

---

**TABLE OF CONTENTS**

<u>Section</u>	<u>Title</u>	<u>Page</u>
CHAPTER 19	PROBABILISTIC RISK ASSESSMENT .....	19.1-1
19.1	Introduction .....	19.1-1
19.1.1	Background and Overview .....	19.1-1
19.1.2	Objectives .....	19.1-2
19.1.3	Technical Scope .....	19.1-3
19.1.4	Project Methodology Overview .....	19.1-4
19.1.5	Results .....	19.1-5
19.1.6	Plant Definition .....	19.1-6
	19.1.6.1 General Description .....	19.1-6
	19.1.6.2 AP600 Design Improvement as a Result of Probabilistic Risk Assessment Studies .....	19.1-6
	19.1.7 References .....	19.1-8
19.2	Internal Initiating Events .....	19.2-1
19.3	Modeling of Special Initiators .....	19.3-1
19.4	Event tree models .....	19.4-1
19.5	Support systems .....	19.5-1
19.6	Success criteria analysis .....	19.6-1
19.7	Fault tree guidelines .....	19.7.1
19.8	Passive Core Cooling System - Passive Residual Heat Removal .....	19.8-1
19.9	Passive Core Cooling System - Core Makeup Tanks .....	19.9-1
19.10	Passive Core Cooling System - Accumulator .....	19.10-1
19.11	Passive Core Cooling System - Automatic Depressurization System .....	19.11-1
19.12	Passive Core Cooling System - In-Containment Refueling Water Storage Tank .....	19.12-1
19.13	Passive Containment Cooling .....	19.13-1
19.14	Main and Startup Feedwater System .....	19.14-1
19.15	Chemical and Volume Control System .....	19.15-1
	19.15.1 System Description .....	19.15-1
	19.15.2 System Operation .....	19.15-1
	19.15.3 Performance during Accident Conditions .....	19.15-1
	19.15.4 Initiating Event Review .....	19.15-1
	19.15.5 System Logic Models .....	19.15-1
	19.15.5.1 Assumptions and Boundary Conditions .....	19.15-1
	19.15.5.2 Fault Tree Models .....	19.15-1
	19.15.5.3 Human Interactions .....	19.15-1
	19.15.5.4 Common Cause Failures .....	19.15-1
19.15.6	References .....	19.15-2
19.16	Containment Hydrogen Control System .....	19.16-1
19.17	Normal Residual Heat Removal System .....	19.17-1
19.18	Component Cooling Water System .....	19.18-1

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19.19	Service Water System . . . . .	19.19-1
19.20	Central Chilled Water System . . . . .	19.20-1
19.21	AC Power System . . . . .	19.21-1
19.22	Class 1E dc & UPS System . . . . .	19.22-1
19.23	Non-class 1E dc & UPS System . . . . .	19.23-1
19.24	Containment Isolation . . . . .	19.24-1
19.25	Compressed and Instrument Air System . . . . .	19.25-1
19.26	Protection and Safety Monitoring System . . . . .	19.26-1
19.27	Diverse Actuation System . . . . .	19.27-1
19.28	Plant Control System . . . . .	19.28-1
19.29	Common Cause Failure . . . . .	19.29-1
19.30	Human Reliability Analysis . . . . .	19.30-1
19.31	Other Event Tree Node Probabilities . . . . .	19.31-1
19.32	Data Analysis and Data Bank . . . . .	19.32-1
19.33	Fault Tree and Core Damage Quantification . . . . .	19.33-1
19.34	Severe Accident Phenomena Treatment . . . . .	19.34-1
	19.34.1 Introduction . . . . .	19.34-1
	19.34.2 Treatment of Physical Processes . . . . .	19.34-1
	19.34.2.1 In-Vessel Retention of Molten Core Debris . . . . .	19.34-2
	19.34.2.2 Fuel-Coolant Injection (Steam Explosions) . . . . .	19.34-2
	19.34.2.3 Hydrogen Combustion and Detonation . . . . .	19.34-3
	19.34.2.4 High-Pressure Melt Ejection . . . . .	19.34-4
	19.34.2.5 Core Debris Coolability . . . . .	19.34-5
	19.34.2.6 Elevated Temperatures (Equipment Survivability) . . . . .	19.34-5
	19.34.2.7 Summary . . . . .	19.34-6
	19.34.3 Analysis Method . . . . .	19.34-6
	19.34.4 Severe Accident Analysis . . . . .	19.34-6
	19.34.5 Summary . . . . .	19.34-6
	19.34.6 Insights and Conclusions . . . . .	19.34-6
	19.34.7 References . . . . .	19.34-7
19.35	Containment Event Tree Analysis . . . . .	19.35-1
19.36	Reactor Coolant System Depressurization . . . . .	19.36-1
	19.36.1 Introduction . . . . .	19.36-1
	19.36.2 Definition of High Pressure . . . . .	19.36-1
	19.36.3 References . . . . .	19.36-2
19.37	Containment Isolation . . . . .	19.37-1
19.38	Reactor Vessel Reflooding . . . . .	19.38-1
19.39	In-Vessel Retention of Molten Core Debris . . . . .	19.39-1
	19.39.1 Introduction . . . . .	19.39-1

