ESBWR Plant Performance

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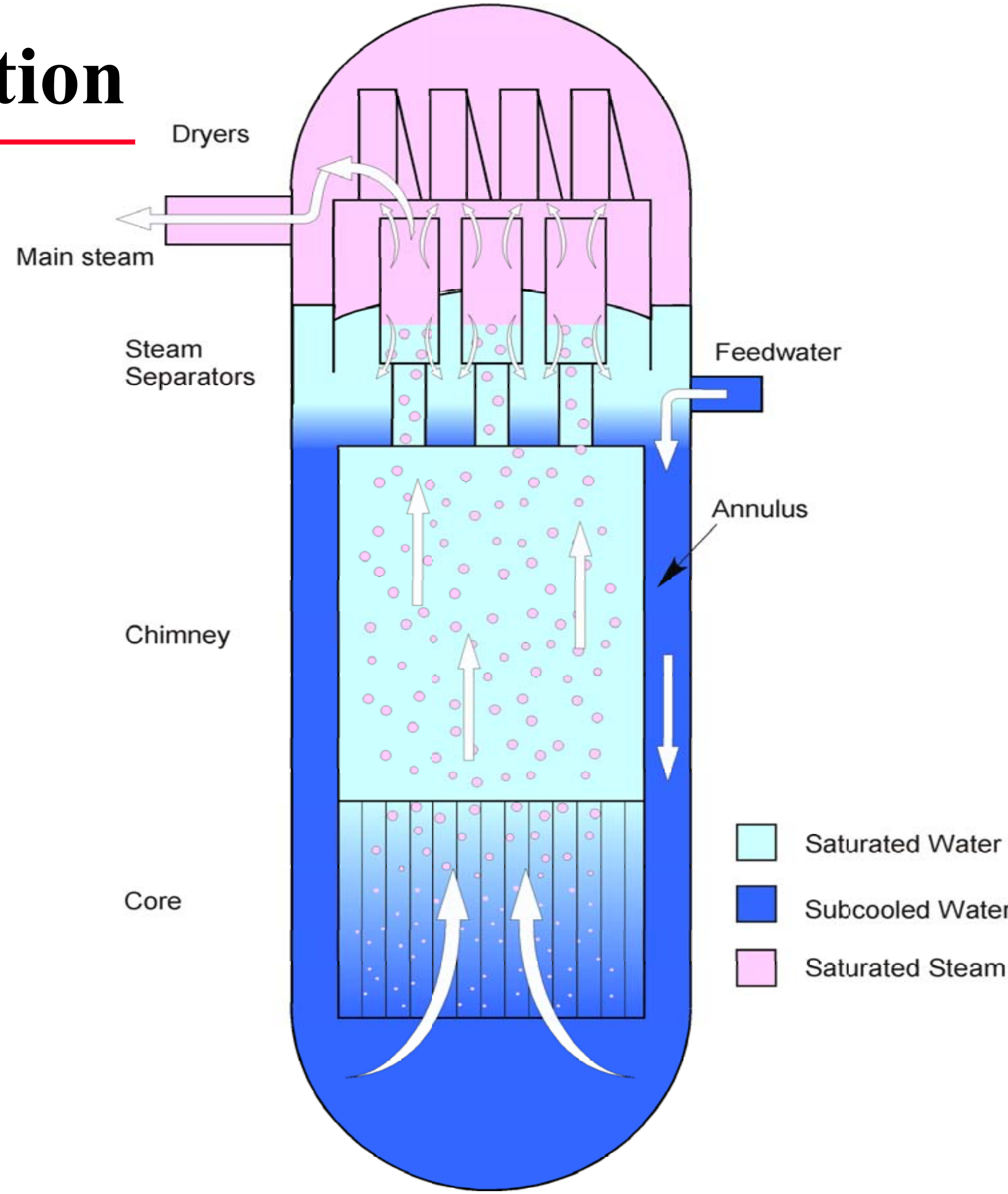
NRC Staff - GE Meeting
June 20 and 21, 2002
Rockville, Maryland

Outline

- Normal Operation
- Transients
- LOCA and Containment
- Comparison to operating plants and ABWR
- Summary

ESBWR Normal Operation

- No recirculation pumps – total reliance on natural circulation
- Significant natural circulation flow exists in all BWR's
- For a given core power, there is a corresponding natural circulation flow
- ESBWR uses enhanced design features to increase the flow compared to standard BWR's

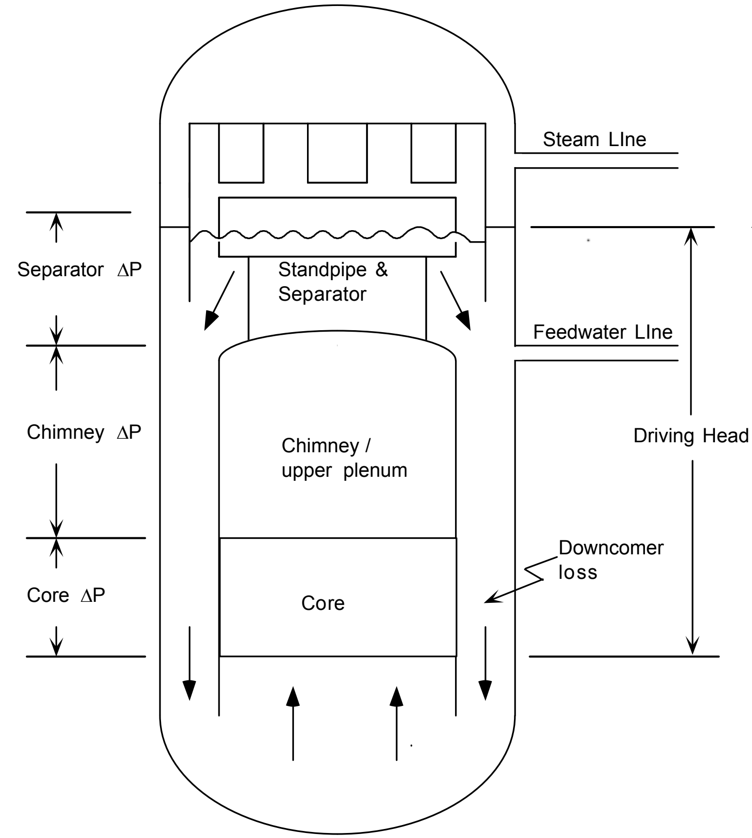


Performance and Core Flow

- **Parametric studies show that**
  - Minimum Critical Power Ratio (MCPR) and Stability Ratio are strong functions of core flow
- **Design was enhanced to increase core flow for improved plant performance**

Key Design Parameters Affecting Natural Circulation

- **Core flow depends on**
  - driving head
  - losses through the loop
- **Driving head**
  - proportion to chimney height
    - **Void Fraction**
- **Loop losses**
  - downcomer
    - **Single-phase pressure drop, handbook loss coefficient**
  - core (fuel bundle)
    - **Two-phase pressure drop, data/correlation**
  - chimney ~ very small
  - Separator
    - **Two-phase pressure drop, data/correlation**



Schematic of Flow and Pressure Drops in a Reactor

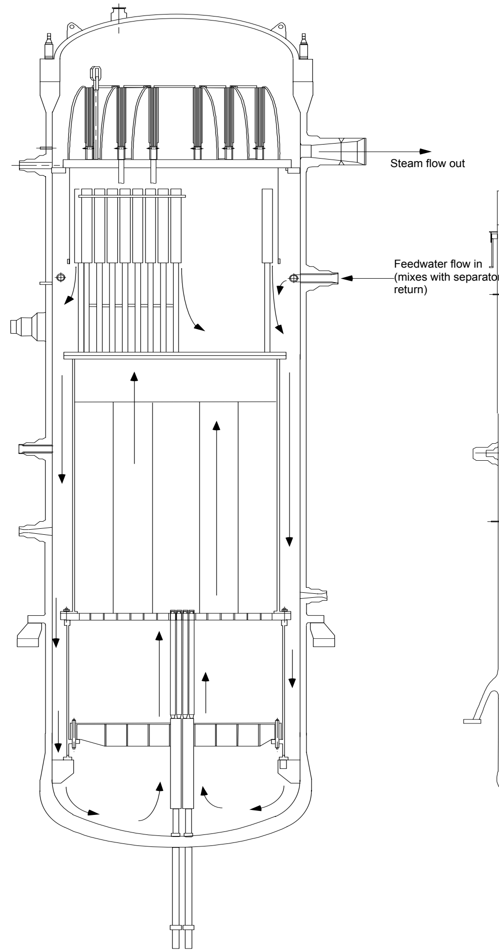
Downcomer Losses Depend on the Plant Design

- **Jet pump plant**
  - Large loss at the jet pump suction (~ 0.034 sq.m. per jet pump)
- **Internal pump plant**
  - Very large loss at the internal pump minimum flow area
- **Natural circulation plant (ESBWR)**
  - insignificant loss

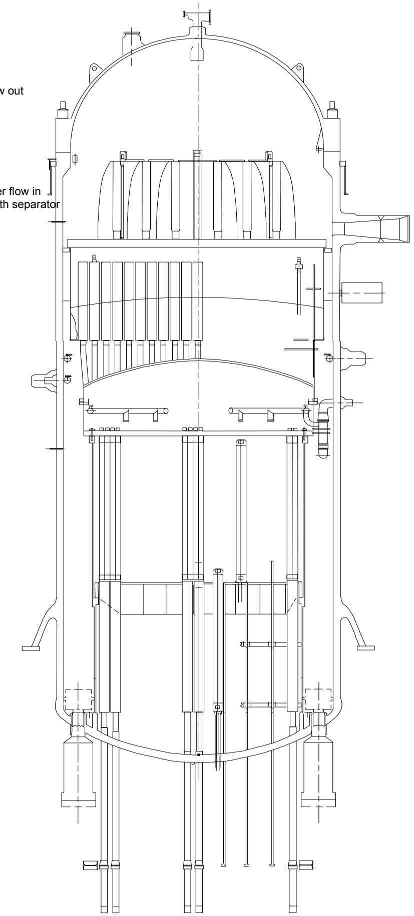
Comparison of ESBWR and ABWR

	ESBWR	ABWR
Fuel Length	3.05 m	3.66 m
Chimney/upper plenum	tall	short
Downcomer flow area	open	restricted

- **Key parameters that increase core flow in ESBWR**
  - Shorter fuel
  - Tall chimney
  - Un-restricted downcomer

