

TABLE OF CONTENTS

INTRODUCTION	5
SUMMARY SEQUENCE OF EVENTS	8
CORE DAMAGE	13
THERMAL HYDRAULICS	14
CHEMISTRY	16
TMI-2 DECAY POWER AND FISSION PRODUCTS	22
CONTAINMENT: TRANSPORT OF RADIOACTIVITY FROM THE TMI-2 CORE TO THE ENVIRONS	23
RADIATION RELEASES AND VENTING OF TANKS FRIDAY MORNING, MARCH 30, 1979	24
ALTERNATIVE EVENT SEQUENCES	26
TMI-2 SITE MANAGEMENT	32
SELECTION, TRAINING, QUALIFICATION, AND LICENSING OF THREE MILE ISLAND REACTOR OPERATING PERSONNEL	34
CONTROL ROOM DESIGN AND PERFORMANCE	36
TECHNICAL ASSESSMENT OF OPERATING, ABNORMAL, AND EMERGENCY PROCEDURES	38
SIMULATORS -- TRAINING AND ENGINEERING DESIGN	41
EQUIPMENT CONSERVATISM	49
SAFETY DESIGN MARGINS	51
PILOT-OPERATED RELIEF VALVE DESIGN AND PERFORMANCE	54
CONDENSATE POLISHING SYSTEM	56
QUALITY ASSURANCE	58
PRE- AND POST-ACCIDENT SECURITY STATUS AT THREE MILE ISLAND	60

CLOSED EMERGENCY FEEDWATER VALVES	62
PAST ACCIDENTS IN NUCLEAR REACTOR FACILITIES	64
RECOVERY: TMI-2 CLEANUP AND DECONTAMINATION	70
COST OF THE ACCIDENT	76
IODINE FILTER PERFORMANCE	83
WASH 1400	84
APPENDIX A -- MELTDOWN: A PERSPECTIVE IN HISTORY	87
APPENDIX B -- DEFINITION AND APPLICATION OF "SAFETY-RELATED"	89

TABLE OF CONTENTS

INTRODUCTION	94
A. PLANT CONDITIONS PRIOR TO THE INITIATING EVENT	95
B. THE INITIATING EVENT	96
C. INITIAL PLANT RESPONSE TO THE ACCIDENT.....	97
D. DECLARATION OF EMERGENCY AND STABILIZATION OF THE PLANT	106
APPENDIX A -- DECAY HEAT REMOVAL METHODS -- TMI-2	108
APPENDIX B -- SIGNIFICANT EQUIPMENT PROBLEMS	115
APPENDIX C -- SUMMARY OF INCORRECT OPERATIONAL ACTIONS	120
FIGURES	126

TABLE OF CONTENTS

SUMMARY AND FINDINGS	4
INTRODUCTION	6
ZIRCONIUM REACTIONS	7
Findings	8
FISSION PRODUCTS	9
Findings	11
HYDROGEN BUBBLE	12
Hydrogen Burned in Containment	12
Hydrogen Inventory	13
Getting Rid of the Hydrogen Bubble	14
Hydrogen Explosion in the Reactor?	14
Findings	16
MAXIMUM HYDROGEN EXPLOSION IN THE CONTAINMENT BUILDING	18
Findings.....	19
HYDROGEN RECOMBINATION	21
Findings	22
REFERENCES	23

