Licensing Analysis of RPV and BOP Blowdown for the Event of FWLB with RELAP5-3D/K for Lungmen

ABWR Containment Design

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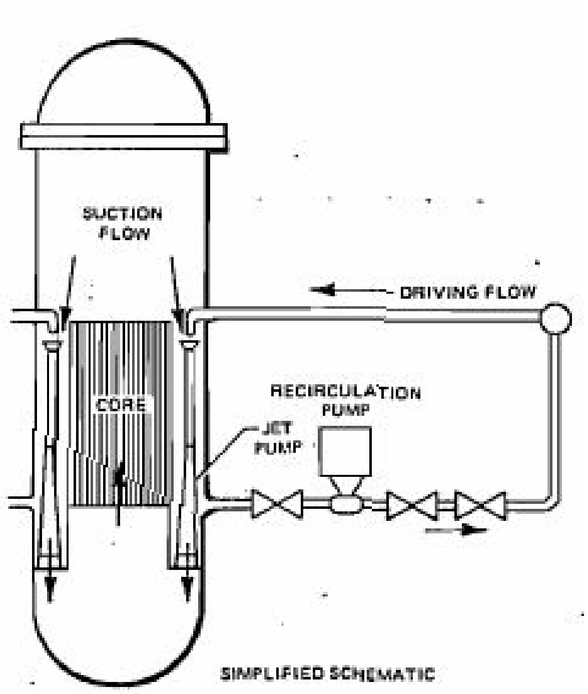
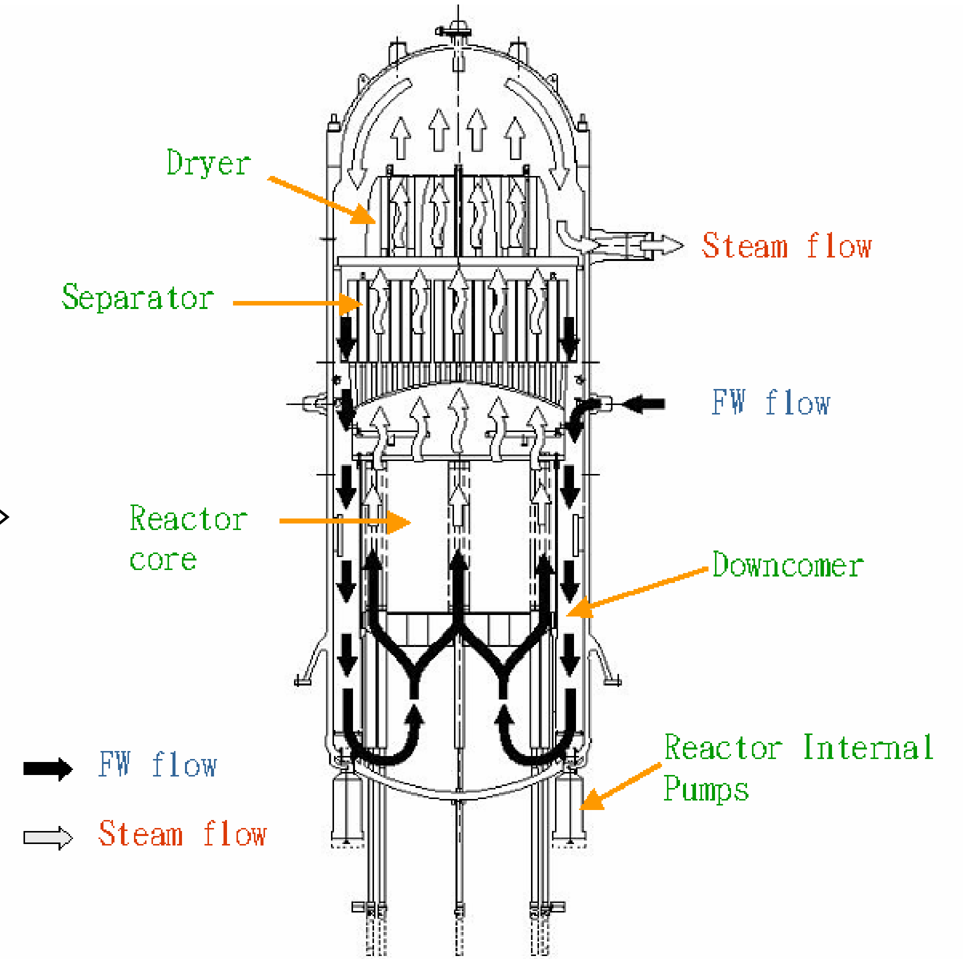
Contents

Introduction

- **Conventionally, the limiting break for BWR containment design is the recirculation line break.**
- **In the ABWR design, the jet pumps driven by the recirculation loops are replaced by the reactor internal pumps (RIPs).**
- **As a result, the limiting break for ABWR containment design shifts to the Feedwater Line Break (FWLB).**

Introduction



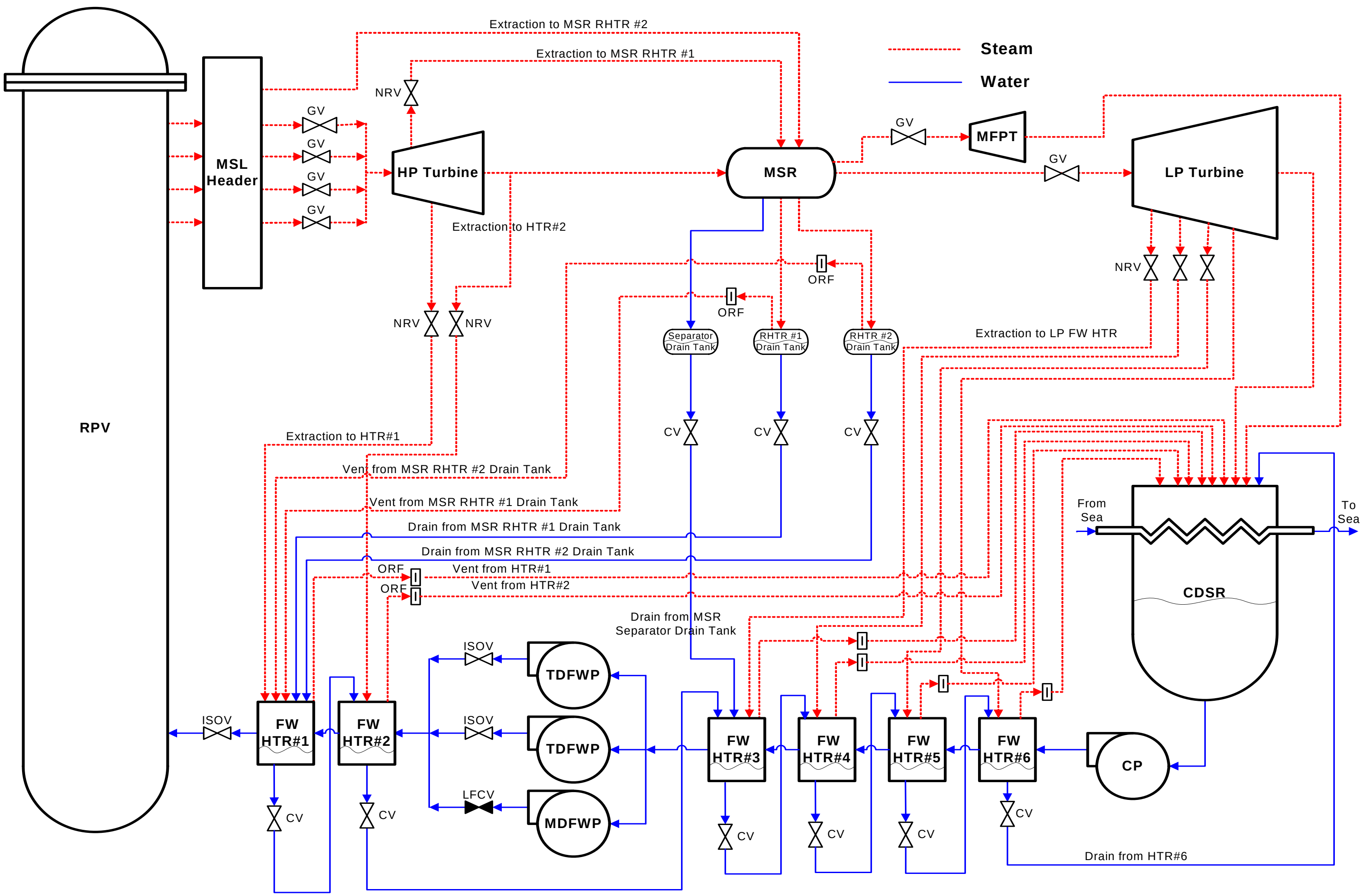


Essential Processes to be calculated

(1) Critical flow at the break ends or the internals, such as FW sparger and venturi;
(2) Flashing of RPV inventory and FW near the break;
(3) Run out and coast down of the FW pumps;
(4) Steam extractions to FW heaters and FWP turbines;
(5) Flashing of saturated water initially stored inside the FW heater shell sides and MSR drain tanks;
(6) Energy release from saturated water and system metal,
(7) Cold water transportation from the main condenser to the break; and
(8) ECC injections and associated level variations.