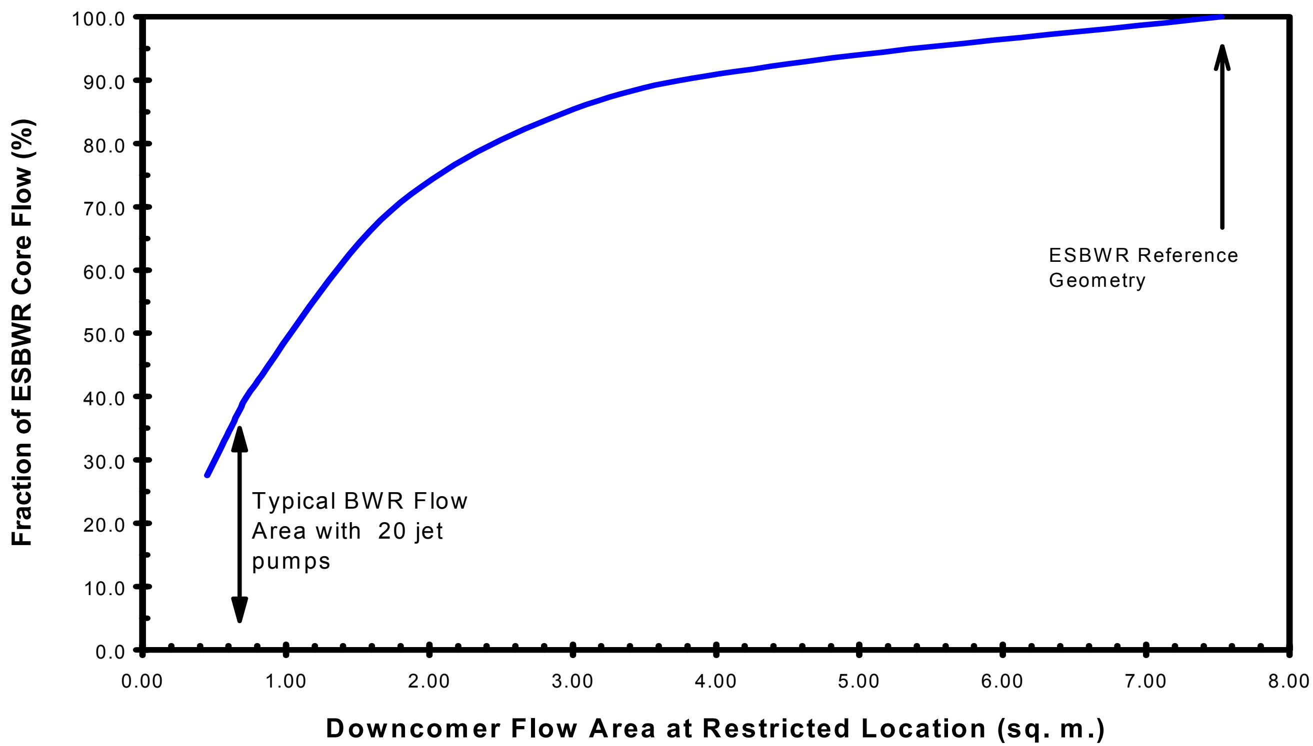


ESBWR

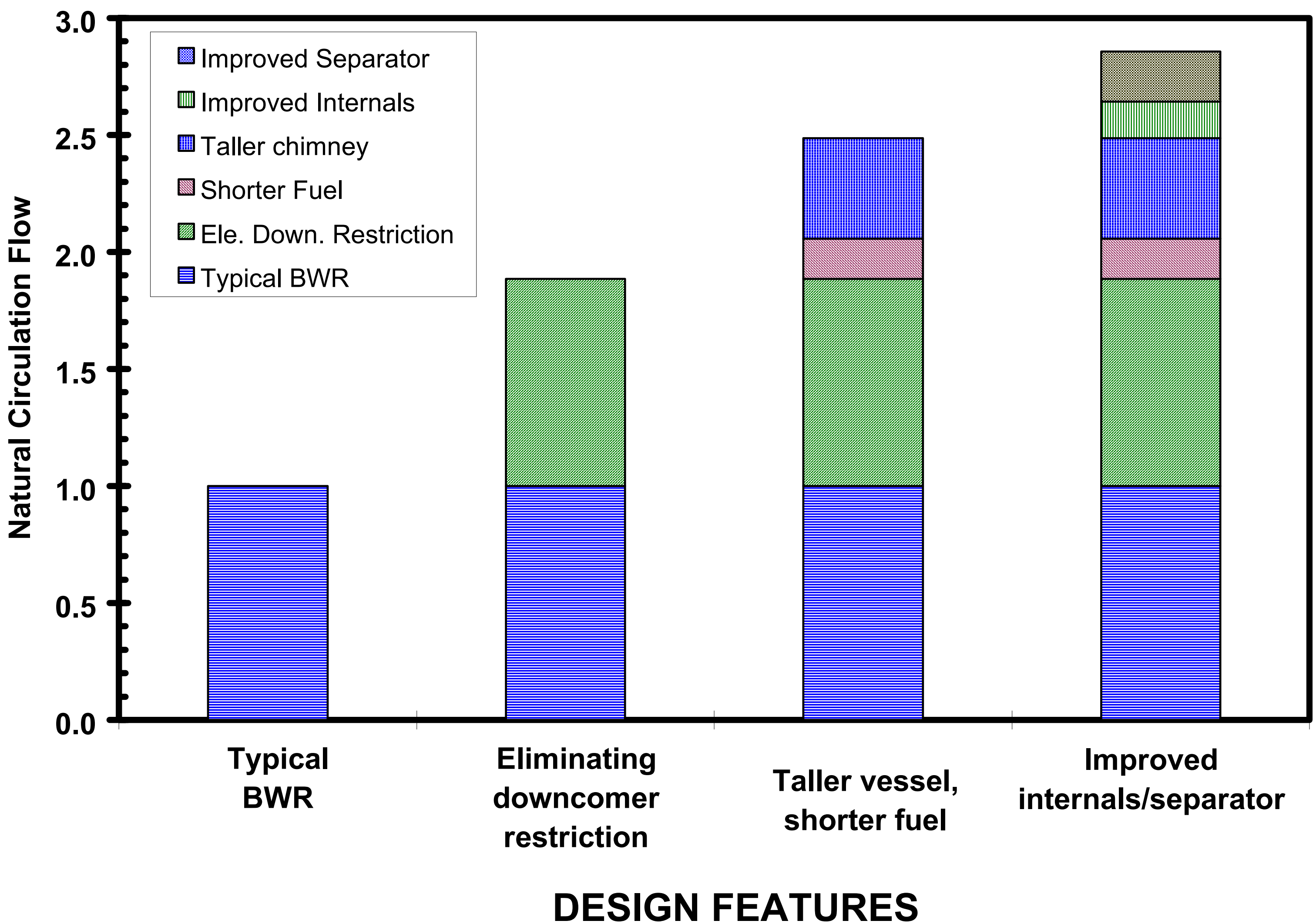


ABWR

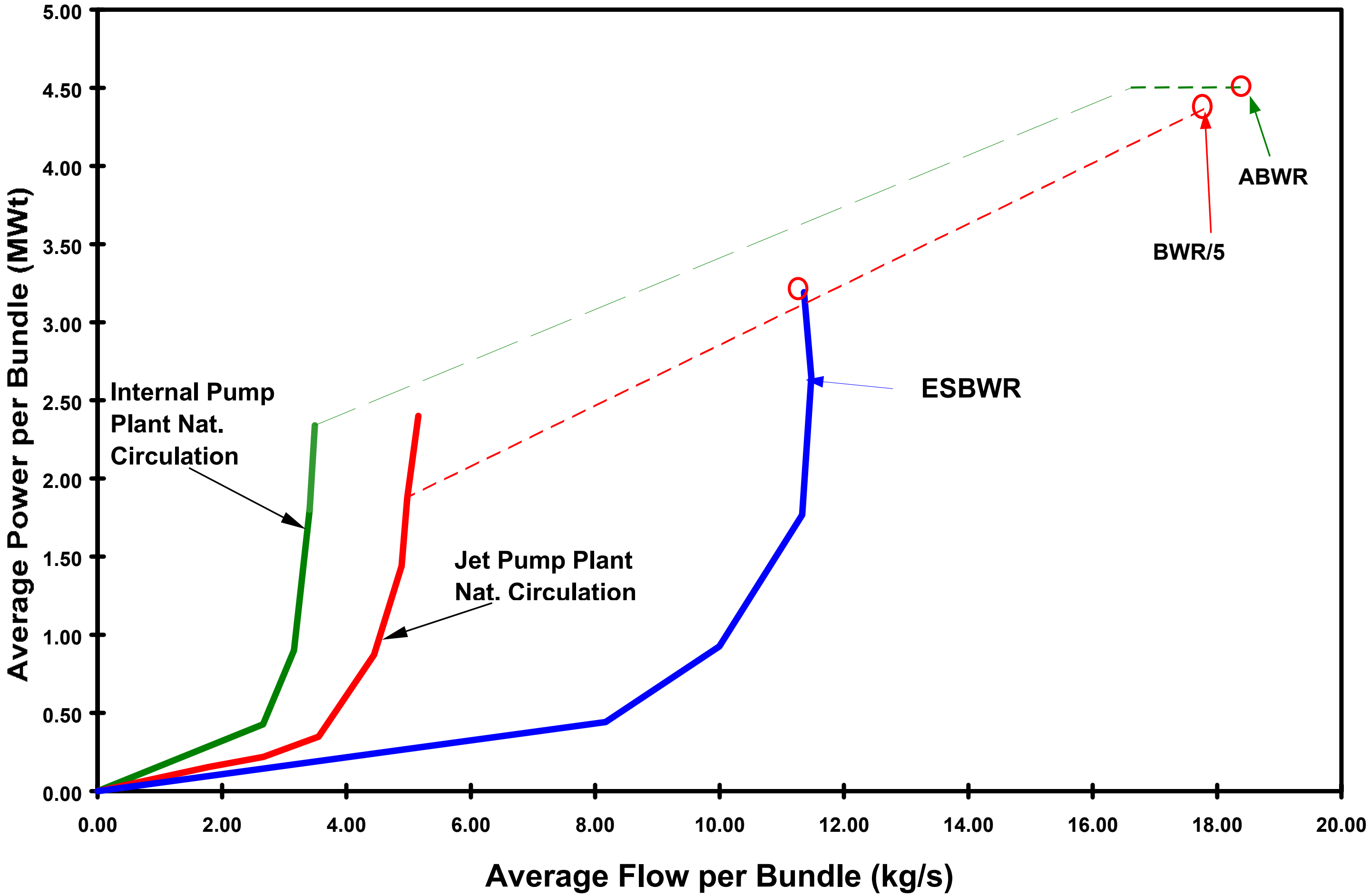
Effect of Downcomer Flow Area on Total Core Flow



Effects of ESBWR Design Features on Natural Circulation Flow



Comparison of Natural Circulation Flow for BWRs

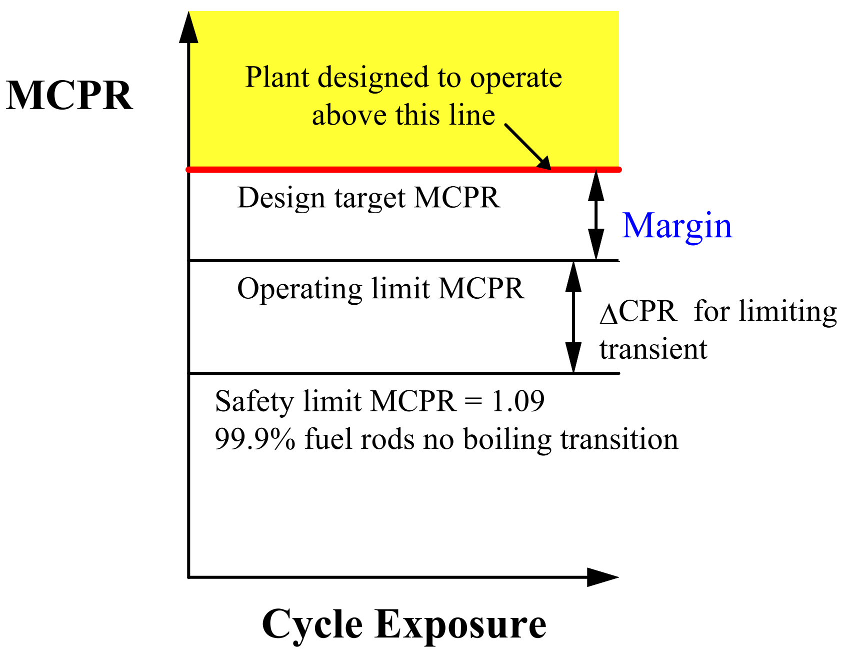


POWFLO-2.xls chart 9(3)

ESBWR has 2 to 3 times more natural circulation flow; power/flow ratio same as pumped plants at rated condition

Minimum Critical Power Ratio (MCPR)

- Assures no boiling transition will occur during normal plant operational transients
- MCPR is the ratio of the critical bundle power, at which boiling transition is calculated to occur, to the operating bundle power
- Operating limit MCPR = Safety limiting MCPR + ΔCPR



ESBWR ΔCPR

- **ESBWR Transient Analyses -- ΔCPR**

Case	Event and condition	ΔCPR
1	Generator load rejection with failure of all bypass valves (Stop valve position scram, similar to ABWR – K6/7)	0.095
2	Feedwater controller failure, (maximum demand at 150%)	0.101

- **For 33% Bypass capacity, limiting ΔCPR is 0.1**

Margins to Operating Limit MCPR

ESBWR Design Target	**1.38**
Bypass Capacity	**33%**
Scram signal	Valve Position
Safety Limit MCPR for GE12	1.09
Target ΔCPR	0.1
Operating Limit MCPR	**1.19**
Margin to Operating Limit	16%

LOCA and Containment Responses

- **TRACG used to perform both the LOCA and containment analyses**
- **For LOCA (0 to 1 hours)**
  - Fine nodalization in RPV, coarse nodalization in containment to provide system responses to the RPV
  - Key output: mixture level inside shroud and Peak Cladding Temperature (PCT)
- **For containment (0 to 72 hours)**
  - Fine nodalization in containment, coarse nodalization in RPV to provide system responses to the containment
  - Key output: Long term containment pressure

