AP1000 Probabilistic Risk Assessment

Presentation to NRC Staff

May 1, 2002

Agenda for Today's Meeting

• 9:00	Introduction / Objectives	Mike Corletti
• 9:20	Overview of AP1000 Plant	Terry Schulz
• 10:20	Overview of AP1000 PRA	Selim Sancaktar
• 10:40	Level 1 PRA	Selim Sancaktar
• Lunch Break		
• 2:00	Level 2 and 3 PRA	Jim Scobel
• 3:00	Success Criteria	Terry Schulz
• 4:00	Feedback from Staff	
• 4:30	Public Comment	

AP1000 Design Certification

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Phased Approach to AP1000 Licensing

- **Phase 1**
  - –Establish goals and estimate for Prelicensing Review
  - –Westinghouse prepare submittals to support goals
- **Phase 2**
  - –NRC perform Prelicensing Review
  - –NRC estimate Cost and Schedule for AP1000 Design Certification
  - –Westinghouse develop Safety Analysis Report
- **Phase 3**
  - –NRC perform Design Certification Review

Results from Pre-Certification Review (Phase 2)

Pre-Certification Review Complete

- SECY-02-0059
  - –Design Acceptance Criteria can be used for AP1000
    - –Main Control Room and I&C - Same approach as AP600
    - –Piping DAC approach is acceptable
      - –Detailed review will be performed as part of Design Certification
- March 25th Letter to Westinghouse on Remaining Issues
  - –AP600 tests are applicable to AP1000
  - –AP600 analysis codes validated to these tests can also be used for AP1000
    - –Treatment of entrainment phenomenon in the upper plenum / hot leg in SBLOCA analysis will be addressed in Design Certification review
- ACRS Letter Endorsing AP1000 Conclusions

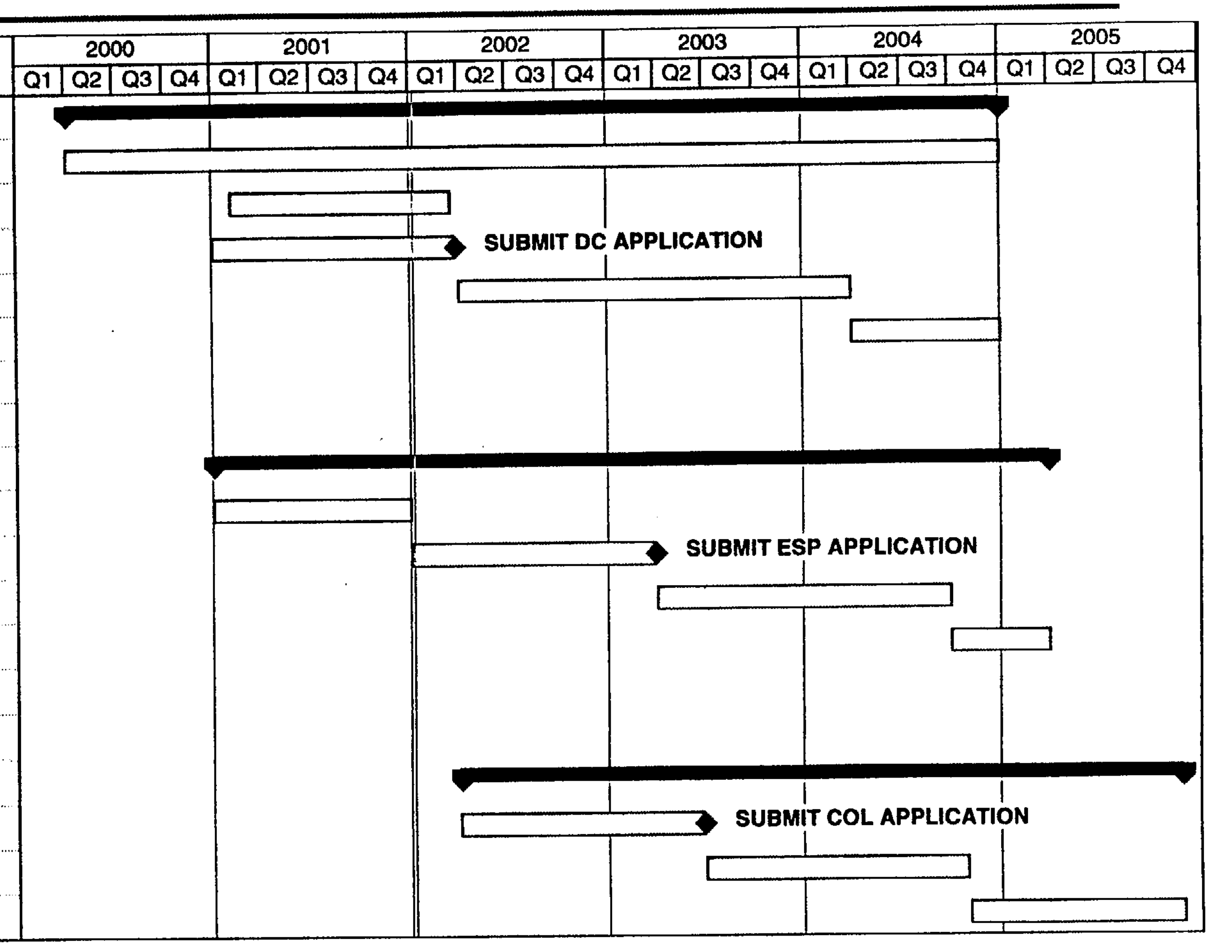
AP1000 Design Certification Application

Submitted March 28, 2002

- AP1000 Design Control Document (DCD)
  - –Tier 1 Information
    - –Inspections, Tests, Analysis and Acceptance Criteria (ITAAC)
  - –Tier 2 - Information
    - –Standard Safety Analysis Report
    - –Technical Specifications
    - –PRA Insights
- AP1000 PRA Report submitted with application

Schedule for AP1000 Design Certification

ID	Task Name
1	**AP1000 Design Certification**
2	Engineering Design
3	NRC Pre-Certification Review
4	Prepare Safety Analysis Report
5	NRC Review (Issue FDA)
6	Hearings / Rule (Issue DC)
7	
8	
9	**U.S. Utilities Early Site Permit**
10	Decide on Plan and Select Site
11	Prepare Application
12	NRC Review
13	Hearings (Issue ESP)
14	
15	
16	**U.S. Utility Combined Op License**
17	Prepare Application
18	NRC Review (Issue SER)
19	Hearings (Issue COL)



Overview of AP1000 Plant

Terry Schulz
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AP1000 Design Objectives

- **Reduce Cost by Increasing Plant Power Rating**
  - –Obtain a capital cost that can compete in U.S. market $1000/KWe for n^{th} twin plant
- **Retain AP600 Objectives and Design Detail**
  - –Increase the capability/capacity within "space constraints" of AP600
  - –Retain credibility of "proven components"
  - –Retain the basis for the cost estimate, construction schedule and modularization scheme
- **Retain AP600 Licensing Basis**
  - –Meet regulatory requirements for Advanced Passive Plants
  - –Accept AP600 policy issues

AP1000 Design Features

- Integrated Power Plant Design
- Proven Power Producing Components (Reactor, Fuel, ...)
- Simplified RCS Loops with Canned Motor Pumps
- Simplified Passive Safety Systems
  - –Increase safety margins and address severe accidents
- Simplified Nonsafety DID Systems
- Microprocessor, Digital Technology Based I&C
- Compact Control Room, Electronic Operator Interface
- Optimized Plant Arrangement
  - –Construction, Operation, Maintenance, Safety, Cost
- Extensive Use of Modular Construction

AP600 to AP1000 Design Changes

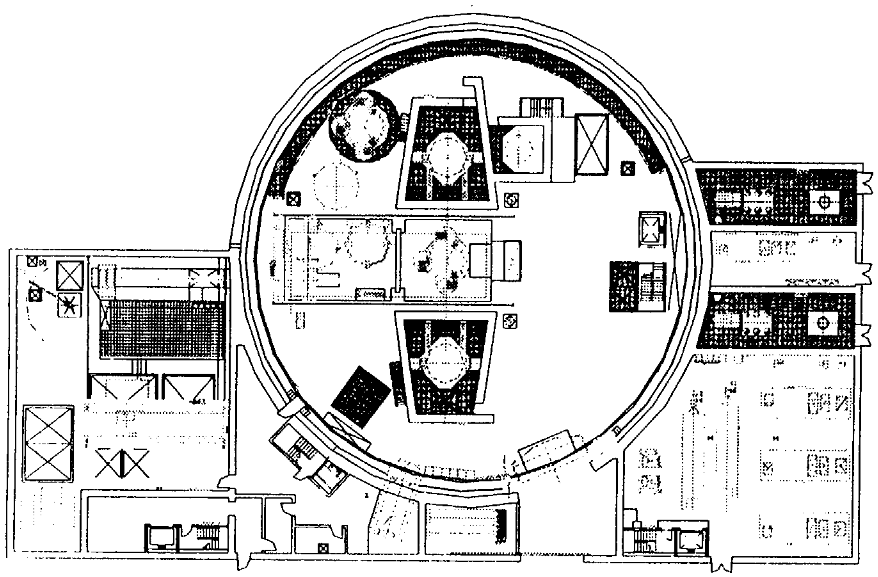
- **Increase Core Length & Number of Assemblies**
- **Increase Size of Key NSSS Components**
  - –Increased height of Reactor Vessel
  - –Steam Generators (Δ125, similar to ANO replacement)
  - –Larger canned RCPs (variable speed controller)
  - –Larger Pressurizer
- **Increase Containment Height**
- **Some Capacity Increases in Passive Safety System Components**
- **Turbine Island Capacity Increased for Power Rating**

Retained Nuclear Island Footprint

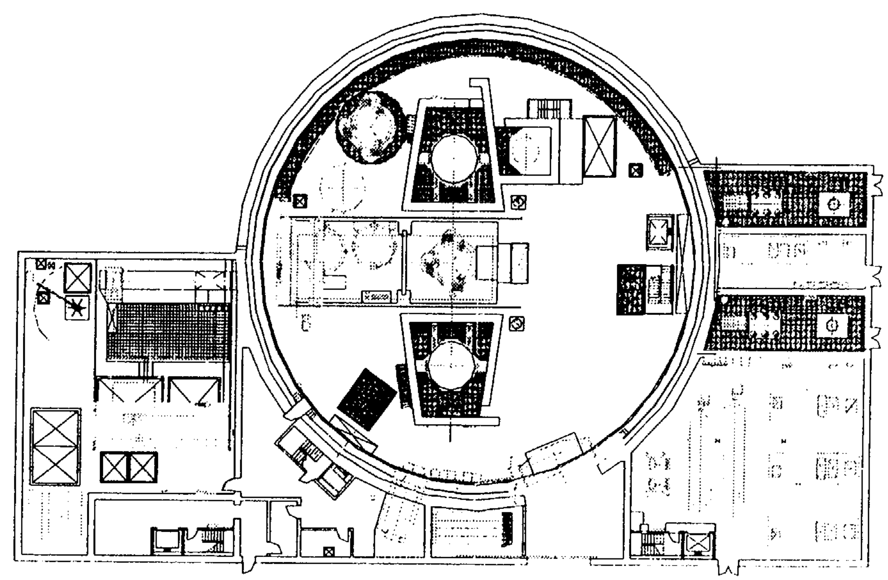
AP1000 General Arrangement

Plan at Elevation 135'

AP600

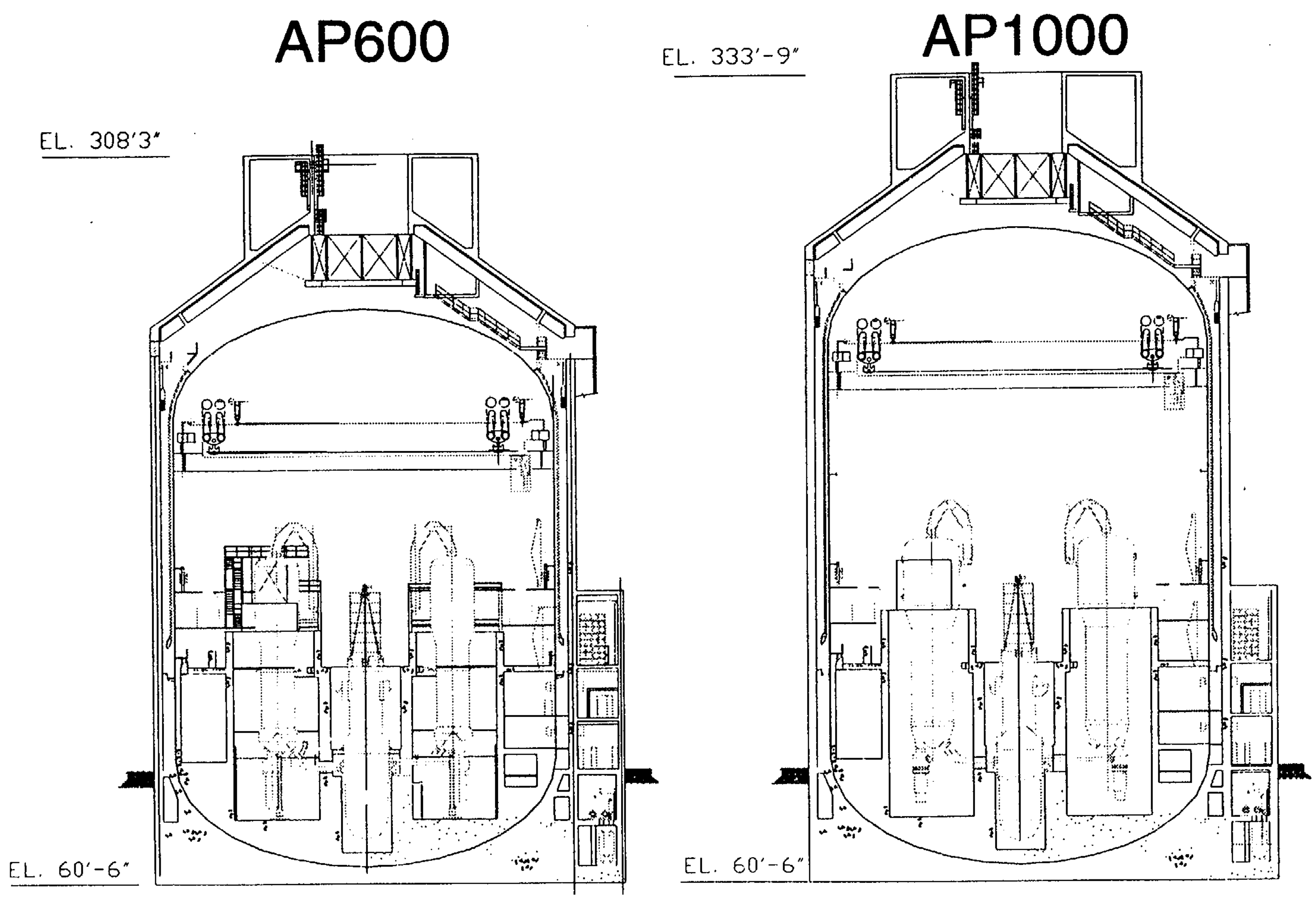


AP1000



AP1000 General Arrangement

Containment Section View

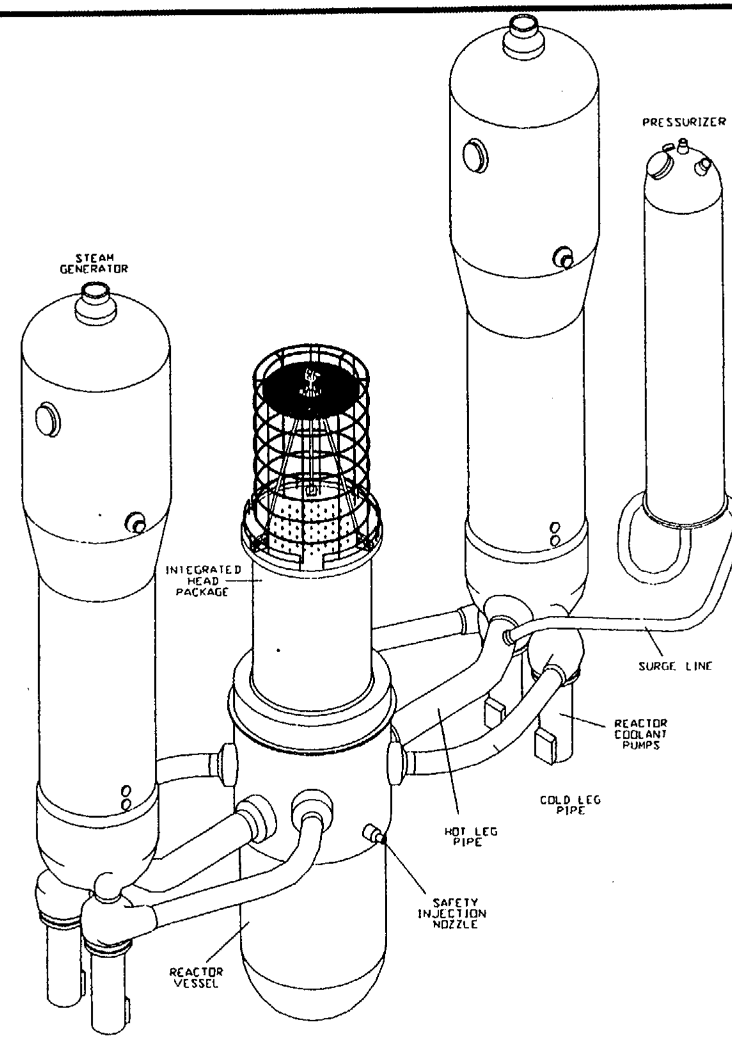


Comparison of Selected Parameters

PARAMETER	West 3XL	AP600	AP1000
Net Electric Output, MWe	985	610	1117
Reactor Power, MWt	2988	1933	3400
Hot Leg Temperature, °F	626	600	610
Number of Fuel Assemblies	157	145	157
Type of Fuel Assembly	17x17	17x17	17x17
Active Fuel Length, ft	14	12	14
Control Rods / Gray Rods	52 / 0	45 / 16	53 / 16
R/V I.D., inches	157	157	157
Vessel flow (Thermal Design)	295,500	194,200	300,000
Steam Generator Surface Area, ft^2	68,000	75,000	125,000
Pressurizer Volume, ft^3	1400	1600	2100

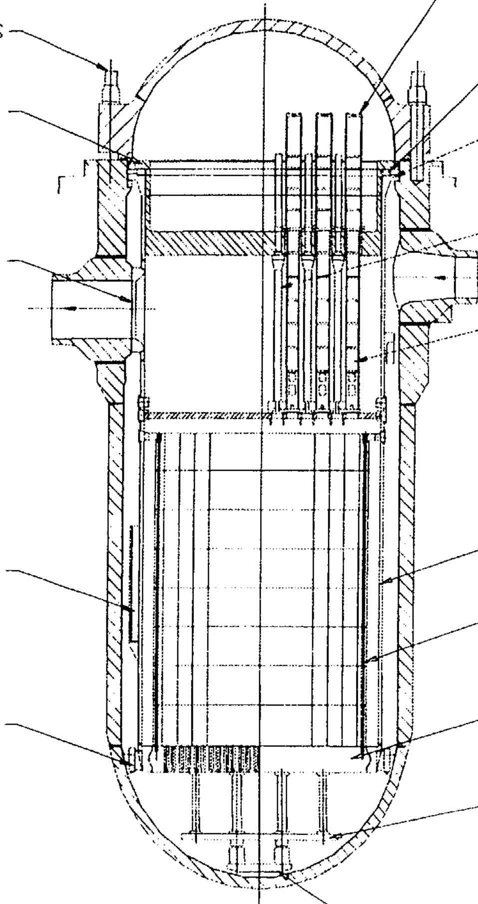
AP1000 Major Components

- **Reactor Vessel**
  - –W 3XL Vessel
  - –No bottom-mounted instrumentation
  - –Improved materials - 60 yr life
- **Δ125 Steam Generators**
  - –ANO RSG
- **Reactor Coolant Pump**
  - –Canned motor pumps
    - –Naval reactors; AP600; early commercial reactors
- **Simplified Main Loop**
  - –Same as AP600
  - –Reduced welds / supports

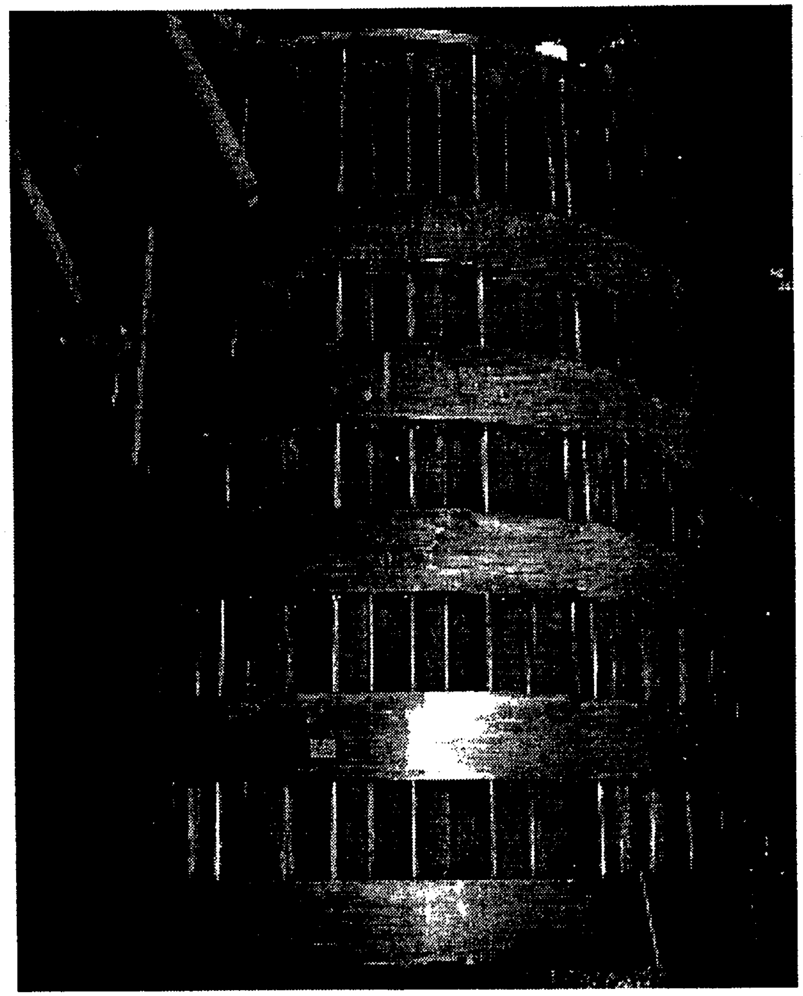


AP1000 Reactor Vessel

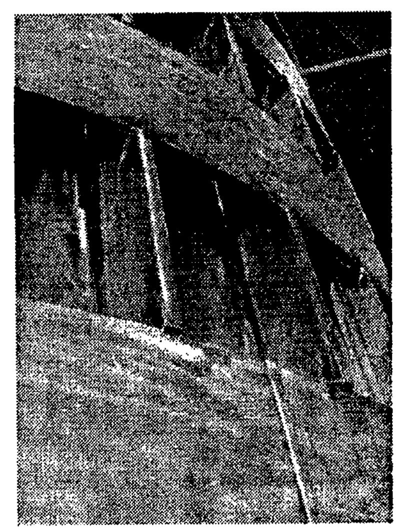
- **West. 3 Loop Reactor**
  - –157" ID, 157 fuel assemblies
  - –Ring forged construction
    - –No welds in core region
  - –Improved materials permit 60 yr design life
  - –W-CE type Core Shroud
    - –Replaces radial reflector
    - –All-welded design
  - –Top mounted incore I&C
    - –Fixed position, online readout
    - –No penetrations in bottom of vessel