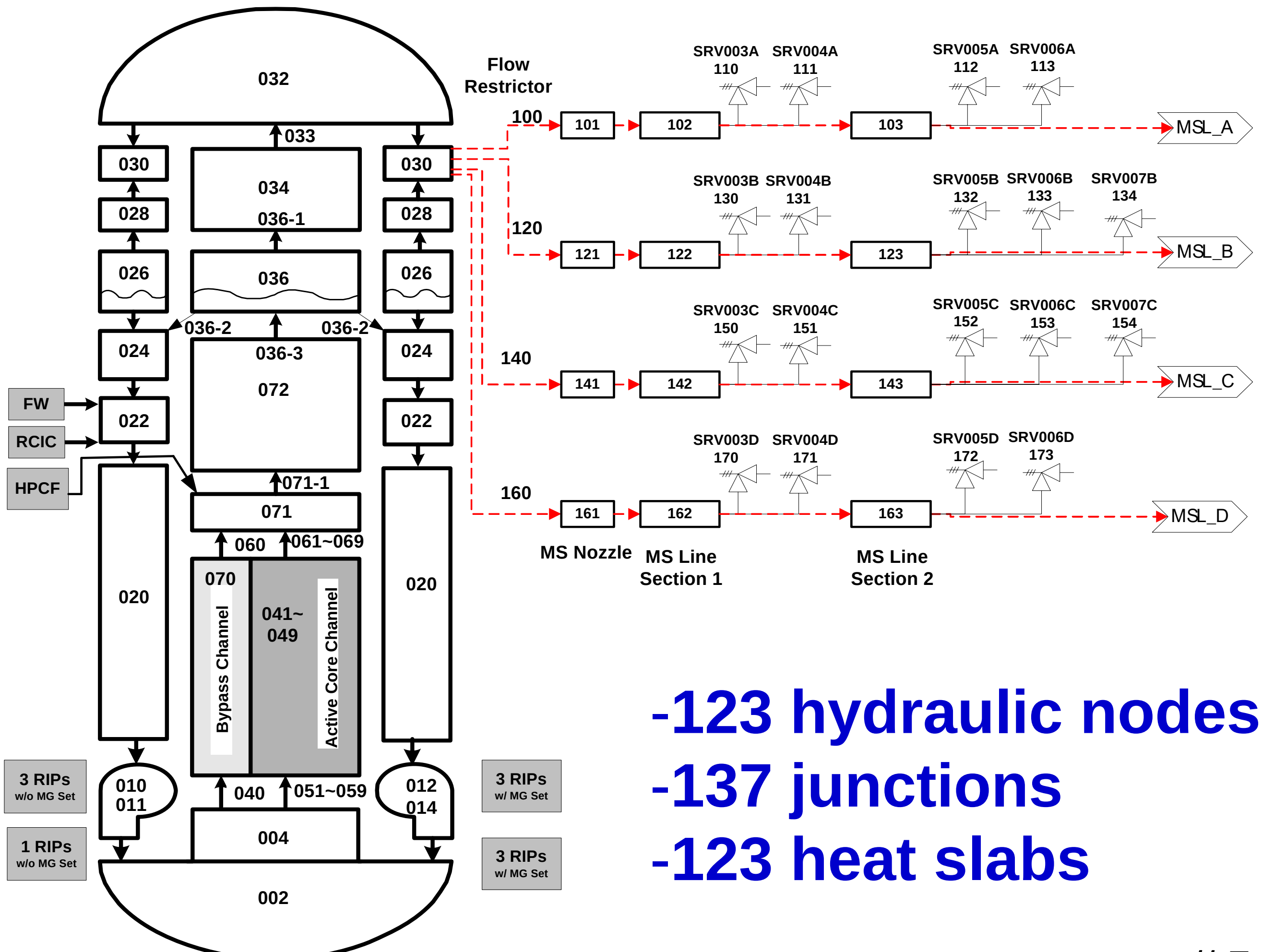
System Modeling with RELAP5-3D

-Modeling Scope-



NPP4 System Simulation Diagram

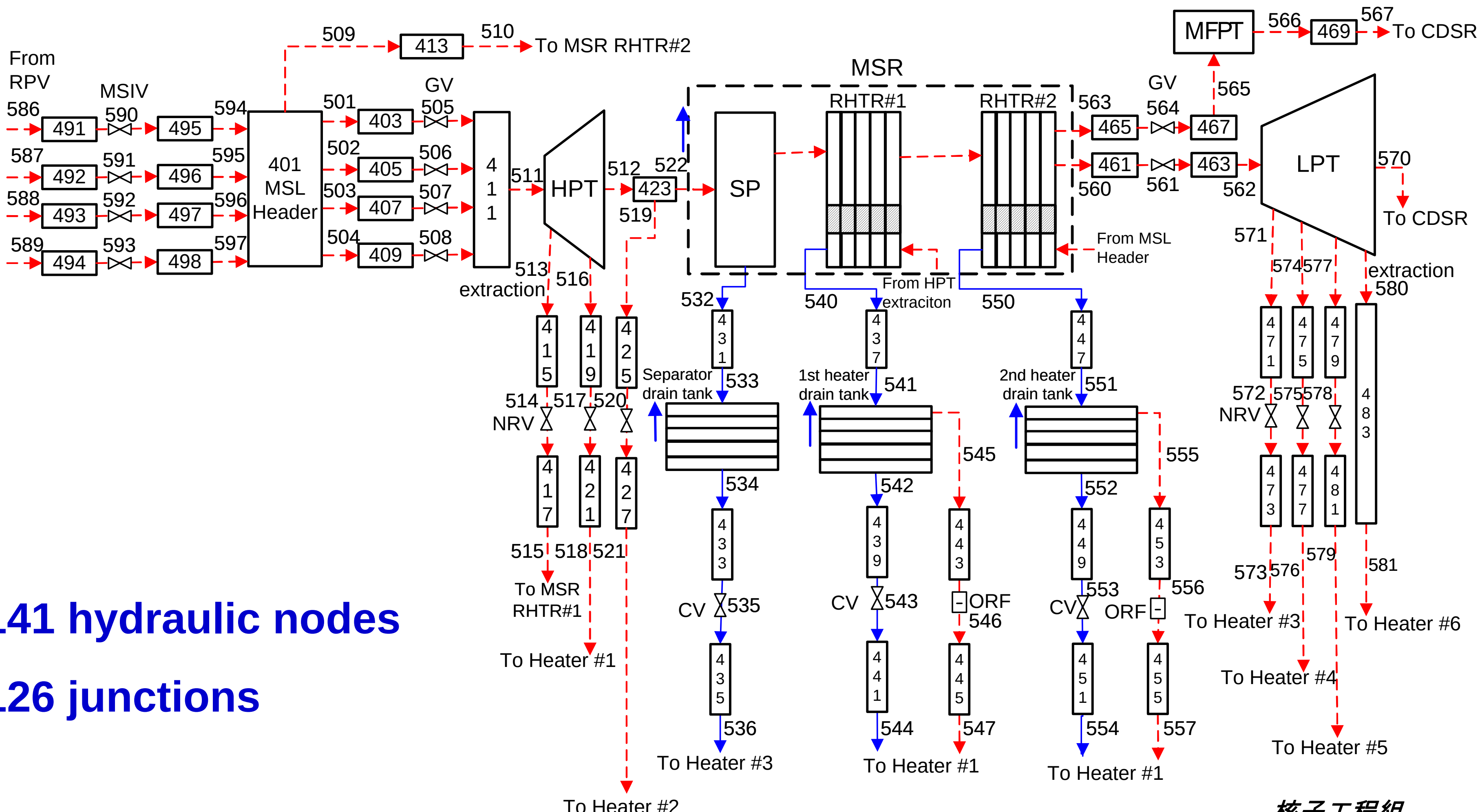
Modeling of RPV and Steam Lines



- -123 hydraulic nodes
- -137 junctions
- -123 heat slabs