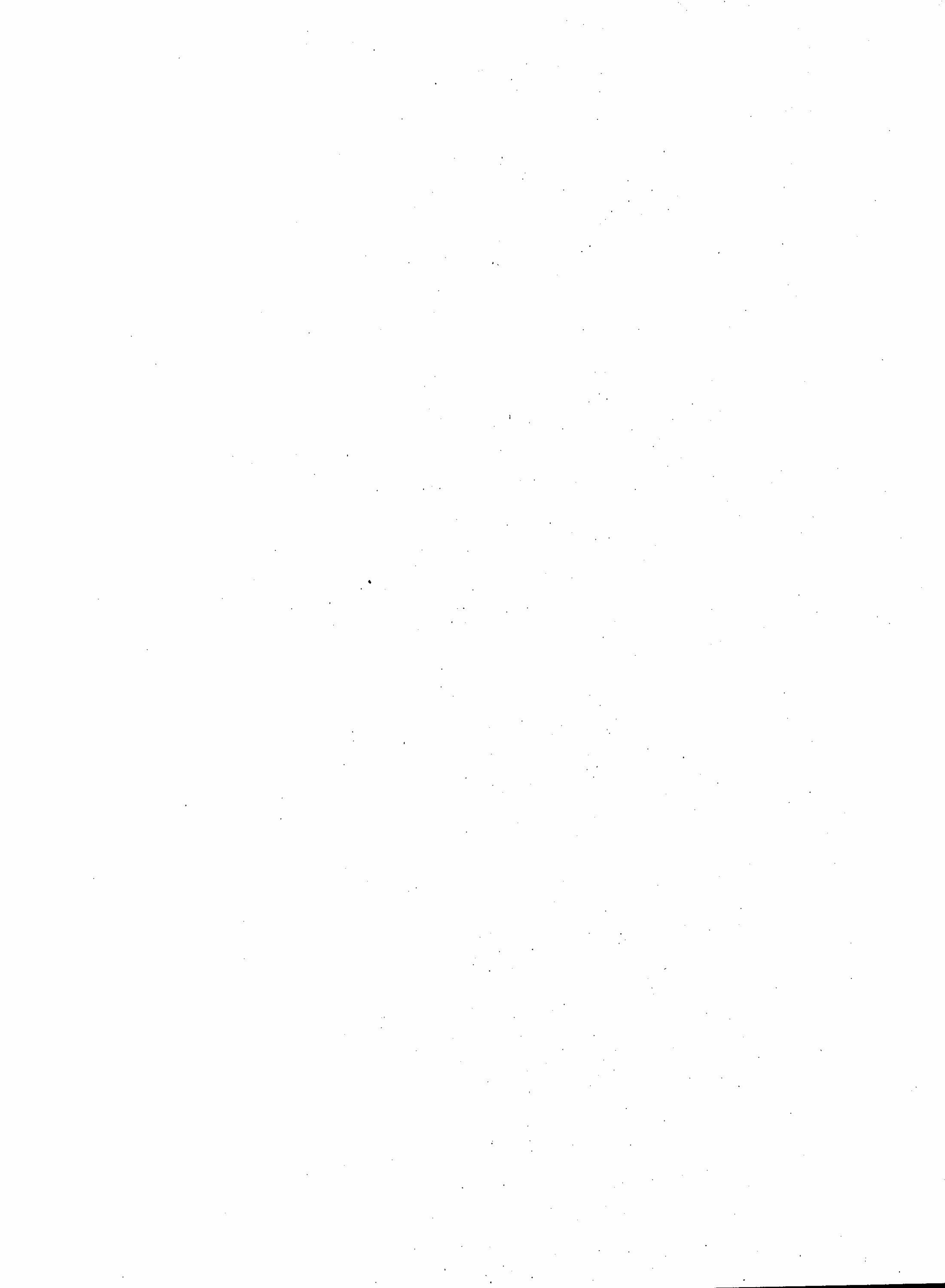


TABLE OF CONTENTS

SUMMARY AND FINDINGS	30
INTRODUCTION	31
ANALYSIS OF REACTOR TRANSIENTS AT TMI-2	32
Finding	37
STOPPING THE REACTOR COOLANT PUMPS	38
Findings	38
NATURAL CIRCULATION	40
Findings	42
REFERENCES	44