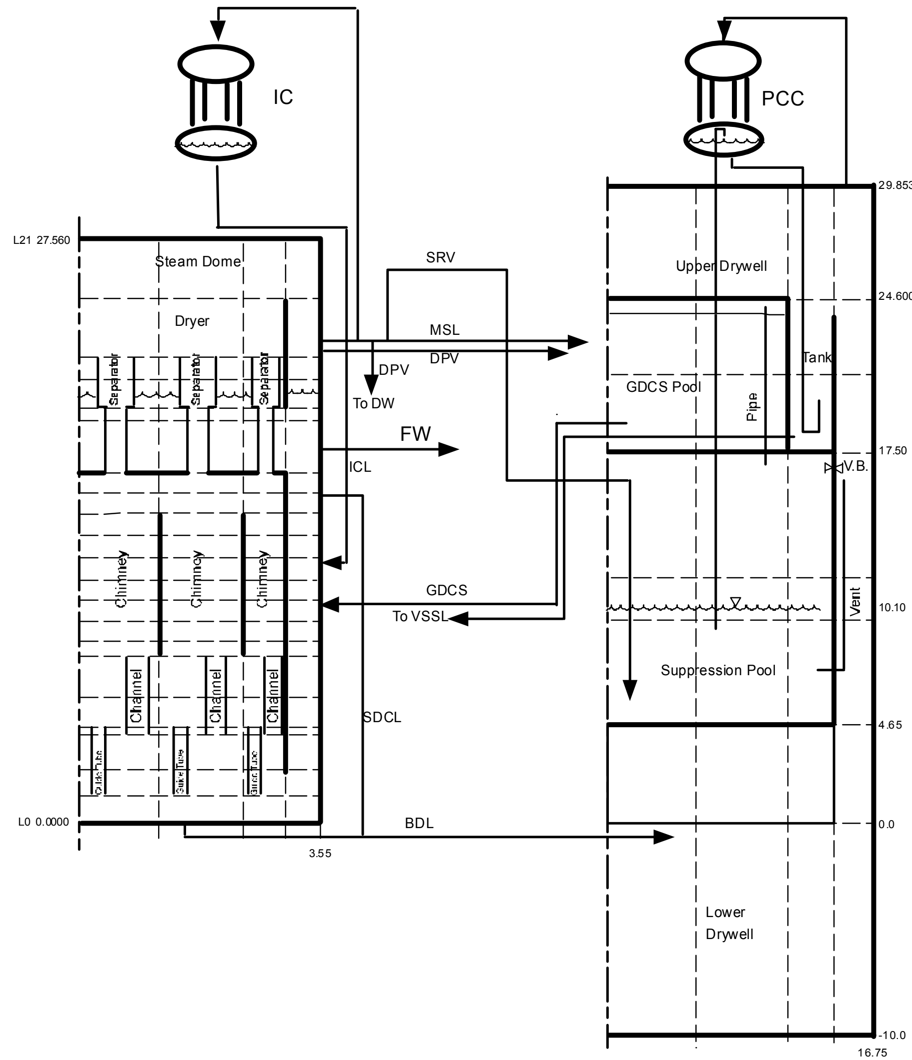
Main Steam Line Break – Largest Pipe Break

- **Objective**
  - To demonstrate the LOCA and Containment responses after a postulated pipe break
  - To show the design margins in the ESBWR
- **Key assumptions**
  - 4 PCCs with a total capacity of 54 MW
  - No credit for the ICs
  - For long term containment calculation, leakage flow between DW and WW included as

$$\frac{A}{\sqrt{k}} = 1.0\text{cm}^2$$

Main Steam Line Break – LOCA

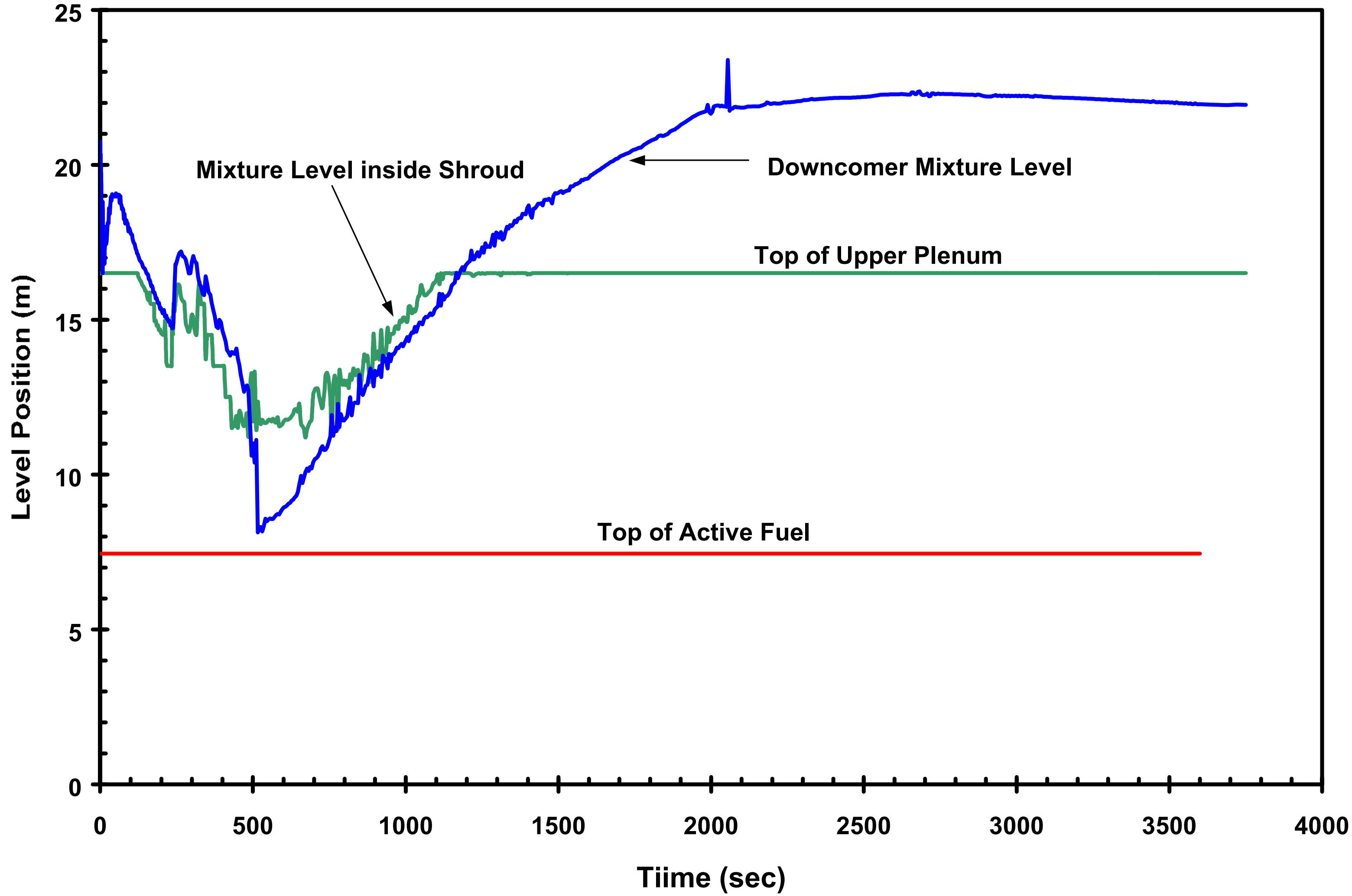
- **Nodalization**
  - Fine nodalization in RPV, coarse nodalization in containment
- **Key design objectives**
  - Core covered by mixture at all times
  - No core heatup