System Modeling with RELAP5-3D

Modeling of Main Steam & Turbine Systems

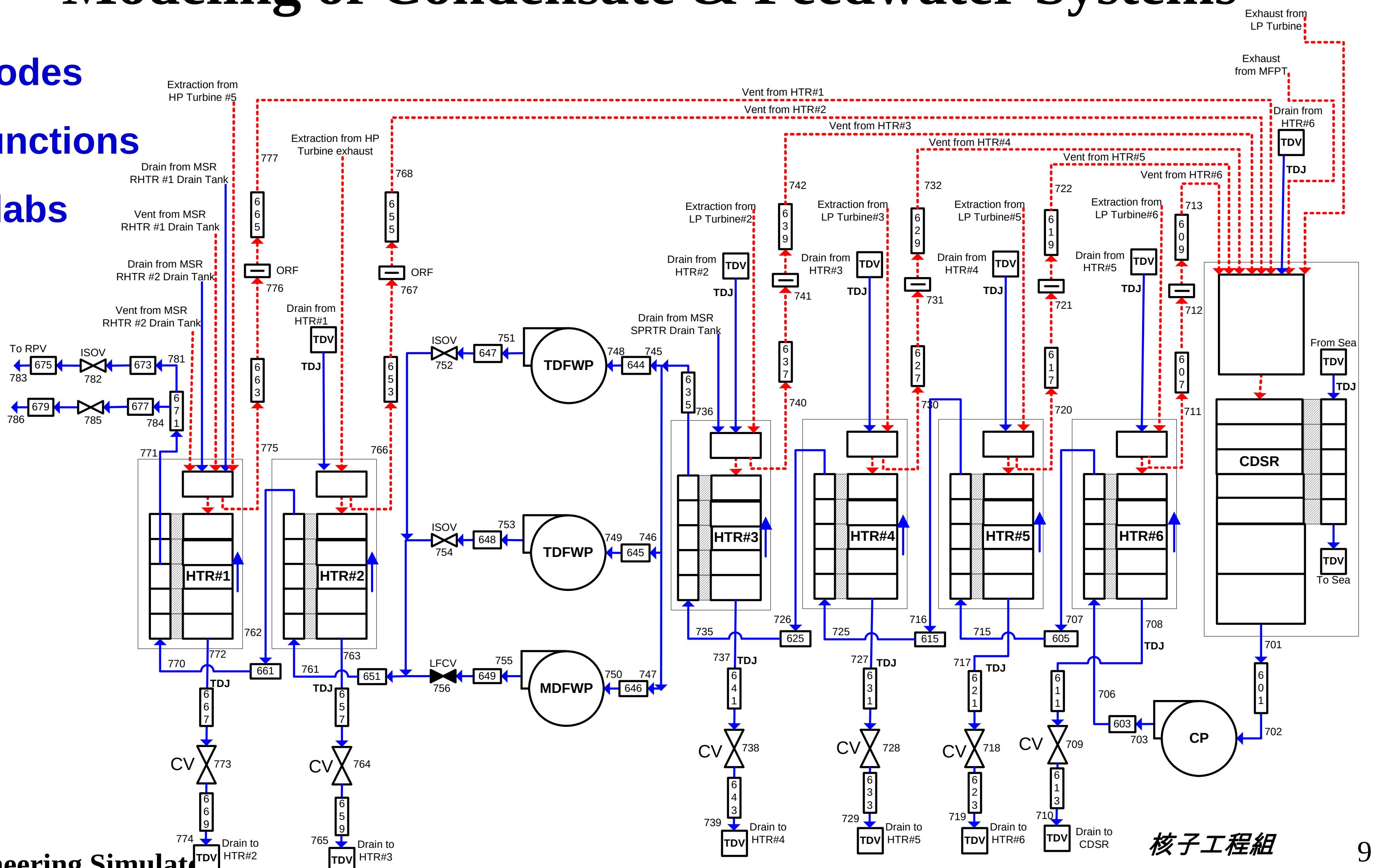


-141 hydraulic nodes

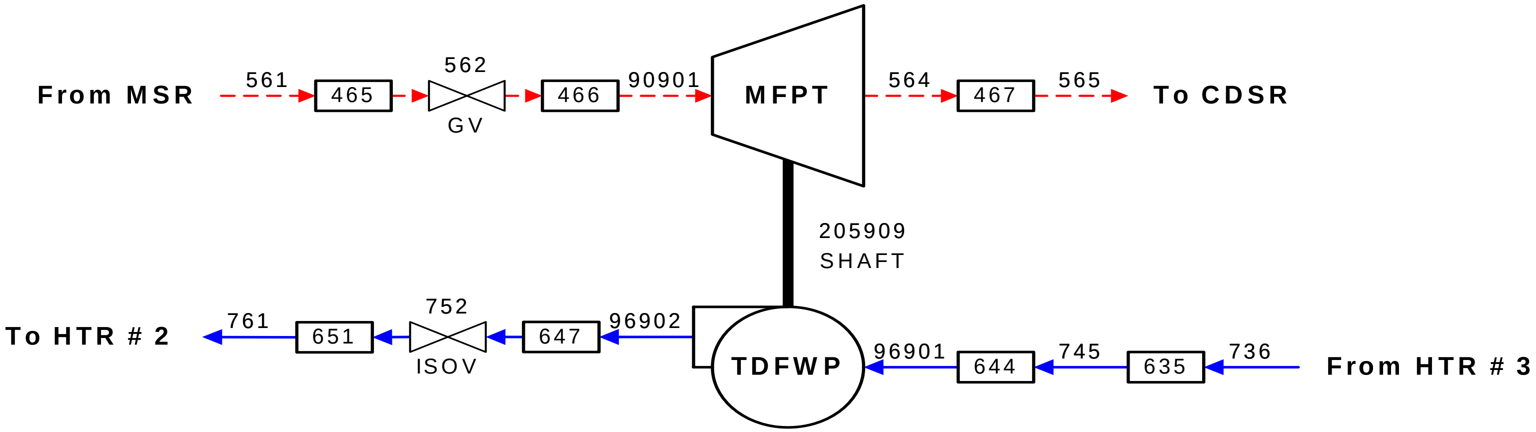
-126 junctions

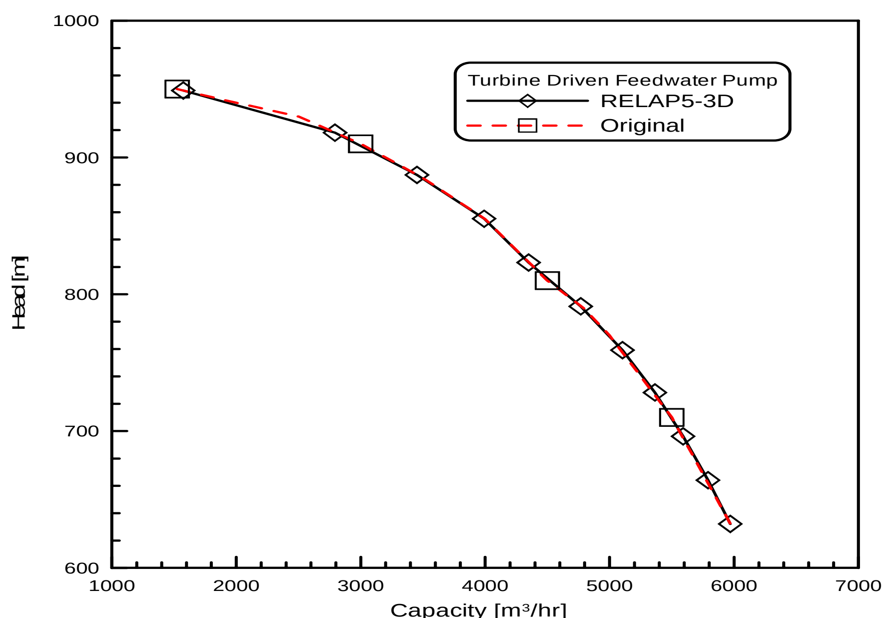
Modeling of Condensate & Feedwater Systems