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19.39.2	Summary of In-Vessel Retention ROAAM . . . . .	19.39-2
19.39.3	Reactor Coolant System Depressurization . . . . .	19.39-3
19.39.4	Reactor Cavity Flooding . . . . .	19.39-3
19.39.5	Reactor Vessel Insulation Design Concept . . . . .	19.39-3
	19.39.5.1 Description of Insulation . . . . .	19.39-4
	19.39.5.2 Determination of Forces on Insulation and Support System . . . . .	19.39-4
19.39.6	Reactor Vessel External Surface Treatment . . . . .	19.39-5
19.39.7	Reactor Vessel Failure . . . . .	19.39-5
19.39.8	Summary . . . . .	19.39-5
19.39.9	References . . . . .	19.39-6
19.40	Passive Containment Cooling . . . . .	19.40-1
19.41	Hydrogen Mixing and Combustion Analysis . . . . .	19.41-1
	19.41.1 Introduction . . . . .	19.41-1
	19.41.2 Controlling Phenomena . . . . .	19.41-1
	19.41.3 Major Assumptions and Phenomenological Uncertainties . . . . .	19.41-3
	19.41.3.1 Hydrogen Generation . . . . .	19.41-3
	19.41.3.2 Containment Pressure . . . . .	19.41-3
	19.41.3.3 Flammability Limits . . . . .	19.41-3
	19.41.3.4 Detonation Limits and Loads . . . . .	19.41-4
	19.41.3.5 Igniter System . . . . .	19.41-4
	19.41.3.6 Other Ignition Sources . . . . .	19.41-4
	19.41.3.7 Severe Accident Management Actions . . . . .	19.41-5
19.41.4	MAAP Hydrogen Cases . . . . .	19.41-5
19.41.5	Early Hydrogen Combustion . . . . .	19.41-5
	19.41.5.1 Hydrogen Generation Rates . . . . .	19.41-5
	19.41.5.2 Hydrogen Release Locations . . . . .	19.41-6
	19.41.5.3 Early Hydrogen Combustion Ignition Sources . . . . .	19.41-7
19.41.6	Diffusion Flame Analysis . . . . .	19.41-8
19.41.7	Early Hydrogen Detonation . . . . .	19.41-8
19.41.8	Sherman-Berman Methodology for Evaluating the Potential for Deflagration-to-Detonation Transition . . . . .	19.41-8
19.41.9	Deflagration in Time Frame 3 . . . . .	19.41-9
19.41.10	Detonation in Intermediate Time Frame . . . . .	19.41-9
19.41.11	Safety Margin Basis Containment Performance Requirement . . . . .	19.41-9
19.41.12	Summary . . . . .	19.41-9
19.41.13	References . . . . .	19.41-10
19.42	Conditional Containment Failure Probability Distribution . . . . .	19.42-1