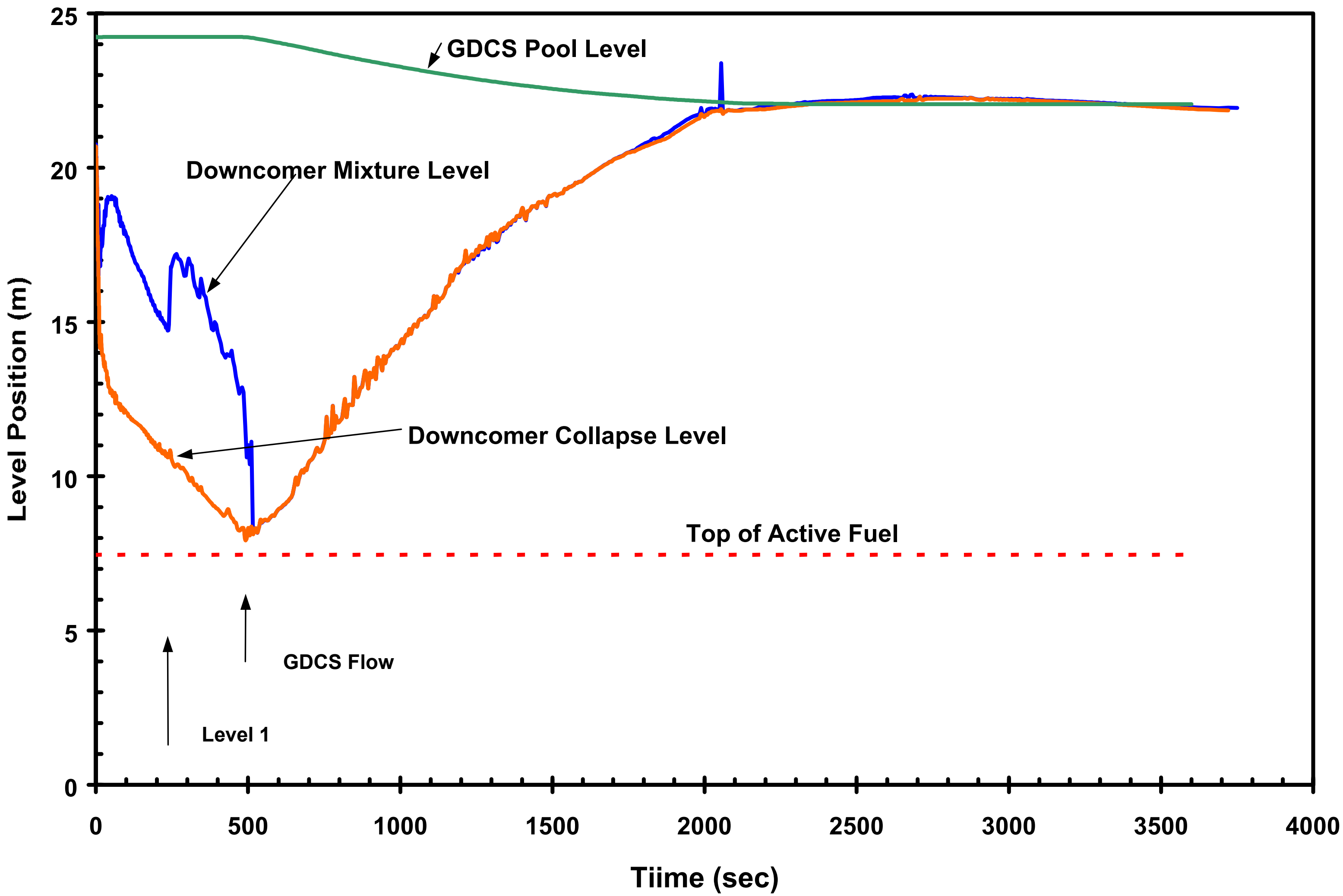
ESBWR TRACG LOCA MODEL

ESBWR1-a.CNV

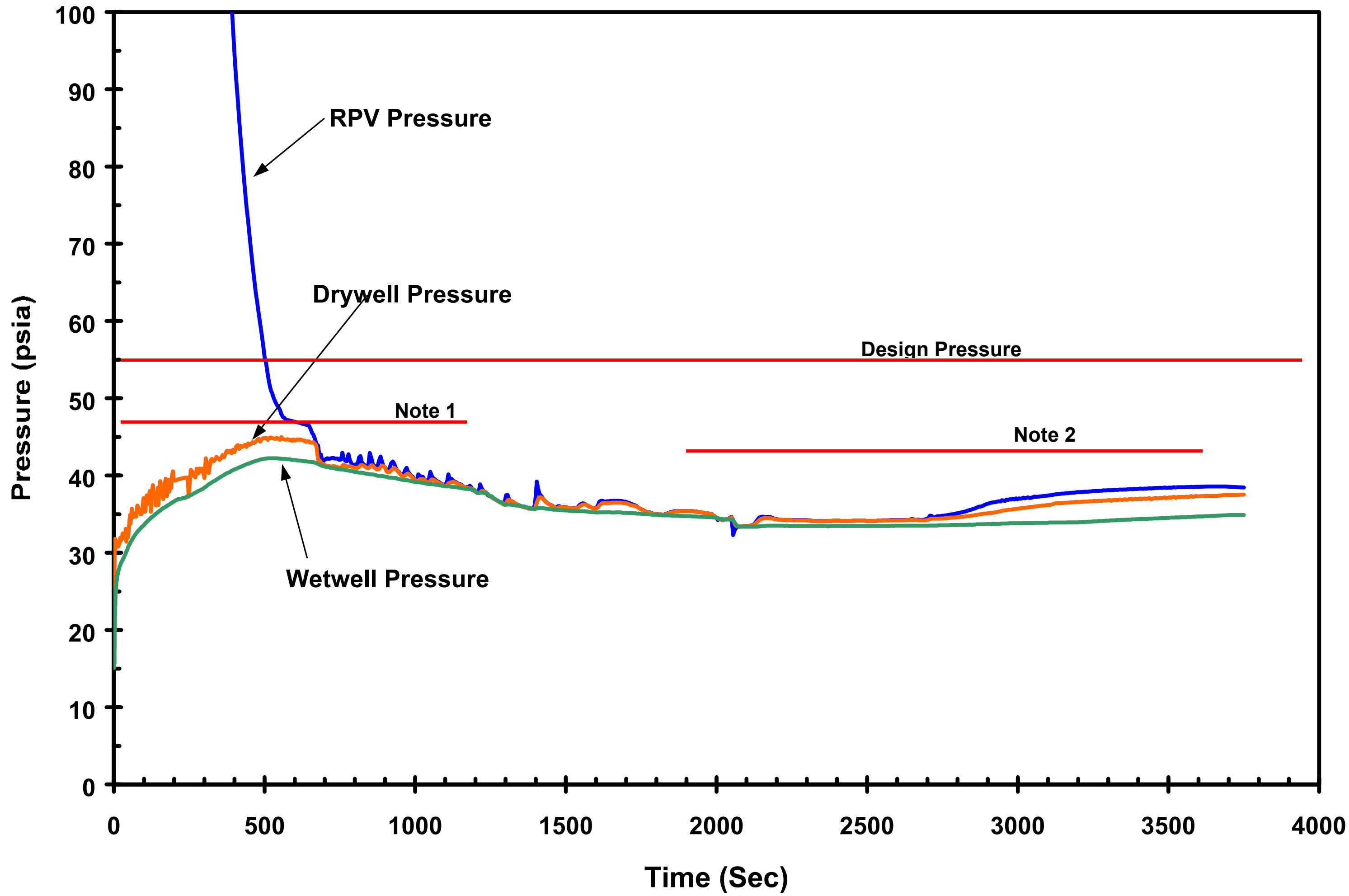
Mixture Levels Inside Shroud and Downcomer



MSL Break LOCA – Downcomer and GDCS Pool Levels



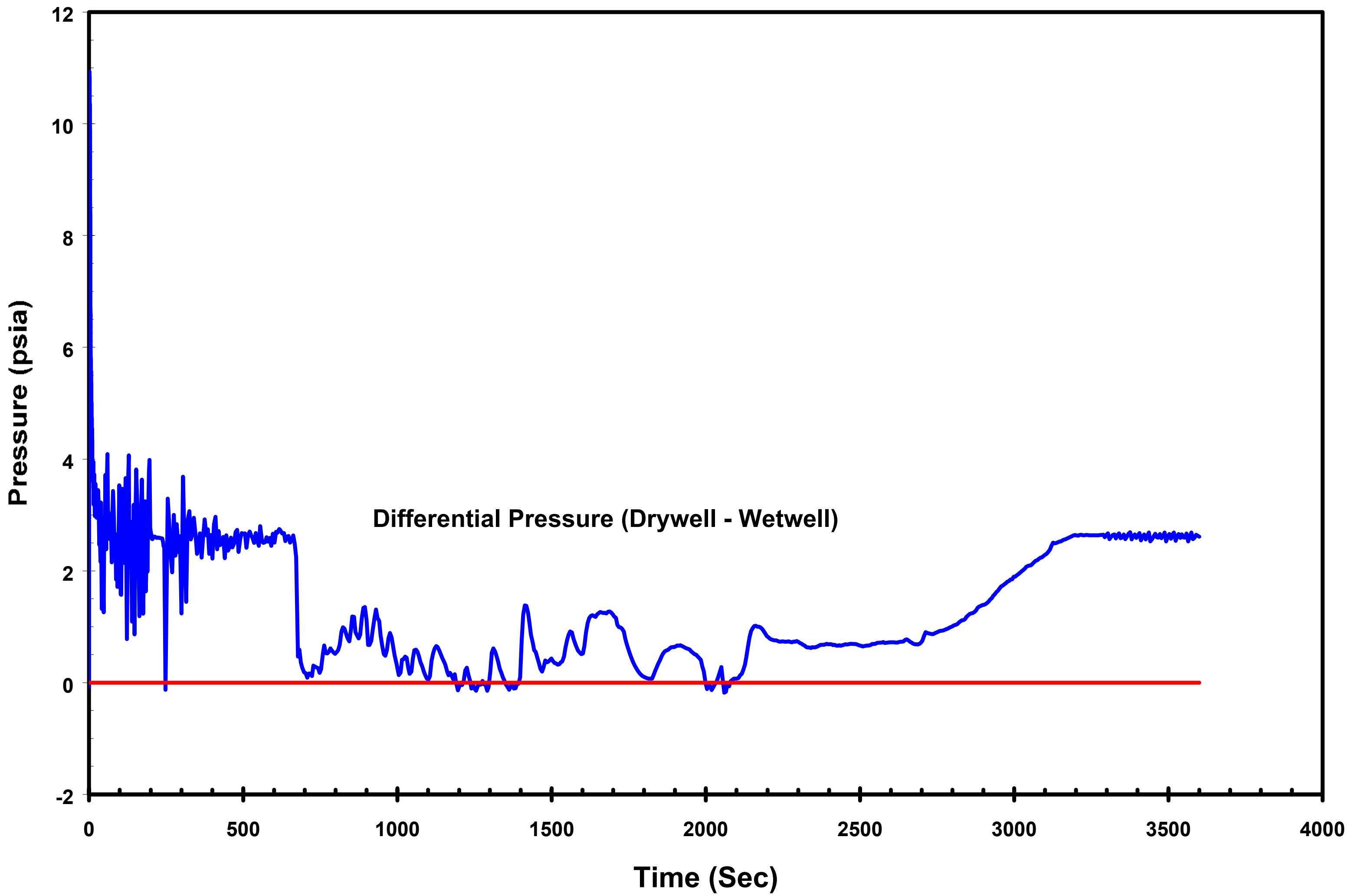
RPV, DW and WW Pressures



Note 1: Bounding estimate, DW Press = all air in WW + PCC vent submergence, before GDCS drain
Note 2: Bounding estimate, DW Press = all air in WW + PCC vent submergence, after GDCS drain

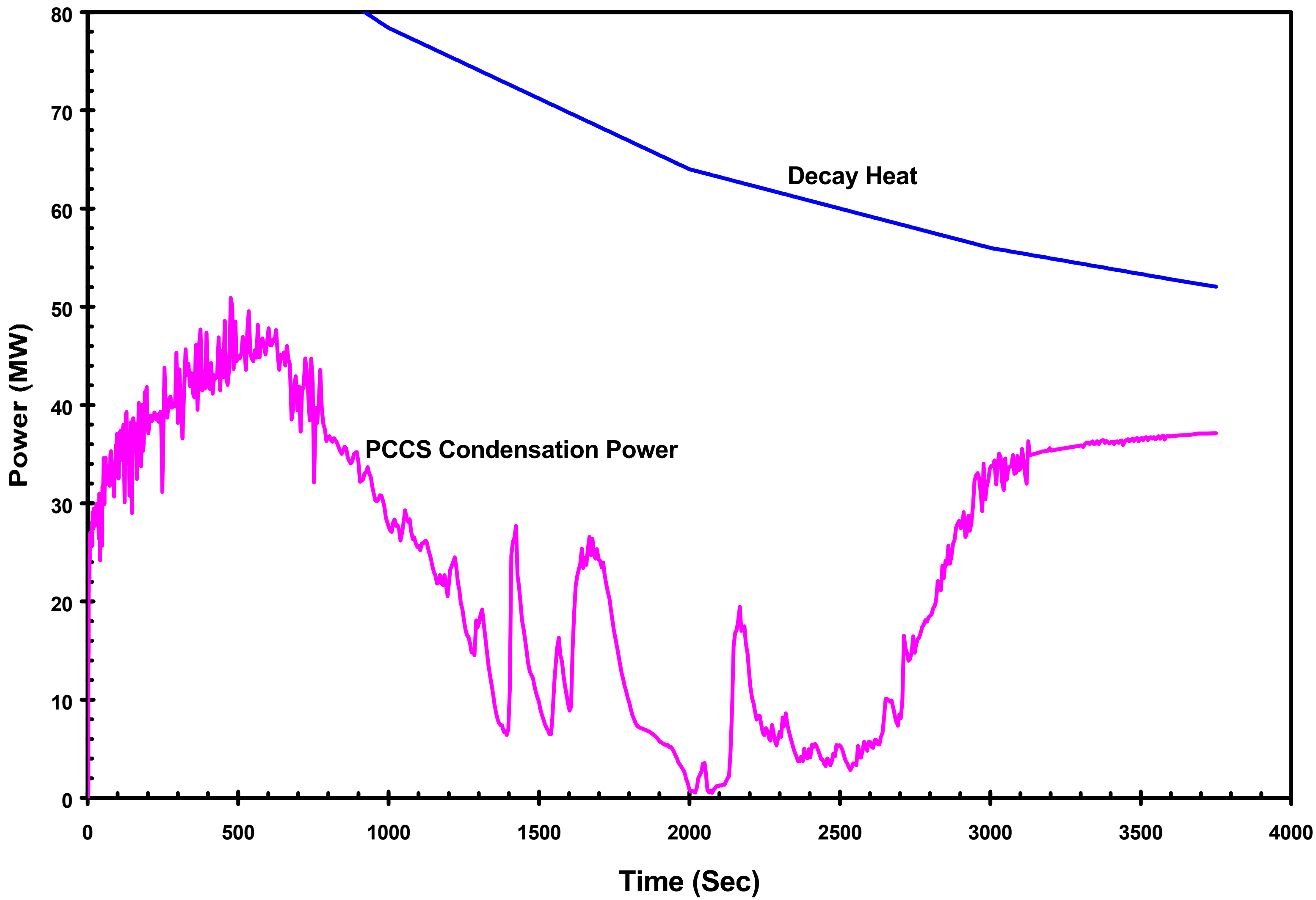
DW pressure shows > 20% Margin to the design pressure

Differential Pressure (DW – WW)