- **-158 nodes**
- **-151 junctions**
- **-133 slabs**

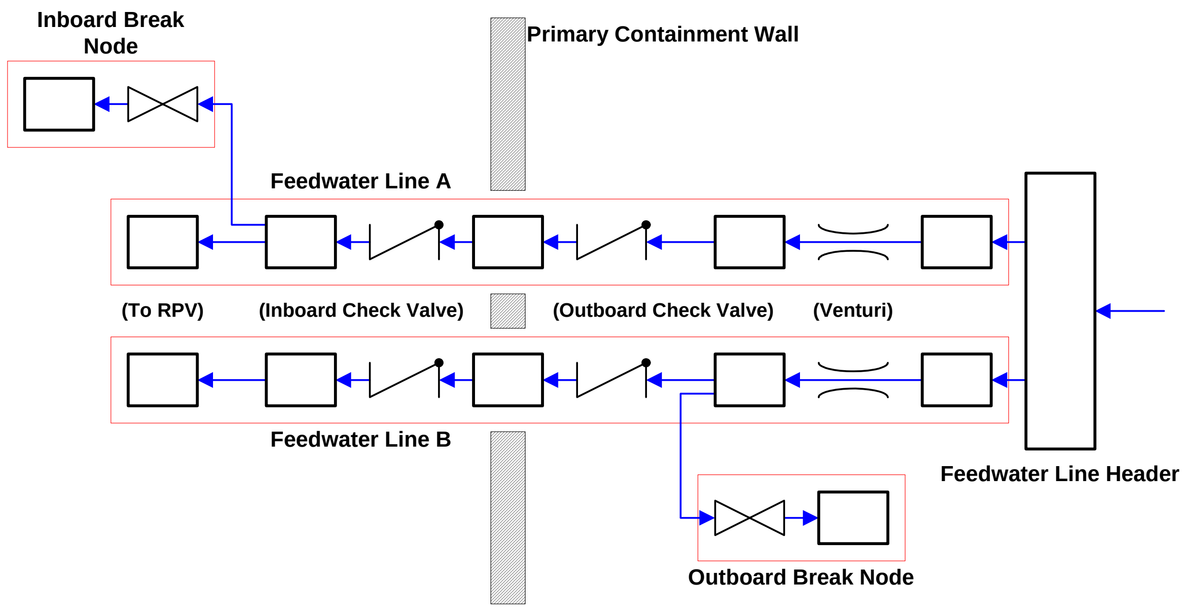


Modeling of FW pump-shaft-turbine module





Modeling of Inboard & Outboard Breaks



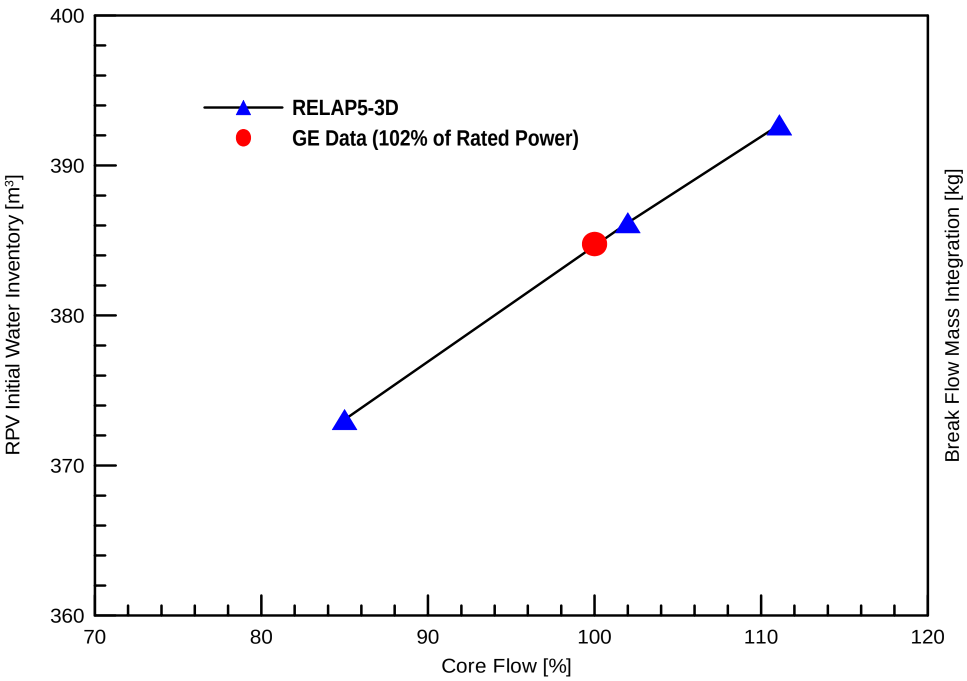
Assumptions

Initial Conditions

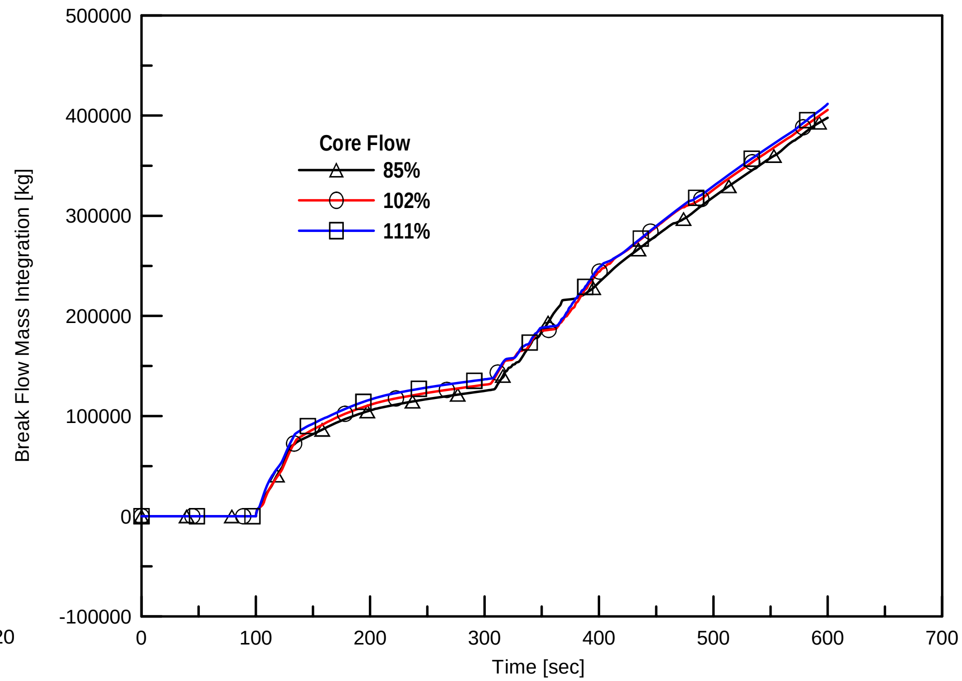
Parameter	Initial Value (INER)	Initial Value (GE)
Reactor Thermal Power [MWt]	4005.0 (102 %)	4005.0 (102%)
RPV Dome Pressure [MPa]	7.31 (102 %)	7.31 (102%)
RPV Core Flow [kg/s]	16,107 (111.1 %)	16,110 (111.1%)
RPV Narrow Range Water Level [cm]	426.0	427.0
Steam and Feedwater Flow [kg/s]	2177.8 (102 %)	2174.0 (102%)
Feedwater Temperature [°C]	216.9 (102 %)	216.9 (102%)

Sensitivity Studies

❑RPV modeling: (1) initial core flow



Effect of Core Flow on the Initial RPV Inventory



Effect of Initial Core Flow on the Accumulated RPV Blowdown Mass

Assumptions

❑ *Plant Operations*

- ➢Extraction steam continues to enter the feedwater heater and the feedwater pump turbines until steam inventory is depleted or blocked by the non-return valves designed to protect main turbines;
- ➢Non-safety systems and components are assumed to fail in ways that maximum the amount of water mass and energy blowdown;
- ➢Feedwater flow to the vessel through the unbroken line continues intermittently through the event, depending on the feedwater line and RPV pressures.
- ➢MSIVs will be fully closed within 3.0-4.5 seconds[3-4], and 3.0 seconds is conservatively assumed for inboard break (RPV and BOP blowdown);
- ➢After 30 minutes after break for long term blowdown calculation, HPCF and RCIC injections will be terminated and LPFL injection will be regulated to maintain water level between L-2 and L-8.