TABLE OF CONTENTS

SUMMARY AND FINDINGS	50
INTRODUCTION	52
THE COURSE OF DAMAGE	53
Rupture of the Fuel Rods	54
Oxidation of the Zirconium Clad	54
Release of Fission Products	55
THERMAL HISTORY OF THE CORE	57
MOLTEN FUEL	60
REFERENCES	61

TABLE OF CONTENTS

WASH 1400 SUMMARY	68
THREE MILE ISLAND EVENTS	70
WASH 1400 Accidents vs. Three Mile Island Accident	72
WASH 1400 PREDICTIONS	73
Lessons That Should Have Been Learned From WASH 1400	74
POTENTIAL ACCIDENTS RESULTING FROM TRANSIENTS IN B&W REACTORS.....	76
General Description of Possible Outcomes of PWR Transients	76
Outcome of Transients in Westinghouse PWRs	77
Outcome of Transients in B&W Reactors	78
Significant Out Come of B&W Transients	80
USE OF EVENT TREES IN SAFETY ANALYSIS	81
FINDINGS FROM STUDY OF WASH 1400	84
FIGURES	85
NOTES	88

TABLE OF CONTENTS

INTRODUCTION, FINDINGS, AND SUMMARY	95
CHRONOLOGY OF EVENTS	100
SPECIFIC ALTERNATIVE EVENT SEQUENCES	104
Case 1 - Effect on the TMI Accident if Auxiliary Feedwater Was Available as Designed	104
Case 2 - Effect on the TMI Accident of Pilot-Operated Relief Valve (PORV) Closing as Designed	104
Case 3 - Effect on the TMI Accident of Not Throttling High Pressure Injection (HPI).....	105
Case 4 - Effect on the TMI Accident Radioactivity Release if Containment Isolation Occurred within 10 Minutes....	105
Case 5 - Effect on the TMI Accident of Properly Functioning Iodine Filters.....	106
Case 6 - Auxiliary Feedwater Remains Unavailable.....	106
Case 7 - PORV Remains Open at 142 Minutes.....	107
Case 8 - PORV Remains Closed at 192.5 Minutes.....	108
Case 9 - The HPI Remains Throttled.....	110
Case 10 - Containment Sump Pump Operation Continues.....	110
Case 11 - Containment Not Isolated.....	111
Case 12 - Greater Deterioration of the Iodine Filters in the Auxiliary Building.....	111
Case 13 - All Hydrogen from Core Damage Burned in the Containment Building.....	112
Case 14 - Effect on the TMI Accident if an Adequate Hydrogen Recombiner had been Available.....	113
Case 15 - Effect of Different Meteorological Conditions in the Vicinity of the Plant Site.....	114
Case 16 - Criticality of the TMI-2 Core.....	114
Case 17 - The Effect on the TMI-2 Accident if the Core Fuel Were in Equilibrium at End-of-Cycle.....	115
HYPOTHETICAL FUEL-MELTING ACCIDENTS	118

REFERENCES	123
APPENDIX A -- Consequences of a Hypothetical Fuel-Melting Accident at TMI.....	125
APPENDIX B -- Fuel Damage Estimates with the Transient Reactor Analysis Code (TRAC).....	137
APPENDIX C -- Potential for Damage to Reactor Vessel or Containment due to Steam Explosions Associated with Fuel-Melting Accidents.....	149
APPENDIX D -- Penetration of the Concrete Basemat.....	157
APPENDIX E -- Fission Products Within the Reactor Containment Building as a Consequence of the Hypothetical Fuel-Melting Accident	163
APPENDIX F -- Behavior of Iodine Under Accident Conditions at Three Mile Island.....	175
APPENDIX G -- An Estimate of Airborne Fission Products in the TMI-2 Containment Atmosphere for Postulated Fuel Melting	195

Table of Contents

	<u>Page</u>
I. INTRODUCTION	1
II. SUMMARY AND CONCLUSIONS	2
III. ASSUMED ACCIDENT CONDITIONS	4
IV. AIRBORNE HALOGENS IN THE CONTAINMENT ATMOSPHERE	7
V. AIRBORNE PARTICULATE FISSION PRODUCTS IN CONTAINMENT ATMOSPHERE	16
VI. REFERENCES	33