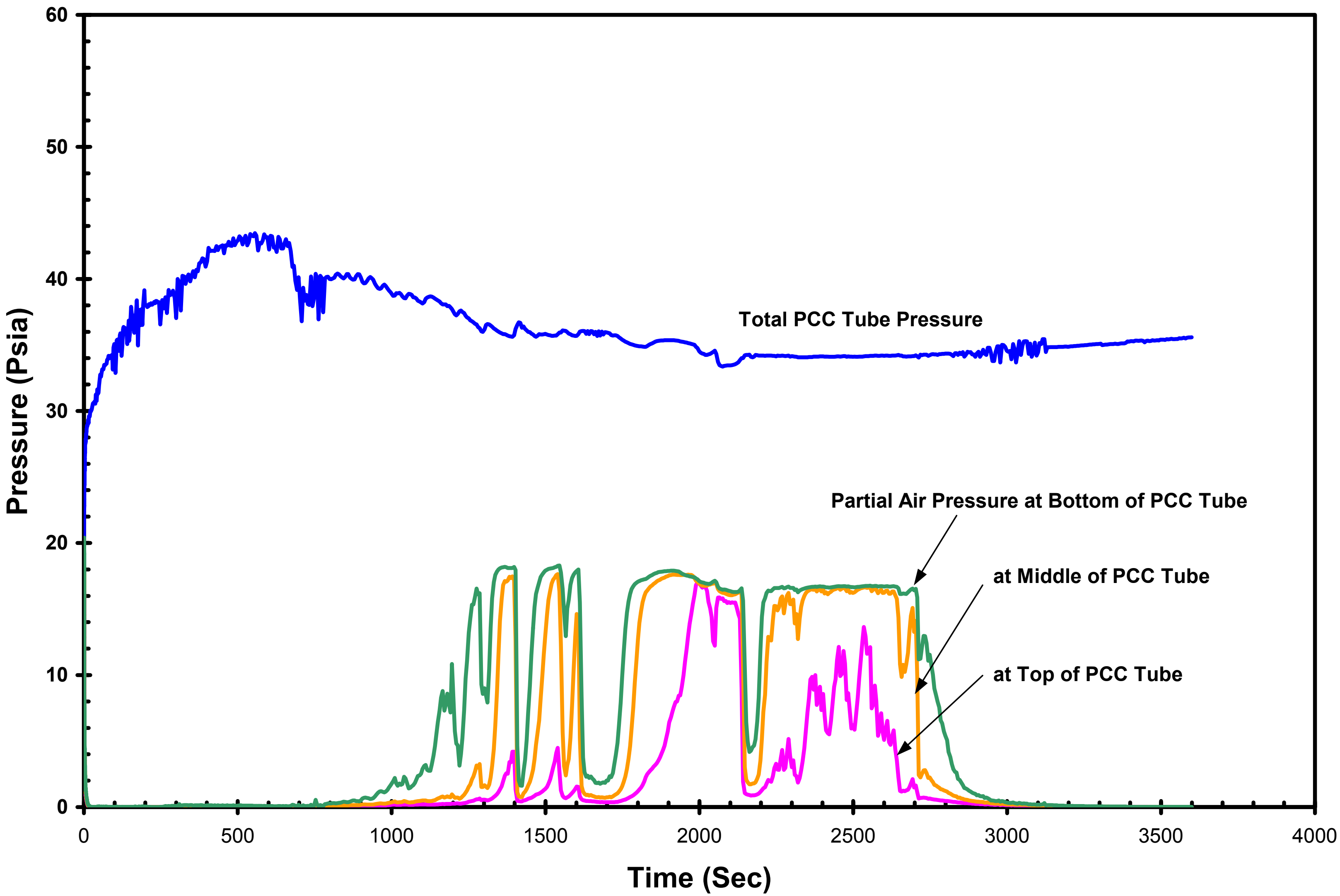
DW/WW pressure difference drives the flow through the PCC heat exchangers

Reactor Decay Heat and PCCS Heat Removal

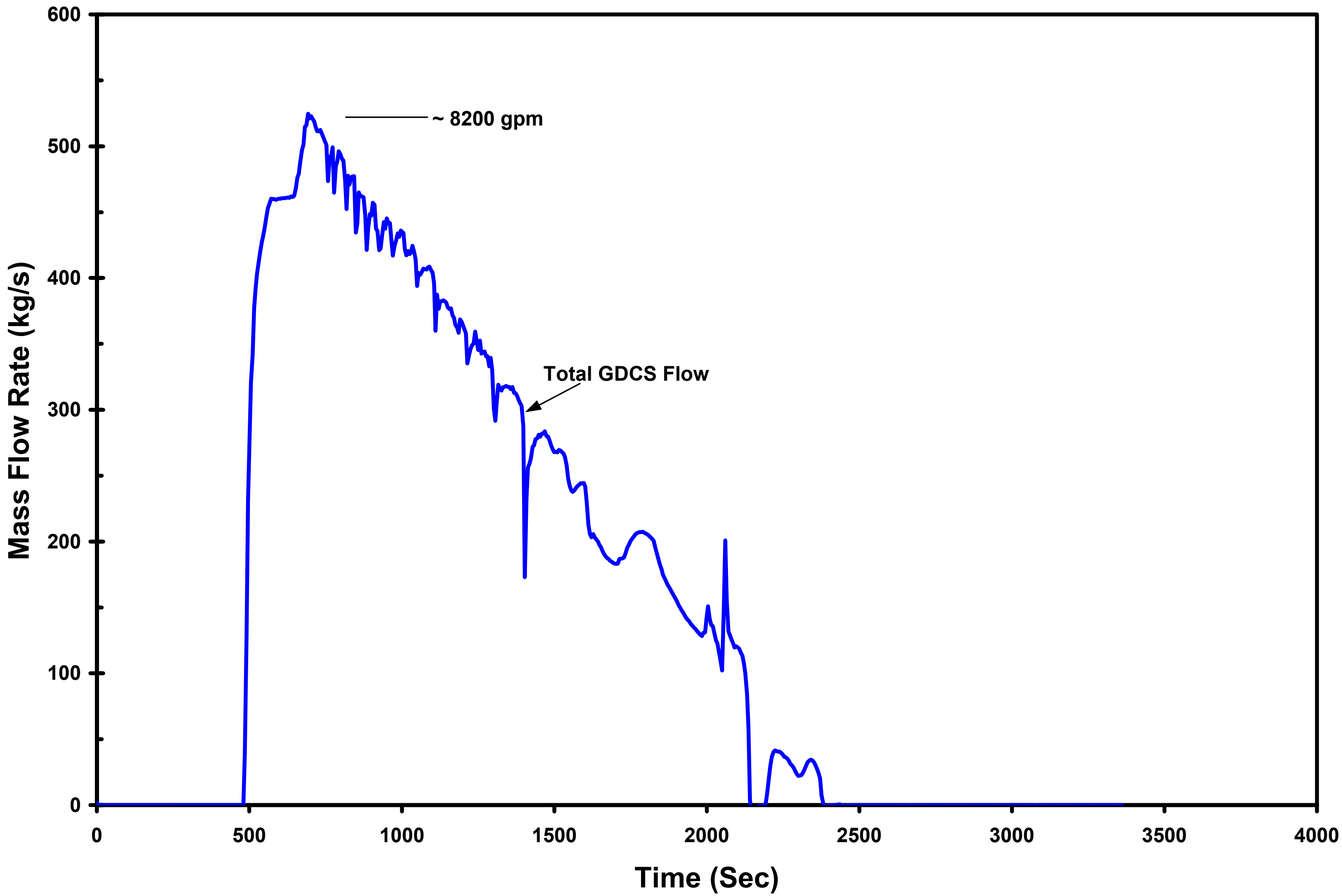


PCCS removes heat during the blowdown phase, limiting suppression pool heatup

PCC Tube Total and Partial Air Pressures



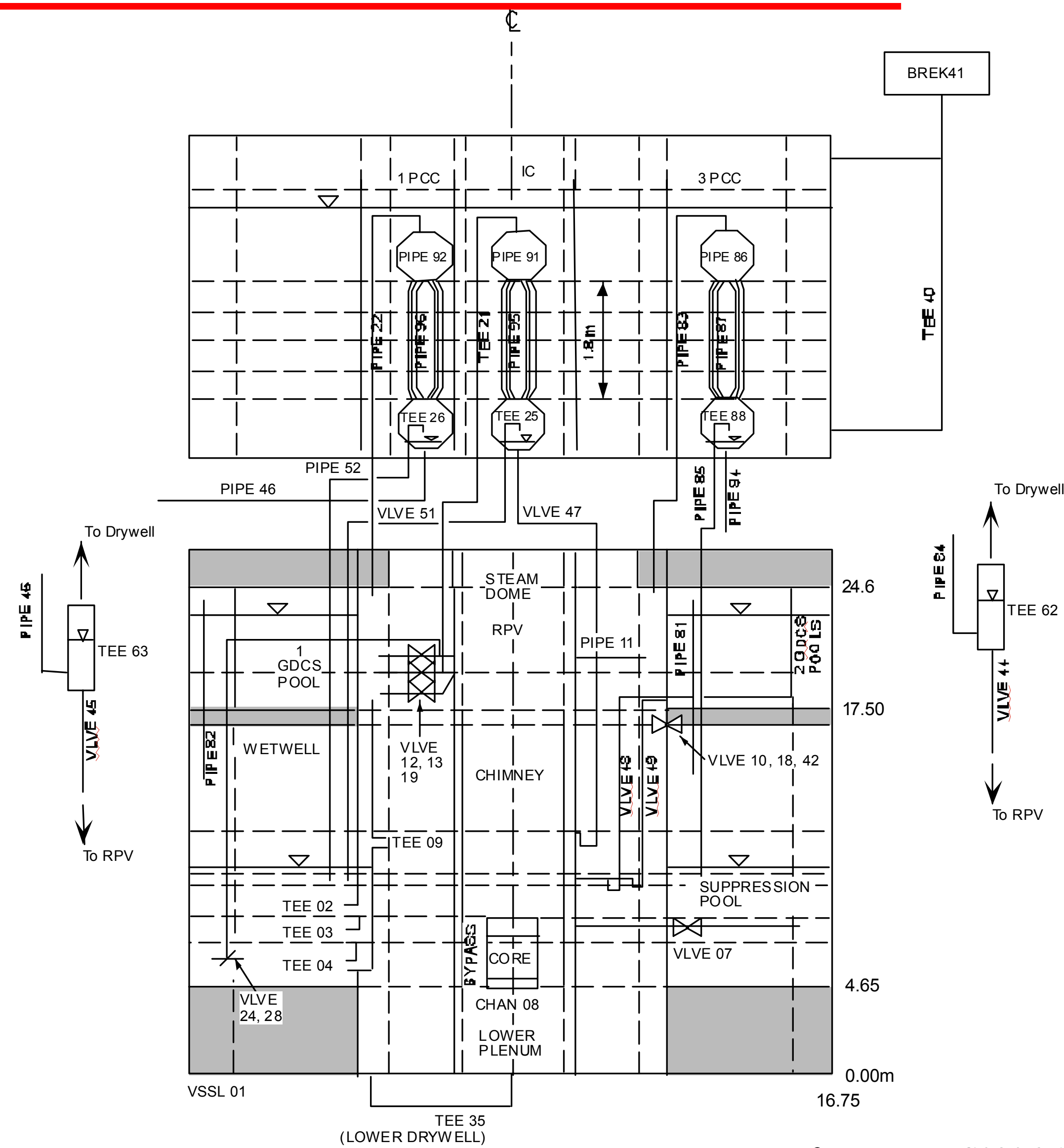
GDCS Flow



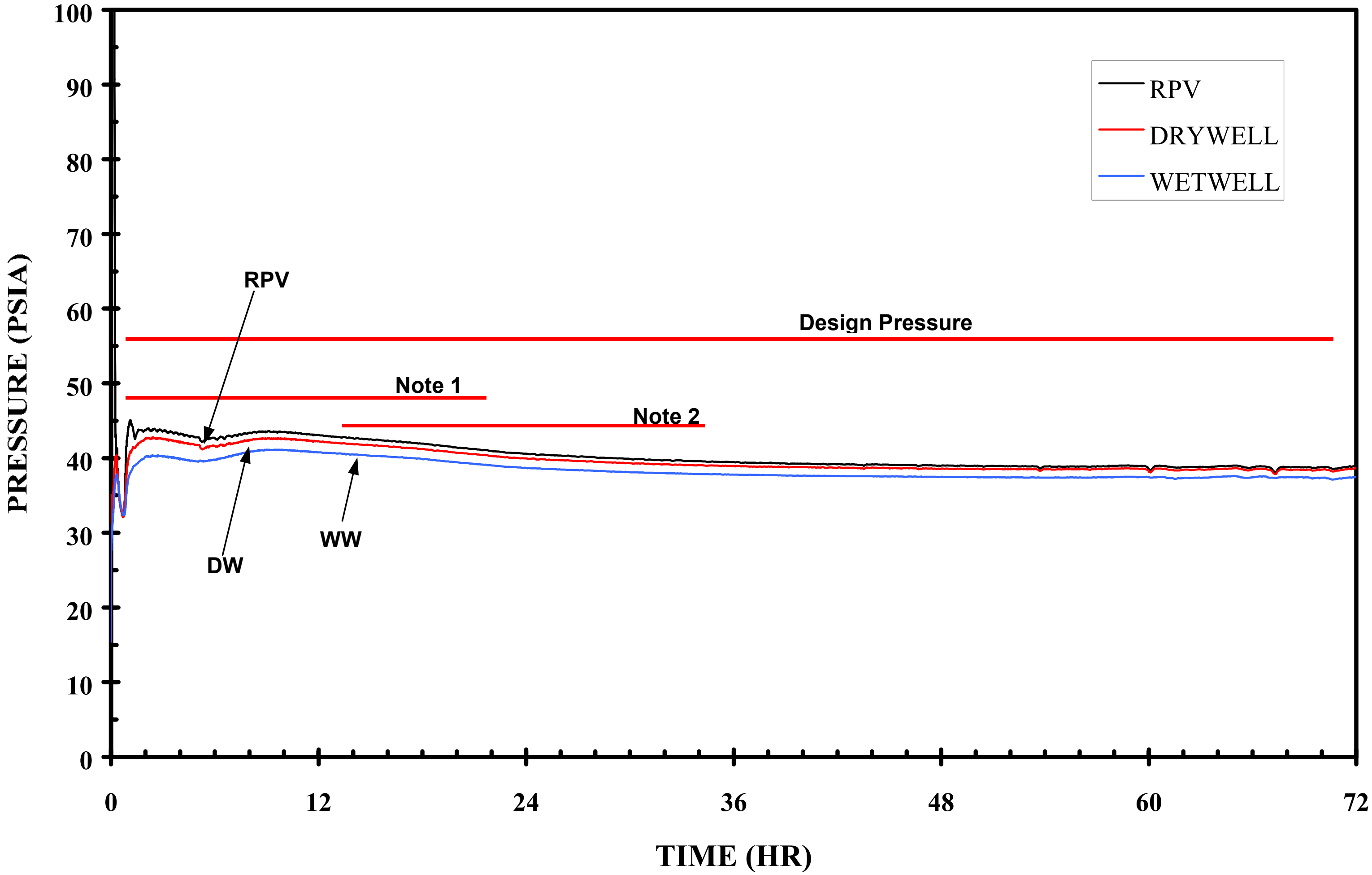
GDCS - Low pressure and low flow rate makeup system