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19.43	Release Frequency Quantification . . . . .	19.43-1
19.44	MAAP4.0 Code Description and AP600 Modeling . . . . .	19.44-1
19.45	Fission Product Source Terms . . . . .	19.45-1
19.46	Deleted . . . . .	19.46-1
19.47	Deleted . . . . .	19.47-1
19.48	Deleted . . . . .	19.48-1
19.49	Offsite Dose Evaluation . . . . .	19.49-1
19.50	Importance and Sensitivity Analysis . . . . .	19.50-1
19.51	Uncertainty Analysis . . . . .	19.51-1
19.52	RTNSS - Focused PRA Sensitivity Study . . . . .	19.52-1
19.53	Deleted . . . . .	19.53-1
19.54	Low Power and Shutdown PRA Assessment . . . . .	19.54-1
19.55	Seismic Margin Analysis . . . . .	19.55-1
19.55.1	Introduction . . . . .	19.55-1
19.55.2	Calculation of HCLPF Values . . . . .	19.55-1
19.55.2.1	Seismic Margin HCLPF Methodology . . . . .	19.55-1
19.55.2.2	Calculation of HCLPF Values . . . . .	19.55-1
19.55.3	Seismic Margins Model . . . . .	19.55-3
19.55.4	Calculation of Sequence and Plant HCLPF . . . . .	19.55-3
19.55.5	Sensitivity Analyses . . . . .	19.55-3
19.55.6	SMA Results and Insights . . . . .	19.55-3
19.55.7	References . . . . .	19.55-3
19.56	PRA Internal Flooding Analysis . . . . .	19.56-1
19.57	Internal Fire Analysis . . . . .	19.57-1
19.58	Winds, Floods, and Other External Events . . . . .	19.58-1
19.59	PRA Results and Insights . . . . .	19.59-1
19.59.1	Introduction . . . . .	19.59-1
19.59.2	Use of PRA in the Design Process . . . . .	19.59-3
19.59.2.1	Stage 1 - Use of PRA During the Early Design Stage . . . . .	19.59-4
19.59.2.2	Stage 2 - Preliminary PRA . . . . .	19.59-5
19.59.2.3	Stage 3 - AP600 PRA Submitted to NRC (1992) . . . . .	19.59-7
19.59.2.4	Stage 4 - PRA Report Revision 1 (1994) . . . . .	19.59-7
19.59.2.1	Stage 5 - PRA Report Revisions 2-13 (1995-1998) . . . . .	19.59-8
19.59.3	Core Damage Frequency from Internal Initiating Events at Power . . . . .	19.59-9
19.59.3.1	Dominant Core Damage Sequences . . . . .	19.59-11
19.59.3.2	Component Importances for At-Power Core Damage Frequency . . . . .	19.59-26
19.59.3.3	System Importances for At-Power Core Damage . . . . .	19.59-26

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19.59.3.4	System Failure Probabilities for At-Power Core Damage . . . . .	19.59-26
19.59.3.5	Common Cause Failure Importances for At-Power Core Damage . . . . .	19.59-26
19.59.3.6	Human Error Importances for At-Power Core Damage	19.59-26
19.59.3.7	Accident Class Importances . . . . .	19.59-26
19.59.3.8	Sensitivity and Importance Analyses Summary for At-Power Core Damage Frequency . . . . .	19.59-26
19.59.3.9	Summary of Important Level 1 At-Power Results . . . .	19.59-29
19.59.4	Large Release Frequency for Internal Initiating Events at Power . . . . .	19.59-32
19.59.4.1	Dominant Large Release Frequency Sequences . . . . .	19.59-32
19.59.4.2	Sensitivity Analyses for Containment Response . . . . .	19.59-38
19.59.4.3	Comparison of Initiating Event Importance for Core Damage Frequency and Large Frequency Release . . . .	19.59-38
19.59.4.4	Summary of Important Level 2 At-Power Results . . . .	19.59-39
19.59.5	Core Damage and Severe Release Frequency from Events at Shutdown . . . . .	19.59-41
19.59.5.1	Summary of Shutdown Level 1 Results . . . . .	19.59-41
19.59.5.2	Large Release Frequency for Shutdown and Low-Power Events . . . . .	19.59-45
19.59.5.3	Shutdown Results Summary . . . . .	19.59-45
19.59.6	Insights from Internal Flooding, Internal Fire and Seismic Margin Analyses . . . . .	19.59-45
19.59.6.1	Insights from Internal Flooding Assessment . . . . .	19.59-45
19.59.6.2	Insights from Internal Fire Assessment . . . . .	19.59-46
19.59.6.3	Insights from Seismic Margin Analysis . . . . .	19.59-48
19.59.7	Plant Dose Risk from Release of Fission Products . . . . .	19.59-49
19.59.8	Overall Plant Risk Results . . . . .	19.59-49
19.59.9	Plant Features Important to Reducing Risk . . . . .	19.59-50
19.59.9.1	Reactor Design . . . . .	19.59-51
19.59.9.2	Systems Design . . . . .	19.59-51
19.59.9.3	Instrumentation and Control Design . . . . .	19.59-54
19.59.9.4	Plant Layout . . . . .	19.59-55
19.59.9.5	Plant Structures . . . . .	19.59-55
19.59.9.6	Containment Design . . . . .	19.59-55
19.59.10	PRA input to the Design Certification Process . . . . .	19.59-59
19.59.10.1	PRA Input Reliability Assurance Program . . . . .	19.59-59
19.59.10.2	PRA Input to Tier 1 Information . . . . .	19.59-60

TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
	19.59.10.3 PRA Input to MMI / Human Factors / Emergency Response Guidelines . . . . .	19.59-60
	19.59.10.4 Summary of PRA Based Insights . . . . .	19.59-60
	19.59.10.5 Combined License Information . . . . .	19.59-60
19.59.11	References . . . . .	19.59-61
APPENDIX 19A MAAP4 ANALYSIS TO SUPPORT SUCCESS CRITERIA . . . . .		19A-1
APPENDIX 19B EX-VESSEL SEVERE ACCIDENT PHENOMENA . . . . .		19B-1
19B.1	Reactor Vessel Failure . . . . .	19B-2
19B.2	Direct Containment Heating . . . . .	19B-4
19B.3	Ex-Vessel Steam Explosions . . . . .	19B-5
19B.3.1	Ex-Vessel Steam Explosion Loads . . . . .	19B-5
19B.3.2	Structural Response to Steam Explosions . . . . .	19B-5
19B.3.2.1	Assessment of the Reactor Cavity Concrete and Steel Structures . . . . .	19B-5
19B.3.2.2	Reactor Pressure Vessel Response . . . . .	19B-6
19B.4	Core Concrete Interactions . . . . .	19B-6
19B.4.1	Containment Pressurization Due to Core Concrete Interactions . . . . .	19B-8
19B.5	Conclusions . . . . .	19B-9
19B.6	References . . . . .	19B-9
APPENDIX 19C DESIGN CHANGES THAT OCCURRED AFTER THE PRA ANALYSES WERE COMPLETED . . . . .		19C-1
APPENDIX 19D EQUIPMENT SURVIVABILITY ASSESSMENT . . . . .		19D-1
19D.1	Introduction . . . . .	19D-1
19D.2	Applicable Regulations and Criteria . . . . .	19D-1
19D.3	Definition of Controlled, Stable State . . . . .	19D-2
19D.4	Definition of Equipment Survivability Time Frames . . . . .	19D-3
19D.4.1	Time Frame 0 - Pre-Core Uncovery . . . . .	19D-3
19D.4.2	Time Frame 1 - Core Heatup . . . . .	19D-3
19D.4.3	Time Frame 2 - In-Vessel Severe Accident Phase . . . . .	19D-3
19D.4.4	Time Frame 3 - Ex-Vessel Severe Accident Phase . . . . .	19D-3
19D.5	Definition of Active Operation Time . . . . .	19D-4
19D.6	Equipment and Instrumentation for Severe Accident Management . . . . .	19D-5
19D.6.1	Time Frames 0 and 1 - Accident Initiation, Core Uncovery and Heatup . . . . .	19D-5

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
	19D.6.1.1 Injection into the RCS . . . . .	19D-5
	19D.6.1.2 Injection into Containment . . . . .	19D-6
	19D.6.1.3 Decay Heat Removal . . . . .	19D-6
	19D.6.1.4 Depressurize Reactor Coolant System . . . . .	19D-7
	19D.6.1.5 Depressurize Steam Generators . . . . .	19D-8
	19D.6.1.6 Containment Heat Removal . . . . .	19D-8
	19D.6.1.7 Containment Isolation . . . . .	19D-9
	19D.6.1.8 Hydrogen Control . . . . .	19D-9
	19D.6.1.9 Mitigate Fission Product Releases . . . . .	19D-9
	19D.6.1.10 Accident Monitoring . . . . .	19D-9
19D.6.2	Time Frame 2 - In-Vessel Core Melting and Relocation . . . . .	19D-10
	19D.6.2.1 Injection into the RCS . . . . .	19D-10
	19D.6.2.2 Injection into Containment . . . . .	19D-10
	19D.6.2.3 Decay Heat Removal . . . . .	19D-10
	19D.6.2.4 Depressurize RCS . . . . .	19D-11
	19D.6.2.5 Depressurize Steam Generators . . . . .	19D-11
	19D.6.2.6 Containment Heat Removal . . . . .	19D-11
	19D.6.2.7 Containment Isolation . . . . .	19D-11
	19D.6.2.8 Hydrogen Control . . . . .	19D-12
	19D.6.2.9 Mitigate Fission Product Releases . . . . .	19D-12
	19D.6.2.10 Accident Monitoring . . . . .	19D-12
19D.6.3	Time Frame 3 - Ex-Vessel Core Relocation . . . . .	19D-12
	19D.6.3.1 Injection into the RCS . . . . .	19D-12
	19D.6.3.2 Injection into Containment . . . . .	19D-12
	19D.6.3.3 Decay Heat Removal . . . . .	19D-13
	19D.6.3.4 Depressurize RCS . . . . .	19D-13
	19D.6.3.5 Depressurize Steam Generators . . . . .	19D-13
	19D.6.3.6 Containment Heat Removal . . . . .	19D-13
	19D.6.3.7 Containment Isolation and Venting . . . . .	19D-13
	19D.6.3.8 Combustible Gas Control . . . . .	19D-13
	19D.6.3.9 Mitigate Fission Product Releases . . . . .	19D-13
	19D.6.3.10 Accident Monitoring . . . . .	19D-14
19D.6.4	Summary of Equipment and Instrumentation . . . . .	19D-14
19D.7	Severe Accident Environments . . . . .	19D-14
19D.8	Assessment of Equipment Survivability . . . . .	19D-14
	19D.8.1 Approach to Equipment Survivability . . . . .	19D-14
	19D.8.1.1 Equipment Type . . . . .	19D-14
	19D.8.1.2 Equipment Location . . . . .	19D-14
	19D.8.1.3 Time Duration Required . . . . .	19D-15
	19D.8.1.4 Severe Environment Experiments . . . . .	19D-15