TABLE OF CONTENTS

I.	SUMMARY	4
II.	INTRODUCTION	8
III.	ANALYSIS OF SELECTION, TRAINING, QUALIFICATION, LICENSING, AND STAFFING	9
	Requirements for Selction, Training, Licensing, and Staffing of Reactor Operating Personnel	9
	Implementation of Requirements	10
	Evaluation of Operator, Selection, Training, Lincensing, and Staffing	28
	Nuclear Regulatory Commission	28
	Baboock and Wilcox	35
	Three Mile Island	60
IV.	FINDINGS	85
	ACRONYMS	89
	NOTES	90
	REFERENCES	97
	APPENDICES	98

TABLE OF CONTENTS

SUMMARY	105
INTRODUCTION	107
ANALYSIS	108
Operating Procedure 2102-2.1, Power Operations, Revision 11, March 20, 1979	108
Operating Procedure 2103-1.3, Pressurizer Operations, Revision 3, July 19, 1978	109
Operating Procedure 2103-1.4, Reactor Coolant Pump Operations, Revision 6, Aug. 16, 1979	110
Operating Procedure 2104-1.3, Decay Heat Removal System, Revision 11, June 23, 1978	111
Operating Procedure 2102-3.3, Decay Heat Removal via OTSG, Revision 6, April 17, 1978	112
Operating Procedure 2104-1.1, Core Flooding System, Revision 8, Sept. 29, 1978	113
Operating Procedure 2104-1.4, Reactor Building Spray, Revision 3, April 18, 1978	113
Operating Procedure 2104-6.3, Emergency Feedwater, Revision 4, June 8, 1978	113
Operating Procedure 2105-1.3, Safety Features Actuation System, Revision 2, Oct. 25, 1978	114
Abnormal Procedure 2202-2.2, Turbine Trip, Revision 7, Oct. 25, 1978	114
Abnormal Procedure 2203-2.6, Post-Accident Hydrogen Control, Revision 1, June 23, 1978	115
Emergency Procedure 2202-2.2, Loss of Steam Generator Feed, Revision 3, Oct. 13, 1978	116
Emergency Procedure 2202-1.5, Pressurizer System Failure, Revision 3, Sept. 29, 1978	117
Emergency Procedure 2202-1.1, Reactor Trip, Revision 6, Oct. 25, 1978	120
Emergency Procedure 2202-1.3, Loss of Reactor Coolant/ Reactor Coolant System Pressure, Revision 11, Oct. 6, 1978 ...	121

FINDINGS	126
ACRONYMS	129
APPENDIX A -- Three Mile Island Nuclear Station, Unit #2 Emergency Procedure 2202-1.5, Pressurizer System Failure	130
APPENDIX B -- Three Mile Island Nuclear Station, Unit #2 Emergency Procedure 2202-1.3, Loss of Reactor Coolant/Reactor Coolant System Pressure	142
APPENDIX C -- Duke Power Company, Oconee Nuclear Station, Loss of Reactor Coolant	168

TABLE OF CONTENTS

SUMMARY	180
INTRODUCTION	183
ANALYSIS	184
General	184
Nuclear Regulatory Commission Requirements and Industry Guidance	184
Description of the TMI-2 Control Room	185
Evaluation	188
Performance of the Control Room During the Accident	190
Aids That Might Have Assisted the Operator	191
FINDINGS	194
NOTES	195
APPENDIX A: REGULATORY AND INDUSTRY GUIDANCE REGARDING CONTROL ROOM DESIGN	196
REFERENCES	202