Assumptions

❑ *Modeling Assumptions*

- Homogeneous Moody model is applied to calculate blowdown flow rate;
- The effects of internal choking at Venturi of FW system and Spargers inside RPV are considered;
- The pump curves of flow run out are used to model the FWPs;
- Flashing of water depressurized below its saturation point and the associated effect of flashing on steam supply are considered;
- The effect of stored heat from metal and saturated water stored in feedwater heater shell sides on the feedwater heating are considered;

Results

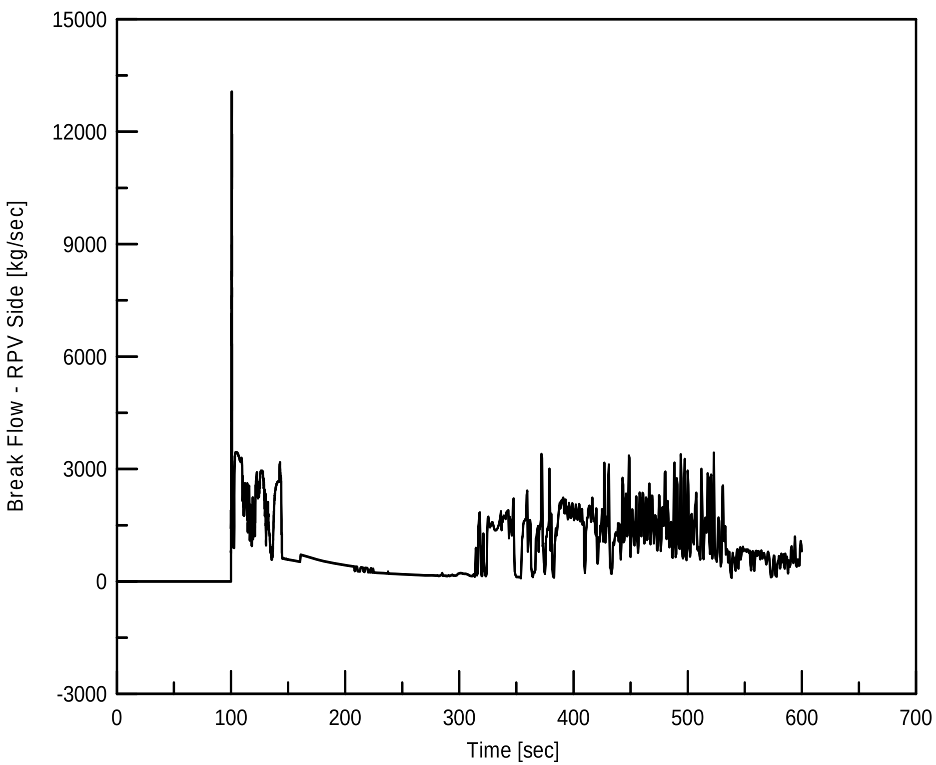
❑ *RPV Short-Term Inboard Break*

Sequence of Events of FWLB Inboard Break

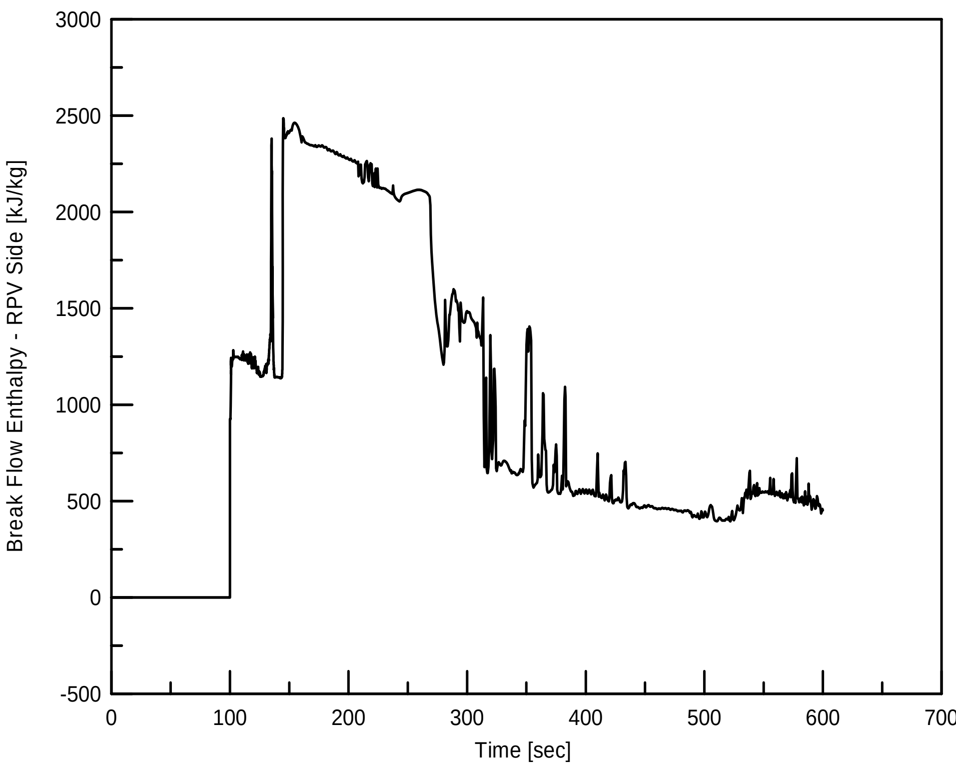
Time [s]	Events
0.000	Feedwater line break.
0.310	L-4 and 10 RIPs Runback (L-4 + 0.0s, not apply).
5.000	Reactor scram by drywell high pressure (Assumption).
5.393	L-3, Trip of 4 RIPs without MG set (L-3 + 0.0s).
12.629	L-8, Turbine trip (L-8 + 0.0s, not apply), and Feedwater pump turbine trip (L-8 + 0.0s, not apply).
19.268	MSIVs closure by main steam line low pressure.
26.742	L-2, Trip of 3 RIPs with MG set (L-2 + 0.0s).
31.000	HPCF startup complete (Drywell high pressure + 26.0s).
32.742	Trip of other RIPs with MG set (L-2 + 6.0s).
34.000	RCIC startup complete (Drywell high pressure + 29.0s).
41.000	LPFL startup complete (Drywell high pressure + 36.0s).