Main Steam Line Break – Containment

- **Nodalization**
  - Fine nodalization in containment, coarse nodalization in RPV
- **Key design objectives**
  - Long term DW pressure below design value with margin

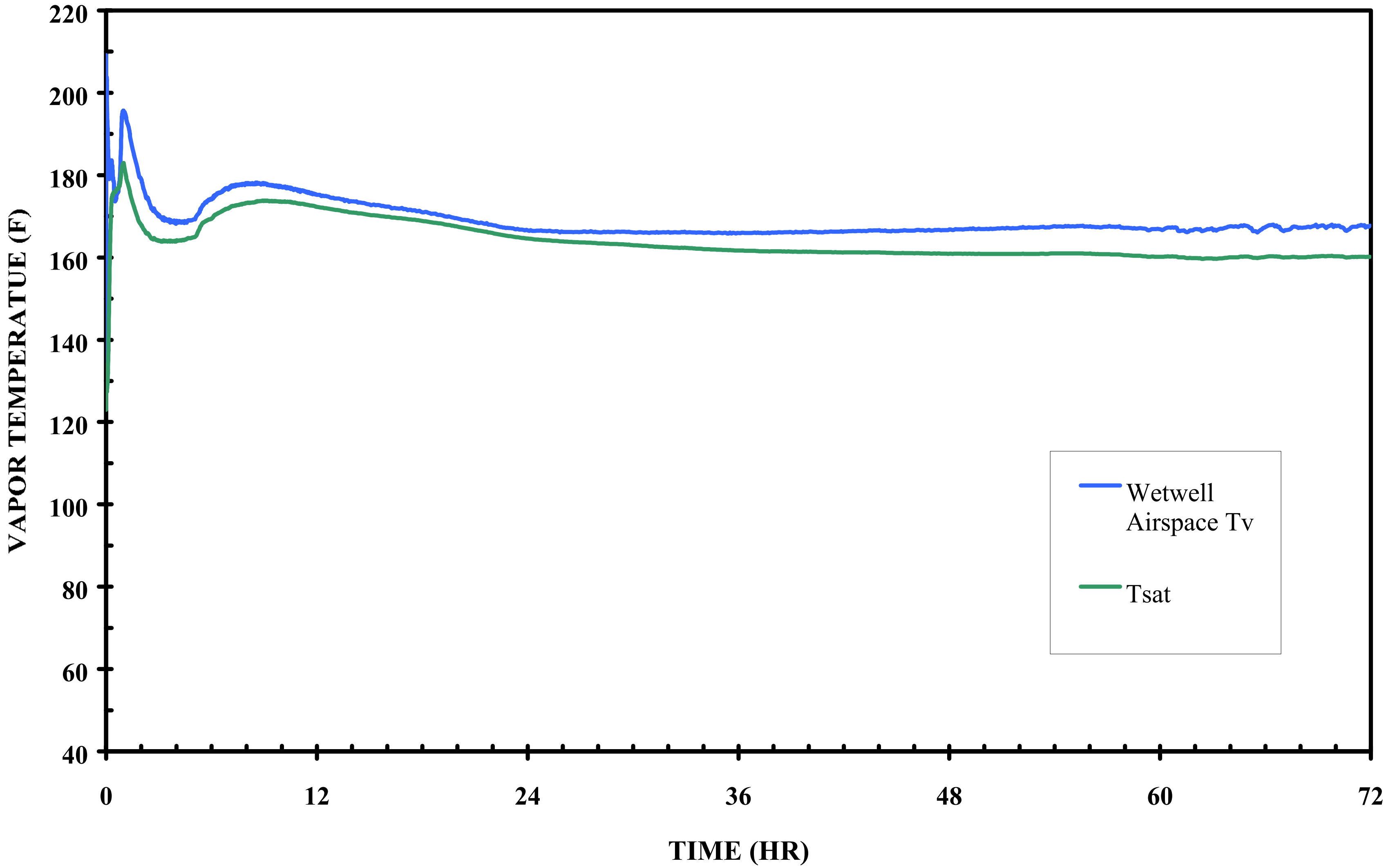


MSL Break Containment – RPV, DW and WW Press.