TABLE OF CONTENTS

I.	SUMMARY.....	4
II.	INTRODUCTION.....	6
	A. Purpose of Report.....	6
	B. Classical Roles	6
	C. NRC Requirements.....	7
	D. Organizations Involved	8
	E. Scope of Investigation.....	9
III.	ANALYSIS.....	11
	A. Requirements and Regulations.....	11
	B. The Operational Quality Assurance Program.....	21
	C. Procedure Systems, Generation, and Execution.....	71
	D. Nonconformance Reporting System.....	77
	E. Configuration Control.....	87
	F. Comparison of the Nuclear Assurance Program to That of Other Safety Critical Programs.....	95
IV.	FINDINGS AND CONCLUSIONS.....	100
	A. Specific Findings.....	100
	B. Conclusions.....	105
	ACRONYMS.....	107
	METHODOLOGY.....	109
	REFERENCES.....	110

TABLE OF CONTENTS

SUMMARY	124
INTRODUCTION	126
ANALYSIS	128
Related Activity Just Prior to the Accident	128
Reported Post-Accident Inspection Results	128
Pre-Accident Related Experience	129
Design	131
Procedures	133
Records Search and Quality Control	134
Relation to Another Equipment Problem	135
Post-Accident Investigation of Condensate Polisher	135
DETAILED FINDINGS	137
SIGNIFICANT FINDINGS AND CONCLUSION	139
REFERENCES	140
APPENDICES	141

TABLE OF CONTENTS

SUMMARY	148
Findings	148
Conclusions	149
INTRODUCTION	150
Analysis Plans	150
General Description of Feedwater System	151
ANALYSIS	152
Material from Reference 1	152
Analyses in Conjunction With Those of Reference 1	154
Additional Analyses	159
FINDINGS AND CONCLUSIONS	163
Findings	163
Conclusions	164
REFERENCES	165
APPENDICES	166

TABLE OF CONTENTS

SUMMARY	174
Findings	174
Conclusions	175
INTRODUCTION	176
Role of the PORV in the TMI Accident	176
The PORV: What is It? Where is It?	176
Long History of PORV Failures	177
Design, Review, Standards, and Verification	179
Scope of the Investigation	179
ANALYSIS	182
General Design Considerations	182
PORV Design Requirements	183
Codes and Standards	186
Inspection Requirements	188
PORV Failures Other Than in B&W Units	189
PORV Failures in B&W Units Other Than TMI-2	191
PORV Failures at TMI-2	198
Configuration Control at TMI-2	200
Role of the PORV in the TMI-2 Accident	201
Performance and Reliability of PORV	202
Single Failure Criterion and the PORV	206
FINDINGS AND CONCLUSIONS	209
ACRONYMS	211
FIGURES	213
ATTACHMENTS	219

Attachment 1	-- Letter, J. Schuyler to M. Green, July 24, 1979, re: ANSI B16.41	219
Attachment 2	-- Memorandum for record, visit to Plant, Dresser Industries, Alexandria, La., September 20, 1979	220
Attachment 3	-- Memorandum for record, visit to Dresser Industries, Alexandria, La., September 25, 1979	222
Attachment 4	-- B&W inspection report, March 13-14, 1973, at Dresser Industries	227
Attachment 5	-- Memorandum (NRC), R. Bosnak to W. Anderson, September 26, 1978, re: IWV1100	228
Attachment 6	-- The Beznau, Switzerland, Incident, August 20, 1974	229
Attachment 7	-- The Palisades Incident, September 8, 1971 ..	230
Attachment 8	-- Arkansas Nuclear One-1 Incident, Before September 1974	231
Attachment 9	-- Memorandum (B&W), G. Fairburn to D. H. Roy, May 9, 1979	232
Attachment 10	-- GPU Startup Problem Report 2718, March 30, 1978	233
Attachment 11	-- Memorandum Burns and Roe, W03475, Jersey Central Power and Light Company, Three Mile Island Nuclear Station Unit 2, Electromatic Relief Valve, RC-R2 Controls, August 1, 1979	235
Attachment 12	-- Elementary Diagram, B&W Diagram 113658 C1 ..	238
Attachment 13	-- RC-RV2 Logic, B&W Diagram 134175	239
Attachment 14	-- Control Logic, FSAR Figure 7.6-7	240
Attachment 15	-- Engineering Change Memorandum S5934 and B&W SPR #183	241
Attachment 16	-- Letter on Single Failure Cirteria, Institute of Electrical and Electronic Engineers, April 19, 1976	248
Attachment 17	-- Excerpt from "Generic Items List" Advisory Committee on Reactor Safeguards	250