Results

❑ *RPV Short-Term Inboard Break*



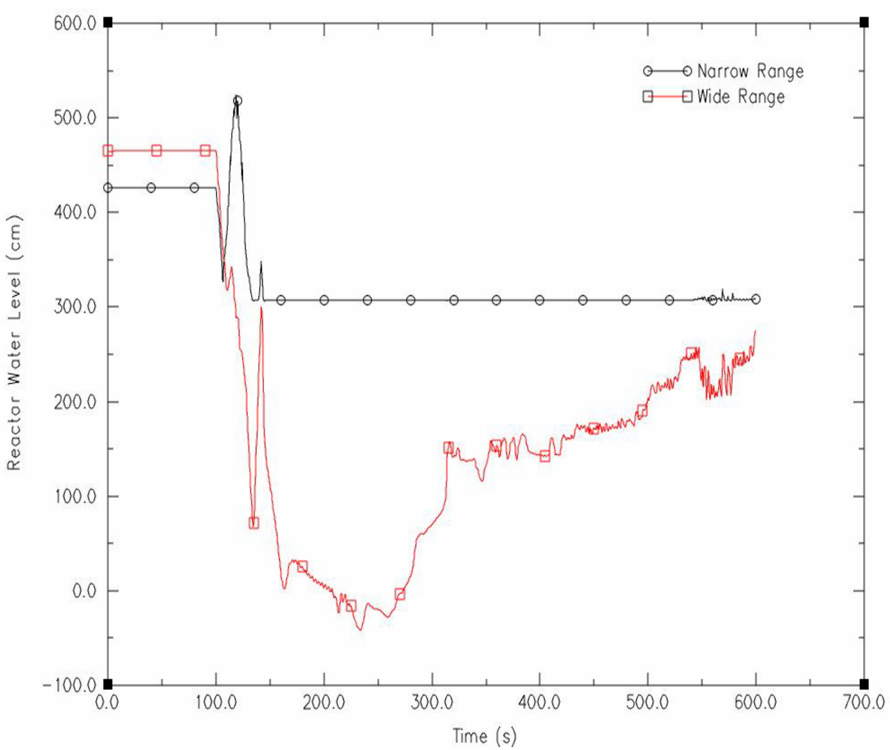
Break Flow from RPV Side



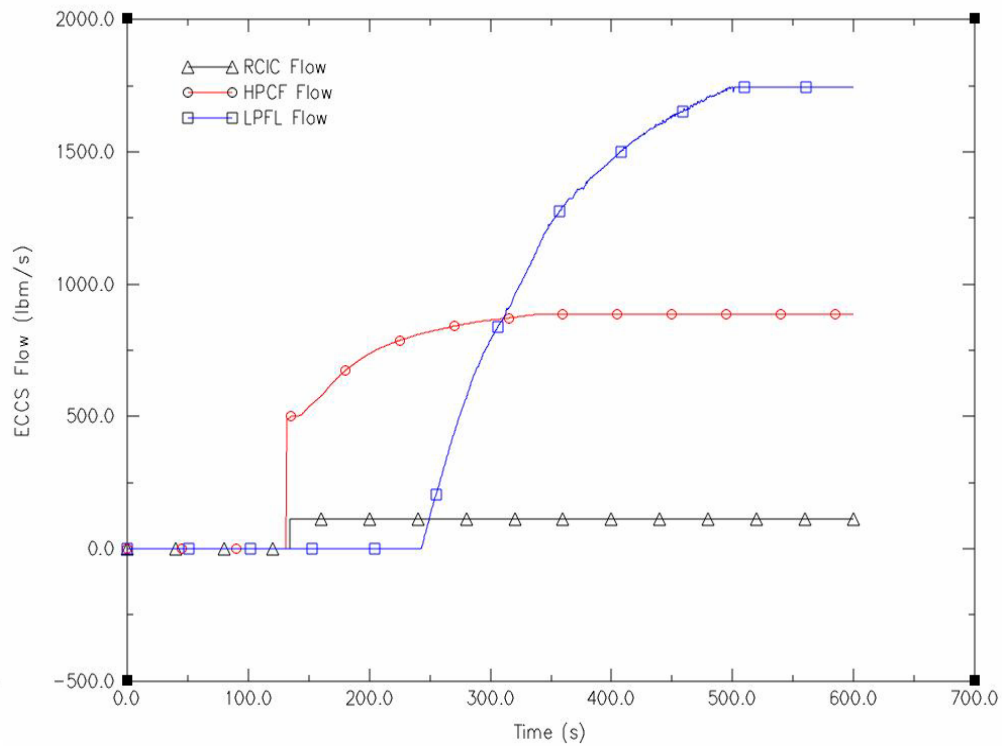
Break Flow Enthalpy from RPV Side

Results

❑ *RPV Short-Term Inboard Break*



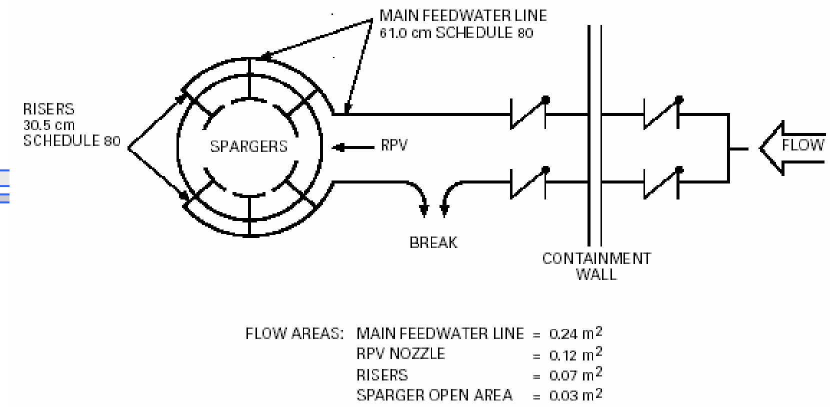
Reactor Water Levels

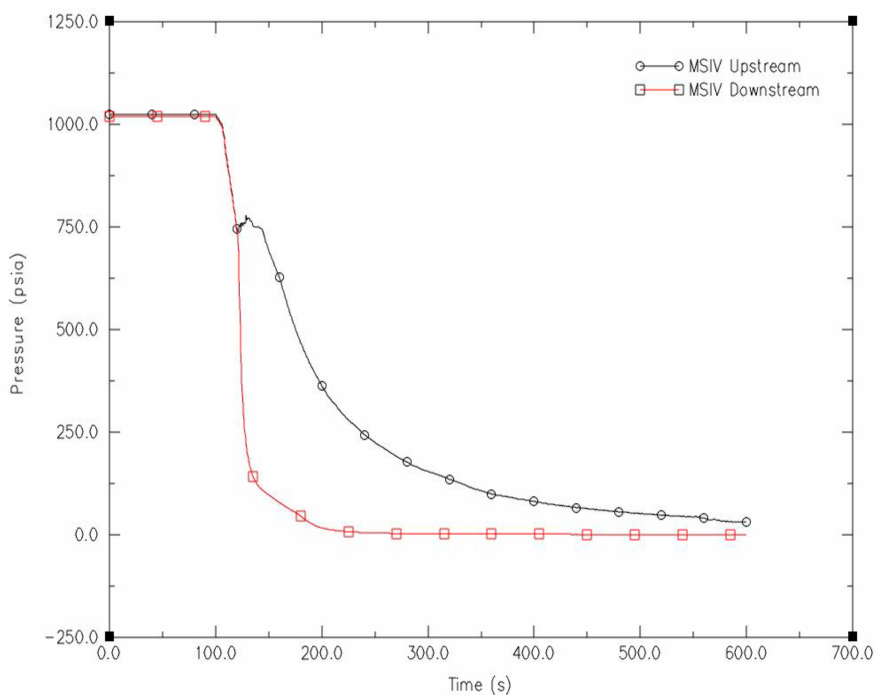


ECC Injection Flows

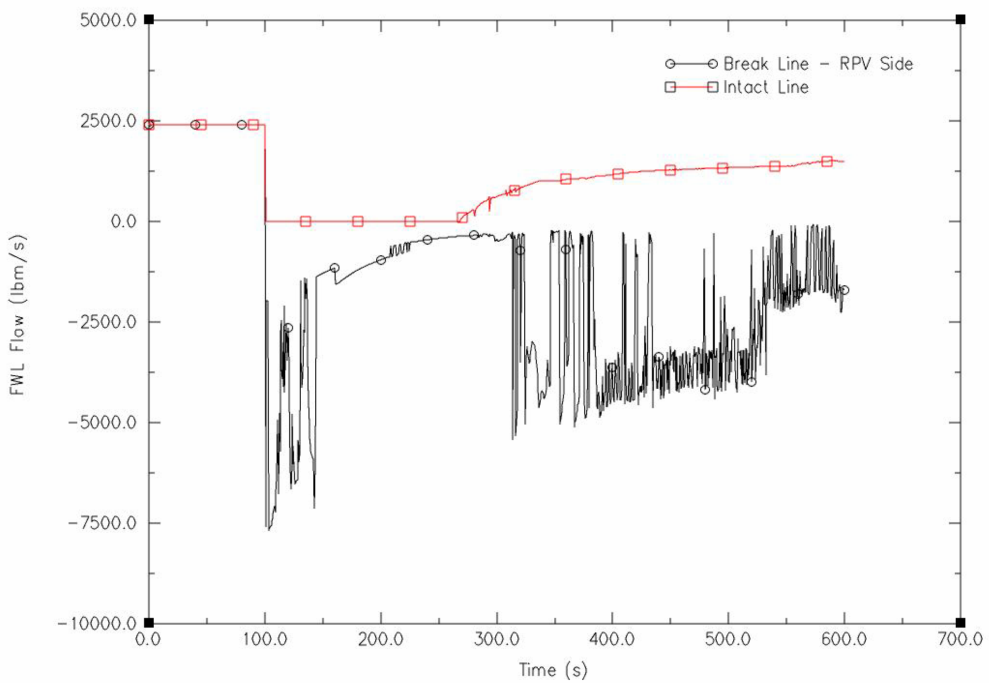
Results

- *RPV Short-Term Inboard Break*





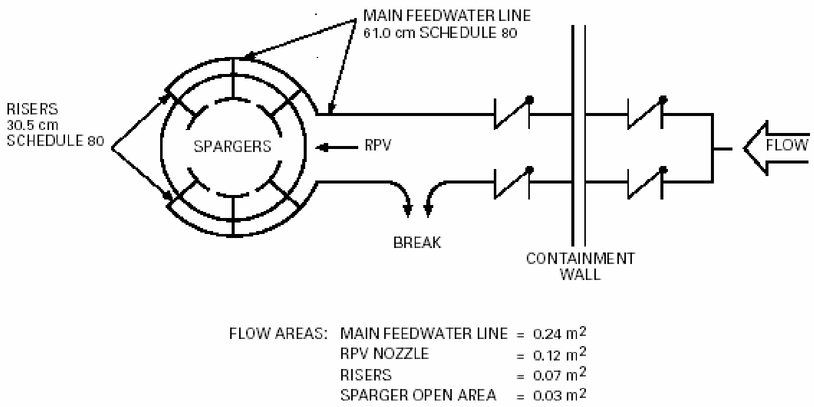
Pressure Responses before and after MSIV