YGN-5 Core Shroud



Y-Brace

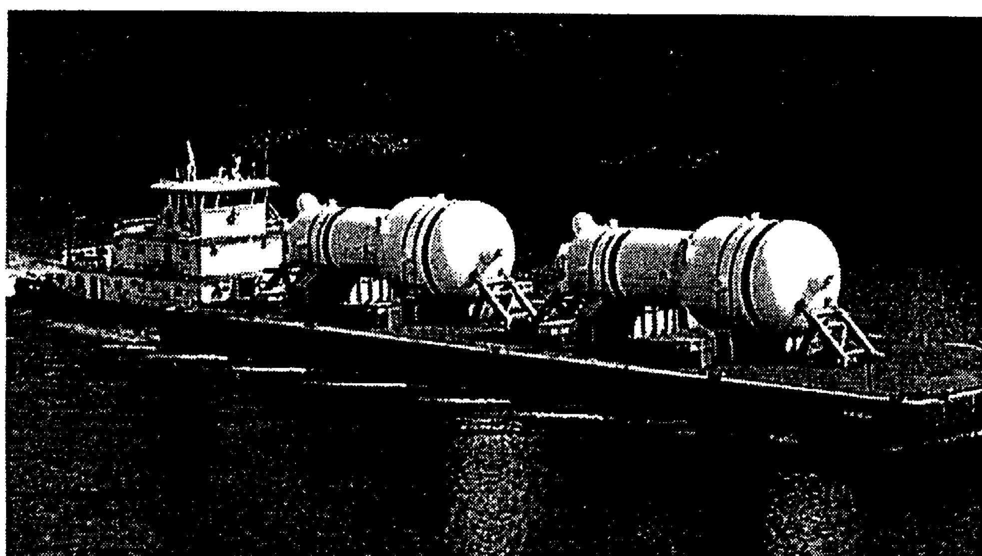


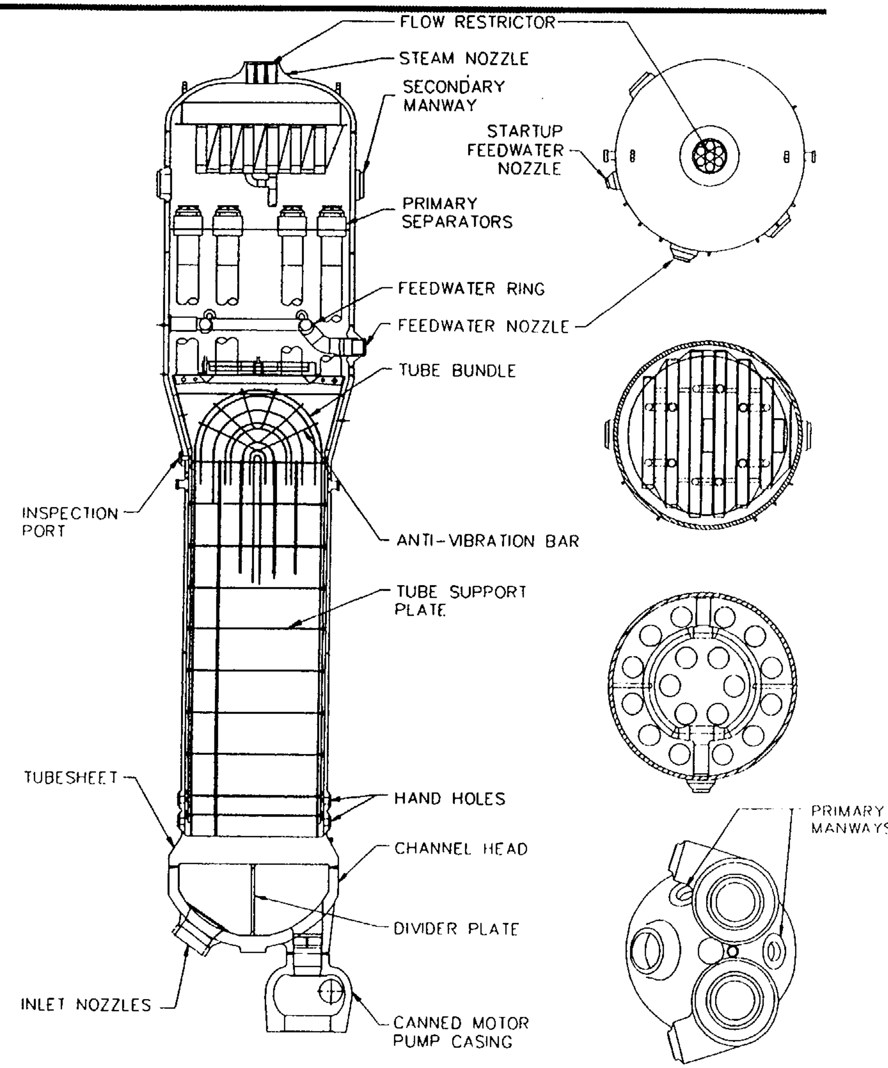
Rib

AP1000 Steam Generator

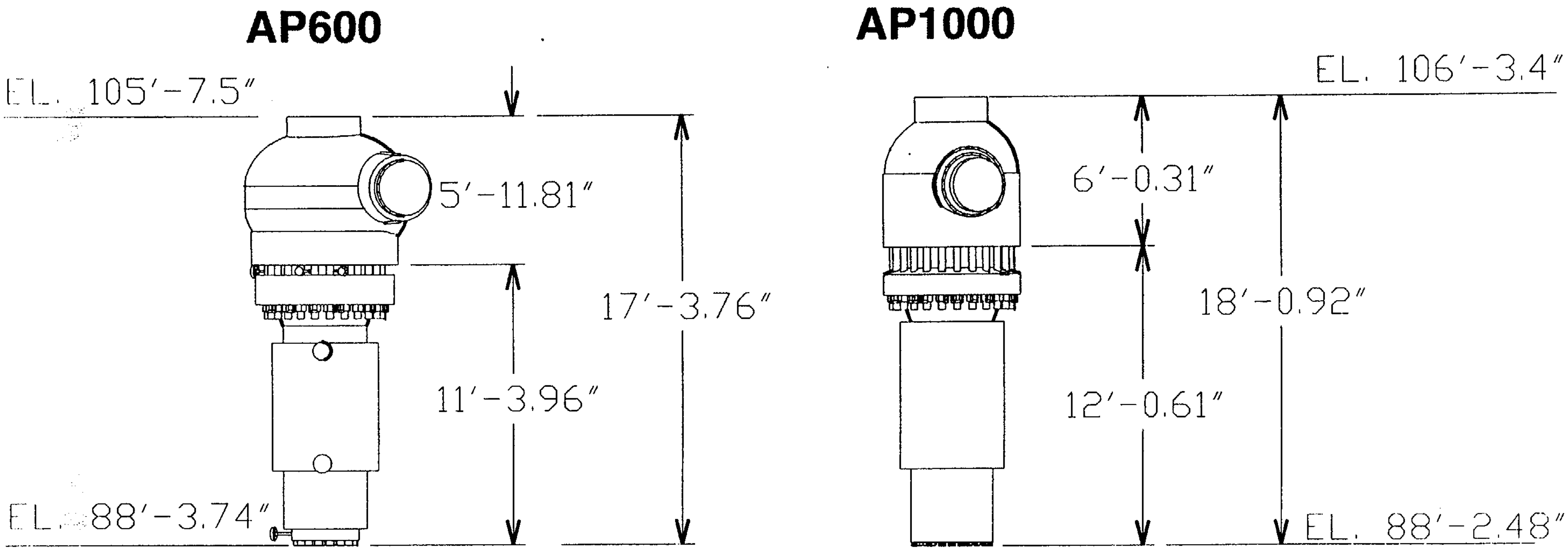
–Based on Proven W Designs

- –AP1000 design based on ANO RSG
- –Design Features
  - –Inconel 690 TT tubes
  - –Stainless steel support plates
  - –Improved access
- –Excellent Operating Experience
- –Over 1200 SG years of operation
- –Less than 0.1% total tubes plugged





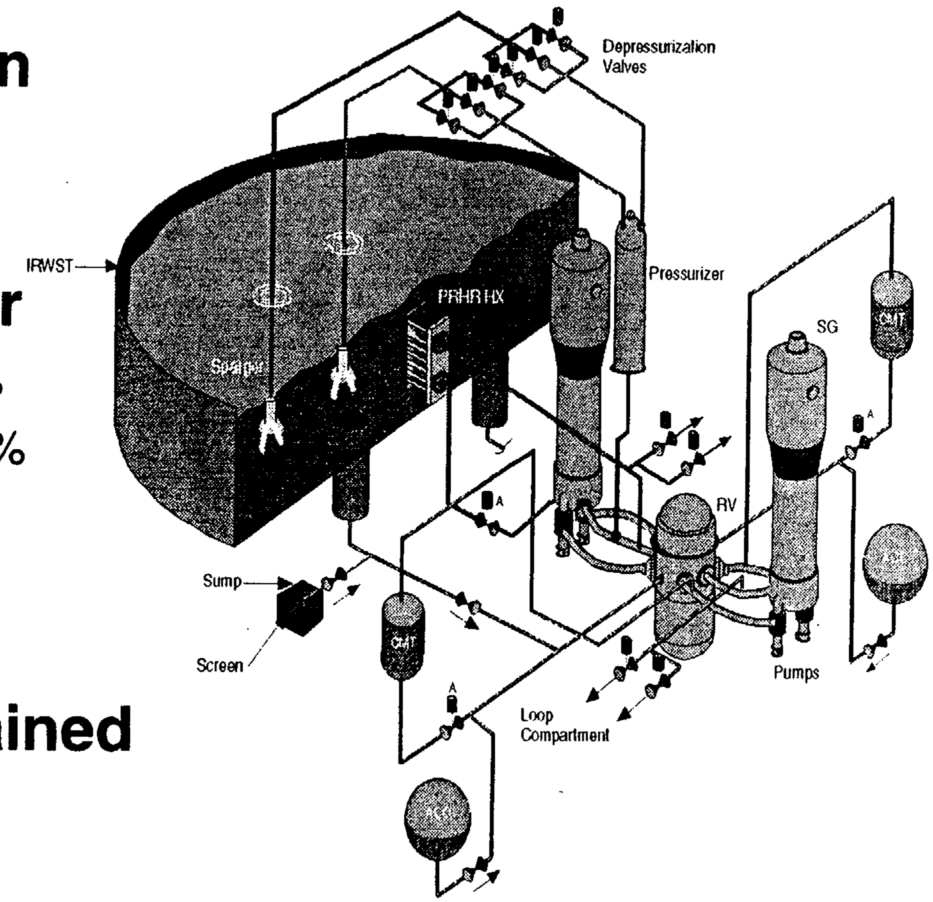
Reactor Coolant Pump



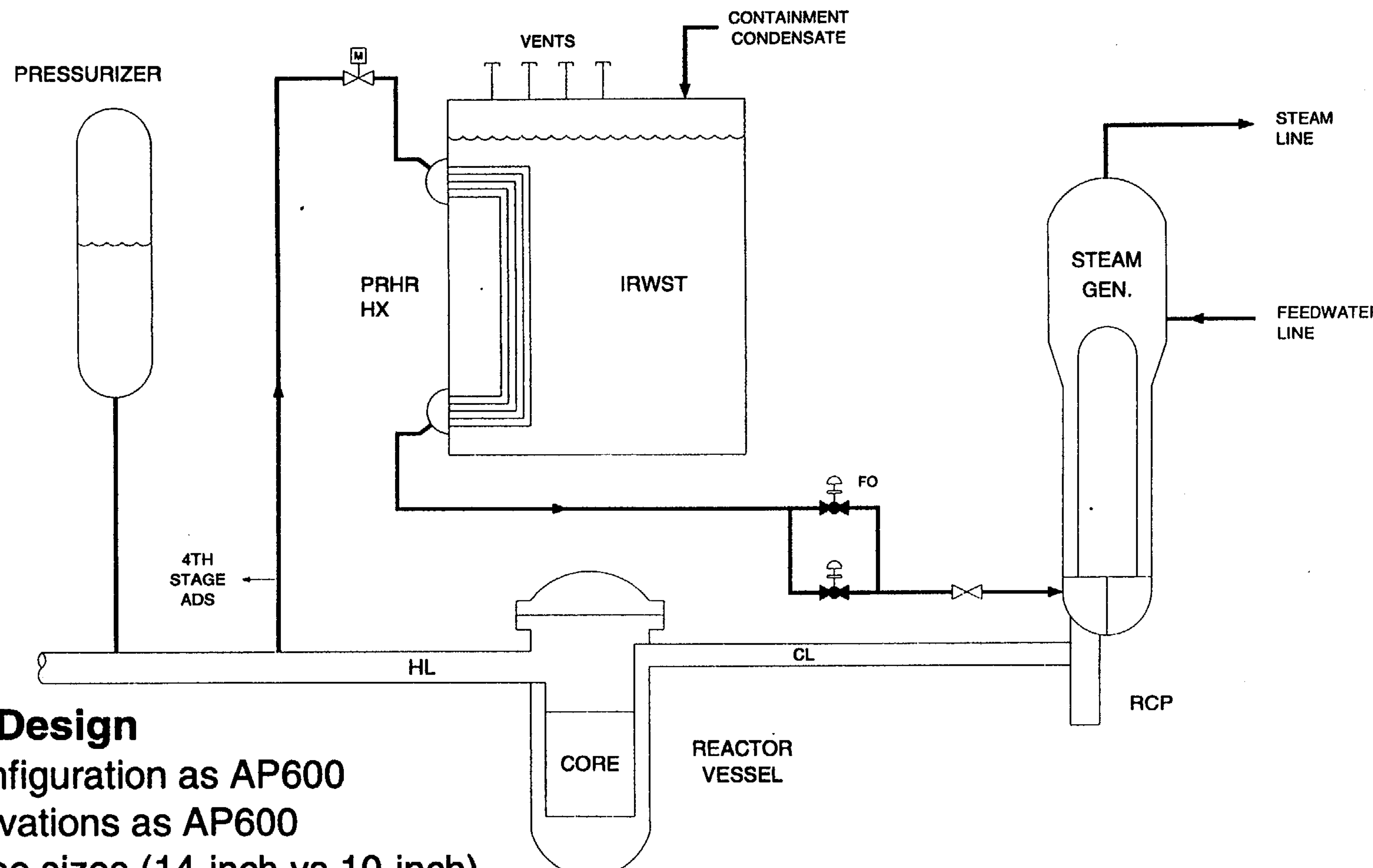
Parameter	AP600	AP1000
Design Flow, gpm	51,000	78,750
Design Head, ft	240	365
Rotating Inertia, lb-ft^2	5,000	16,500
Motor Rating, Hp	3200	7000

AP1000 Passive Core Cooling System

- **AP600 System Configuration Retained**
- **Capacities Increased to Accommodate Higher Power**
  - –PRHR HX Capacity Increased 72%
  - –CMT Volume & Flow Increased 25%
  - –ADS 4 Flow Increased 89%
  - –IRWST Injection Increased 84%
  - –Cont. Recirc. Increased 113%
- **System Performance Maintained**
  - –No core uncovery for SBLOCA
    - – DVI line break
  - –Large margin to PCT limit



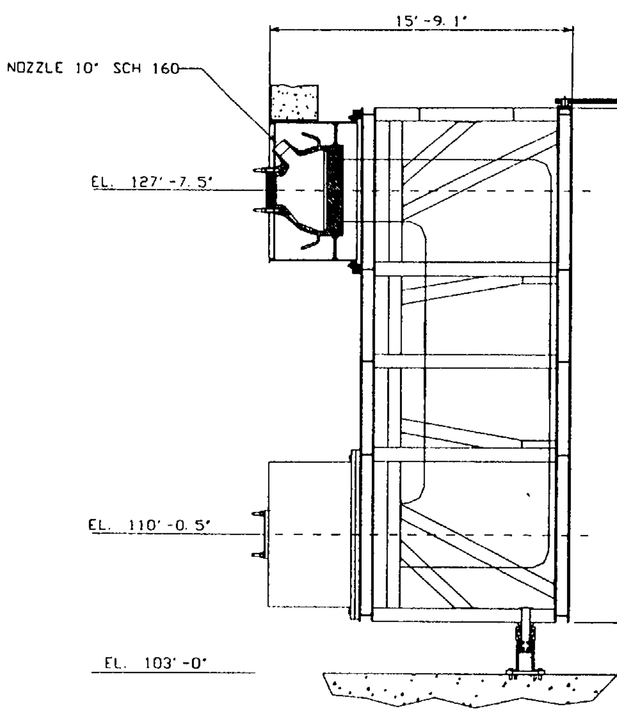
Passive Decay Heat Removal



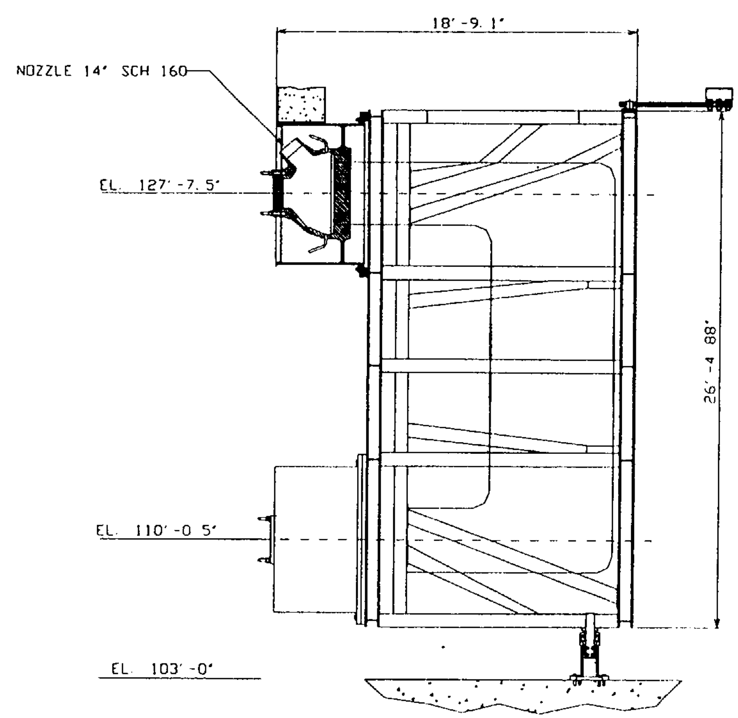
- **PRHR HX Design**
  - Same configuration as AP600
  - Same elevations as AP600
  - Larger pipe sizes (14-inch vs 10-inch)
  - Increased HX surface (more / longer horizontal tubes)