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19D.8.2	Equipment Located in Containment . . . . .	19D-15
19D.8.2.1	Differential Pressure and Pressure Transmitters . . . . .	19D-15
19D.8.2.2	Thermocouples . . . . .	19D-16
19D.8.2.3	Resistance Temperature Detectors (RTDs) . . . . .	19D-16
19D.8.2.4	Hydrogen Monitors . . . . .	19D-16
19D.8.2.5	Radiation Monitors . . . . .	19D-16
19D.8.2.6	Solenoid Valve . . . . .	19D-17
19D.8.2.7	Motor-Operated Valves . . . . .	19D-17
19D.8.2.8	Squib Valves . . . . .	19D-17
19D.8.2.9	Limit Switches . . . . .	19D-18
19D.8.2.10	Hydrogen Ignitors . . . . .	19D-18
19D.8.2.11	Electrical Containment Penetration Assemblies . . . . .	19D-18
19D.8.2.12	Cables . . . . .	19D-18
19D.8.2.13	Assessment of Equipment for Sustained Burning . . . . .	19D-19
19D.8.3	Equipment Located Outside Containment . . . . .	19D-19
19D.9	Conclusions of Equipment Survivability . . . . .	19D-19
19D.10	References . . . . .	19D-10
APPENDIX 19E SHUTDOWN EVALUATION REPORT . . . . .		19E-1
19E.1	Introduction . . . . .	19E-1
19E.1.1	Purpose . . . . .	19E-1
19E.1.2	Scope . . . . .	19E-1
19E.1.3	Background . . . . .	19E-1
19E.2.	Major Systems Designed to Operate During Shutdown . . . . .	19E-2
19E.2.1	Reactor Coolant System . . . . .	19E-2
19E.2.1.1	System Description . . . . .	19E-2
19E.2.1.2	Design Features to Address Shutdown Safety . . . . .	19E-2
19E.2.2	Steam Generator and Feedwater Systems . . . . .	19E-7
19E.2.2.1	System Description . . . . .	19E-7
19E.2.2.2	Design Features to Address Shutdown Safety . . . . .	19E-7
19E.2.3	Passive Core Cooling System . . . . .	19E-8
19E.2.3.1	System Description . . . . .	19E-8
19E.2.3.2	Design Features to Address Shutdown Safety . . . . .	19E-8
19E.2.3.3	Shutdown Operations . . . . .	19E-11
19E.2.4	Normal Residual Heat Removal System . . . . .	19E-12
19E.2.4.1	System Description . . . . .	19E-12
19E.2.4.2	Design Features to Address Shutdown Safety . . . . .	19E-12
19E.2.5	Component Cooling and Service Water Systems . . . . .	19E-15



## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19E.2.6	Containment Systems . . . . .	19E-15
	19E.2.6.1 System Description . . . . .	19E-15
	19E.2.6.2 Design Features to Address Shutdown Safety . . . . .	19E-15
19E.2.7	Chemical and Volume Control System . . . . .	19E-16
	19E.2.7.1 System Description . . . . .	19E-16
	19E.2.7.2 Design Features to Address Shutdown Safety . . . . .	19E-16
19E.2.8	Spent Fuel Pool Cooling System . . . . .	19E-17
	19E.2.8.1 System Description . . . . .	19E-17
	19E.2.8.2 Design Features to Address Shutdown Safety . . . . .	19E-17
19E.2.9	Control and Protection Systems . . . . .	19E-18
19E.3	Shutdown Maintenance Guidelines and Procedures . . . . .	19E-18
19E.3.1	Maintenance Guidelines and Insights Important to Reducing Shutdown Risk . . . . .	19E-18
	19E.3.1.1 Availability Requirements for Safety-Related Systems . .	19E-19
	19E.3.1.2 Availability Guidelines for Regulatory Treatment of Nonsafety Related (RTNSS) Important Systems . . . .	19E-19
	19E.3.1.3 Reactor Coolant System Precautions and Limitations at Shutdown . . . . .	19E-19
19E3.2	Shutdown Risk Management . . . . .	19E-22
19E3.3	Shutdown Emergency Response Guidelines Overview . . . . .	19E-22
19E.4.	Safety Analyses and Evaluations . . . . .	19E-23
19E.4.1	Introduction . . . . .	19E-23
	19E.4.1.1 Matrix of Tier 2 Information Chapter 15 Events . . . . .	19E-23
	19E.4.1.2 Adequacy of Codes Used for Analyses from Shutdown Conditions . . . . .	19E-24
19E.4.2	Increase in Heat Removal from the Primary System . . . . .	19E-26
	19E.4.2.1 Feedwater System Malfunctions Which Increase Heat Removal from the Primary System . . . . .	19E-26
	19E.4.2.2 Excessive Increase in Secondary Steam Flow . . . . .	19E-27
	19E.4.2.3 Credible and Hypothetical Steamline Breaks . . . . .	19E-28
	19E.4.2.4 Inadvertant PRHR HX Operation . . . . .	19E-29
19E.4.3	Decrease in Heat Removal by the Secondary System . . . . .	19E-30
	19E.4.3.1 Loss of Load and Turbine Trip . . . . .	19E-30
	19E.4.3.2 Loss of ac Power . . . . .	19E-31
	19E.4.3.3 Loss of Normal Feedwater . . . . .	19E-31
	19E.4.3.4 Feedwater System Pipe Break . . . . .	19E-32
19E.4.4	Decrease in Reactor Coolant Flow Rate . . . . .	19E-32
	19E.4.4.1 Partial and Complete Loss of Forced RCS Flow . . . . .	19E-32
	19E.4.4.2 Reactor Coolant Pump Shaft Seizure or Break . . . . .	19E-33

## TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Title</u>	<u>Page</u>
19E.4.5	Reactivity and Power Distribution Anomalies . . . . .	19E-33
19E.4.5.1	Uncontrolled RCCA Bank Withdrawal from a Subcritical Condition . . . . .	19E-33
19E.4.5.2	Uncontrolled RCCA Bank Withdrawal at Power . . . . .	19E-34
19E.4.5.3	RCCA Misalignment . . . . .	19E-34
19E.4.5.4	Startup of an Inactive Reactor Coolant Pump at an Incorrect Temperature . . . . .	19E-35
19E.4.5.5	Chemical and Volume Control System Malfunction That Results in a Decrease in the Boron Concentration in the Reactor Coolant System . . . . .	19E-36
19E.4.5.6	Inadvertent Loading of a Fuel Assembly in an Improper Position . . . . .	19E-36
19E.4.5.7	RCCA Ejection . . . . .	19E-36
19E.4.6	Increase in Reactor Coolant System Inventory . . . . .	19E-36
19E.4.7	Decrease in Reactor Coolant System Inventory . . . . .	19E-37
19E.4.7.1	Inadvertent Opening of a Pressurizer Safety Valve or inadvertent Operation of the Automatic Depressurization System . . . . .	19E-37
19E.4.7.2	Failure of Small Lines Carrying Primary Coolant Outside Containment . . . . .	19E-38
19E.4.7.3	Steam Generator Tube Rupture in Lower Modes . . . . .	19E-38
19E.4.8	Loss-of-Coolant Accident Events in Shutdown Modes . . . . .	19E-39
19E.4.8.1	Double-ended Cold Leg Guillotine . . . . .	19E-41
19E.4.8.2	Inadvertent Actuation of Automatic Depressurization System Results . . . . .	19E-42
19E.4.8.3	Double-ended Direct Vessel Injection Line Break Results	19E-43
19E.4.8.4	Spectrum of Small-Break LOCAs . . . . .	19E-44
19E.4.8.5	Loss of RNS Cooling . . . . .	19E-45
19E.4.9	Radiological Consequences (Tier 2 Information Section 15.7 and Appendix 15A . . . . .	19E-50
19E.4.10	Other Evaluations and Analyses . . . . .	19E-51
19E.4.10.1	Low Temperature Overpressure Protection . . . . .	19E-51
19E.4.10.2	Shutdown Temperature Evaluation . . . . .	19E-51
19E.5	Technical Specifications . . . . .	19E-53
19E.5.1	Summary of Shutdown Technical Specifications . . . . .	19E-53
19E.5.2	Compliance with SECY-93-190 . . . . .	19E-53
19E.6	Shutdown Risk Evaluation . . . . .	19E-54
19E.7	Compliance with NUREG-1449 . . . . .	19E-54
19E.8	Conclusion . . . . .	19E-54
19E.9	References . . . . .	19E-54

## LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
19.55-1	Seismic Margins HCLPF Values .....	19.55-4
19.55-10	Sequence HCLPFs .....	19.55-10
19.55-12	Large Release HCLPFs .....	19.55-13
19.59-29	AP600 PRA Based Insights .....	19.59-66
19D-1	Definition of Equipment Survivability Time Frames .....	19D-21
19D-2	AP600 High Level Actions Relative to Accident Management Goals .....	19D-22
19D-3	Equipment and Instrumentation Operation Prior to End of Time Frame 1 - Core Uncovery and Heatup .....	19D-23
19D-4	Equipment and Instrumentation Operation Prior to End of Time Frame 2 - In Vessel Core Melting and Relocation .....	19D-25
19D-5	Equipment and Instrumentation Operation Prior to End of Time Frame 3 - Ex-Vessel Core Relocation .....	19D-27
19D-6	Sustained Hydrogen Combustion Survivability Assessment .....	19D-29
19E.2-1	Evaluation of a Loss of RNS at Mid-loop with no IRWST Injection .....	19E-57
19E.4.1-1	AP600 Accidents requiring Shutdown Evaluation or Analysis .....	19E-58
19E.4.8-1	Double Ended Cold Leg Guillotine Break Sequence of Events .....	19E-60
19E.4.8-2	Inadvertent ADS Actuation Sequence of Events .....	19E-61
19E.4.8-3	DEDVI Break Sequence of Events .....	19E-62
19E.4.8-4	Loss of RNS Cooling in Mode 4 with RCS Intact Sequence of Events .....	19E-63
19E.4.8-5	Loss of RNS Cooling in Mode 5 with RCS Open Sequence of Events .....	19E-64
19E.4.10-1	Sequence of Events Following a Loss of Normal Feedwater Flow with Condensate from the Containment Shell Being Returned to the IRWST .....	19E-65

## LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
19.39-5	Containment floodable region . . . . .	19.39-8
19.39-6	Containment Floodable Region - Expanded View . . . . .	19.39-9
19B-1	Illustration of Hinging Type of Failure Resulting in Rapid Melt Release . . . . .	19B-11
19B-2	Illustration of Localized Type of Failure Resulting in Slow Melt Release . . . . .	19B-12
19E.2-1	Reactor Coolant System Level Instruments Used During Shutdown . . . . .	19E-66
19E.2-2	IRWST Injection Flow Path . . . . .	19E-67
19E.2-3	AP600 Permanent Reactor Cavity Seal . . . . .	19E-68
19E.4.8-1	Mode 3 $C_D = 0.8$ DECLG Break, Break Flow Rates, Vessel and RCP Sides . . . . .	19E-69
19E.4.8-2	Mode 3 $C_D = 0.8$ DECLG Break, Pressurizer Pressure . . . . .	19E-70
19E.4.8-3	Mode 3 $C_D = 0.8$ DECLG Break, Upper Plenum Collapsed Liquid Level . . . . .	19E-71
19E.4.8-4	Mode 3 $C_D = 0.8$ DECLG Break, Downcomer Collapsed Liquid Level . . . . .	19E-72
19E.4.8-5	Mode 3 $C_D = 0.8$ DECLG Break, CMT Flowrates . . . . .	19E-73
19E.4.8-6	Mode 3 $C_D = 0.8$ DECLG Break, Core Collapsed Liquid Level . . . . .	19E-74
19E.4.8-7	Pressurizer Pressure, Inadvertent ADS Actuation . . . . .	19E-75
19E.4.8-8	Pressurizer Level, Inadvertent ADS Actuation . . . . .	19E-76
19E.4.8-9	Core Stack Mixture Level, Inadvertent ADS Actuation . . . . .	19E-77
19E.4.8-10	Loop 1 CMT to DVI Flow, Inadvertent ADS Actuation . . . . .	19E-78
19E.4.8-11	Downcomer Mixture Level, Inadvertent ADS Actuation . . . . .	19E-79
19E.4.8-12	Loop 1 IRWST Injection Flow, Inadvertent ADS Actuation . . . . .	19E-80
19E.4.8-13	Primary Mass Inventory, Inadvertent ADS Actuation . . . . .	19E-81
19E.4.8-14	Break Liquid Flow, DEDVI Break . . . . .	19E-82
19E.4.8-15	Pressurizer Pressure, DEDVI Break . . . . .	19E-83
19E.4.8-16	Loop 1, CMT to DVI flow, DEVDI Break . . . . .	19E-84
19E.4.8-17	Core Stack Mixture Level, DEVDI Break . . . . .	19E-85
19E.4.8-18	Loop 2, CMT to DVI Flow, DEVDI Break . . . . .	19E-86
19E.4.8-19	Downcomer Mixture level, DEVDI Break . . . . .	19E-87
19E.4.8-20	Primary Mass Inventory, DEVDI Break . . . . .	19E-88
19E.4.8.21	Pressurizer Pressure, 10-Inch Cold Leg Break . . . . .	19E-89
19E.4.8.22	CMT Injection Flow, 10-Inch Cold Leg Break . . . . .	19E-90
19E.4.8.23	Core Stack Mixture Level, 10-Inch Cold Leg Break . . . . .	19E-91
19E.4.8.24	Downcomer Mixture Level, 10-Inch Cold Leg Break . . . . .	19E-92
19E.4.8.25	Primary Mass Inventory, 10-Inch Cold Leg Break . . . . .	19E-93
19E.4.8-26	Core Outlet Fluid Temperature, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-94
19E.4.8-27	Pressurizer Pressure, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-95
19E.4.8-28	Pressurizer Mixture Level, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-96
19E.4.8-29	Core Stack Mixture Level, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-97
19E.4.8-30	Downcomer Mixture Level, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-98