Attachment 18	-- Excerpt from "Abnormal Occurrences Reported to Congress"	251
Attachment 19	-- Excerpts from "Unresolved Safety Issues Reported to Congress"	253
REFERENCES	255
APPENDICES	257

TABLE OF CONTENTS

I.	EXECUTIVE SUMMARY	263
II.	PURPOSE AND SUMMARY	265
III.	DESCRIPTION OF ACCIDENT	267
IV.	DESCRIPTION OF CORE BEHAVIOR	272
V.	PATHWAYS FROM THE REACTOR PRIMARY SYSTEM	274
	Let-Down/Make-Up System	274
	Reactor Building Sump to the Auxiliary Building Sump	276
	Reactor Coolant Drain Tank to Reactor Coolant Bleed Holdup Tanks	278
	Reactor Coolant Drain Tank Vent to Vent Gas Header in the Auxiliary Building	280
	Reactor Coolant Drain Tank Vent to the Reactor Coolant Bleed Holdup Tanks	280
	Reactor Coolant Pump Seals to Seal Return Coolers in the Auxiliary Building	283
	Let-Down Coolers Cooling Water	283
	Leakage Coolers Cooling Water	283
VI.	INTERCONNECTION OF LIQUID AND GAS SYSTEM	286
VII.	RADIATION MONITORING IN THE PLANT	290
VIII.	POTENTIAL PRESSURE TRANSIENTS IN EACH SYSTEM	295
	Let-Down/Make-Up System	295
	Reactor Building Sump to Auxiliary Building Sump	296
	Reactor Coolant Drain Tank to the Reactor Coolant Bleed Holdup Tanks	296
	Reactor Coolant Drain Tank Vent to Vent Gas Header in Auxiliary Building Sump	297
	Reactor Coolant Drain Tank Vent to Reactor Coolant Bleed Holdup Tanks	298
	Reactor Coolant Pump Seals to the Seal Return Coolers in Auxiliary Building	299

Let-Down Coolers Cooling Water.....	299
Leakage Coolers Cooling Water	299
Interconnection Pressure Transients	299
IX. RESPONSE OF RADIATION MONITORS DURING THE ACCIDENT	301
X. DISCUSSION AND RATING OF POTENTIAL PATHWAYS	307
XI. MOST PROBABLE PATHWAY	309
APPENDIX A -- DISCUSSION OF METROPOLITAN EDISON/GENERAL PUBLIC UTILITIES CORPORATION'S PRELIMINARY REPORT ON SOURCES AND PATHWAYS OF TMI-2 RELEASES OF RADIOACTIVE MATERIAL, JULY 16, 1979, REVISION 0	310
APPENDIX B -- DISCUSSION OF THE NUCLEAR REGULATORY COMMISSION'S EVALUATION OF RADIOACTIVE RELEASE PATHWAYS	311
APPENDIX C -- COMPARISON OF RATING OF PATHWAYS OF RADIOACTIVITY TO THE ENVIRONS	312
REFERENCES	313

TABLE OF CONTENTS

I. FINDINGS.....332

II. INTRODUCTION.....333

III. OVERVIEW.....334

IV. EXPERIENCE AND PROGRESS TO DATE.....336

V. RADIOACTIVE WASTE DISPOSAL.....339

VI. DISCUSSION AND CONCLUSIONS.....342

METHODOLOGY343

REFERENCES.....344