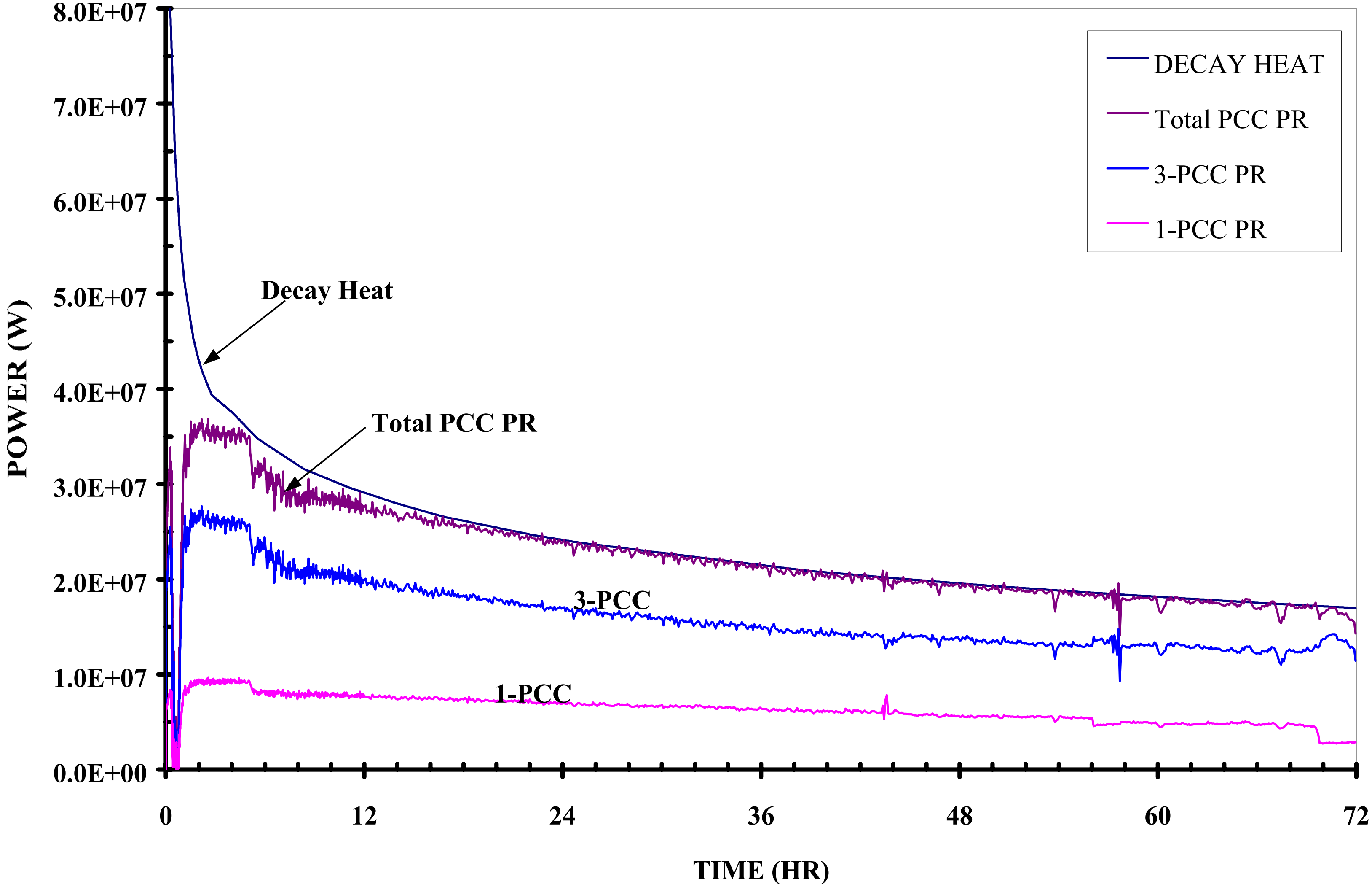


DW pressure shows > 20% margin to the design pressure

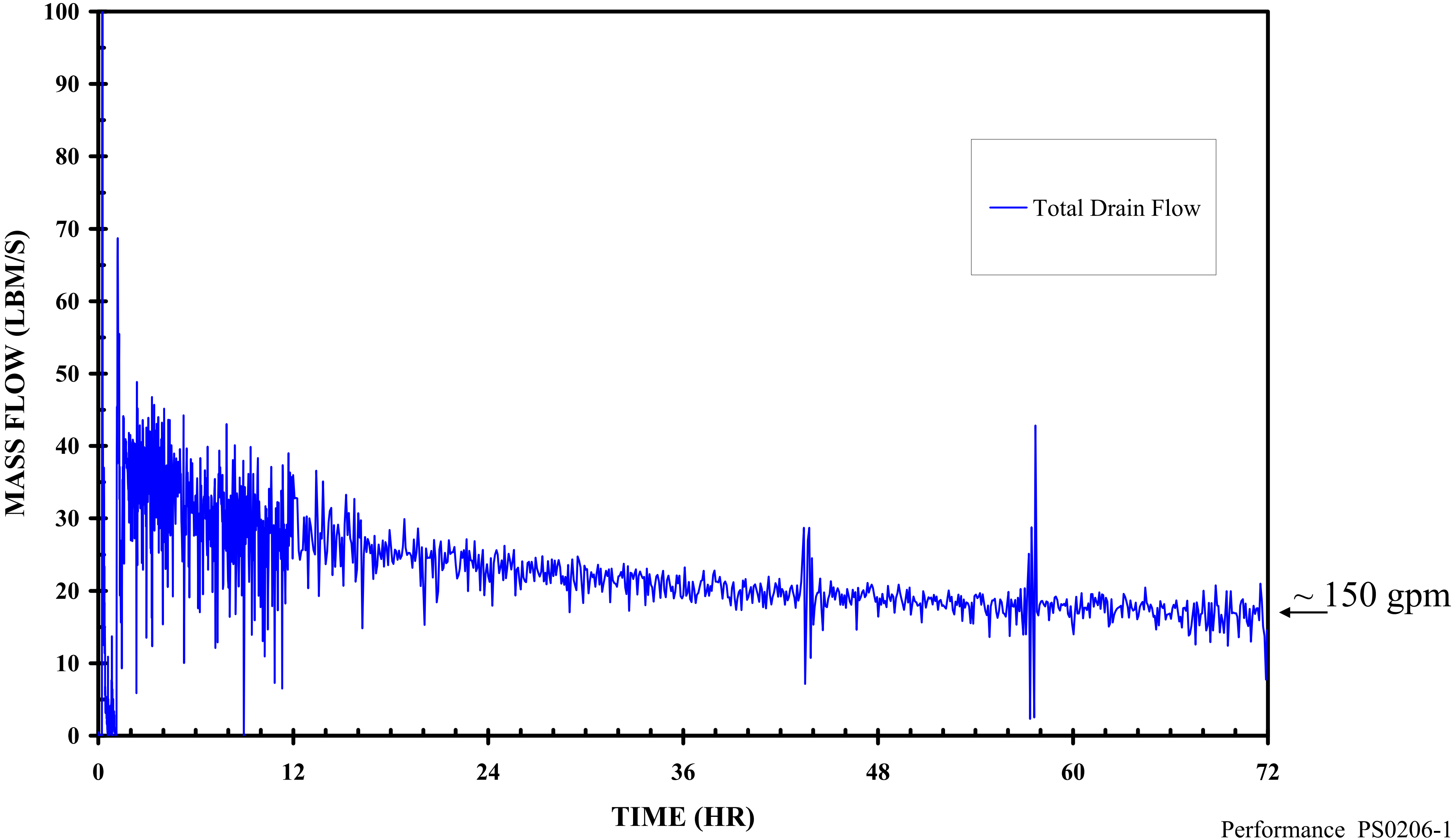
WW Airspace Temperatures



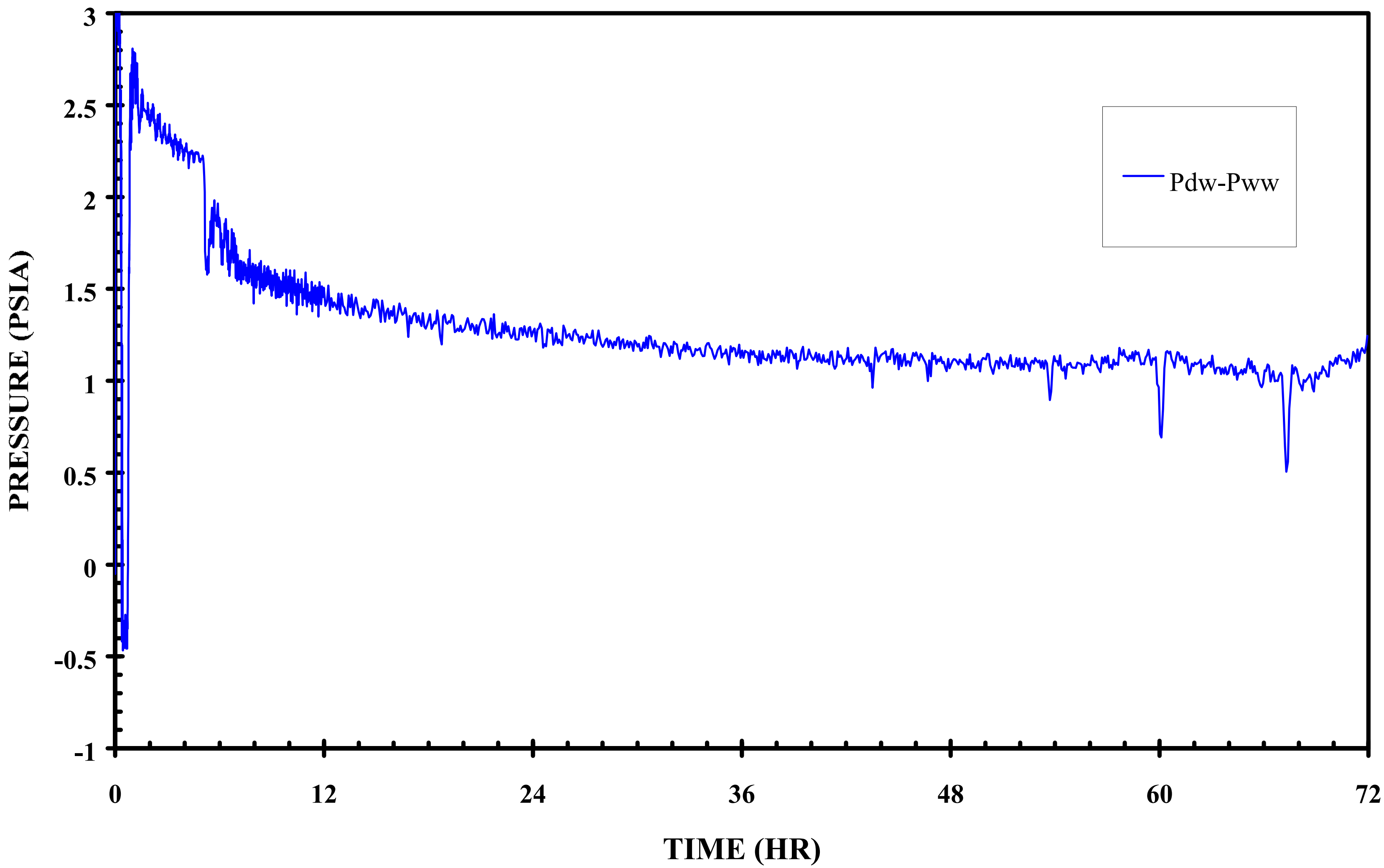
Reactor Decay Heat and PCCS Condensation Power



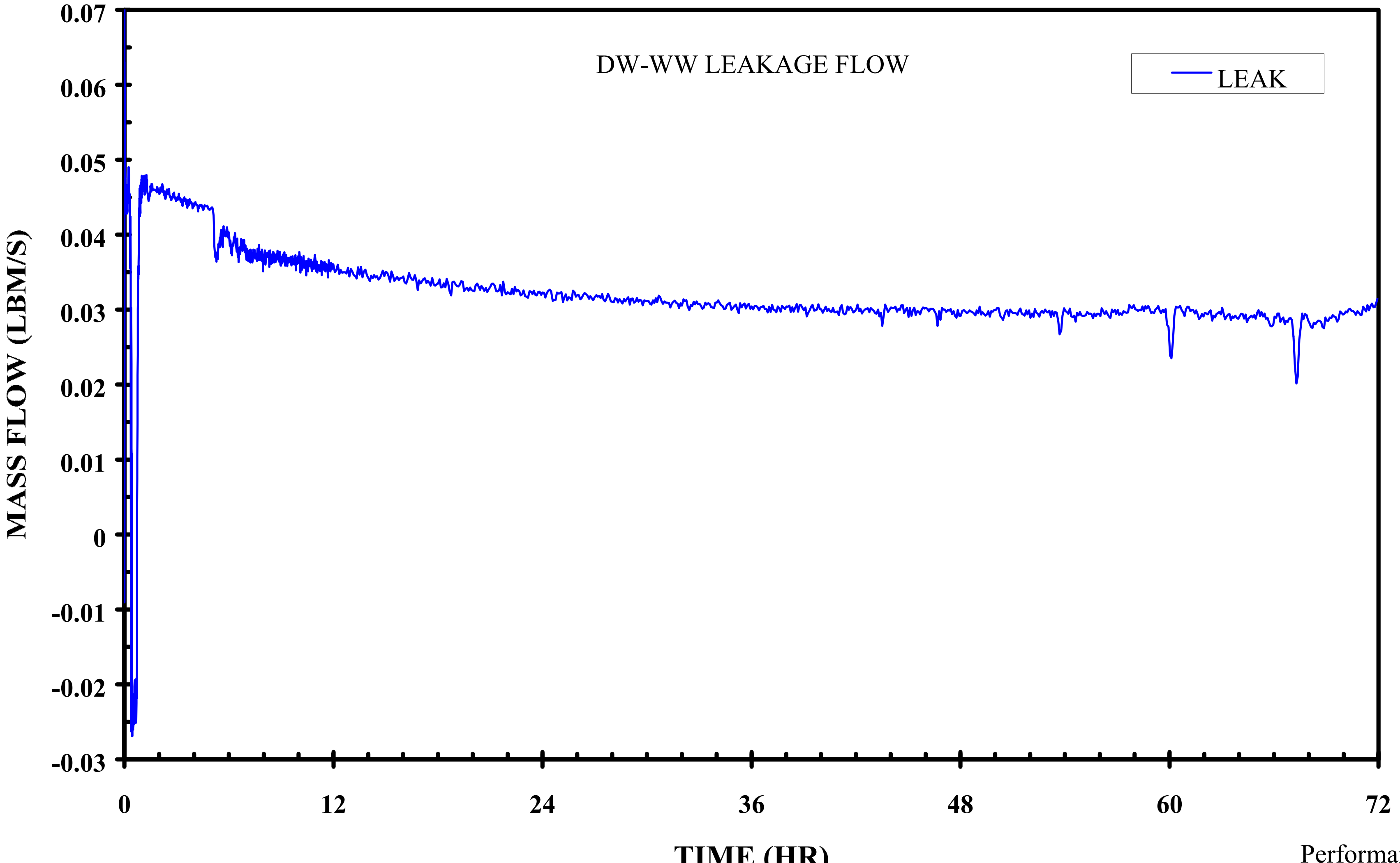
Total PCCS Drain Flow to RPV



Differential Pressure (DW – WW)



Leakage Flow (DW to WW)



Summary of Main Steam Line Break (largest break) Analyses

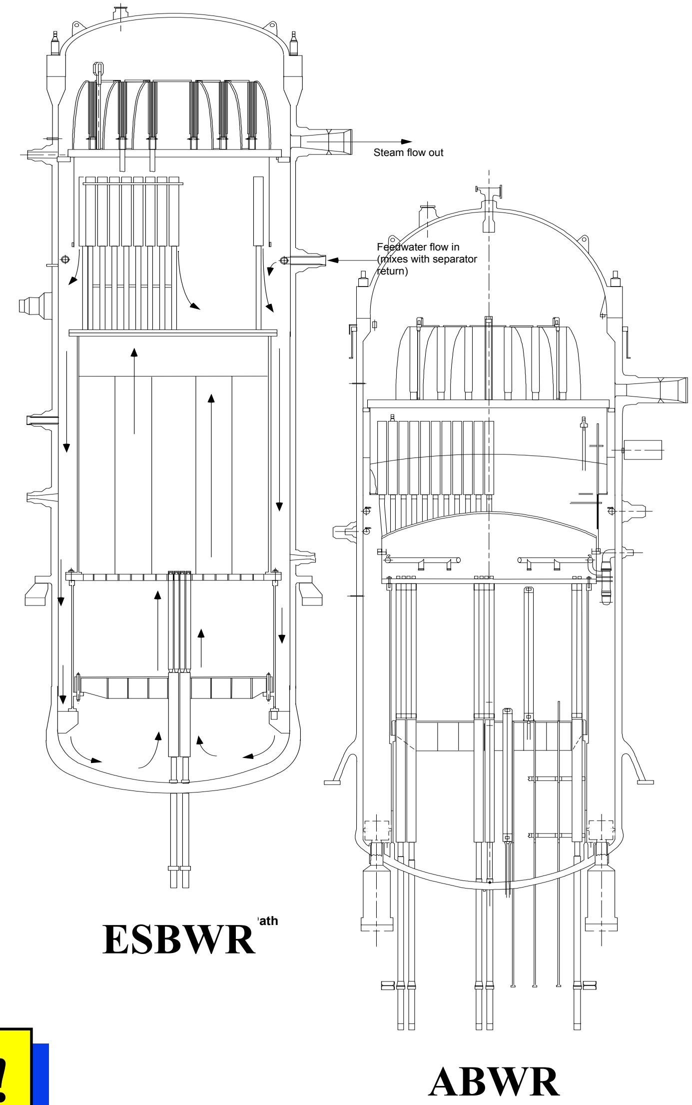
- **ESBWR has large margin (> 3m) to core uncovery and heatup**
- **Calculated DW pressure shows > 20% Margin to the design pressure**
- **Total PCCS heat removal capacity greater than decay heat (after 2 hours)**
- **Overall pressure and level (inventory) responses are mild in nature, NO requirements for fast action**

