
Transient Analyses *279*
Core Operating Data *280*
Criticality Safety Analysis *280*
7.13 Interaction of Reactor Physics and Reactor Thermal Hydraulics *281*
Power Distribution *281*
Temperature Reactivity Effects *282*
Coupled Reactor Physics and Thermal Hydraulics Calculations *282*

8 Reactor Safety *285*
8.1 Elements of Reactor Safety *285*
Radionuclides of Greatest Concern *285*
Multiple Barriers to Radionuclide Release *285*
Defense in Depth *287*
Energy Sources *287*
8.2 Reactor Safety Analysis *287*
Loss of Flow or Loss of Coolant *288*
Loss of Heat Sink *289*
Reactivity Insertion *289*
Anticipated Transients without Scram *289*
8.3 Quantitative Risk Assessment *289*
Probabilistic Risk Assessment *289*
Radiological Assessment *290*
Reactor Risks *293*
8.4 Reactor Accidents *294*
Three Mile Island *294*
Chernobyl *298*
Fukushima *300*
8.5 Passive Safety *300*
Pressurized Water Reactors *300*
Boiling Water Reactors *301*
Integral Fast Reactors *301*
Passive Safety Demonstration *301*

Part 2 Advanced Reactor Physics *305*

9 Neutron Transport Theory *307*
9.1 Neutron Transport Equation *307*
Boundary Conditions *309*
Scalar Flux and Current *310*
Partial Currents *311*
9.2 Integral Transport Theory *312*
Isotropic Point Source *313*
Isotropic Plane Source *313*
Anisotropic Plane Source *315*
Transmission and Absorption Probabilities *317*
Escape Probability *317*
First-Collision Source for Diffusion Theory *318*
Inclusion of Isotropic Scattering and Fission *318*
Distributed Volumetric Sources in Arbitrary Geometry *320*
Flux from a Line Isotropic Source of Neutrons *320*
Bickley Functions *321*
Probability of Reaching a Distance t from a Line Isotropic Source without a Collision *322*
9.3 Collision Probability Methods *323*
Reciprocity Among Transmission and Collision Probabilities *323*
Collision Probabilities for Slab Geometry *324*
Collision Probabilities in Two-Dimensional Geometry *325*
Collision Probabilities for Annular Geometry *326*
9.4 Interface Current Methods in Slab Geometry *327*
Emergent Currents and Reaction Rates Due to Incident Currents *327*
Emergent Currents and Reaction Rates Due to Internal Sources *331*
Total Reaction Rates and Emergent Currents *333*
Boundary Conditions *334*
Response Matrix *335*
9.5 Multidimensional Interface Current Methods *336*
Extension to Multidimension *336*
Evaluation of Transmission and Escape Probabilities *338*
Transmission Probabilities in Two-Dimensional Geometries *339*
Escape Probabilities in Two-Dimensional Geometries *342*
Simple Approximations for the Escape Probability *343*
9.6 Spherical Harmonics (P_L) Methods in One-Dimensional Geometries *344*
Legendre Polynomials *344*
Neutron Transport Equation in Slab Geometry *345*
P_L Equations *346*
Boundary and Interface Conditions *347*
P_1 Equations and Diffusion Theory *348*
Simplified P_L or Extended Diffusion Theory *350*
P_L Equations in Spherical and Cylindrical Geometries *351*