Passive RHR Heat Exchanger

AP600

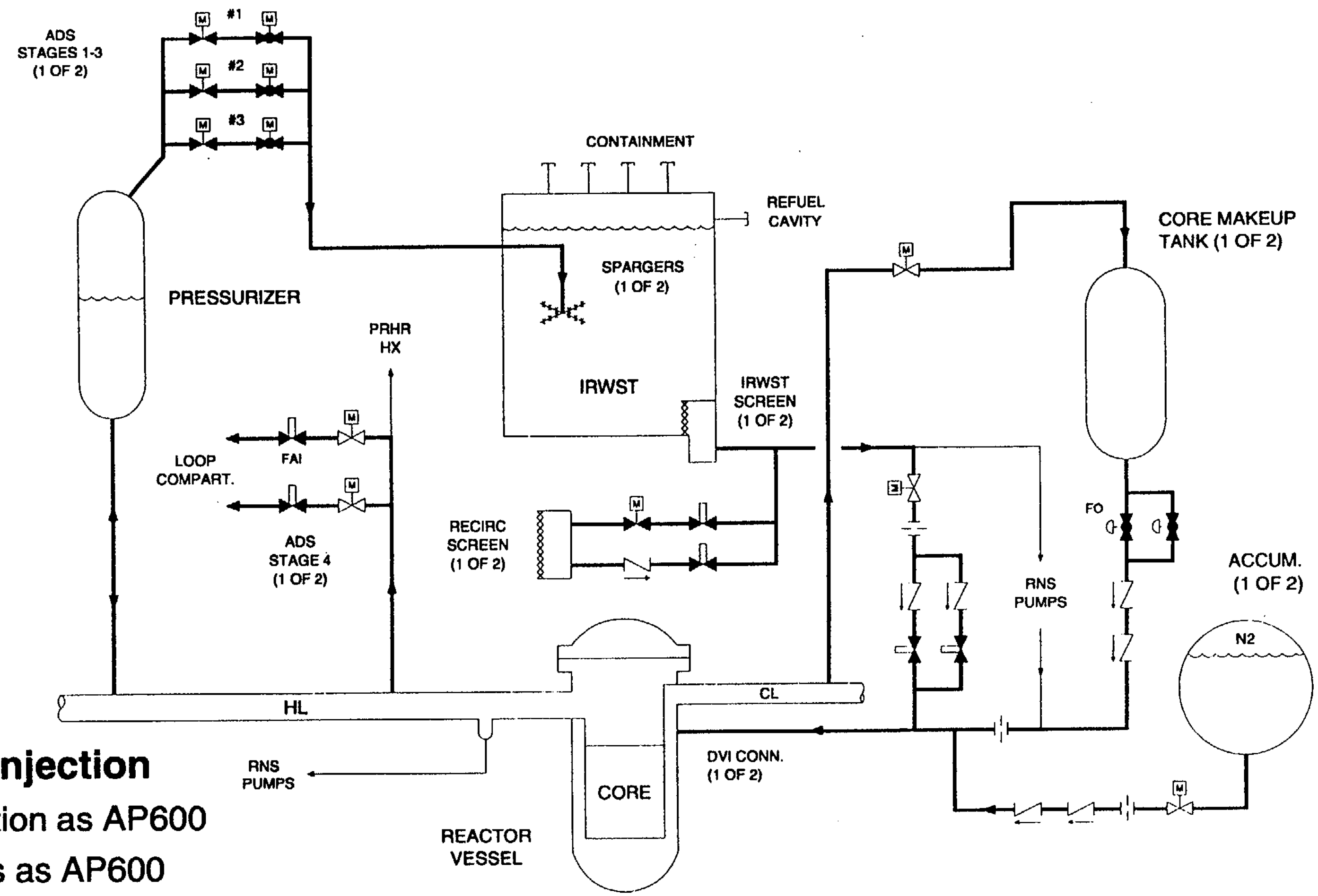


AP1000



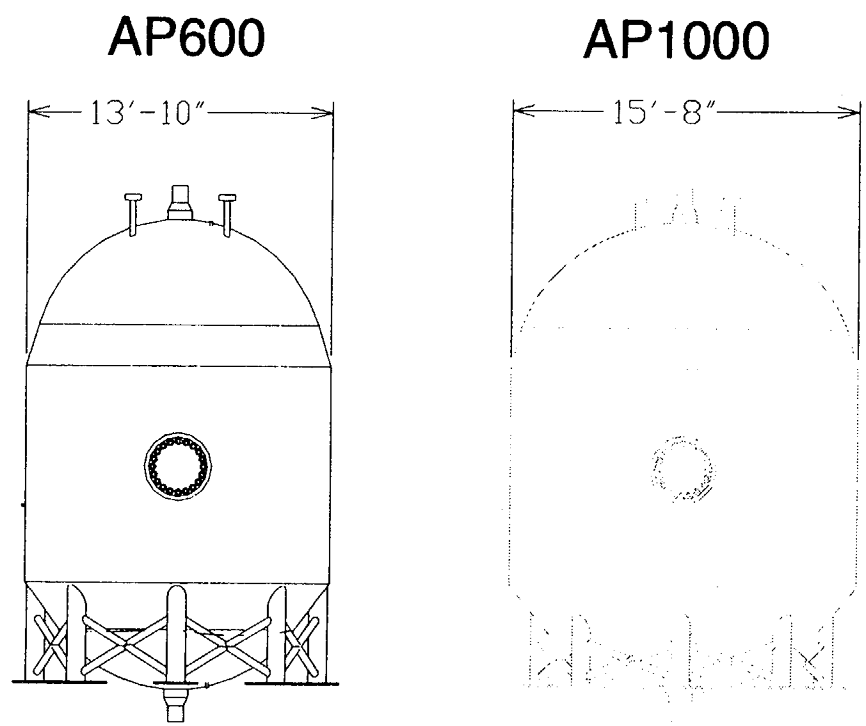
- PRHR Heat Transfer Capacity Increased 72%

AP1000 Passive Safety Injection



- **Passive Safety Injection**
  - Same configuration as AP600
  - Same elevations as AP600
  - Larger CMT and CMT flow tuning orifice
  - Larger IRWST, Recirc, ADS 4 pipe sizes

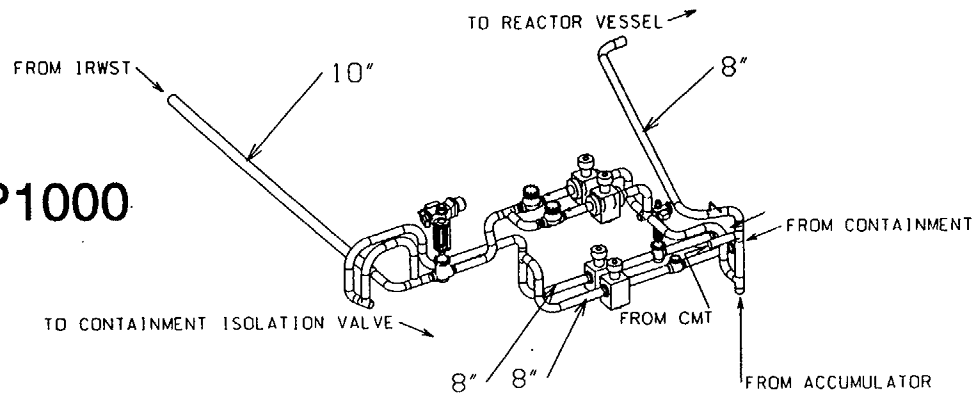
Core Makeup Tanks



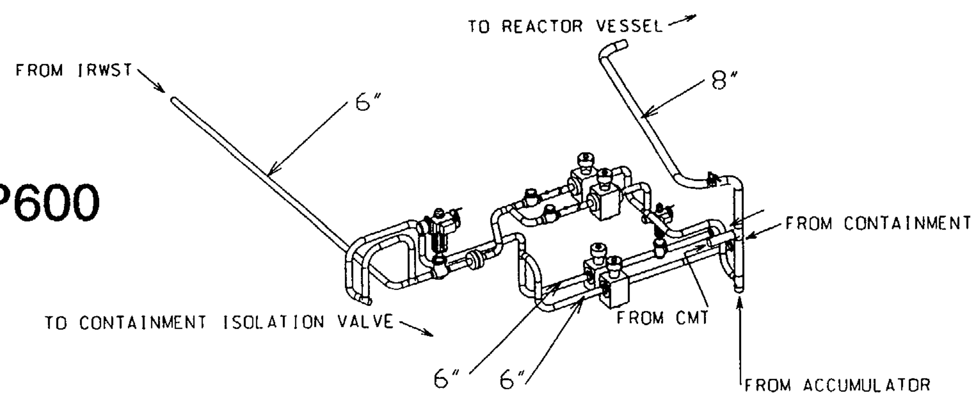
- Core Makeup Tank volume and flow rate increased 25%
  - Tank volume increased 2000 to 2500ft^3
  - Pipe / valves stay same, flow tuning orifice made less restrictive
  - Maintains same ADS timing

Comparison of IRWST Injection & Cont. Recirc.

AP1000



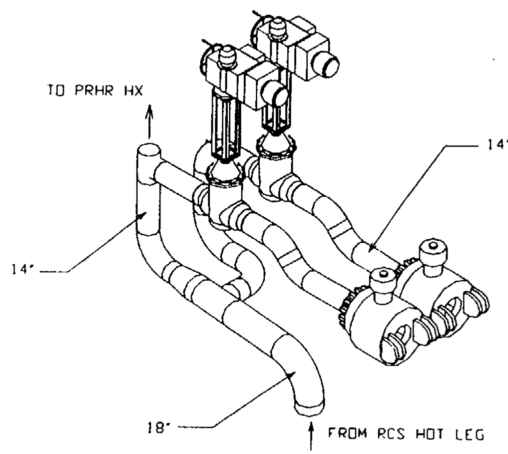
AP600



- **AP1000 IRWST Injection Capacity Increased**
  - Pipe / valves 6/8" > 8/10"
  - Initial water level increased
  - Flow capacity increased 84%
- **AP1000 Cont. Recirc. Capacity Increased**
  - Pipe / valves 6/8" > 8"
  - Initial IRWST level increased
  - Initial flooding of refueling cavity prevented > check valves
  - RNS suction from outside cont.
  - Flow capacity increased 113%

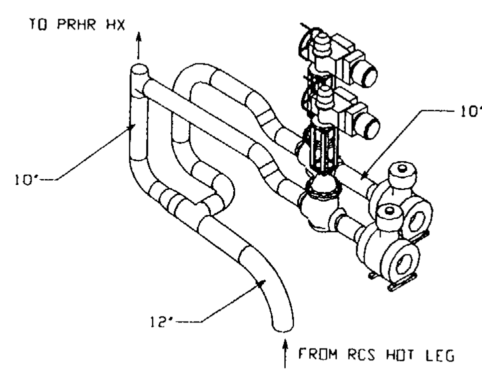
Comparison of 4th Stage ADS

AP1000



AP1000

AP600



AP600

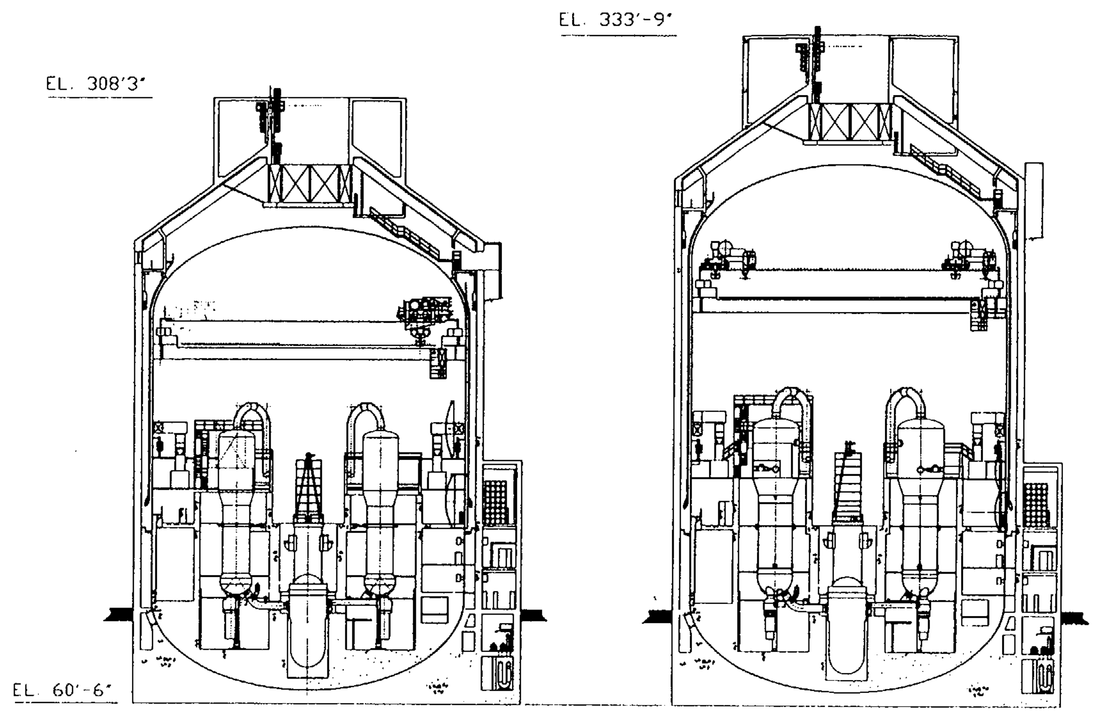
- **AP1000 ADS 4 Capacity Increased**
  - Pipe / valves 10" > 14"
  - Flow capacity increased 89%

AP1000 Safety Margins

	Typical Plant	AP600	AP1000
Loss Flow Margin to DNBR Limit	~ 1 – 5%	15.8%	~19%
Feedline Break Subcooling Margin	>0°F	~170°F	~140°F
SG Tube Rupture	Operator actions required in 10 min	Operator actions ***NOT*** required	Same as AP600
Small LOCA	3" LOCA core uncovers PCT ~1500 °F	≤ 8" LOCA ***NO*** core uncovery	Same as AP600
Large LOCA PCT (with uncertainty)	2000 – 2200°F	1676°F	~2120°F

AP1000 Containment Comparison

AP600



AP1000

	AP600	AP1000
Total Free Volume	100%	122%
Design Pressure, psig	45	59
Shell Thickness	1 5/8"	1 3/4"
Material	A537 Class 2	SA738 Grade B
PCS Water Drain Vol (72 hr)	100%	162%
Design – Peak Cont. Pres. (psi)	1.6 (LLOCA) 0.9 (MSLB)	3.6 (LLOCA) 1.7 (MSLB)

AP1000 Design Changes Considered in PRA

- **Core Power**
  - vs PXS / PCS increased capacities
  - Low boron core improves ATWT response
- **Larger SG**
  - More / longer SG tubes impacts SGTR IE Freq.
- **Variable Speed RCPs**
  - Only used during startup / shutdown conditions
- **More SG Safety Valves**
  - Impacts steam line break IE Freq.
- **Main Feedwater**
  - 3 constant speed pumps vs 2 variable speed pumps
- **Circulating Water Pumps**, 2 > 3 pumps

AP1000 Design Changes Considered in PRA

- **PXS Design Changes**
  - –PRHR, ADS 4, IRWST inject & Cont Recirc capacities increased by power ratio
    - –Verify success criteria with T&H analysis
    - –Larger PRHR HX could affect PRHR HX tube rupture IE Freq.
  - –CMT size & injection rate increased 25%
    - –Verify success criteria with T&H analysis
  - –Accum size not increased
    - –Impacts success criteria for large CL LOCAs
    - –Verify success criteria with T&H analysis
  - –IRWST vents changed to prevent H2 release near containment wall

AP1000 Design Changes Considered in PRA

- **PCS Design Changes**
  - –PCS design pressure increased
    - –Thicker wall, higher strength steel, code changes
    - –Reduces overpressure margin for PRA
    - –Check performance without PCS water drain
      - –3rd / diverse PCS water drain valve reduces importance
- **Nonsafety Defense-In-Depth Systems**
  - –RNS injection water supply changed from IRWST to Cask Load Pit
    - –Outside containment water supply avoids possible adverse interaction
  - –Other DID system capacities increased to cover power increase
- **Electrical Bus / Component Train Assignments**

Summary

- **AP1000 Plant Is Very Similar To AP600**
  - –Same RCS configuration
  - –Same Safety system arrangement, capabilities
  - –Same Non-Safety DID system functions, arrangement, capabilities
- **AP1000 Uses AP600 PRA As Starting Point**
  - –Make few changes to account for differences

OVERVIEW OF AP1000 PRA

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OBJECTIVES

- The purpose of the AP1000 PRA is to provide inputs to the optimization of the AP1000 design and to verify that the US NRC PRA safety goals have been satisfied.
- As in the AP600, the PRA is being performed interactively with the design, analysis and operating procedures.

TECHNICAL SCOPE

- Since the configuration of the AP1000 reactor and safety systems is the same as the AP600, the AP600 PRA is used as the basis of the AP1000 PRA with relevant changes implemented in the model to reflect the AP1000 design changes.

TECHNICAL SCOPE

- AP1000 plant-specific T&H analyses are performed in order to determine the system success criteria.
- The CDF and LRF are calculated for internal events at-power. The off-site dose risk analysis is also performed. The external events and shutdown models are also assessed to derive plant insights and plant risk conclusions.

AP1000 PRA Report Outline

AP1000 PRA Report Outline

CHAPTER 34	SEVERE ACCIDENT PHENOMENA TREATMENT
CHAPTER 35	CONTAINMENT EVENT TREE ANALYSIS
CHAPTER 36	REACTOR COOLANT SYSTEM DEPRESSURIZATION
CHAPTER 37	CONTAINMENT ISOLATION
CHAPTER 38	REACTOR VESSEL REFLOODING
CHAPTER 39	IN-VESSEL RETENTION OF MOLTEN CORE DEBRIS
CHAPTER 40	PASSIVE CONTAINMENT COOLING, LONG TERM CONTAINMENT
CHAPTER 41	HYDROGEN MIXING AND COMBUSTION ANALYSIS
CHAPTER 42	CONDITIONAL CONTAINMENT FAILURE PROBABILITY DISTRIBUTION
CHAPTER 43	RELEASE FREQUENCY QUANTIFICATION
CHAPTER 44	MAAP4 CODE DESCRIPTION AND AP1000 MODELING
CHAPTER 45	FISSION-PRODUCT SOURCE TERMS
CHAPTERS 46 THROUGH 48 NOT USED	
CHAPTER 49	OFFSITE DOSE RISK QUANTIFICATION
CHAPTER 50	IMPORTANCE AND SENSITIVITY ANALYSIS
CHAPTER 51	UNCERTAINTY ANALYSIS
CHAPTERS 52 AND 53 NOT USED	
CHAPTER 54	LOW-POWER AND SHUTDOWN RISK ASSESSMENT
CHAPTER 55	AP1000 SEISMIC MARGINS EVALUATION
CHAPTER 56	INTERNAL FLOODING ANALYSIS
CHAPTER 57	FIRE RISK ASSESSMENT
CHAPTER 58	WINDS, FLOODS, AND OTHER EXTERNAL EVENTS
CHAPTER 59	PRA RESULTS AND INSIGHTS
APPENDIX A	THERMAL HYDRAULIC ANALYSIS TO SUPPORT SUCCESS CRITERIA
APPENDIX B	EX-VESSEL SEVERE ACCIDENT PHENOMENA
APPENDIX C	ADDITIONAL ASSESSMENT OF AP1000 DESIGN FEATURES
APPENDIX D	EQUIPMENT SURVIVABILITY ASSESSMENT
APPENDIX E	AP1000 PRA FAULT TREE PICTURES FOR LEVEL 1 ANALYSIS FOR EVENTS AT POWER OPERATION

LEVEL I PRA

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CONTENTS

- Internal Events at Power
  - –Initiating Events
  - –Event trees and success criteria
  - –Systems Analysis
  - –CDF Quantification
  - –Sensitivity and Importance Analyses
  - –Uncertainty Analysis

CONTENTS

- Shutdown Events
- Internal Flooding and Fire
- Seismic Margins Evaluation
- Other External Events
- Summary of Results

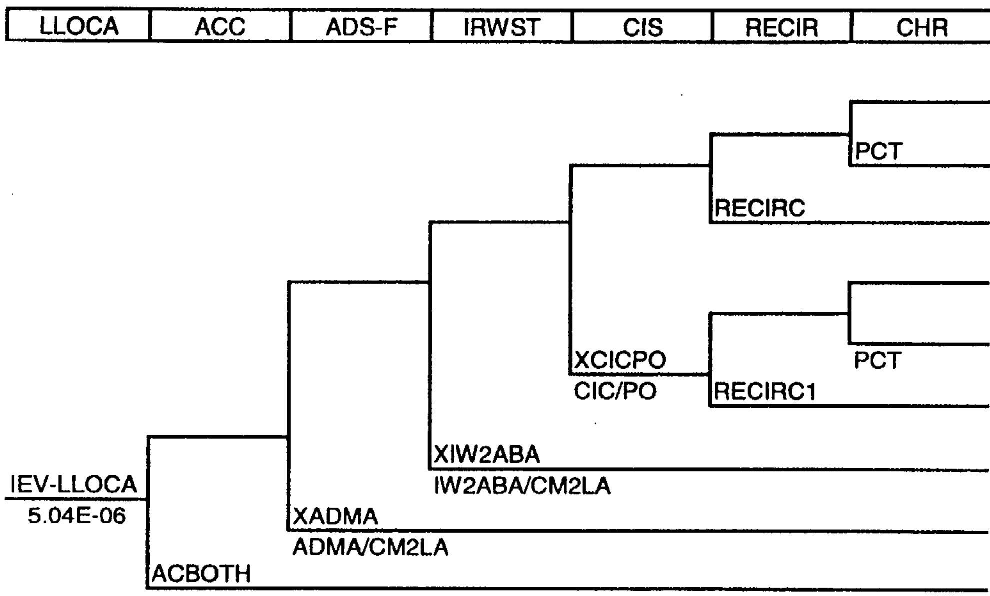
Comparison of AP600 and AP1000 Initiating Events

	Event Category	AP1000 Frequency	AP600 Frequency	Reason for Change
1	Large LOCA	5.04E-06	1.05E-04	use industry data
2	Large Spurious ADS Actuation	5.40E-05	N/A	new category - moved out of Large LOCA
3	Medium LOCA	4.36E-04	1.62E-04	use industry data
4	Core makeup tank line break	9.31E-05	8.94E-05	number of pipe segments
5	Safety injection line break	2.12E-04	1.04E-04	number of pipe segments
	Intermediate LOCA	N/A	0.00077	included in mloca
6	Small LOCA	5.00E-04	1.01E-04	use industry data
7	RCS leakage	6.20E-03	1.20E-02	use industry data
8	Passive residual heat removal tube rupture	1.34E-04	2.50E-04	number of pipe segments; updated database
9	Steam generator tube rupture	3.88E-03	5.20E-03	number of pipe segments; updated database
10	Reactor vessel rupture	1.00E-08	1.00E-08	
11	Interfacing system LOCA	5.00E-11	5.00E-11	
12	Transient with main FW	1.40E+00	1.44E+00	
13	Loss of RCS flow	1.80E-02	1.80E-02	
14	Loss of main FW to one steam generator	1.92E-01	1.92E-01	
15	Core power excursion	4.50E-03	4.50E-03	
16	Loss of component cooling water/service water	1.44E-01	1.44E-01	
17	Loss of main FW to both steam generators	3.35E-01	3.35E-01	
18	Loss of condenser	1.12E-01	1.12E-01	
19	Loss of compressed air	3.48E-02	3.48E-02	
20	Loss of offsite power	1.20E-01	1.20E-01	
21	Main steam line break downstream of MSIVs	5.96E-04	5.96E-04	
22	Main steam line break upstream of MSIVs	3.72E-04	3.72E-04	
23	Main steam line stuck-open valve	2.39E-03	1.21E-03	number of valves increased
24	ATWS precursor without main feedwater	4.81E-01	4.81E-01	
25	ATWS precursor With SI	1.48E-02	2.05E-02	contributing events changed
26	ATWS precursor with main feedwater	1.17E+00	1.17E+00	
	Total (Excluding ATWS precursors) =	2.38E+00	2.42E+00	

EVENT TREES AND SUCCESS CRITERIA

- For each initiating event, an event tree model is created.
- Differences between AP600 and AP1000 ET models are discussed in the next slide.
- Success criteria for each event tree node is reviewed and modified if needed.