## LIST OF FIGURES (Cont.)

<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
19E.4.8-31	CMT to DVI Flow, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-99
19E.4.8-32	CMT Mixture Level, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-100
19E.4.8-33	ADS Stages 1-3 Vapor Flow, Loss of RNS in Mode 4 with RCS Intact . . . .	19E-101
19E.4.8-34	ADS Stages 1-3 Liquid Flow, Loss of RNS in Mode 4 with RCS Intact . . . .	19E-102
19E.4.8-35	ADS Stage 4 Vapor Flow, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-103
19E.4.8-36	ADS Stage 4 Liquid Flow, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-104
19E.4.8-37	Loop 1 IRWST Injection Flow, Loss of RNS in Mode 4 with RCS Intact . . .	19E-105
19E.4.8-38	Primary Mass Inventory, Loss of RNS in Mode 4 with RCS Intact . . . . .	19E-106
19E.4.8-39	Core Outlet Fluid Temperature, Loss of RNS in Mode 5 with RCS Open . . .	19E-107
19E.4.8-40	Pressurizer Pressure, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-108
19E.4.8-41	Pressurizer Mixture Level, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-109
19E.4.8-42	ADS Stages 1-3 Vapor Flow, Loss of RNS in Mode 5 with RCS Open . . . .	19E-110
19E.4.8-43	ADS Stages 1-3 Liquid Flow, Loss of RNS in Mode 5 with RCS Open . . . .	19E-111
19E.4.8-44	Core Stack Mixture Level, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-112
19E.4.8-45	Downcomer Mixture Level, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-113
19E.4.8-46	Loop 1 Hot Leg Mixture Level, Loss of RNS in Mode 5 with RCS Open . . .	19E-114
19E.4.8-47	ADS Stage 4 Vapor Flow, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-115
19E.4.8-48	ADS Stage 4 Liquid Flow, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-116
19E.4.8-49	IRWST Injection Flow, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-117
19E.4.8-50	Primary Mass Inventory, Loss of RNS in Mode 5 with RCS Open . . . . .	19E-118
19E.4.10-1	Shutdown Temperature Evaluation, RCS Temperature (Loop with PRHR HX)	19E-119
19E.4.10-2	Shutdown Temperature Evaluation, RCS Temperature Loop without PRHR HX) . . . . .	19E-120
19E.4.10-3	Shutdown Temperature Evaluation, PRHR Heat Transfer . . . . .	19E-121
19E.4.10-4	Shutdown Temperature Evaluation, PRHR Flowrate . . . . .	19E-122
19E.4.10-5	Shutdown Temperature Evaluation, IRWST Heatup . . . . .	19E-123
19E.4.10-6	Shutdown Temperature Evaluation, IRWST Water Level . . . . .	19E-124
19E.4.10-7	Shutdown Temperature Evaluation, RCS Temperature, No Condensate Return to IRWST . . . . .	19E-125