Diffusion Equations in One-Dimensional Geometry *354*
Half-Angle Legendre Polynomials *354*
Double-P_L Theory *355*
D-P_0 Equations *357*
9.7 Multidimensional Spherical Harmonics (P_L) Transport Theory *357*
Spherical Harmonics *357*
Spherical Harmonics Transport Equations in Cartesian Coordinates *359*
P_1 Equations in Cartesian Geometry *360*
Diffusion Theory *361*
9.8 Discrete Ordinates Methods in One-Dimensional Slab Geometry *362*
P_L and D-P_L Ordinates *363*
Spatial Differencing and Iterative Solution *366*
Limitations on Spatial Mesh Size *367*
9.9 Discrete Ordinates Methods in One-Dimensional Spherical Geometry *368*
Representation of Angular Derivative *368*
Iterative Solution Procedure *369*
Acceleration of Convergence *371*
Calculation of Criticality *372*
9.10 Multidimensional Discrete Ordinates Methods *372*
Ordinates and Quadrature Sets *372*
S_N Method in Two-Dimensional x–y Geometry *375*
Further Discussion *378*
9.11 Even-Parity Transport Formulation *379*
9.12 Monte Carlo Methods *380*
Probability Distribution Functions *380*
Analog Simulation of Neutron Transport *381*
Statistical Estimation *383*
Variance Reduction *385*
Tallying *387*
Criticality Problems *389*
Source Problems *390*
Random Numbers *390*

10 Neutron Slowing Down *395*
10.1 Elastic Scattering Transfer Function *395*
Lethargy *395*
Elastic Scattering Kinematics *395*
Elastic Scattering Kernel *396*
Isotropic Scattering in Center-of-Mass System *398*
Linearly Anisotropic Scattering in Center-of-Mass System *399*
10.2 P_1 and B_1 Slowing-Down Equations *400*
Derivation *400*
Solution in Finite Uniform Medium *404*
B_1 Equations *405*
Few-Group Constants *407*

10.3 Diffusion Theory *407*
Lethargy-Dependent Diffusion Theory *407*
Directional Diffusion Theory *408*
Multigroup Diffusion Theory *409*
Boundary and Interface Conditions *410*
10.4 Continuous Slowing-Down Theory *411*
P_1 Equations in Slowing-Down Density Formulation *411*
Slowing-Down Density in Hydrogen *415*
Heavy Mass Scatterers *415*
Age Approximation *416*
Selengut–Goertzel Approximation *416*
Consistent P_1 Approximation *416*
Extended Age Approximation *417*
Grueling–Goertzel Approximation *418*
Summary of P_l Continuous Slowing-Down Theory *419*
Inclusion of Anisotropic Scattering *419*
Inclusion of Scattering Resonances *421*
P_l Continuous Slowing-Down Equations *422*
10.5 Multigroup Discrete Ordinates Transport Theory *423*

11 Resonance Absorption *429*
11.1 Resonance Cross Sections *429*
11.2 Widely Spaced Single-Level Resonances in a Heterogeneous Fuel–Moderator Lattice *429*
Neutron Balance in Heterogeneous Fuel–Moderator Cell *429*
Reciprocity Relation *432*
Narrow Resonance Approximation *433*
Wide Resonance Approximation *434*
Evaluation of Resonance Integrals *434*
Infinite Dilution Resonance Integral *436*
Equivalence Relations *436*
Heterogeneous Resonance Escape Probability *436*
Homogenized Multigroup Resonance Cross Section *438*
Improved and Intermediate Resonance Approximations *438*
11.3 Calculation of First-Flight Escape Probabilities *439*
Escape Probability for an Isolated Fuel Rod *439*
Closely Packed Lattices *442*
11.4 Unresolved Resonances *444*
Multigroup Cross Sections for Isolated Resonances *446*
Self-Overlap Effects *447*
Overlap Effects for Different Sequences *448*
11.5 Multiband Treatment of Spatially Dependent Self-Shielding *449*
Spatially Dependent Self-Shielding *449*
Multiband Theory *450*
Evaluation of Multiband Parameters *453*
Calculation of Multiband Parameters *454*
Interface Conditions *455*

11.6 Resonance Cross Section Representations *456*
R-Matrix Representation *456*
Practical Formulations *457*
Generalization of the Pole Representation *461*
Doppler Broadening of the Generalized Pole Representation *464*