AP1000 Large LOCA Event Tree



	PDS	FREQ.		LCF
1	LLO-OK1			
2	LCF		lcllo-02	6.87E-12
3	3BL	8.43E-11	2lllo-03	
4	LLO-OK2			
5	LCF		lcllo-05	1.60E-12
6	3BL	1.77E-14	2lllo-06	
7	3BE	3.40E-10	2ello-07	
8	3D	1.97E-09	3dllo-08	
9	3BR	4.26E-08	2rllo-09	
Total CDF =		4.50E-08		8.47E-12

List of Top Events

Event	**Description**
LLOCA	Large LOCA Event Occurs
ACC	Accumulators Inject
ADS-F	Full RCS Depressurization by ADS occurs
IRWST	RCS Refill from IRWST by Gravity Injection Occurs
CIS	Containment Isolation Occurs
RECIR	Water Recirculation to RPV from the Sump Occurs
CHR	Containment Cooling is Established

Event Tree Node Success Criteria

Internal Events At-Power

Node	Node Description	Success Criteria
AC1A	FAILURE OF 1/1 ACCUMULATOR	Same as AP600
AC2AB	FAILURE OF 2/2 ACCUMULATORS	Same as AP600
ACBOTH	ANY ONE OF TWO ACCUMULATOR TRAINS FAIL	Same as AC2AB except failure of 1 of 2 accumulators - for Large LOCA
AD1	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
AD1A	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADA	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADAB	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADAL	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADB	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADF	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600
ADL	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADM	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADMA	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADQ	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADR	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADRA	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADS	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADT	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADU	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADUM	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADV	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
ADW	FAILURE OF FULL ADS DEPRESSURIZATION	Same as AP600 except 3/4 stage 4 ADS lines need to open
ADZ	FAILURE OF PARTIAL ADS DEPRESSURIZATION	Same as AP600 except 2 stage 2/3 ADS lines need to open
BL	MSLB UPSTREAM OF MSIVs OUTSIDE CONTAINMENT	Same as AP600
CIA	FAILURE OF SG ISOLATION	Same as AP600
CIB	FAILURE OF SG ISOLATION	Same as AP600
CIC	CONTAINMENT ISOLATION FAILURE	Same as AP600

Event Tree Node Success Criteria

Internal Events At-Power

Node	Node Description	Success Criteria
CM1A	RCPS DO NOT TRIP OR 1 TRAIN OF C MT FAILS - 1/1 CMT TRAIN AVAILA.	Same as AP600
CM2AB	FAILURE OF TWO OF TWO CORE MAKEUP TANKS	Same as AP600
CM2LA	FAILURE TWO OF TWO CORE MAKEUP TANKS	Same as AP600
CM2NL	FAILURE OF 2/2 CMT	Same as AP600
CM2P	FAILURE OF TWO OF TWO CORE MAKEUP TANKS	Same as AP600
CM2SL	FAILURE OF TWO OF TWO CORE MAKEUP TANKS	Same as AP600
COND	TURBINE BYPASS TO MAIN CONDENSER (2/4 VALVES TO OPEN)	Same as AP600
COND1	FAILURE OF STEAM DUMP TO CONDENSER	Same as AP600
CSAX	FAILURE OF PRIMARY DEPRESSURIZATION BY CVS	Same as AP600
CSBOR1	FAILURE OF MANUAL BORATION BY CVS	Same as AP600
CSP	FAILURE OF CVS	Same as AP600
CVS1	FAILURE OF CVS	Same as AP600
DAS	FAILURE OF DIVERSE ACTUATION SYSTEM	Same as AP600
DAS1	FAILURE OF DIVERSE ACTUATION SYSTEM	Same as AP600
DGEN	FAILURE OF TWO OF TWO DIESEL GENERATORS	Same as AP600
FWF	MAIN FEEDWATER SYSTEM FAILS TO CONTINUE OPERATING	Same as AP600 - although 3 MFW pumps are available, only two are credited
FWT	FAILURE OF MFW SYSTEM	Same as AP600 - although 3 MFW pumps are available, only two are credited
IW1A	FAILURE OF ONE OF ONE IRWST INJECTION LINE	Same as AP600
IW1AM	FAILURE OF ONE OF ONE IRWST INJECTION LINE	Same as AP600
IW2AB	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABA	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABB	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABBM	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABM	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABP	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
IW2ABPM	FAILURE OF TWO OF TWO IRWST INJECTION LINES	Same as AP600
MGSET	CONTROL ROD MG SETS FAIL TO TRIP	Same as AP600

Event Tree Node Success Criteria

Internal Events At-Power

Node	Node Description	Success Criteria
PCB	PASSIVE CONTAINMENT COOLING SYSTEM FAILS - AFTER SBO EVENT	same as PCT - with Station blackout power support system conditions
PCP	PASSIVE CONTAINMENT COOLING FAILS	Same as PCT - with loss of offsite power support system conditions
PCT	PASSIVE CONTAINMENT COOLING SYSTEM FAILS	1/3 PCS lines must inject; other wise the same as AP600
PO	PRE-EXISTING CONTAINMENT OPENING > 100 SQ CM	Same as AP600 (scalar quantity, no additional success criterion is needed.)
PRES	PRZ SV FAILURE FOR LOSS OF MFW ATWS, NO UET	Same as AP600
PRESU	INADEQUATE PRS RELIEF FOR LOSS OF MFW ATWS, WITH UET	Same as AP600 with UET = 0
PRI	PRHR ISOLATION FAILURE FOLLOWING PRHR TUBE RUPTURE	Same as AP600 and at least 1/2 gutter isolation valves must close
PRL	FAILURE OF PASSIVE RHR SYSTEM	Same as AP600 and at least 1/2 gutter isolation valves must close
PRP	FAILURE OF PASSIVE RHR SYSTEM	Same as AP600 and at least 1/2 gutter isolation valves must close
PRS	FAILURE OF PASSIVE RHR SYSTEM	Same as AP600 and at least 1/2 gutter isolation valves must close
PRSOV	EITHER PRZR SV FAILS TO RECLOSE	Same as AP600 and at least 1/2 gutter isolation valves must close
PRT	FAILURE OF PASSIVE RHR SYSTEM	Same as AP600 and at least 1/2 gutter isolation valves must close
PRTA	FAILURE OF PRHR	Same as AP600 and at least 1/2 gutter isolation valves must close
PRW	FAILURE OF PASSIVE RHR SYSTEM	Same as AP600 and at least 1/2 gutter isolation valves must close
R05	FAILURE TO RECOVER OFFSITE AC POWER IN 30 MINUTES	Same as AP600
RCL	FAILURE OF REACTOR COOLANT PUMPS TO TRIP	Same as AP600
RCN	FAILURE OF RCP TRIP	Same as AP600
RCT	FAILURE OF REACTOR COOLANT PUMPS TO TRIP	Same as AP600
RECIRC	FAILURE OF RECIRCULATION	Same as AP600
RECIRC1	CONTAINMENT SUMP RECIRCULATION FAILS	Same as RECIRC with 2/4 recirculation lines need to open (after failure of CIS)
RECIRC1B	RECIRC FAILS DUR BLACKOUT GIVEN CONTAIN ISOL. FAILS	Same as RECIRC with 2/4 recirculation lines need to open (after failure of CIS)
RECIRC1P	RECIRC FAILS DUR LOSP GIVEN CONT. ISOL. FAILS	Same as RECIRC with 2/4 recirculation lines need to open (after failure of CIS)
RECIRCB	CONTAINMENT SUMP RECIRCULATION FAILS	Same as AP600
RECIRCP	FAILURE OF RECIRCULATION	Same as AP600
RNH	RNS FAILS TO INJ ECT / RECIRCULATE / REMOVE HEAT	Same as RNR plus at least 1/2 CCW HX must remove decay heat

Event Tree Node Success Criteria

Internal Events At-Power

Node	Node Description	Success Criteria
RNHP	RNS FAILS TO INJECT /RECIRC/ REMOVE HEAT WITH LOSP	Same as RNH - with loss of offsite power support system conditions
RNN	RNS FAILS TO REMOVE DECAY HEAT FOR TRANS WITH PRHR SUCC	At least 1/2 RNS pump trains take suction from the IRWST and inject into the IRWST; the HX in the operating train(s) remove heat through CCW
RNNP	RNS FAILS TO REMOVE DECAY HEAT FOR TRANS WITH PRHR SUCC, FOLLOWING A LOSS OF OFFSITE POWER EVENT	Same as RNN - with loss of offsite power support system conditions
RNP	FAILURE OF NORMAL RHR IN INJECTION MODE	Same as RNR - with loss of offsite power support system conditions
RNR	FAILURE OF NORMAL RHR IN INJECTION / RECIRCULATION MODE	Same as AP600 with initial suction source coming from Cask loading pit.
RTPMS	FAILURE OF ROD INSERTION BY PMS	Same as AP600
RTPMS1	FAILURE OF ROD INSERTION BY PMS	Same as AP600
RTSTP	FAILURE OF MANUAL REACTOR TRIP	Same as AP600
SDMAN	OPERATOR FAILS TO PERFORM CNTRL REACTOR SHUTDOWN DURING ACCIDENT	Same as AP600
SFW	STARTUP FEEDWATER FAILS	Same as AP600
SFW1	FAILURE OF STARTUP FEEDWATER SYSTEM	Same as AP600
SFWA	FAILURE OF STARTUP FEEDWATER SYSTEM	Same as AP600
SFWM	FAILURE OF SFW SYSTEM WITH LOSS OF COMPRESSED AIR	Same as AP600
SFWP	FAILURE OF STARTUP FEEDWATER SYSTEM	Same as AP600
SFWT	FAILURE OF STARTUP FEEDWATER SYSTEM	Same as AP600
SGHL	FAILURE OF CVS AND STARTUP FEEDWATER ISOLATION	Same as AP600
SGTR	CONSEQUENTIAL SGTR OCCURS	Same as AP600
SGTR1	SINGLE CONSEQUENTIAL SGTR	Same as AP600
SLSOV	ANY SECOND. SIDE RELIEF VALVE FAILS TO RECLOSE (1 SV + PORV)	Same as AP600
SLSOV1	ANY SECOND. SIDE RELIEF VALVE FAILS TO CLOSE (2 SV + PORV)	Same as AP600
SLSOV2	ANY SECOND. SIDE RELIEF VALVE FAILS TO CLOSE (1 SV)	Same as AP600
SLSOV3	FAILURE TO RECLOSE OF SG PORV & 1 SG SV ON RUPTURED SG	Same as AP600

SYSTEMS ANALYSIS

- Fault tree models are used for systems analysis
- Same FT guidelines as AP600 PRA are used.
- Fault trees are modified as needed to reflect the current AP1000 design.

Typical AP1000 PRA System Failure Probabilities

Failure System/Function	Probability	Fault Tree Name
CMT Valve Signal	5.70E-07	CMT-IC11 (one train; auto and manual actuation)
PRHR Valve Signal	1.10E-06	RHR-IC01 (one train; auto and manual actuation)
Passive Cont. Cool.	1.80E-06	PCT
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Reactor Trip by PMS	1.20E-05	RTPMS (including operator actions)
Accumulators	6.90E-05	AC2AB
IRWST inj.	6.90E-05	IW2AB
ADS	9.30E-05	ADS (including operator actions)
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Passive PRHR	2.00E-04	PRT
Core Makeup Tanks	1.10E-04	CM2SL
125 vdc 1E Bus	3.10E-04	IDADS1 (one bus only)
DC Bus (Non-1E)	3.40E-04	ED1DS1 (one bus only)
RC Pump Trip	5.90E-04	RCT
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Chilled Water	1.40E-03	VWH
Containment Isol.	1.60E-03	CIC
Reactor Trip by DAS failure))	1.70E-03	DAS (including operator action; excluding MGSET
6900 vac Bus	3.20E-03	ECES1 (obe bus only)
CVS	3.40E-03	CVS1
480 vac Bus	5.90E-03	ECEK11 (one bus only)
Service Water	6.20E-03	SWT
Comp. Cooling Water	6.30E-03	CCT
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Diesel Generators	1.00E-02	DGEN
Startup Feedwater	1.70E-02	SFWT
Compressed Air	1.30E-02	CAIR
Condenser	2.40E-02	CDS
Main Feedwater	2.80E-02	FWT (including condenser)
RNS	9.10E-02	RNR
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Hydrogen Control	1.00E-01	VLH

CDF QUANTIFICATION

- 26 event trees are quantified sequence by sequence
- 190 of the sequences had frequencies calculated for them
- The plant CDF is calculated to be 2.41e-07/year.

Contribution of Initiating Events to AP1000 CDF

	IEV CATEGORY	CONTRIBUTION TO CDF %	CONTRIBUTION TO CDF %	IEV FREQUENCY	NUMBER OF CUTSETS	CONDITIONAL CDF
1	IEV-SI-LB	9.50E-08	39.43	2.12E-04	1160	4.48E-04
2	IEV-LLOCA	4.50E-08	18.66	5.00E-06	286	8.99E-03
3	IEV-SPADS	2.96E-08	12.28	5.40E-05	1078	5.48E-04
4	IEV-SLOCA	1.81E-08	7.5	5.00E-04	1638	3.62E-05
5	IEV-MLOCA	1.61E-08	6.69	4.36E-04	1681	3.70E-05
6	IEV-RV-RP	1.00E-08	4.15	1.00E-08	1	1.00E+00
7	IEV-SGTR	6.79E-09	2.82	3.88E-03	3076	1.75E-06
8	IEV-CMTLB	3.68E-09	1.53	9.31E-05	987	3.95E-05
9	IEV-ATWS	3.61E-09	1.5	4.81E-01	136	7.49E-09
10	IEV-TRANS	3.08E-09	1.28	1.40E+00	1500	2.20E-09
11	IEV-RCSLK	1.71E-09	0.71	6.20E-03	1526	2.75E-07
12	IEV-POWEX	1.66E-09	0.69	4.50E-03	701	3.69E-07
13	IEV-LCOND	1.24E-09	0.52	1.12E-01	858	1.11E-08
14	IEV-LOSP	9.58E-10	0.4	1.20E-01	530	7.98E-09
15	IEV-LMFW	8.70E-10	0.36	3.35E-01	1334	2.60E-09
16	IEV-ATW-T	7.12E-10	0.3	1.17E+00	13	6.09E-10
17	IEV-LCAS	6.72E-10	0.28	3.48E-02	417	1.93E-08
18	IEV-SLB-V	6.06E-10	0.25	2.39E-03	305	2.54E-07
19	IEV-PRSTR	5.02E-10	0.21	1.34E-04	317	3.74E-06
20	IEV-LMFW1	4.53E-10	0.19	1.92E-01	763	2.36E-09
21	IEV-LCCW	3.23E-10	0.13	1.44E-01	690	2.24E-09
22	IEV-SLB-U	1.31E-10	0.05	3.72E-04	160	3.51E-07
23	IEV-ATW-S	1.11E-10	0.05	1.48E-02	55	7.48E-09
24	IEV-ISLOC	5.00E-11	0.02	5.00E-11	1	1.00E+00
25	IEV-LRCS	3.52E-11	0.01	1.80E-02	143	1.96E-09
26	IEV-SLB-D	9.15E-12	0	5.96E-04	18	1.54E-08
	Totals =	**2.41E-07**	**100**	**2.38***	**19374**	

* - The total initiating event frequency excludes the three ATWS precursor frequencies

Comparison of AP600 and AP1000 CDF

IEV CATEGORY	AP600 CONTRIBUTION TO CDF	AP600 CONTRIBUTION TO CDF (%)	AP600 IEV FREQUENCY	AP600 CONDITIONAL CDP (P1)	AP1000 CONTRIBUTION TO CDF	AP1000 CONTRIBUTION TO CDF (%)	AP1000 IEV FREQUENCY	AP1000 CONDITIONAL CDP (P2)	RATIO P2/P1
IEV-LLOCA	5.02E-08	29.67	1.05E-04	4.78E-04	4.50E-08	18.66	5.00E-06	8.99E-03	18.8
IEV-SI-LB	3.82E-08	22.58	1.04E-04	3.67E-04	9.50E-08	39.43	2.12E-04	4.48E-04	1.2
IEV-NLOCA	3.15E-08	18.63	7.70E-04	4.09E-05					
IEV-RV-RP	1.00E-08	5.91	1.00E-08	1.00E+00	1.00E-08	4.15	1.00E-08	1.00E+00	1
IEV-ATWS	8.98E-09	5.31	4.81E-01	1.87E-08	3.61E-09	1.5	4.81E-01	7.49E-09	0.4
IEV-MLOCA	6.23E-09	3.68	1.62E-04	3.85E-05	1.61E-08	6.69	4.36E-04	3.70E-05	1
IEV-SGTR	6.08E-09	3.6	5.20E-03	1.17E-06	6.79E-09	2.82	3.88E-03	1.75E-06	1.5
IEV-SLOCA	4.05E-09	2.4	1.01E-04	4.01E-05	1.81E-08	7.5	5.00E-04	3.62E-05	0.9
IEV-CMTLB	3.54E-09	2.09	8.94E-05	3.96E-05	3.68E-09	1.53	9.31E-05	3.95E-05	1
IEV-RCSLK	2.26E-09	1.34	1.20E-02	1.89E-07	1.71E-09	0.71	6.20E-03	2.75E-07	1.5
IEV-POWEX	1.83E-09	1.08	4.50E-03	4.07E-07	1.66E-09	0.69	4.50E-03	3.69E-07	0.9
IEV-TRANS	1.14E-09	0.67	1.40E+00	8.14E-10	3.08E-09	1.28	1.40E+00	2.20E-09	2.7
IEV-LCOND	1.03E-09	0.61	1.12E-01	9.23E-09	1.24E-09	0.52	1.12E-01	1.11E-08	1.2
IEV-LOSP	1.01E-09	0.6	1.20E-01	8.40E-09	9.58E-10	0.4	1.20E-01	7.98E-09	1
IEV-ATW-T	7.12E-10	0.42	1.17E+00	6.09E-10	7.12E-10	0.3	1.17E+00	6.09E-10	1
IEV-PRSTR	5.58E-10	0.33	2.50E-04	2.23E-06	5.02E-10	0.21	1.34E-04	3.74E-06	1.7
IEV-SLB-V	4.82E-10	0.28	1.21E-03	3.98E-07	6.06E-10	0.25	1.21E-03	5.01E-07	1.3
IEV-ATW-S	3.82E-10	0.23	2.05E-02	1.86E-08	1.11E-10	0.05	1.48E-02	7.48E-09	0.4
IEV-LMFW	3.03E-10	0.18	3.35E-01	9.04E-10	8.70E-10	0.36	3.35E-01	2.60E-09	2.9
IEV-LMFW1	1.76E-10	0.1	1.92E-01	9.16E-10	4.53E-10	0.19	1.92E-01	2.36E-09	2.6
IEV-LCAS	1.73E-10	0.1	3.48E-02	4.98E-09	6.72E-10	0.28	3.48E-02	1.93E-08	3.9
IEV-SLB-U	1.23E-10	0.07	3.72E-04	3.31E-07	1.31E-10	0.05	3.72E-04	3.51E-07	1.1
IEV-LCCW	1.23E-10	0.07	1.44E-01	8.52E-10	3.23E-10	0.13	1.44E-01	2.24E-09	2.6
IEV-ISLOC	5.00E-11	0.03	5.00E-11	1.00E+00	5.00E-11	0.02	5.00E-11	1.00E+00	1
IEV-LRCS	1.27E-11	0.01	1.80E-02	7.06E-10	3.52E-11	0.01	1.80E-02	1.96E-09	2.8
IEV-SLB-D	9.46E-12	0.01	5.96E-04	1.59E-08	9.15E-12	0	5.96E-04	1.54E-08	1
IEV-SPADS					2.96E-08	12.28	5.40E-05	5.48E-04	
Totals:	**1.69E-07**	**100**	**2.38E+00**		**2.41E-07**	**100**	**2.37E+00**		

AP1000 PRA Dominant CDF Sequences

	Sequence Frequency	% Contrib	Cum. % Contrib	Sequence ID	Sequence Description	Event Identifier
1	6.88E-08	28.52	28.52	2esil-07	SAFETY INJECTION LINE BREAK INITIATING EVENT OCCURS	IEV-SI-LB
					RCPS TRIP AND CMT INJECTION IS SUCCESSFUL - 1 OF 2 CMT TRAINS	DEL-XCM1A
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADM
					FAILURE OF ONE OF ONE IRWST INJECTION LINE	SYS-IW1A
2	4.26E-08	17.66	46.18	2rllo-09	LARGE LOCA INITIATING EVENT OCCURS	IEV-LLOCA
					ANY ONE OF TWO ACCUMULATOR TRAINS FAIL	SYS-ACBOTH
3	2.13E-08	8.82	55	3dsad-08	SPURIOUS ADS INITIATING EVENT OCCURS	IEV-SPADS
					SUCCESS OF 1/2 OR 2/2 ACCUMULATORS	DEL-AC2AB
					FAILURE OF ADS OR CMT	SYS-XADMA
4	1.98E-08	8.23	63.23	3dsil-08	SAFETY INJECTION LINE BREAK INITIATING EVENT OCCURS	IEV-SI-LB
					RCPS TRIP AND CMT INJECTION IS SUCCESSFUL - 1 OF 2 CMT TRAINS	DEL-XCM1A
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADM
5	1.00E-08	4.15	67.38	3crvr-02	REACTOR VESSEL RUPTURE INITIATING EVENT OCCURS	IEV-RV-RP
6	8.44E-09	3.5	70.88	2lslo-05	SMALL LOCA INITIATING EVENT OCCURS	IEV-SLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADS
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					SUCCESS OF TWO OF TWO IRWST INJECTION LINES	DEL-IW2AB
					SUCCESS OF CIS & PRE-EXISTING CONTAINMENT OPENING	DEL-XCICPO
					FAILURE OF RECIRCULATION	SYS-RECIRC