Other breaks expected to have similar responses

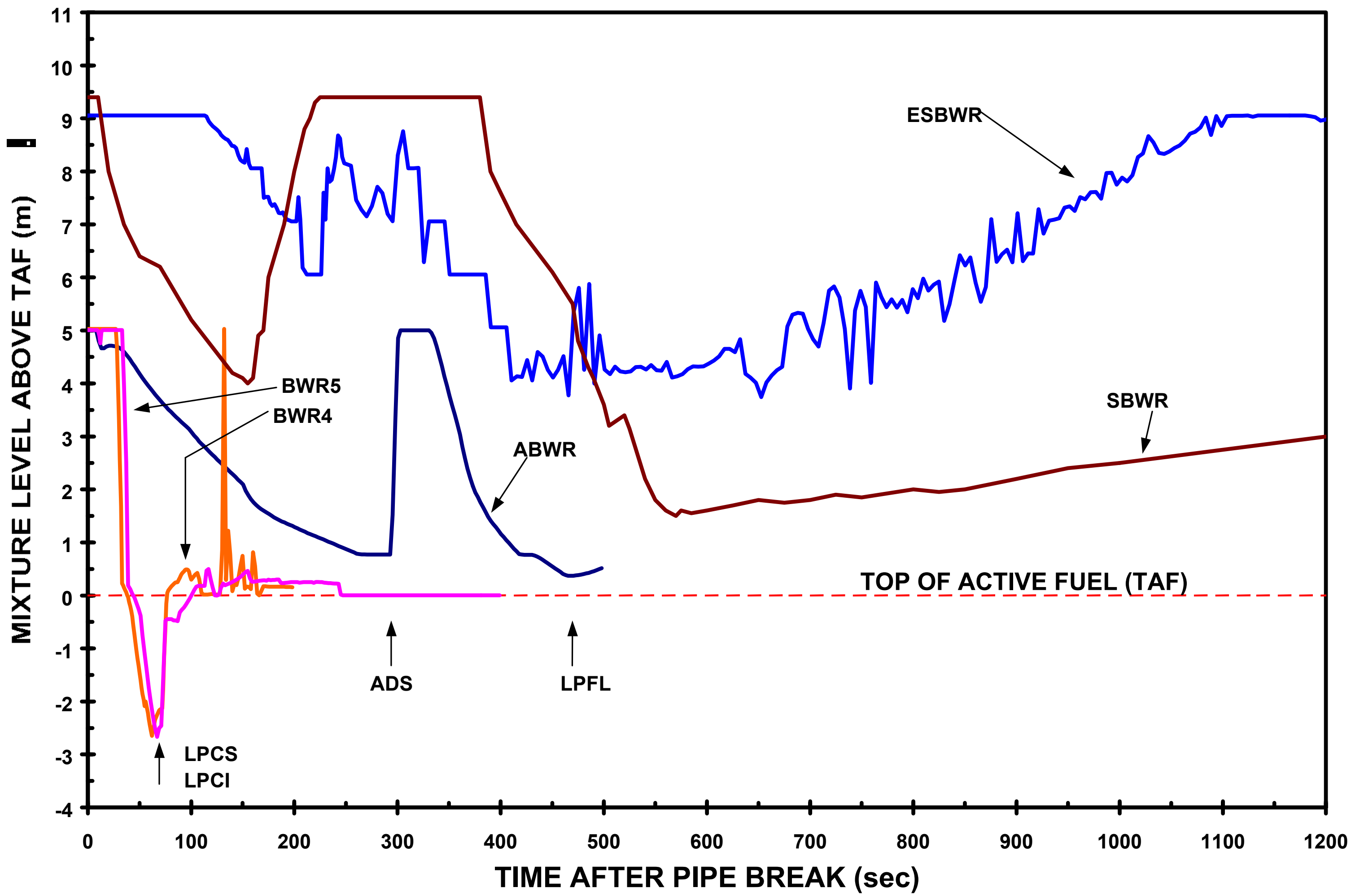
Design Features Affecting LOCA Response

	ESBWR	ABWR	BWR5	BWR4
Large pipes below core	No	No	Yes	Yes
Core height, m	3.05	3.66	~3.66	~3.66
TAF above RPV bottom	~ 1/4	~ 1/2	~1/2	~1/2
Separator standpipes	Long	Short	Short	Short
Vessel height, m	27.7	21.1	~21.9	~21.8
Water volume outside shroud (above TAF), m^3	222	88	94	92

ESBWR has much more water inventory!



Comparison of Mixture Levels Inside Shroud Following a Pipe Break

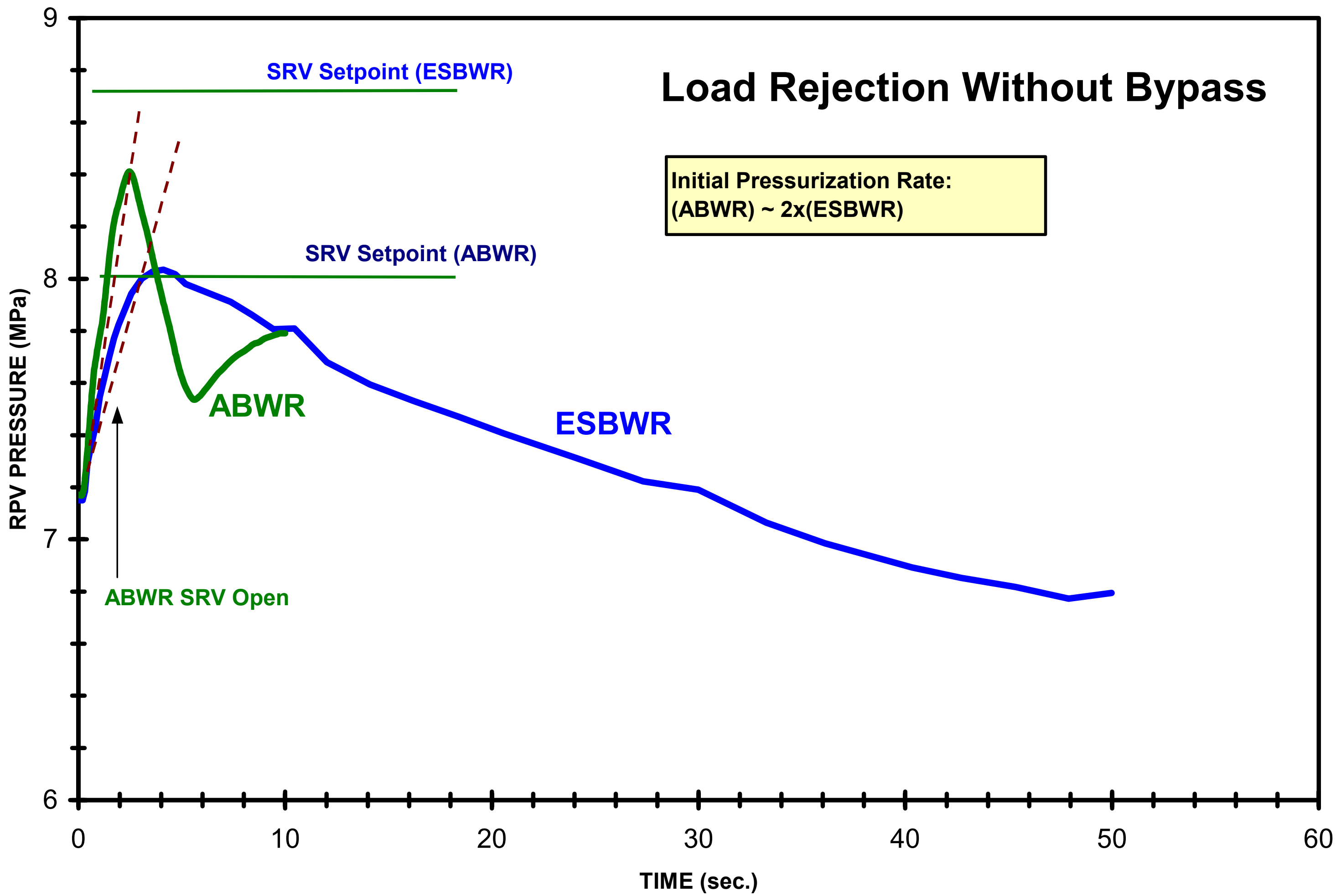


ESBWR has large margin to core uncovery and heatup – other breaks expected to have similar responses

ESBWR Features That Improve Transient Pressure Response

- **Taller reactor vessel**
- **Large steam volume in the chimney region**
- **Higher safety valve setpoint to prevent valve opening and inventory loss**

Reactor Pressure Response to Isolation Events

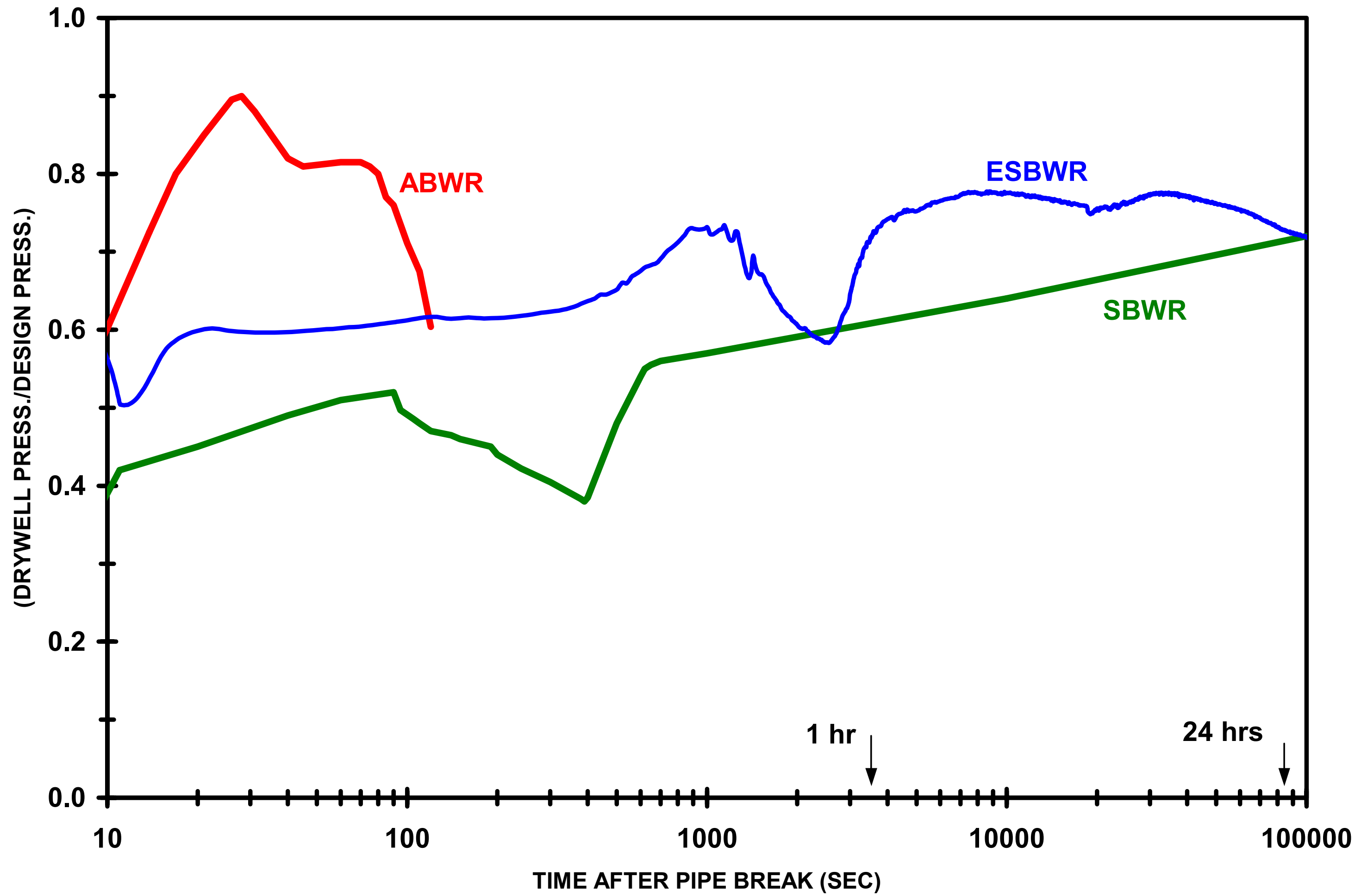


ESBWR has slower pressurization - no relief valves open

ESBWR Design Features That Improve Containment Response

- **Wetwell gas space volume increased**
  - GDCS pool gas space connected to wetwell
  - 10 to 25% increase in wetwell volume after GDCS pool drains
- **PCCS capacity increased**
  - Total PCCS heat removal capacity greater than decay heat (after 2 hours)
- **Containment overpressure relief system added**

Containment Pressure Following a Pipe Break



ESBWR has > 20% margin to design pressure

Summary

- **Natural circulation flow increased**
  - Un-restricted downcomer, tall chimney, shorter fuel & taller vessel
  - Power/flow ratio same as pump plants at rated condition
- **LOCA response improved**
  - Taller vessel and larger initial inventory in the vessel downcomer
  - No need for fast acting, high pressure and large flow rate inventory makeup
  - Large margin to core uncovery and heatup
- **Containment response improved**
  - Wetwell volume increased by moving GDCS pool
  - Containment overpressure relief system added
  - ESBWR containment has > 20% margin to design pressure even with lower containment design pressure than ABWR/SBWR

ESBWR design features improve plant performance