12 Neutron Thermalization *469*
12.1 Double Differential Scattering Cross Section for Thermal Neutrons *469*
12.2 Neutron Scattering from a Monatomic Maxwellian Gas *470*
Differential Scattering Cross Section *470*
Cold Target Limit *471*
Free-Hydrogen (Proton) Gas Model *471*
Radkowsky Model for Scattering from H_2O *471*
Heavy Gas Model *472*
12.3 Thermal Neutron Scattering from Bound Nuclei *473*
Pair Distribution Functions and Scattering Functions *473*
Intermediate Scattering Functions *474*
Incoherent Approximation *475*
Gaussian Representation of Scattering *475*
Measurement of the Scattering Function *476*
Applications to Neutron Moderating Media *476*
12.4 Calculation of the Thermal Neutron Spectra in Homogeneous Media *478*
Wigner–Wilkins Proton Gas Model *480*
Heavy Gas Model *483*
Numerical Solution *486*
Moments Expansion Solution *486*
Multigroup Calculation *490*
Applications to Moderators *491*
12.5 Calculation of Thermal Neutron Energy Spectra in Heterogeneous Lattices *492*
12.6 Pulsed Neutron Thermalization *494*
Spatial Eigenfunction Expansion *494*
Energy Eigenfunctions of the Scattering Operator *494*
Expansion in Energy Eigenfunctions of the Scattering Operator *496*

13 Perturbation and Variational Methods *501*
13.1 Perturbation Theory Reactivity Estimate *501*
Multigroup Diffusion Perturbation Theory *501*
13.2 Adjoint Operators and Importance Function *504*
Adjoint Operators *504*
Importance Interpretation of the Adjoint Function *506*
Eigenvalues of the Adjoint Equation *507*
13.3 Variational/Generalized Perturbation Reactivity Estimate *508*
One-Speed Diffusion Theory *508*
Other Transport Models *511*

Reactivity Worth of Localized Perturbations in a Large PWR Core Model *512*
Higher Order Variational Estimates *512*
13.4 Variational/Generalized Perturbation Theory Estimates of Reaction Rate Ratios in Critical Reactors *512*
13.5 Variational/Generalized Perturbation Theory Estimates of Reaction Rates *515*
13.6 Variational Theory *516*
Stationarity *516*
Roussopolos Variational Functional *517*
Schwinger Variational Functional *517*
Rayleigh Quotient *518*
Construction of Variational Functionals *519*
13.7 Variational Estimate of Intermediate Resonance Integral *519*
13.8 Heterogeneity Reactivity Effects *521*
13.9 Variational Derivation of Approximate Equations *522*
Inclusion of Interface and Boundary Terms *523*
13.10 Variational Even-Parity Transport Approximations *524*
Variational Principle for the Even-Parity Transport Equation *524*
Ritz Procedure *525*
Diffusion Approximation *526*
One-Dimensional Slab Transport Equation *527*
13.11 Boundary Perturbation Theory *527*

14 Homogenization *535*
14.1 Equivalent Homogenized Cross Sections *536*
14.2 ABH Collision Probability Method *537*
14.3 Blackness Theory *541*
14.4 Fuel Assembly Transport Calculations *543*
Pin Cells *543*
Wigner–Seitz Approximation *543*
Collision Probability Pin-Cell Model *544*
Interface Current Formulation *548*
Multigroup Pin-Cell Collision Probabilities Model *549*
Resonance Cross Sections *550*
Full Assembly Transport Calculation *550*
14.5 Homogenization Theory *551*
Homogenization Considerations *551*
Conventional Homogenization Theory *552*
14.6 Equivalence Homogenization Theory *553*
14.7 Multiscale Expansion Homogenization Theory *556*
14.8 Flux Detail Reconstruction *560*