AP1000 PRA Dominant CDF Sequences

	Sequence Frequency	% Contrib	Cum. % Contrib	Sequence ID	Sequence Description	Event Identifier
7	7.35E-09	3.05	73.93	2lmlo-05	MEDIUM LOCA INITIATING EVENT OCCURS	IEV-MLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2NL
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADM
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					SUCCESS OF TWO OF TWO IRWST INJECTION LINES	DEL-IW2AB
					SUCCESS OF CIS & PRE-EXISTING CONTAINMENT OPENING	DEL-XCICPO
					FAILURE OF RECIRCULATION	SYS-RECIRC
8	5.11E-09	2.12	76.05	3dmlo-12	SMALL LOCA INITIATING EVENT OCCURS	IEV-SLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADS
					SUCCESS OF PARTIAL ADS DEPRESSURIZATION	DEL-ADV
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
9	4.46E-09	1.85	77.9	3dmlo-12	MEDIUM LOCA INITIATING EVENT OCCURS	IEV-MLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2NL
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADM
					SUCCESS OF PARTIAL ADS DEPRESSURIZATION	DEL-ADU
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
10	3.72E-09	1.54	79.44	2rsad-09	SPURIOUS ADS INITIATING EVENT OCCURS	IEV-SPADS
					FAILURE OF 2/2 ACCUMULATORS	SYS-AC2AB
11	3.67E-09	1.52	80.96	2esad-07	SPURIOUS ADS INITIATING EVENT OCCURS	IEV-SPADS
					SUCCESS OF 1/2 OR 2/2 ACCUMULATORS	DEL-AC2AB
					SUCCESS OF ADS & CMT	DEL-XADMA
					FAILURE OF IRW OR CMT	SYS-XIW2ABA

AP1000 PRA Dominant CDF Sequences

	Sequence Frequency	% Contrib	Cum. % Contrib	Sequence ID	Sequence Description	Event Identifier
12	3.57E-09	1.48	82.44	2lsil-03	SAFETY INJECTION LINE BREAK INITIATING EVENT OCCURS	IEV-SI-LB
					RCPS TRIP AND CMT INJECTION IS SUCCESSFUL - 1 OF 2 CMT TRAINS	DEL-XCM1A
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADM
					IRWST INJECTION IS SUCCESSFUL - 1 OF 1 TRAINS	DEL-IW1A
					SUCCESS OF CIS & PRE-EXISTING CONTAINMENT OPENING	DEL-XCICPO
					FAILURE OF RECIRCULATION	SYS-RECIRC
13	3.55E-09	1.47	83.91	6esgt-41	SGTR EVENT SEQUENCE CONTINUES	SYS-SGTRC
					FAILURE OF CMT OR RCP TRIP	SYS-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADT
					FAILURE OF PARTIAL ADS DEPRESSURIZATION	SYS-ADZ
14	3.31E-09	1.37	85.28	3aatw-23	ATWS PRECURSOR WITH NO MFW EVENT SEQUENCE CONTINUES	SYS-ATWSC
					SUCCESS OF SFW OR PRHR SYSTEM	DEL-XSRT
					SUCCESS OF MANUAL REACTOR TRIP	DEL-RTSTP
					FAILURE OF MANUAL BORATION BY CVS	SYS-CSBOR1
					FAILURE OF CMT OR RCP TRIP	SYS-XCM2AB
15	3.30E-09	1.37	86.65	2eslo-09	SMALL LOCA INITIATING EVENT OCCURS	IEV-SLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADS
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					FAILURE OF TWO OF TWO IRWST INJECTION LINES	SYS-IW2AB

AP1000 PRA Dominant CDF Sequences

	Sequence Frequency	% Contrib	Cum. % Contrib	Sequence ID	Sequence Description	Event Identifier
16	2.88E-09	1.19	87.84	2emlo-09	MEDIUM LOCA INITIATING EVENT OCCURS	IEV-MLOCA
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2NL
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADM
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					FAILURE OF TWO OF TWO IRWST INJECTION LINES	SYS-IW2AB
17	2.19E-09	0.91	88.75	6esgt-13	SGTR EVENT SEQUENCE CONTINUES	SYS-SGTRC
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADS
					FAILURE OF PARTIAL ADS DEPRESSURIZATION	SYS-ADV
18	1.97E-09	0.82	89.57	3dllo-08	LARGE LOCA INITIATING EVENT OCCURS	IEV-LLOCA
					ACCUMULATOR INJECTION IS SUCCESS FUL - 2 OF 2 TRAINS	DEL-ACBOTH
					FAILURE OF ADS OR CMT	SYS-XADMA
19	1.57E-09	0.65	90.22	2lcmt-05	CMT LINE BREAK INITIATING EVENT OCCURS	IEV-CMTLB
					RCPS TRIP AND CMT INJECTION IS SUCCESSFUL - 1 OF 2 CMT TRAINS	DEL-XCM1A
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADM
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					SUCCESS OF TWO OF TWO IRWST INJECTION LINES	DEL-IW2AB
					SUCCESS OF CIS & PRE-EXISTING CONTAINMENT OPENING	DEL-XCICPO
					FAILURE OF RECIRCULATION	SYS-RECIRC

AP1000 PRA Dominant CDF Sequences

	Sequence Frequency	% Contrib	Cum. % Contrib	Sequence ID	Sequence Description	Event Identifier
20	1.41E-09	0.59	90.81	1atra-17	TRANSIENT WITH MFW INITIATING EVENT OCCURS	IEV-TRANS
					FAILURE OF MFW & SFW & PRHR SYSTEMS	SYS-XSTW
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2AB
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADA
					FAILURE OF PARTIAL ADS DEPRESSURIZATION	SYS-AD1A
21	1.29E-09	0.54	91.35	3dsil-16	SAFETY INJECTION LINE BREAK INITIATING EVENT OCCURS	IEV-SI-LB
					CMT INJECTION (1 OF 1 TRAINS) OR RCP TRIP FAILS	SYS-XCM1A
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADQ
					FAILURE OF 1/1 ACCUMULATOR	SYS-AC1A
22	1.13E-09	0.47	91.82	6lsgtc05	CONSEQUENTIAL SGTR EVENT OCCURS	SYS-IECSGTR
					SUCCESS OF CMT & RCP TRIP	DEL-XCM2SL
					SUCCESS OF PASSIVE RHR SYSTEM	DEL-PRL
					SUCCESS OF FULL ADS DEPRESSURIZATION	DEL-ADS
					FAILURE OF NORMAL RHR IN INJECTION MODE	SYS-RNR
					SUCCESS OF TWO OF TWO IRWST INJECTION LINES	DEL-IW2AB
					SUCCESS OF CIS & PRE-EXISTING CONTAINMENT OPENING	DEL-XCICPO
					FAILURE OF RECIRCULATION	SYS-RECIRC
23	9.98E-10	0.41	92.23	3dsil-17	SAFETY INJECTION LINE BREAK INITIATING EVENT OCCURS	IEV-SI-LB
					CMT INJECTION (1 OF 1 TRAINS) OR RCP TRIP FAILS	SYS-XCM1A
					FAILURE OF FULL ADS DEPRESSURIZATION	SYS-ADQ

SENSITIVITY AND IMPORTANCE ANALYSES

- A set of sensitivity and importance analyses are made.

- The results of some of these analyses are provided in the attached tables.

AP1000 PRA System Importances

System Name	Case Description	Core Damage Frequency With System Failed (QNEW)	Core Damage Frequency Increasing Factor (R = QNEW / 2.41E-7)
PMS	No credit is taken for PMS in core damage sequences	1.59E-02	65878
DC-1E	No credit is taken for 1E DC Power in core damage sequences	5.65E-03	23454
IRWST-REC	No credit is taken for IRWST Recirculation in core damage sequences	1.47E-03	6119
ADS	No credit is taken for ADS in core damage sequences	1.46E-03	6040
IRWST-INJ	No credit is taken for IRWST Injection in core damage sequences	3.93E-04	1631
CMT	No credit is taken for CMT in core damage sequences	7.08E-05	294
ACC	No credit is taken for Accumulators in core damage sequences	6.01E-05	249
PRHR	No credit is taken for Passive RHR in core damage sequences	1.84E-05	76
PLS	No credit is taken for PLS in core damage sequences	9.00E-06	7
DC-Non 1E	No credit is taken for Non-1E DC Power in core damage sequences	6.56E-06	27
DAS	No credit is taken for DAS in core damage sequences	2.63E-05	16
AC	No credit is taken for AC Power in core damage sequences	2.36E-06	10
CAS	No credit is taken for CAS in core damage sequences	4.14E-07	1.7
N-RHR	No credit is taken for Normal RHR in core damage sequences	4.11E-07	1.7
SWS	No credit is taken for SWS in core damage sequences	4.00E-07	1.7
CCS	No credit is taken for CCS in core damage sequences	3.78E-07	1.6
SFW	No credit is taken for Startup Feedwater in core damage sequences	2.78E-07	1.2
DG	No credit is taken for Diesel Generators in core damage sequences	2.56E-07	1.1
MFW	No credit is taken for Main Feedwater in core damage sequences	2.54E-07	1.1
SG Overfill Protection	No credit is taken for SG Overfill Protection in core damage sequences	2.41E-07	1

Summary of Sensitivity Analysis Results

Case Name	Case Description	Results
CASE 1	Initiating Event Importances Assuming AP600 Initiating Event Frequencies	LLOCA initiating event is the major contributor (88.23%) to CDF. CDF increases by a factor of 4.4.
CASE 2	Set LCF sequences to core damage	SI-LB initiating event is the major contributor (30.64%) to CDF. CDF increases by a factor of 1.3.
CASE 3	Initiating Event Importances	SI-LB (39.43) and LLOCA (18.66) initiating events are the major contributors to CDF
CASE 4	Accident Sequence Importances	IEV-SI-LB, DEL-XCM1A, DEL-ADM, SYS-IW1A (28.52%) is the major sequence contributor to CDF.
CASE 5	End State Importances	3BE (33.4%) and 3D+1D (23.9%) are the major contributors to CDF.
CASE 6	Common Cause Failure Importances	Software CCF of all cards and IRWST sump strainers plugging CCF are the major contributors to CDF.
CASE 7	Human Error Importances	Operator failure to diagnose SG tube rupture event is the major contributor to CDF.
CASE 8	Component Importances	IRWST strainer plugged, PRHR H/X plug/leak and IRWST tank failure are major contributors to CDF.
CASE 9	No credit is taken for ADS in core damage sequences	CDF increases by a factor of 6040.
CASE 10	No credit is taken for CMT in core damage sequences	CDF increases by a factor of 294.
CASE 11	No credit is taken for Accumulators in core damage sequences	CDF increases by a factor of 249.
CASE 12	No credit is taken for IRWST Injection in core damage sequences	CDF increases by a factor of 1631.

Summary of Sensitivity Analysis Results

Case Name	Case Description	Results
CASE 13	No credit is taken for IRWST Recirculation in core damage sequences	CDF increases by a factor of 6119.
CASE 14	No credit is taken for Passive RHR in core damage sequences	CDF increases by a factor of 76.
CASE 15	No credit is taken for PMS in core damage sequences	CDF increase by a factor of 65878.
CASE 16	No credit is taken for PLS in core damage sequences	CDF increases by a factor of 7.
CASE 17	No credit is taken for DAS in core damage sequences	CDF increases by a factor of 16.
CASE 18	No credit is taken for Normal RHR in core damage sequences	CDF increases by a factor of 1.7.
CASE 19	No credit is taken for SG Overfill Protection in core damage sequences	CDF increases by a factor of 1.0.
CASE 20	No credit is taken for Main Feedwater in core damage sequences	CDF increases by a factor of 1.1.
CASE 21	No credit is taken for Startup Feedwater in core damage sequences	CDF increases by a factor of 1.2.
CASE 22	No credit is taken for AC Power in core damage sequences	CDF increases by a factor of 10.
CASE 23	No credit is taken for Diesel Generators in core damage sequences	CDF increases by a factor of 1.1.
CASE 24	No credit is taken for 1E DC Power in core damage sequences	CDF increases by a factor of 23454.

Summary of Sensitivity Analysis Results

Case Name	Case Description	Results
CASE 25	No credit is taken for Non-1E DC Power in core damage sequences	CDF increases by a factor of 27.
CASE 26	No credit is taken for SWS in core damage sequences	CDF increases by a factor of 1.7.
CASE 27	No credit is taken for CCS in core damage sequences	CDF increases by a factor of 1.6.
CASE 28	No credit is taken for CAS in core damage sequences	CDF increases by a factor of 1.7.
CASE 29	Set HEPs to 1.0 in core damage output file (no credit for HEPs)	CDF increases by a factor of 57.
CASE 30	Set HEPs to 0.0 in core damage output file (perfect operator)	CDF decreases 8%.
CASE 31	Set HEPs to 0.1 in core damage output file	CDF increases by a factor of 6.5.
CASE 32	Impact of passive system check valve failure probabilities	CDF increases by a factor of 3.7.
CASE 33	Impact of explosive valve failure probabilities	CDF increases by a factor of 2.7.
CASE 34	Impact of reactor trip breaker failure probabilities	CDF has negligible increase.
CASE 35	Impact of RCP breaker failure probabilities	CDF increases by a factor of 1.2.
CASE 36	Sensitivity to standby non-safety systems (CVS,SFW,RNS,DAS,DG)	CDF increases by a factor of 31.

AP1000 Importance of Non-Safety Systems

- For AP600 - W determined safety importance of Non-Safety Systems
  - –Part of the resolution of Regulatory Treatment of Non-Safety Systems (RTNSS) Policy Issue
  - –Included PRA sensitivity studies / evaluations
    - –IE Frequency Evaluations
    - –Mitigation importance - Focused PRA, NSS importance sensitivity studies
  - –DCD contains availability controls for selected NSS
- For AP1000 - W determined safety importance of Non-Safety systems
  - –Non-safety systems have same functions, configurations, capabilities
  - –PRA risk importance similar for both plants
    - –PRA risk profile of AP1000 is similar to AP600
    - –PRA system importance of NSS is similar to AP600
- AP1000 DCD contains same availability controls as AP600

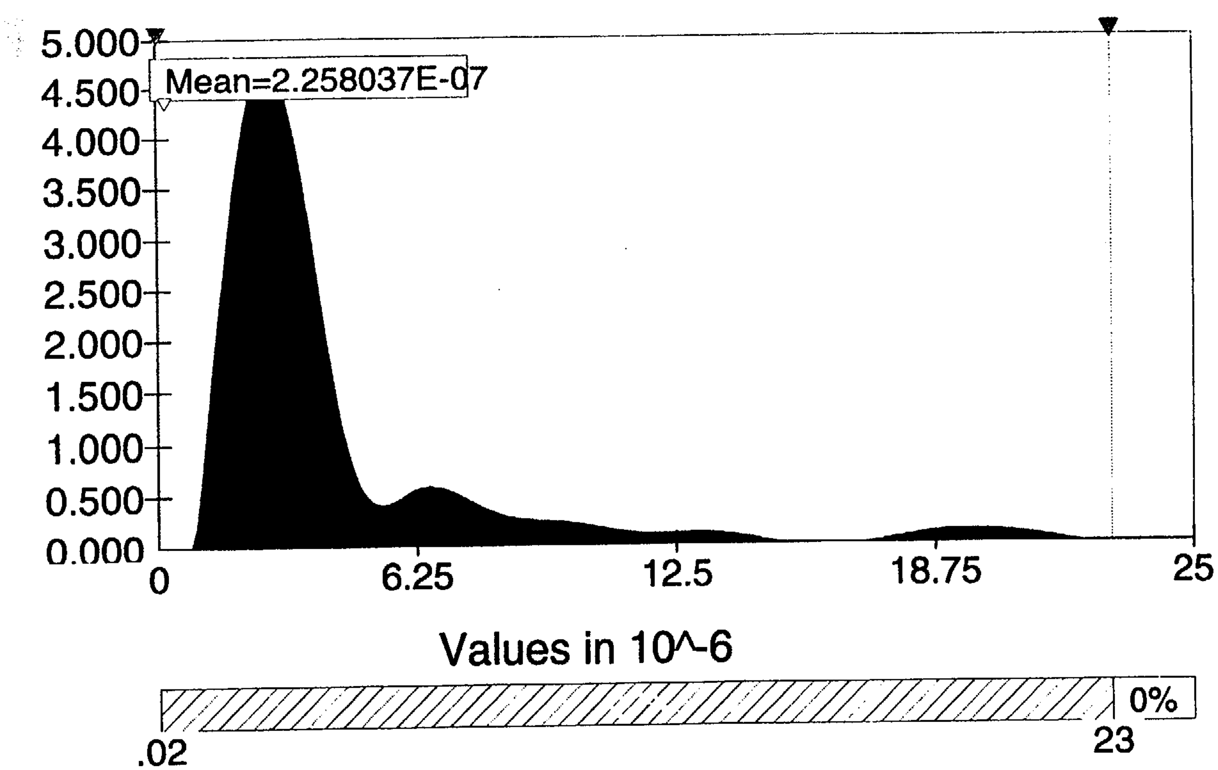
List of Non-Safety Systems Covered by Availability Controls

- Diverse Actuation System
- Normal Residual Heat Removal System
- Component Cooling Water System
- Service Water System
- PCS Ancillary Water Makeup
- MCR and I&C Room Ancillary Fans
- Hydrogen Igniters
- AC Power Supplies (Offsite and / or Standby Diesel Generators)
- Non-Class 1E DC and UPS

UNCERTAINTY ANALYSIS

- The plant CDF uncertainty range is found to be 7.3 E-07 – 2.1 E-08 for the 95% to 05 % interval.
- For a lognormal distribution, this would correspond to an error factor of 6, which can be considered as low for rare events.

Distribution for CDF-1000/B2233



Name	**CDF-1000**
Cell	B2233
Minimum	4.33E-09
Mean	2.26E-07
Maximum	2.11E-05
Std Dev	6.78E-07
Variance	4.60E-13
Skewness	16.32415
Kurtosis	386.4707
Mode	2.91E-08
Left X	1.78E-08
Left P	3%
Right X	0.000023
Right P	100%
Diff. X	2.30E-05
Diff. P	97%
5th Perc.	2.11E-08
95th Perc	7.29E-07
#Errors	0
Filter Min	
Filter Max	
#Filtered	0

UNCERTAINTY ANALYSIS

- The mean values of the dominant accident sequence frequencies are close to the upper bound (95%) estimates;
- Among the initiating event categories, SI-LB has the highest 95-percentile CDF of 3.2E-07 /year.
- Among the dominant sequences, sequence # 07 of SI-LB event has the highest 95-percentile CDF of 2.1E-07/yr.

SHUTDOWN EVENTS

- A quantitative shutdown risk evaluation is performed for AP1000 for internal events.
- The risk profiles of AP1000 and AP600 for events during shutdown conditions are almost identical.
- The AP1000 Shutdown PRA has a CDF of 1.23E-07 events per year. This CDF is an 18% increase of the AP600 Level 1 Shutdown CDF of 1.04E-07 events per year.

SHUTDOWN EVENTS

- The three events dominating the CDF for each plant are loss of component cooling / service water during drained condition, loss of offsite power during drained condition, and loss of RNS during drained condition.
- The initiating event CDF contributions show that the initiating event importance to be similar for the two plants.

SHUTDOWN EVENTS

- The twelve dominant accident sequences comprise 77 percent of the level 1 shutdown CDF. They consist of:

  – Loss of component cooling or service water system initiating event during drained condition with a contribution of 64 percent of the CDF

SHUTDOWN EVENTS

–Loss of RNS initiating event during drained condition with a contribution of 6 percent of the CDF

–Loss of offsite power initiating event during drained condition with a contribution of 5 percent of the CDF

–RCS overdraining event during drainage to mid-loop with a contribution of a 2 percent of the CDF.

INTERNAL FLOODING AND FIRE

- The internal flooding-induced CDF is estimated to be 8.8E-10 events per year for power operations.

- The CDF from flooding events at power is not an appreciable contributor to the overall AP1000 plant CDF.

INTERNAL FLOODING AND FIRE

- The top five at-power flooding scenarios comprise 91 percent of the at-power flooding-induced core damage frequency.
- These scenarios are for large pipe breaks in the turbine building with an initiating event frequency in the range of 1.4 – 2.0 E-03 / year, leading to a loss of CCW/SW event. Each scenario has a CDF of 1.2 – 1.8E-10/year.

INTERNAL FLOODING AND FIRE

- AP600 Fire PRA quantified with bounding focused PRA model
  - –CDF is 6.5E-07 /yr
  - –No credit for non-safety systems
- Extensive fire hazards analysis review completed for AP600 subsequent to fire AP600 PRA
  - –Fire separation improved
  - –Fire suppression features incorporated
  - –Design features incorporated to address hot-shorts

INTERNAL FLOODING AND FIRE

- Qualitative evaluation of risk from fire performed
  - AP600 design features important for fire protection are included in the AP1000
    - Fire separation / fire zones
    - Systems used to achieve safe shutdown
    - Fire suppression features
  - AP1000 design is sufficiently robust that internal fires during power operation or shutdown do not represent a significant contribution to plant CDF

SEISMIC MARGINS EVALUATION

- The seismic margin analysis shows the systems, structures, and components required for safe shutdown. HCLPF values are greater than or equal to 0.50g
- This HCLPF is determined by the seismically induced failure of the fuel in the reactor vessel, core assembly failures, IRWST failure, or containment interior failures

SEISMIC MARGINS EVALUATION

- The SMA result assumes no credit for operator actions at the 0.50g review level earthquake, and assumes a loss of offsite power for all sequences

- The SMA shows the plant to be robust against seismic event sequences that contain station blackout coupled with other seismic or random failures

Comparison of Low HCLPF SSCs in AP1000 and AP600 Designs

Basic Event ID	Description	AP600 HCLPF	AP1000 HCLPF
EQ-CER-INSULATOR	Failure of Ceramic Insulators	0.09g	.09g
EQ-CORE-ASSEMBLY	Core Assembly Failure (not fuel)	0.50g	.50g
EQ-CV-INTER	Interior Containment	0.60g	.50g
EQ-IRWST-TANK	IRWST Failure	0.60g	.50g
EQ-RV-FUEL	Fuel Failure	0.50g	.50g
EQ-AB-EXTWALL	Aux. Building Exterior wall	0.58g	.51g
EQ-AB-FLOOR	Aux. Building Floor	0.58g	.51g
EQ-AB-INTWALL	Aux. Building Interior wall	0.58g	.51g
EQ-PCC-TANK	PCC Tank Failure	0.58g	.51g
EQ-SHDBLD-ROOF	Shield Building Roof	0.58g	.51g
EQ-SHDBLD-WALL	Shield Building Wall	0.58g	.51g
EQ-CABLETRAY	Cable trays - support controlled	0.54g	.54g
EQ-CMT-TANKS	Tank PXS 2A/B (Core Makeup Tank)	0.63g	.54g
EQ-SG-FAILS	Steam Generator Fails	0.65g	.54g
EQ-SGTR	Steam Generator Piping (one or a few)	0.65g	.54g
EQ-ACDISPANEL	120 vac distribution panel	0.51g	.55g
EQ-DC-SWBRD	125 vdc switchboard	0.51g	.55g
EQ-DCDISPANEL	125 vdc distribution panel	0.51g	.55g
EQ-PRZR-FAILS	Pressurizer Fails	0.67g	.55g
EQ-TRSFSWITCH	Transfer switch	0.51g	.55g

OTHER EXTERNAL EVENTS

- High winds and tornadoes
- External floods
- Transportation and nearby facility accidents

  - As per the site selection criteria defined in Chapter 2 of the DCD, a frequency of occurrence of 10^{-6} per year, for an accident external to AP1000 that has a potential consequence serious enough to affect the safety of the plant according to 10 CFR 100 guidelines, is not exceeded.