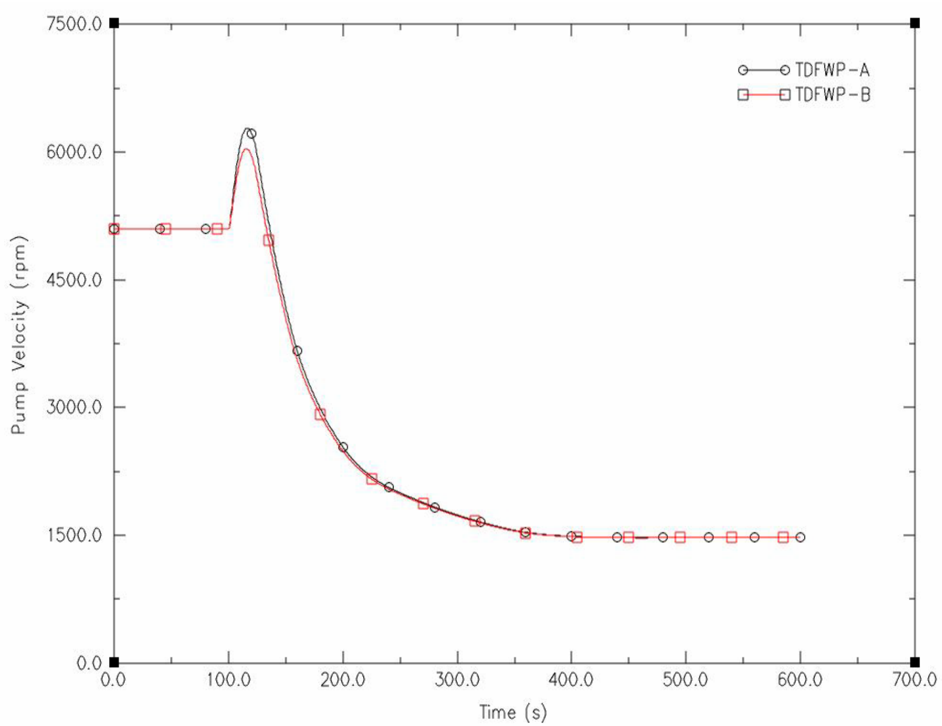


Flows through both the Intact and Broken FW Lines

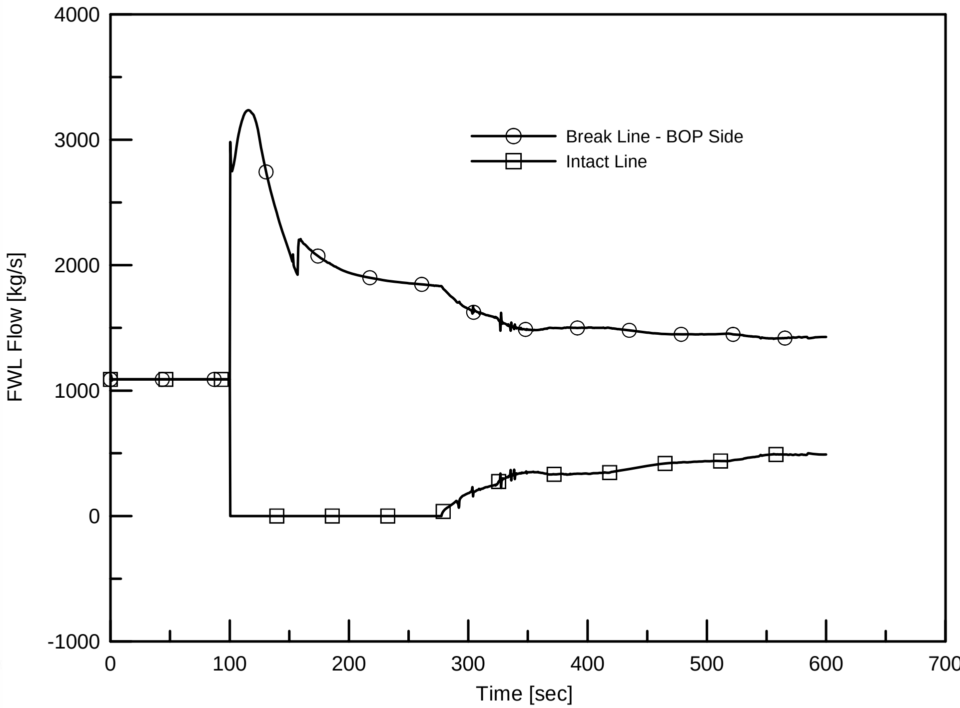
Results

❑ *BOP Short-Term Inboard Break*



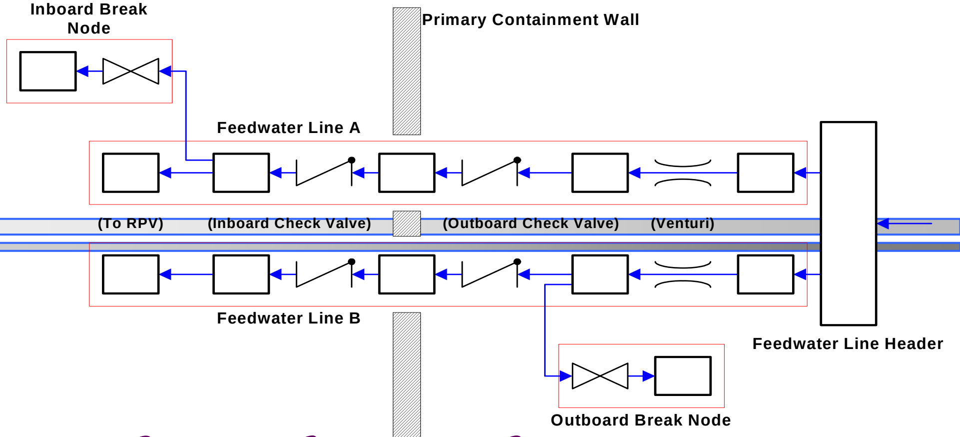


Feedwater Pump Run out Speed

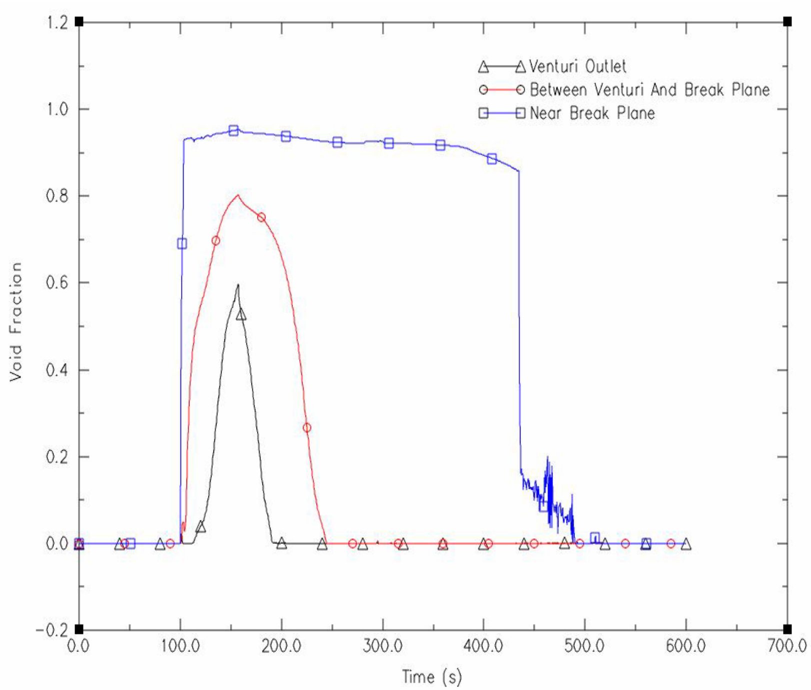


BOP Blowdown Flow Rate