15 Nodal and Synthesis Methods *563*
15.1 General Nodal Formalism *564*
15.2 Conventional Nodal Methods *567*

15.3 Transverse Integrated Nodal Diffusion Theory Methods *570*
Transverse Integrated Equations *570*
Polynomial Expansion Methods *571*
Analytical Methods *576*
Heterogeneous Flux Reconstruction *577*
15.4 Transverse Integrated Nodal Integral Transport Theory Models *577*
Transverse Integrated Integral Transport Equations *577*
Polynomial Expansion of Scalar Flux *581*
Isotropic Component of Transverse Leakage *581*
Double-P_n Expansion of Surface Fluxes *582*
Angular Moments of Outgoing Surface Fluxes *583*
Nodal Transport Equations *584*
15.5 Transverse Integrated Nodal Discrete Ordinates Method *585*
15.6 Finite-Element Coarse-Mesh Methods *586*
Variational Functional for the P_1 Equations *587*
One-Dimensional Finite-Difference Approximation *588*
Diffusion Theory Variational Functional *590*
Linear Finite-Element Diffusion Approximation in One Dimension *591*
Higher Order Cubic Hermite Coarse-Mesh Diffusion Approximation *593*
Multidimensional Finite-Element Coarse-Mesh Methods *595*
15.7 Variational Discrete Ordinates Nodal Method *595*
Variational Principle *596*
Application of the Method *604*
15.8 Variational Principle for Multigroup Diffusion Theory *605*
15.9 Single-Channel Spatial Synthesis *608*
15.10 Multichannel Spatial Synthesis *614*
15.11 Spectral Synthesis *616*

16 Space–Time Neutron Kinetics *623*
16.1 Flux Tilts and Delayed Neutron Holdback *623*
Modal Eigenfunction Expansion *624*
Flux Tilts *625*
Delayed Neutron Holdback *626*
16.2 Spatially Dependent Point Kinetics *626*
Derivation of Point Kinetics Equations *628*
Adiabatic and Quasistatic Methods *630*
Variational Principle for Static Reactivity *631*
Variational Principle for Dynamic Reactivity *632*
16.3 Time Integration of the Spatial Neutron Flux Distribution *635*
Explicit Integration: Forward-Difference Method *635*
Implicit Integration: Backward-Difference Method *636*
Implicit Integration: θ Method *637*
Implicit Integration: Time-Integrated Method *640*
Implicit Integration: GAKIN Method *642*

Alternating Direction Implicit Method *645*
Stiffness Confinement Method *648*
Symmetric Successive Overrelaxation Method *648*
Generalized Runge–Kutta Methods *649*
16.4 Stability *651*
Classical Linear Stability Analysis *651*
Lyapunov's Method *653*
Lyapunov's Method for Distributed Parameter Systems *655*
Control *657*
Variational Methods of Control Theory *657*
Dynamic Programming *659*
Pontryagin's Maximum Principle *661*
Variational Methods for Spatially Dependent Control Problems *662*
Dynamic Programming for Spatially Continuous Systems *665*
Pontryagin's Maximum Principle for a Spatially Continuous System *666*
16.5 Xenon Spatial Oscillations *667*
Linear Stability Analysis *669*
μ-Mode Approximation *671*
λ-Mode Approximation *672*
Nonlinear Stability Criterion *676*
Control of Xenon Spatial Power Oscillations *677*
Variational Control Theory of Xenon Spatial Oscillations *677*
16.6 Stochastic Kinetics *680*
Forward Stochastic Model *680*
Means, Variances, and Covariances *684*
Correlation Functions *685*
Physical Interpretation, Applications, and Initial and Boundary Conditions *686*
Numerical Studies *688*
Startup Analysis *690*

Appendices

A Physical Constants and Nuclear Data *695*

B Some Useful Mathematical Formulas *703*

C Step Functions, Delta Functions, and Other Functions *705*
C.1 Introduction *705*
C.2 Properties of the Dirac δ-Function *706*
Alternative Representations *706*
Properties *706*
Derivatives *707*

D Some Properties of Special Functions *709*

E Introduction to Matrices and Matrix Algebra *713*
E.1 Some Definitions *713*
E.2 Matrix Algebra *715*

F Introduction to Laplace Transforms *717*
F.1 Motivation *717*
F.2 "Cookbook" Laplace Transforms *719*

Index *723*