Comparison of AP600 and AP1000 PRA Results

Scope	AP600	AP1000
Level 1 At-Power Internal Initiating Events	Quantification Performed CDF = 1.7E-07 Several additional cases quantified in response to NRC RAIs	Quantification Performed CDF = 2.4E-07 AP600 additional cases incorporated into the model
Level 2 At-Power Internal Initiating Events	Quantification Performed LRF = 1.8E-08 Containment Effectiveness = 89.5%	Quantification Performed LRF = 2.0E-08 Containment Effectiveness = 91.8%
Level 3 At-Power Internal Initiating Events	Quantification Performed	Quantification Performed
Internal Fire Events	Conservative (via focused PRA) Quantification Performed CDF = 6.5E-07 (internal) CDF = 3.5E-07 (shutdown)	Assessment Performed AP600 fire PRA quantification bounds AP1000
Internal Flooding Events	Quantification Performed CDF = 2.2E-10	Quantification Performed CDF = 8.8E-10
Shutdown Events	Quantification Performed for Level 1 and 2 CDF = 1.0E-07 LRF = 1.5 E-08 Several additional cases quantified in response to NRC RAIs	Quantitative Evaluation Performed CDF = 1.2E-07 AP600 additional cases incorporated into the estimation model
Focused PRA Internal Events At-Power	Quantification Performed CDF = 9.1E-06 LRF = 8.1E-07 Availability controls of NSS adopted	Sensitivity studies performed demonstrate that NSS are not important for AP1000 risk. Same availability controls on NSS adopted for AP1000

SUMMARY OF RESULTS

- The AP1000 PRA results show that
  - The very low risk of the AP600 has been maintained in the AP1000
  - The AP1000 PRA meets the US NRC safety goals with significant margin

AP1000 Level 2 PRA

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Purpose of Level 2 PRA

- Status of containment integrity
  - –system failures (unisolated SGTR, isolation failure)
  - –failure due to high energy phenomena
    - –induced tube rupture
    - –Steam Explosion (in-vessel and ex-vessel)
    - –Hydrogen Combustion
    - –High Pressure Melt Ejection / Direct Containment Heating
    - –Debris Impingement
    - –Core-Concrete Interaction
    - –Long Term Containment Pressurization from Decay Heat Steaming

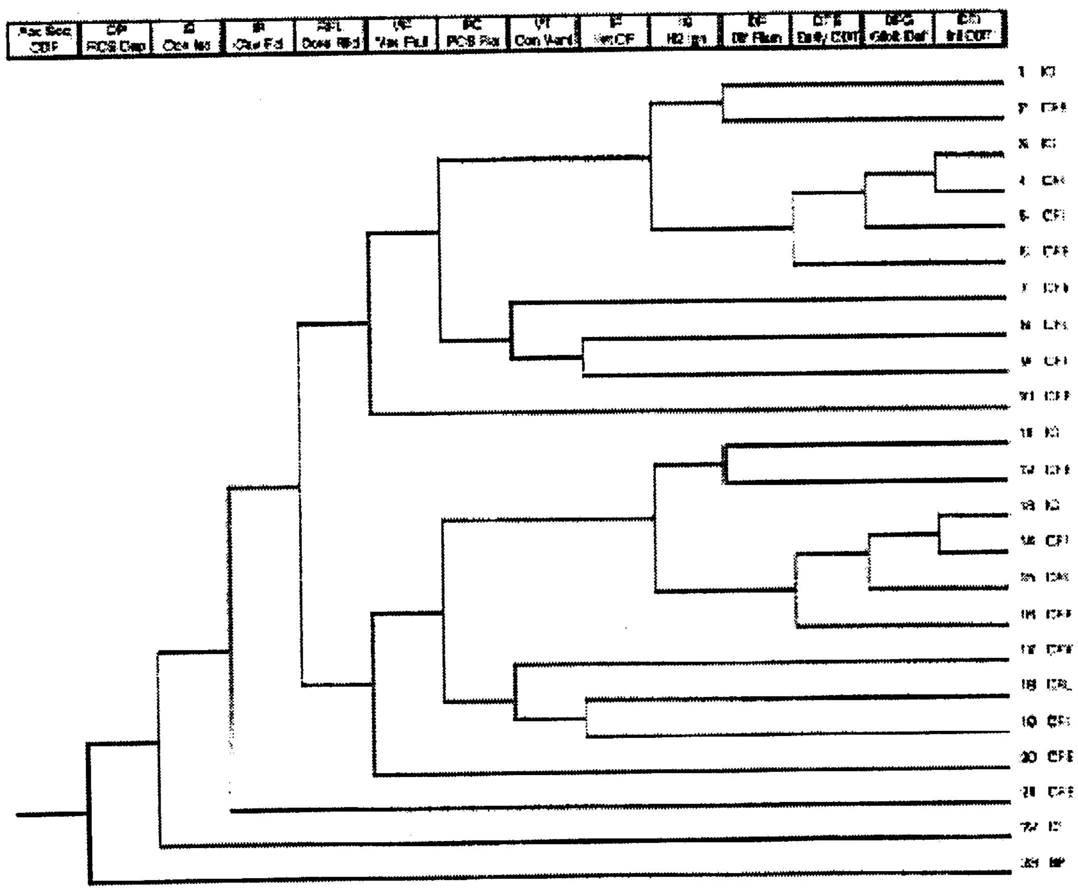
Purpose of Level 2 PRA

- Quantify Magnitude and Timing of Offsite Release
  - –Accident Classes (same as AP600)
  - –Release Categories (same as AP600, plus CFV)
  - –Source Terms (assumed same fractions as AP600)

AP1000 Containment Event Tree

- Pretty much the same as AP600
- Added possibility of containment venting
  - –added CFV release category
  - –assumed failure probability of unity

AP1000 Containment Event Tree



Containment Event Tree Quantification

- System Nodes
  - –Quantification
    - –Linked Fault Trees
    - –Scalars defined by accident class definition
  - –containment isolation
  - –cavity flooding
  - –PCS water cooling
  - –hydrogen control

Containment Event Tree Quantification

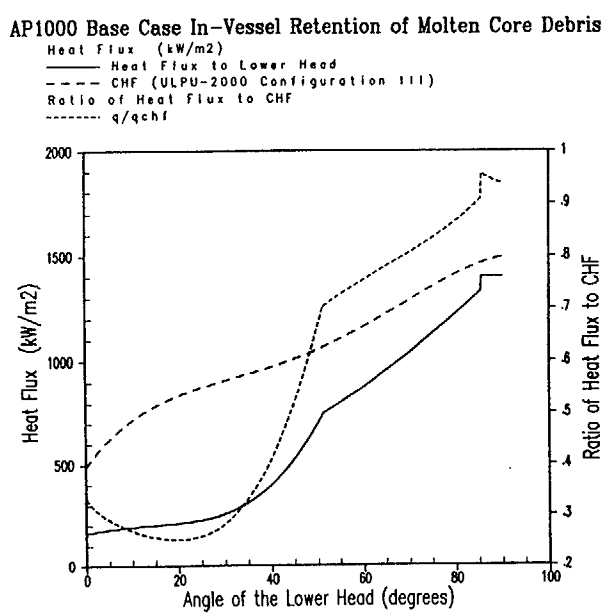
- Phenomenological Nodes
  - –Quantification
    - –Scalars defined by analysis of phenomena
    - –boundary conditions defined by accident class
  - –induced SGTR tube rupture
  - –core reflooding
  - –in-vessel retention of molten core debris
  - –hydrogen combustion
  - –containment integrity

In-Vessel Retention of Molten Core Debris

- Changes to the AP1000 that potentially impact IVR
  - –power is increased to 3400 MWt.
  - –157 14-ft fuel assemblies.
  - –core shroud instead of reflector
  - –lower core support plate is 1" thicker

In-Vessel Retention of Molten Core Debris

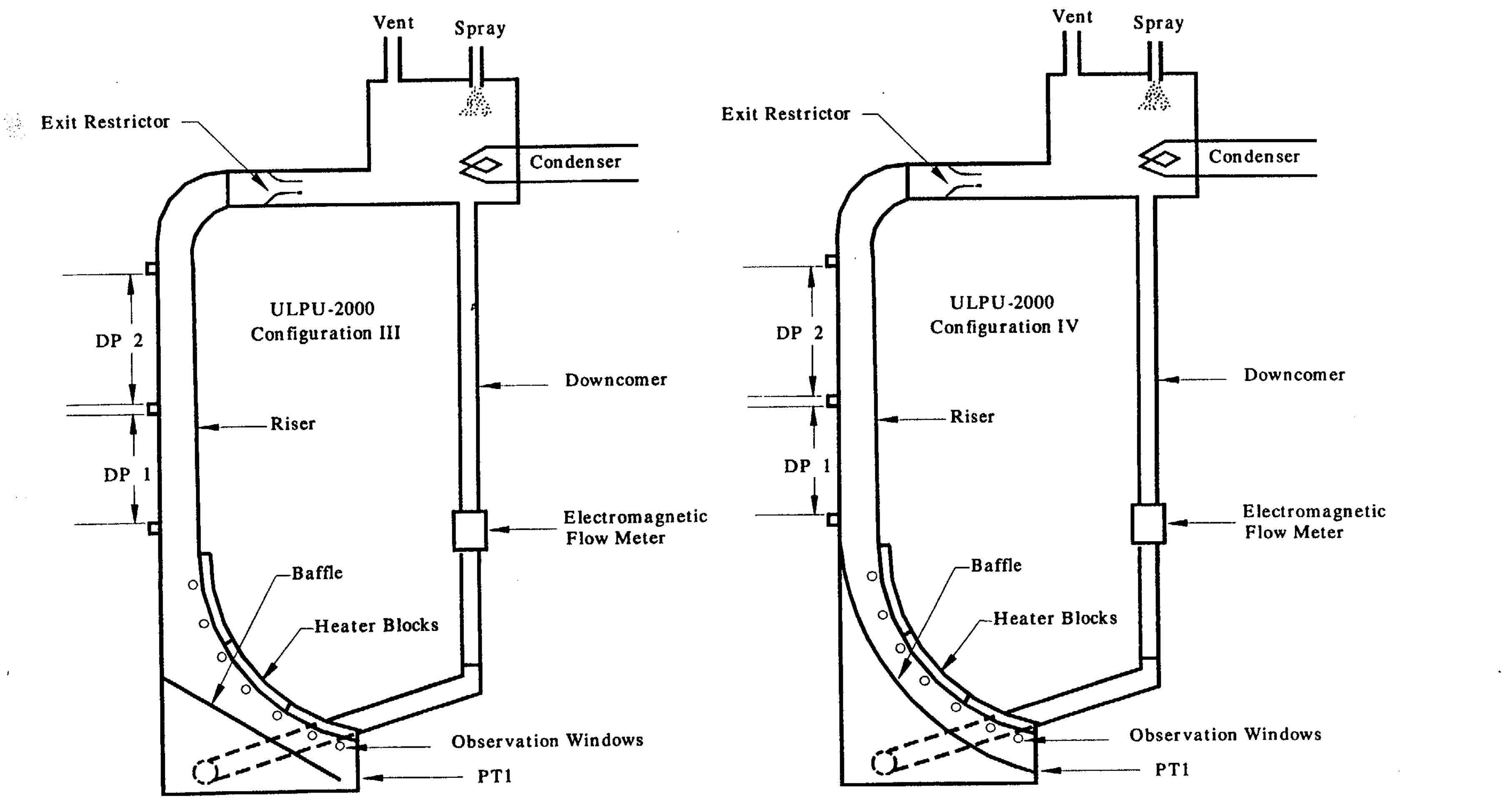
- DOE/ID-10460 methodology to quantify heat flux
  - –AP600 CHF success criterion not sufficient for AP1000



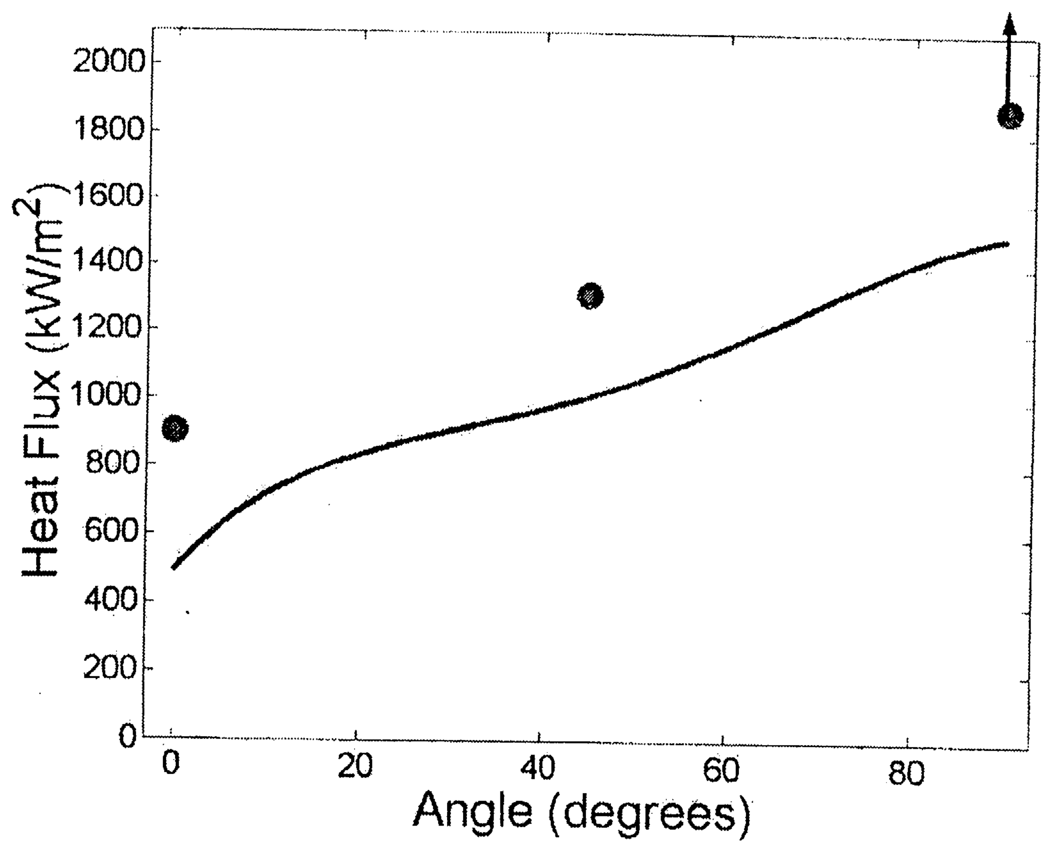
In-Vessel Retention of Molten Core Debris

- Effort to achieve margin similar to AP600
  - –testing
  - –design changes
- Performed UPLU Configuration IV Testing
  - –examined changes to increase CHF on vessel surface
    - –CHF increased more than 30%
  - –two-phase natural circulation is required
  - –insulation geometry and structure is important

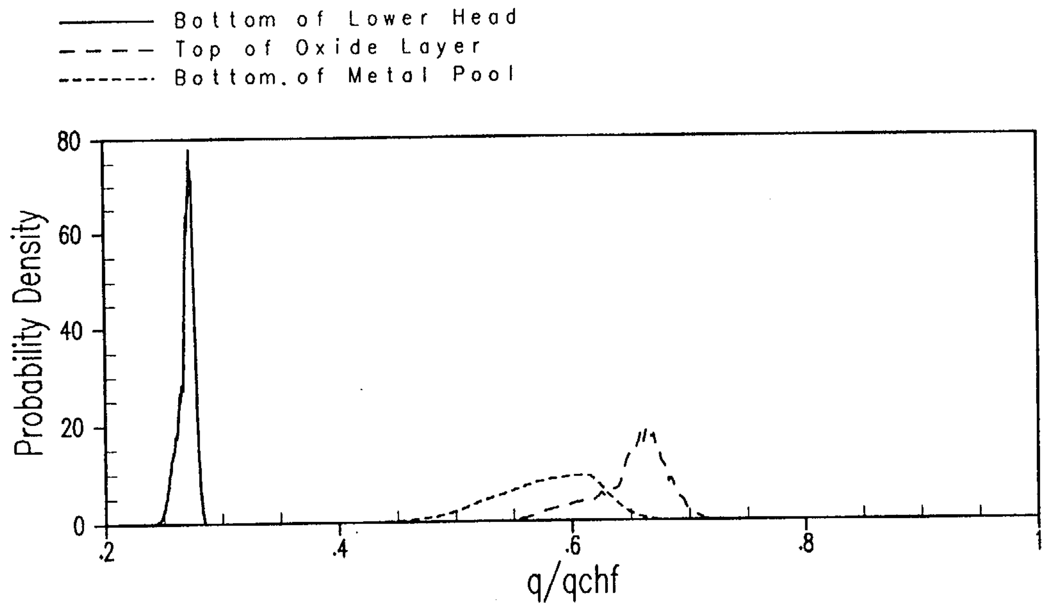
ULPU Configuration IV



ULPU Configuration IV Results



IVR Results



- Reclaim most of the margin of the AP600
- Continuing ULPU program to define design

In-Vessel Steam Explosion

- In-Vessel Steam Explosion Analysis for AP600
  - –DOE/ID 10541 In-Vessel Steam Explosion ROAAM
  - –Large margin to failure
- Debris relocation mechanism for AP1000 same as AP600
  - –sideward failure
  - –similar mass and superheat as AP600
- Geometry the same for AP1000 as AP600
- Extrapolate AP600 results to AP1000

Ex-Vessel Steam Explosion

- Prevented by IVR
- Vessel failure assumed to produce early containment failure on CET
- Assumed same vessel failure modes as AP600
  - –similar mass and superheat in the debris
- AP600 ex-vessel steam explosion results extrapolated to AP1000

Hydrogen Combustion

- Hydrogen control system
  - –PARs (not credited in PRA)
  - –Igniters (same number and layout as AP600)
  - –If igniters working diffusion flame is only failure mode
- PCS water assumed to be working
  - –steam inert if PCS water not working
  - –no consideration of sprays
- Detonation assumed to fail containment

Early Hydrogen Burn

- During H_2 release
  - –before containment is well-mixed
- Diffusion Flames
  - –ADS stage 4 releases hydrogen in loop compts
  - –IRWST release hydrogen away from shell
    - –stand pipe vents near SG doghouse open preferentially
    - –CET failure probability defined by stuck open wall vents in accident classes with no ADS-4
  - –PXS compt vents hydrogen away from shell

Early Hydrogen Burn (continued)

- Deflagration to Detonation Transition
  - –igniter failure
  - –use AP1000 specific sequence conditional probabilities
  - –use AP600 DDT probabilities (Sherman-Berman Method)
  - –CET assumes containment failure if DDT occurs

Intermediate Hydrogen Burn

- Occurs before 24 hours
- Igniter failure
- Containment well-mixed
- Global deflagration
  - –used AP600 probability distributions
    - –hydrogen mass scaled up by mass ratio of active cladding
    - –pre-burn pressure same as AP600
  - –adiabatic peak pressure calculation
  - –containment failure defined by containment fragility curve

Intermediate Hydrogen Combustion

- DDT
  - –acceleration of global burn in well-mixed compartments
  - –CMT compartment considered to be dry air
  - –DDT assumed to fail containment

High Pressure Melt Ejection

- SECY 93-087
  - –provide a reliable depressurization system
  - –provide debris retentive cavity design
- AP1000 has reliable 4 stage ADS
- Cavity layout is water-filled torturous pathway
  - –no direct pathway for debris impingement
- High pressure core melt assumed to fail SG tubes on containment event tree

Core Concrete Interaction

- Mitigated by IVR
- Vessel failure assumed to fail containment on CET
- AP1000 specific analysis
  - –basemat failure not expected within 24 hours
  - –containment overpressurization does not occur before basemat failure

Long Term Containment Pressurization

- Mitigated by PCS water cooling
  - –added third diverse pathway
  - –failure of water produces small probability of cnmt failure
- Containment pressurization with no PCS water
  - –nominal case
    - –Ambient Temp =80 F and best estimate ANS 79 decay heat
  - –bounding case
    - –Ambient Temp = 115 F and ANS 79 + 2 sigma decay heat
- Containment Fragility Curve defines failure

Long Term Containment Pressurization

- Assigned 0.02 failure probability for < 24 hours
  - –assumed failure probability = 1.0 after 24 hours
- Containment Venting
  - –investigated performance with various line sizes
  - –concluded that operator could vent through any line > 4"
  - –containment underpressure
  - –assigned venting failure probability of 1

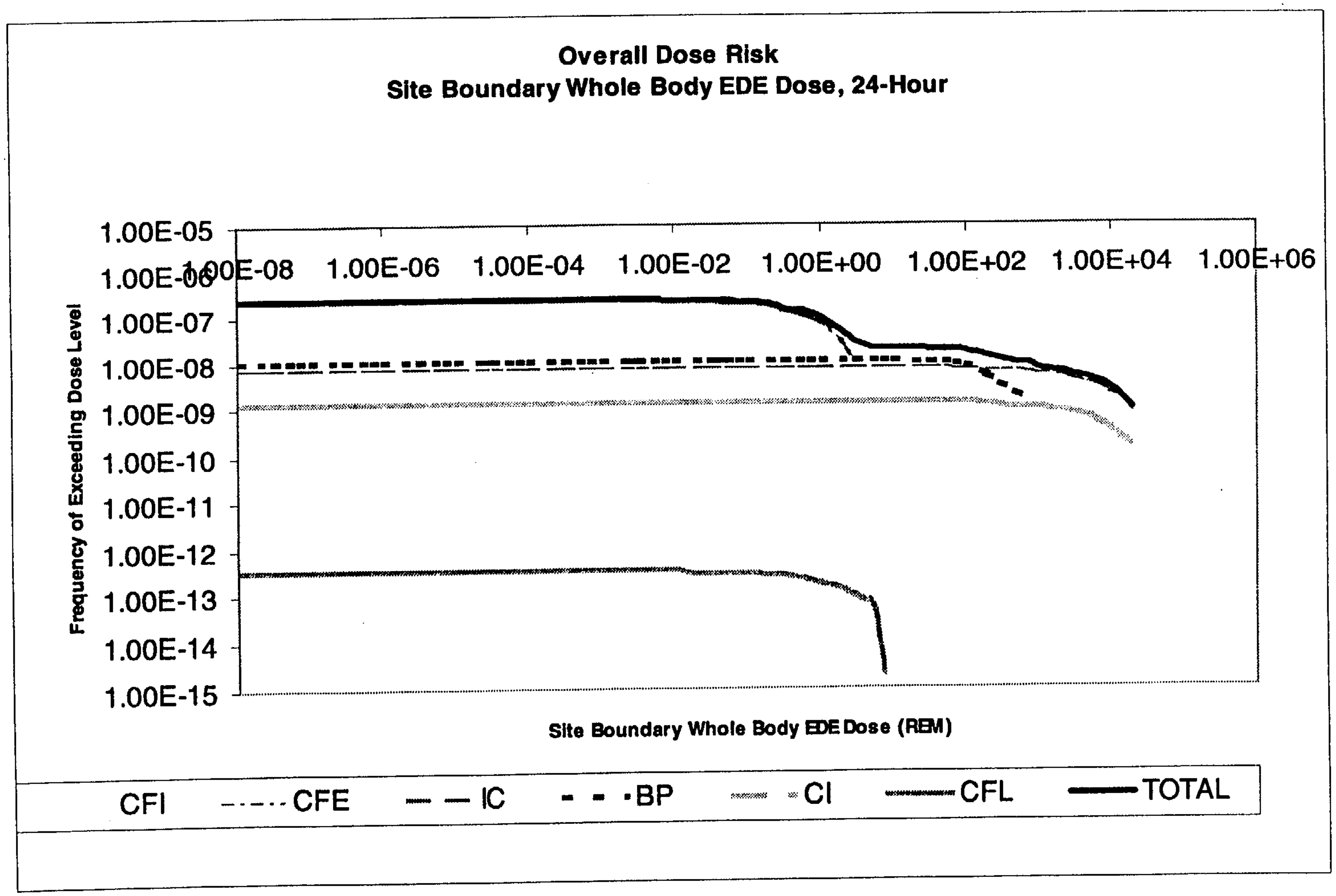
Level 2 At-Power Results

- Core Damage Frequency = $2.41x10^{-7}$ per year
- Large Release Frequency = $1.95x10^{-8}$ per year
- Frequency by Release Categories
  - –Containment Bypass = $1.05x10^{-8}$
  - –Early Containment Failure = $7.47x10^{-9}$

Level 3 PRA

- Used AP600 Release Fractions
  - AP1000 fission product inventories
- Calculated off site doses with MACCS2 1.12

Level 3 PRA Results



Success Criteria / Thermal-Hydraulic Analysis

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Overview

- **Success Criteria (Chapter 6 of PRA)**
  - –Changes in success criteria vs AP600
- **Thermal Hydraulic Analysis (Appendix A of PRA)**
  - –Analysis used, DCD, specific PRA, or other analysis / calculations
  - –Summary of results
  - –ADS analysis
  - –T&H Uncertainty Analysis

AP1000 Success Criteria

- **Based on AP600**
  - –Similar system design, arrangement, capabilities
- **Several Changes Made to the AP1000 Success Criteria**
  - –Due to increase in power vs capacity of mitigating features
  - –Due to design changes to accommodate the power increase
  - –Due to other factors
- **AP1000 Success Criteria More Conservative / Robust**
  - –Requires same or more equipment for success
    - –For example, requires 3/4 ADS 4 instead of 2/4 ADS 4
      - –Even though AP1000 ADS 4 is larger / MW
  - –Reduces T&H issues / uncertainty

AP1000 Success Criteria

Event	Same as AP600	Comments
Transients	yes	
ATWS	yes	UET = 0 because of low boron core
SLB (down MSIV)	yes	
SLB (up MSIV)	yes	
SGTR	yes	
RCS Leak	yes	
PRHR Tube Rupture	yes	
Small LOCA	no	See next slide
Medium LOCA	no	See next slide
CMT BL LOCA	no	See next slide
DVI LOCA	no	See next slide
Spurious ADS (Lg)	no	Requires ADS 4, cont. recirc (was part of AP600 Large LOCA)
Large LOCA	no	Requires 2/2 accum, ADS 4, cont. recirc.

Post ADS Success Criteria

- **Changes Made to Post ADS Success Criteria**
  - –Full ADS (IRWST) >> requires 3/4 ADS stage 4
    - –AP600 PRA used 2/4 ADS stage 4
      - –Later PRA T&H analysis showed that AP600 needed 3/4
    - –AP1000 ADS 4 capacity has been increased by more than power
  - –Partial ADS (RNS) >> requires 2 of 4 ADS stage 2 or 3
    - –AP600 PRA used 1/4 stage 2 or 3
    - –ADS stages 1, 2, 3 capacities not increased for AP1000
  - –Requires PRHR HX for MLOCAs with only Accum
    - –Provides operators more time (> 20 min) to take action
  - –Requires 2/4 Cont Recirc if Cont Isol fails
    - –1/4 Cont Recirc if Cont Isol works

Thermal Hydraulic Analysis

- **Thermal Hydraulic Analysis Has Been Performed to Determine the AP1000 Success Criteria**
  - –Use DCD analysis when applicable
  - –Otherwise
    - –Use special PRA analysis
    - –Use other calculations
    - –Use evaluations
- **Thermal Hydraulic Uncertainty Has Been Performed**
  - –Uses DCD analysis methods to bound T&H uncertainty for low margin / risk important accident scenarios
    - –Same approach as AP600

PRA T&H Analysis

- **Events That Utilize PRA Specific Analysis**
  - –ATWS > LOFTRAN analysis
  - –LTC > DCD analysis, AP600 lessons learned, AP1000 hand calculation (margin)
  - –Spurious ADS (large LOCA) > insights from operating plants (HL vs CL LOCAs), hand calculation (margin)
  - –LOCAs (other than LLOCAs) and Feed-Bleed Cooling > MAAP analysis

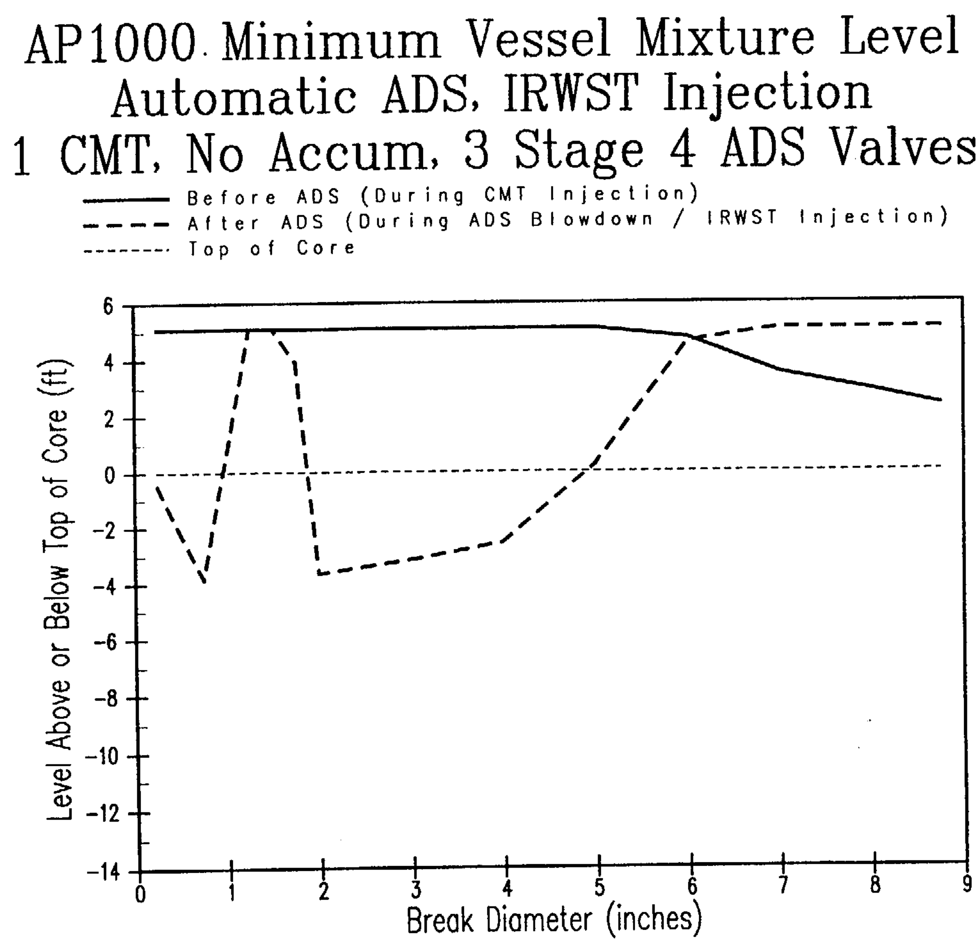
PRA T&H Analysis

- **LOCA and Feed-Bleed Cooling Analysis**
  - –Considers many different factors
    - –Initiating event, LOCA or Feed-Bleed Cooling after non-LOCA
    - –LOCA size and location
    - –Available mitigating equipment including CMT, Accum, RNS, PRHR HX, ADS, IRWST, Cont Recirc
  - –Made use of lessons learned from AP600
    - –Test results, DCD analysis, PRA analysis (both success criteria and T&H uncertainty
    - –Divided into four groups of analysis
      - –Automatic ADS with IRWST gravity injection or RNS injection
      - –Manual ADS with IRWST gravity injection or RNS injection

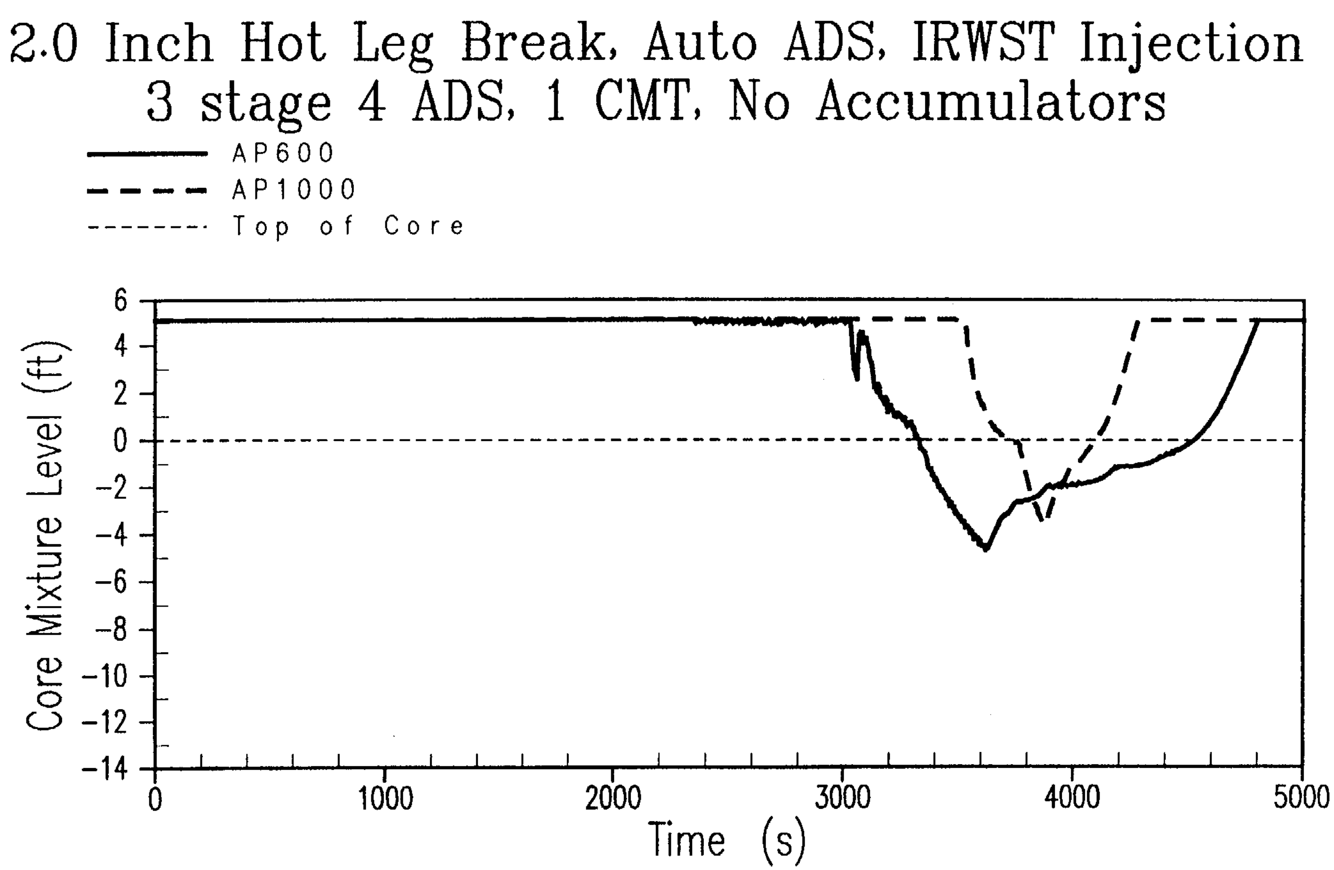
Auto ADS with IRWST Gravity Injection

- **Limiting Equipment Assumed**
  - –Same as AP600
  - –One CMT, no Accum, 1 valve path in one IRWST injection line
  - –3/4 ADS stage 4 , no ADS stage 1/2/3, no PRHR HX
    - –For LOCAs < 2" some ADS 1/2/3 or PRHR HX required to reduce RCS pressure to below ADS 4 pressure interlock
  - –Containment isolation fails
- **MAAP Analysis Was Performed**
  - –Break sizes 0.5" up to 8.75"
  - –Core uncovery depth and duration is less than AP600
    - –Increased capacity PXS, especially ADS 4, IRWST injection
  - –AP600 success criteria remains valid for AP1000

Auto ADS with IRWST Gravity Injection



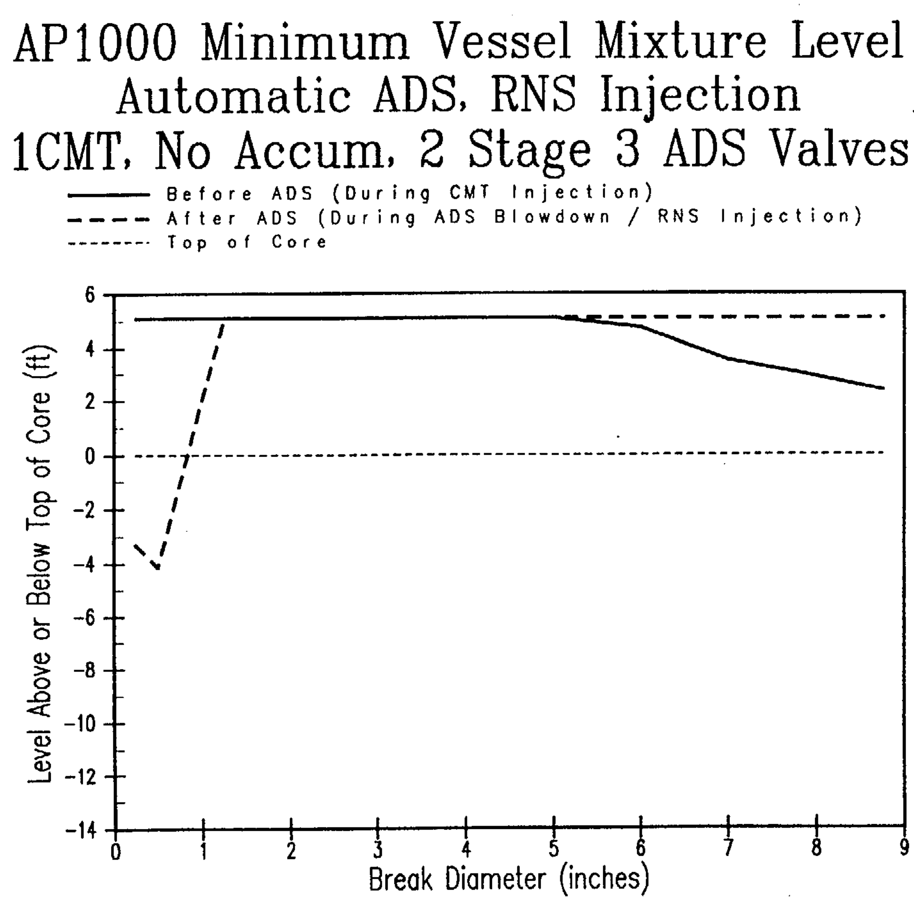
Auto ADS with IRWST Gravity Injection



Auto ADS with Injection By RNS

- **Limiting Equipment Assumed**
  - –Same as AP600, except a second ADS stage 2/3 required
  - –One CMT, no Accum, no IRWST gravity inject line, one RNS pump
  - –2/4 ADS stage 2/3, no ADS stage 1/4, no PRHR HX
  - –Containment isolation fails
- **MAAP Analysis Was Performed**
  - –Break sizes 0.5" up to 8.75"
    - –DVI not analyzed, RNS not credited as success for this LOCA
  - –Core uncovery depth and duration less than with "full" ADS and IRWST gravity injection
  - –AP600 success criteria remains valid for AP1000

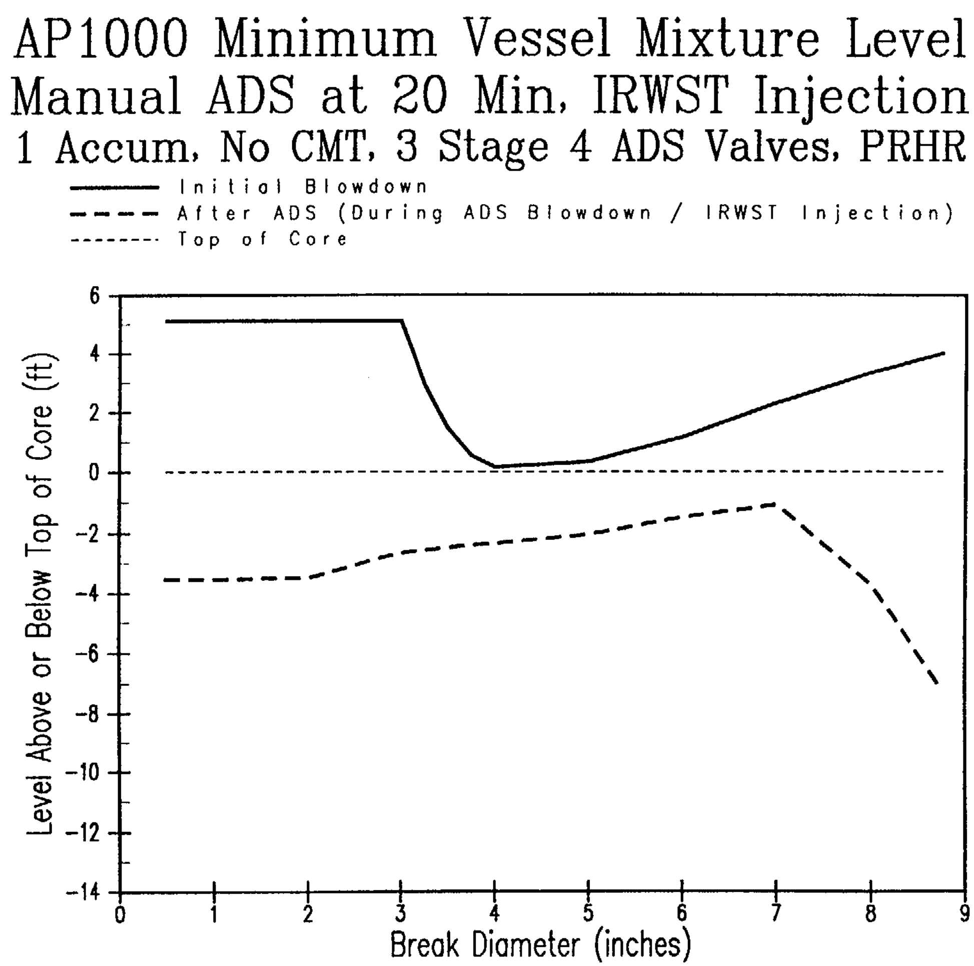
Auto ADS with Injection By RNS



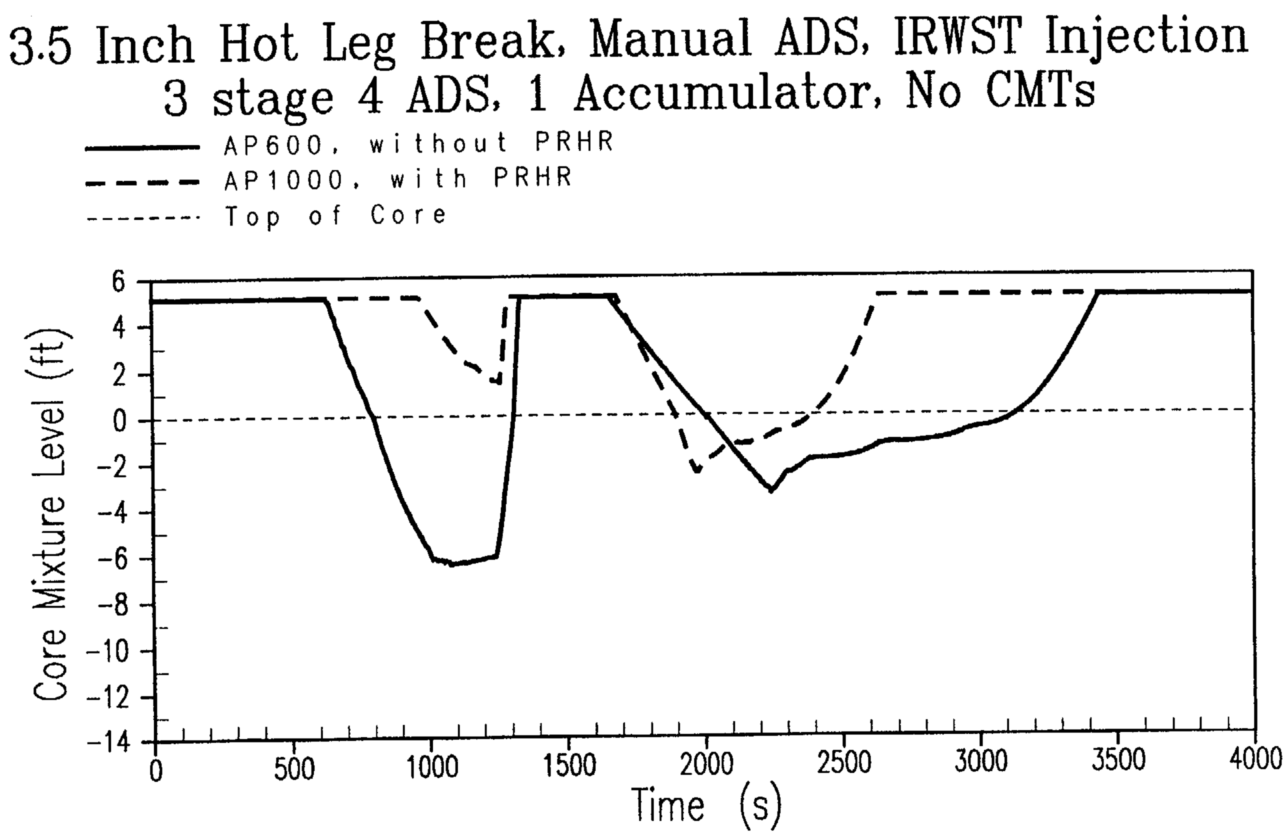
Manual ADS with IRWST Gravity Injection

- **Limiting Equipment Assumed**
  - –Same as AP600, except for use of PRHR HX for MLOCAs
  - –No CMT, 1 Accum, 1 valve path in one IRWST injection line
  - –3/4 ADS stage 4 , no ADS stage 1/2/3, no PRHR HX
    - –For MLOCAs 2" to 9" PRHR HX is required to give operators at least 20 min to open ADS 4
  - –Containment isolation fails
- **MAAP Analysis Was Performed**
  - –Break sizes 0.5" up to 8.75"
  - –Core uncovery depth and duration is similar to AP600
    - –Increased capacity PXS, especially ADS 4, IRWST injection, use of PRHR
  - –AP600 success criteria remains valid for AP1000

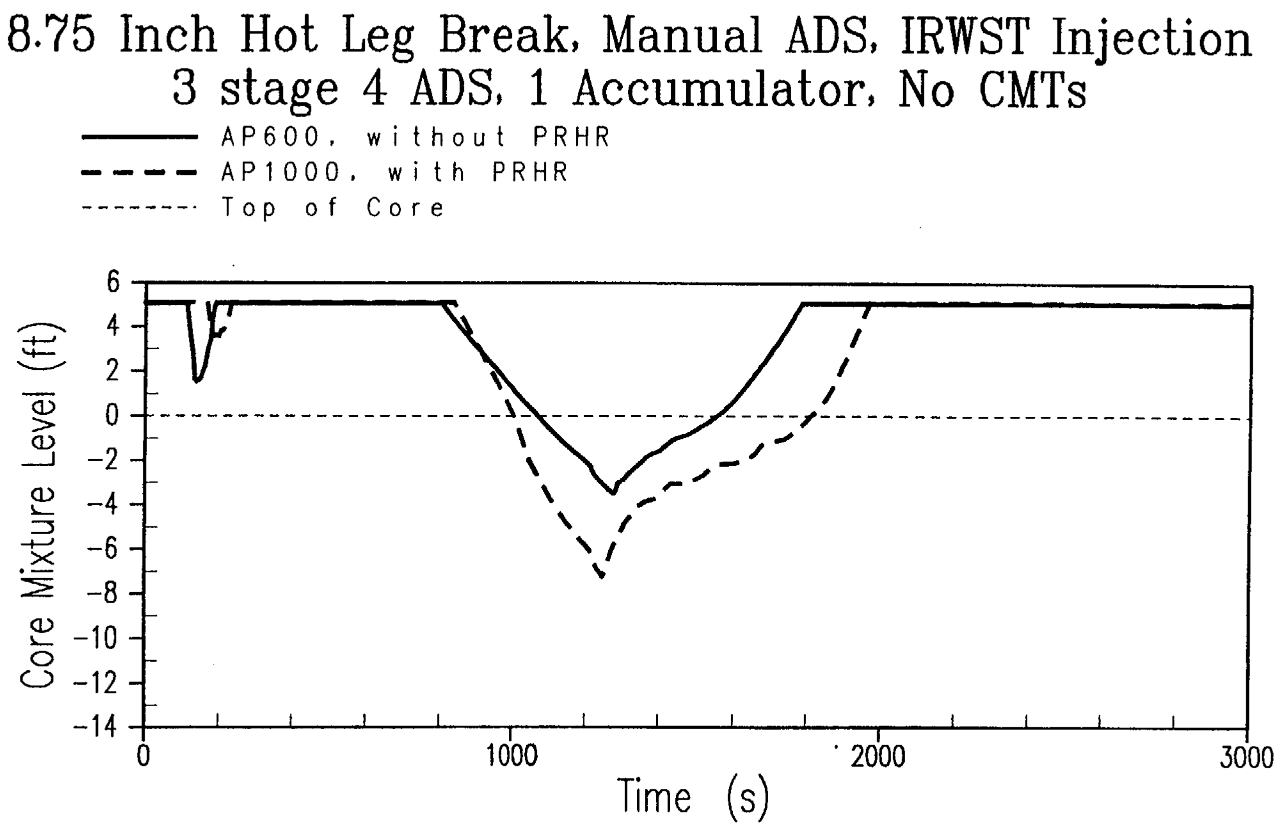
Manual ADS with IRWST Gravity Injection



Manual ADS with IRWST Gravity Injection



Manual ADS with IRWST Gravity Injection

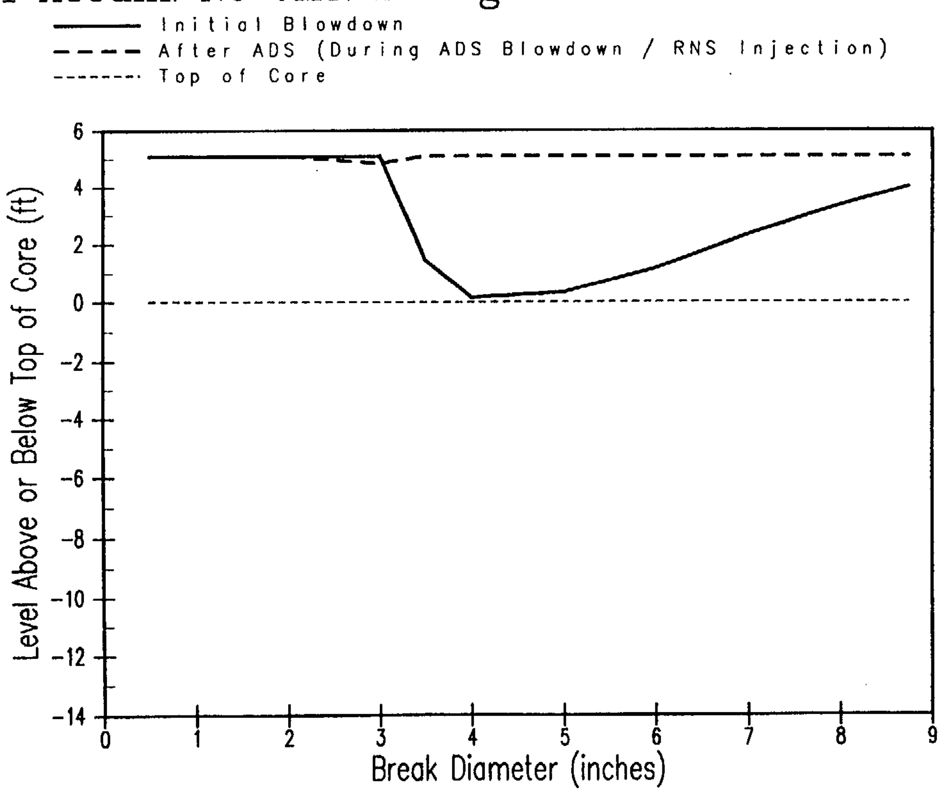


Manual ADS with Injection By RNS

- **Limiting Equipment Assumed**
  - –Same as AP600, except a second ADS stage 2/3 opens
  - –No CMT, 1 Accum, no IRWST gravity inject line, one RNS pump
  - –2/4 ADS stage 2/3, no ADS stage 1/4, no PRHR HX
    - –For MLOCAs 2" to 9" PRHR HX is required to give operators at least 20 min to open ADS 4
  - –Containment isolation fails
- **MAAP Analysis Was Performed**
  - –Break sizes 0.5" up to 8.75"
    - –DVI not analyzed, RNS not credited as success for this LOCA
  - –No core uncovery is calculated for these events
  - –AP600 success criteria remains valid for AP1000

Manual ADS with Injection By RNS

AP1000 Minimum Vessel Mixture Level
Manual ADS at 20 Min, RNS Injection
1 Accum, No CMT, 2 Stage 3 ADS Valves, PRHR



Large LOCA Success Criteria

- **Large LOCA Pipe Breaks**
  - –Use DCD LLOCA analysis since use 2/2 Accum
- **Spurious ADS (Large HL LOCA)**
  - –Uses 1/2 Accum > need specific PRA justification
  - –Less severe than CL large LOCAs, much lower PCT end of blowdown

	AP600	AP1000
Break Location	CL	HL
Break size	DECL	4 x ADS-4 valves
PCT at end of blowdown (°F)	1000	500
Number accumulator injecting	1	1
Core heatup time (sec)	106	120
Core linear power (kw/ft)	4.100	5.707
PCT increase (°F)	786	1239
PCT without uncertainty (°F)	1786	1739
PCT uncertainty (°F)	244	251
PCT with uncertainty (°F)	2030	1990

Post ADS Long Term Cooling

- **For AP600**
  - –T&H uncertainty LTC analysis showed acceptable results
- **For AP1000**
  - –LTC features all improved by more than power increase
    - –Power increase ~ 72%
    - –ADS 4 capacity ~ 89%
    - –IRWST injection ~ 84%
    - –Containment recirc ~113%
  - –AP600 success criteria remains valid for AP1000

T&H Uncertainty

- **AP600 Approach**
  - –Bounds T&H uncertainty
    - –Selected high risk / low margin cases
      - –6 LOCAs, 3 LLOCAs, 3 LTC
    - –Analyzed with DCD codes / assumptions
      - –Conservative decay heat, line resistances, ...
- **AP1000 Approach**
  - –Same as AP600
    - –Because of similarity of designs and PRA results
      - –Considered same T&H uncertainty cases
      - –Some no longer apply because of changes in success criteria

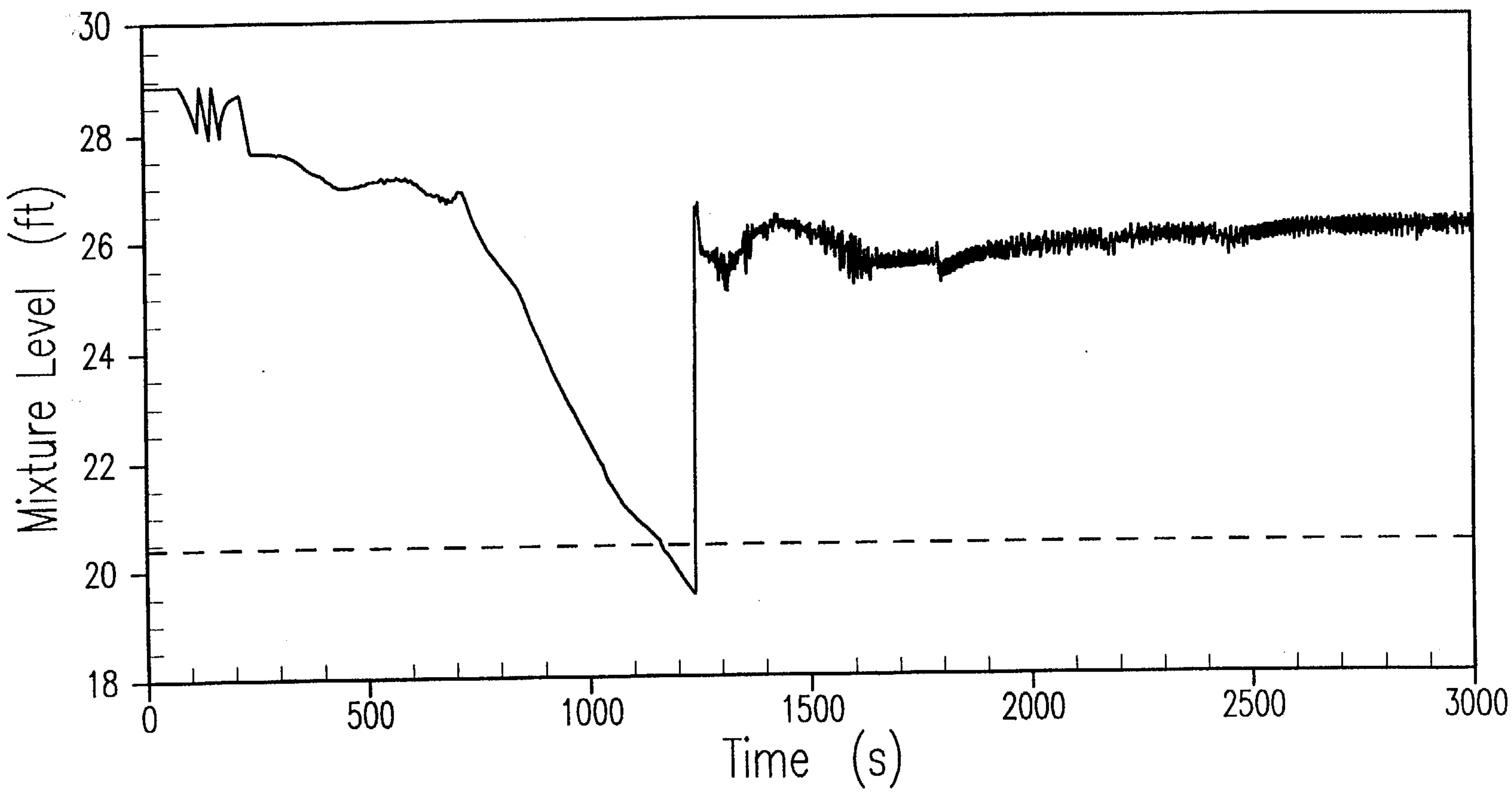
Small LOCA T&H Uncertainty

- **AP600 Small LOCA T&H Uncertainty Cases**
  - –First 3 cases also apply to AP1000
    - –Add PRHR to cases 1 & 2 since required by AP1000 success criteria
  - –Last 3 cases not required for AP1000
    - –Success criteria has changed > these cases would not be success

AP600 T&H Uncertainty Cases / Equipment Availability								Applicable to AP1000	AP600 PCT (F)	AP1000 PCT (F)
	Cont Isol	ADS 1/2/3	ADS 4	CMT	Acc	IRWST Val/Path	Recirc Val/Path			
Small LOCAs										
1. 3.25" HL	yes	0	4	0	1	1/1	na	yes	1157	719
2. DE CMT inlet	yes	0	4	0	2	1/1	na	yes	none	none
3. DE DVI	no	0	3	1	0	1/1	na	yes	1435	1570
4. DE DVI	no	0	2	1	1	1/1	na	no	1235	--
5. 2" HL	yes	0	2	1	1	1/1	na	no	none	--
6. 9" HL	yes	0	0	2	2	1/1	na	no	none	--

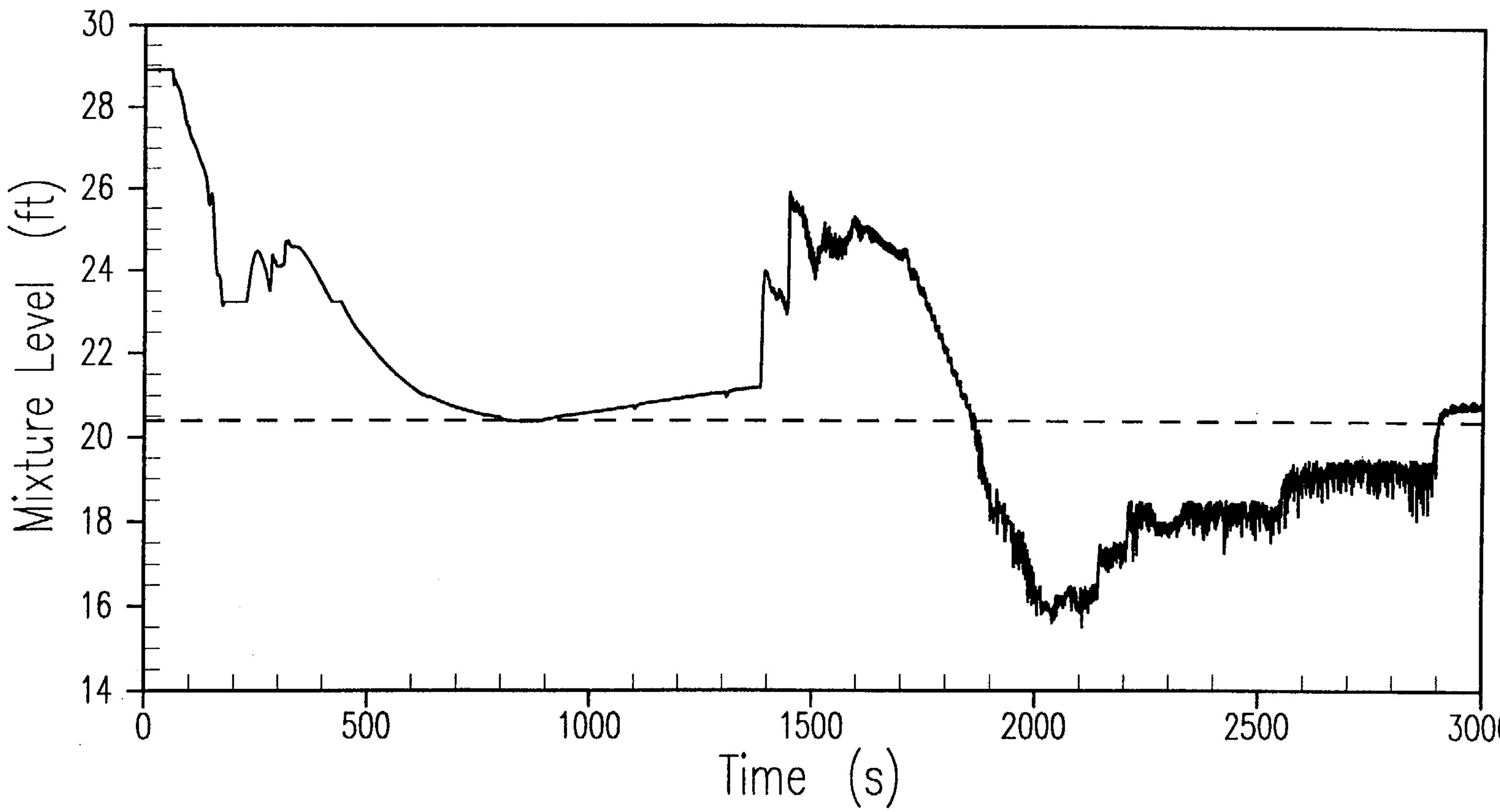
T&H Uncertainty

3.25 Inch Hot Leg Break/Manual ADS4/No Stage 1-2-3 ADS/No CMTs



T&H Uncertainty

DE DVI Break/Auto ADSS4, 1/2 CMTs, 0/2 ACCs, No Stage 1–3 ADS



Large LOCA T&H Uncertainty

- **AP600 Large LOCA T&H Uncertainty Cases**
  - –Performed to verify 1 / 2 Accum was success
  - –AP1000 requires 2 / 2 Accum and 3 / 4 ADS 4
    - –Verified by DCD analysis
    - –T&H uncertainty analysis not required

AP600 T&H Uncertainty Cases / Equipment Availability								Applicable to AP1000	AP600 PCT (F)	AP1000 PCT (F)
	Cont Isol	ADS 1/2/3	ADS 4	CMT	Acc	IRWST Val/Path	Recirc Val/Path			
Large LOCAs										
1. DE CL	yes	na	na	1	1	na	na	no	2017	--
2. Split CL	yes	na	na	1	1	na	na	no	2030	--
3. DE CL	no	na	na	1	2	na	na	no	1925	--

Long Term Cooling T&H Uncertainty

- **AP600 LTC T&H Uncertainty Cases**
  - 3 cases with 2 windows per case
  - 2" LOCAs not limiting > not needed for AP1000
  - Other cases covered by AP1000 DCD analysis and extra margin provided in ADS 4 / IRWST inject / Cont Rcirc

AP600 T&H Uncertainty Cases / Equipment Availability								Applicable to AP1000	AP600 PCT (F)	AP1000 PCT (F)
	Cont Isol	ADS 1/2/3	ADS 4	CMT	Acc	IRWST Val/Path	Recirc Val/Path			
Long Term Cool										
1. 2" CL, IRWST	yes	0	3	0	1	1/1	na	no	na	--
2. 2" CL, recirc	yes	0	3	0	1	1/1	1/1	no	na	--
3. DVI, IRWST	yes	0	3	0	1	2/1	na	no	na	--
4. DVI, recirc	yes	0	3	0	1	2/1	1/1	no	na	--
5. DVI, IRWST	no	0	4	1	1	2/1	na	no	na	--
6. DVI, recirc	no	0	4	1	1	2/1	2/1	no	na	--

AP1000 Success Criteria / T&H Analysis

- **Success Criteria Made More Robust**
  - –Minimizes T&H issues / uncertainty
- **Success Criteria Verified**
  - –DCD analysis, specific PRA analysis or other calculations
  - –Specific PRA Analysis Performed
    - –Used insights / lessons learned from AP600
    - –Analysis shows similar / less severe results than AP600
- **T&H Uncertainty Bounded**
  - –DCD analysis methods used to bound T&H uncertainty for low margin / risk important accident scenarios
  - –Fewer cases analyzed because of more conservative success criteria