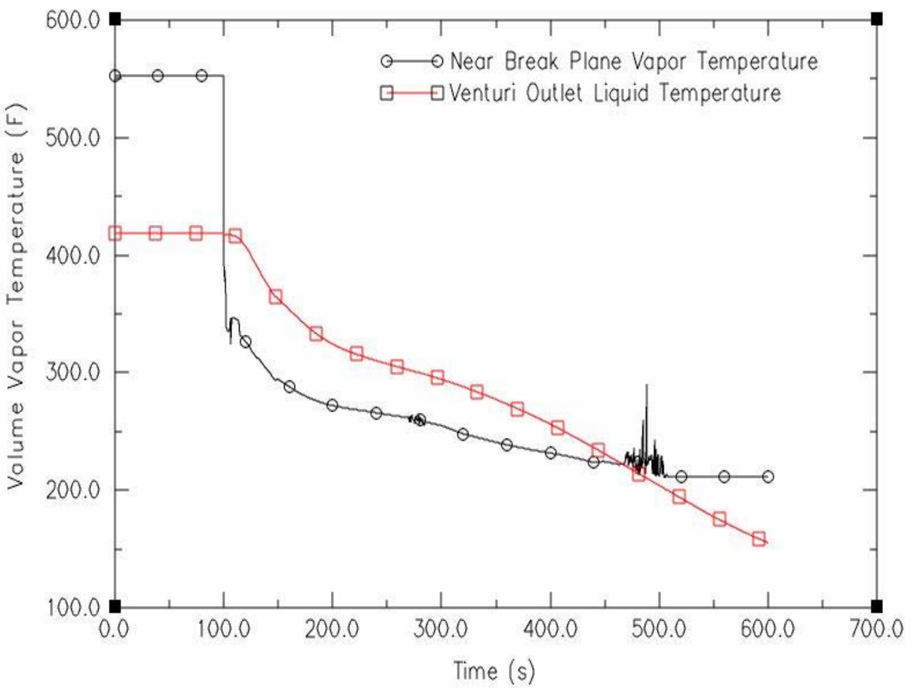
Results



❑ *BOP Short-Term Inboard Break*

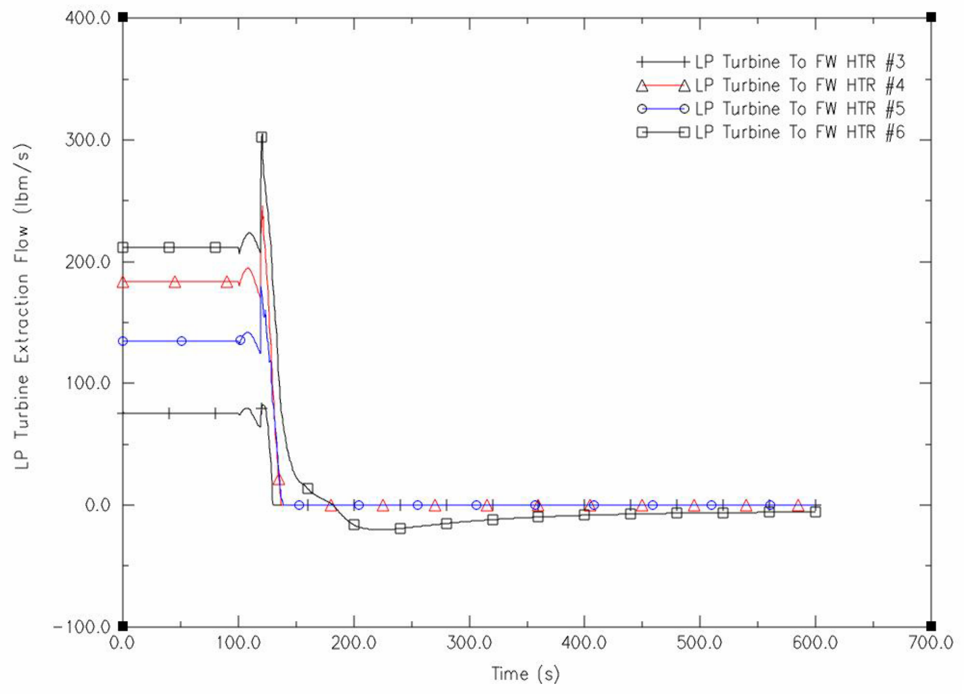


Local voids near the BOP Break End

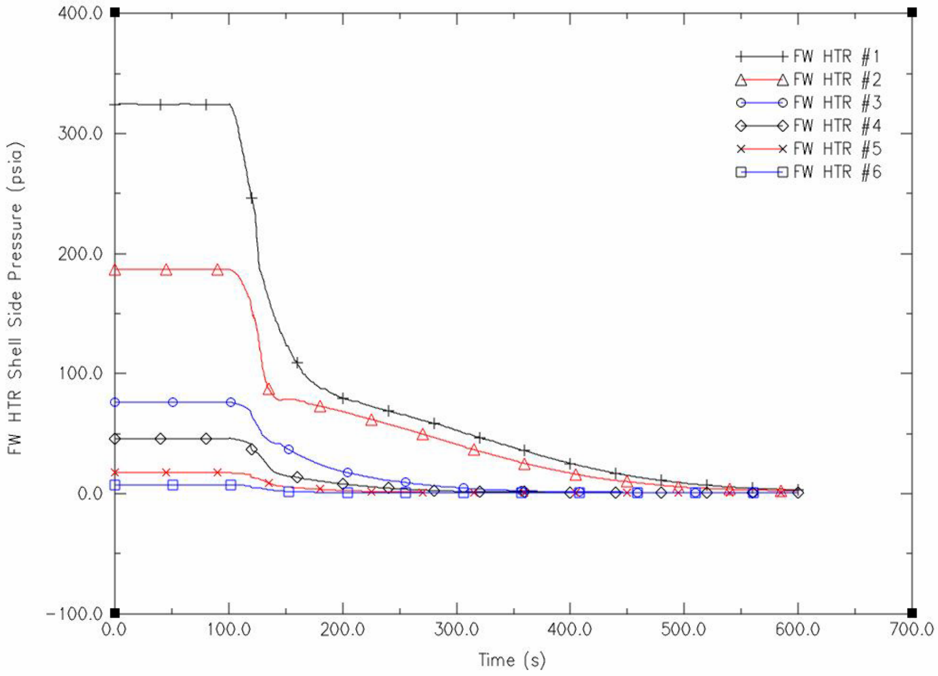


Comparison of the Local Saturation Temperature against the Coming Water Temperature

❑ *BOP Short-Term Inboard Break*



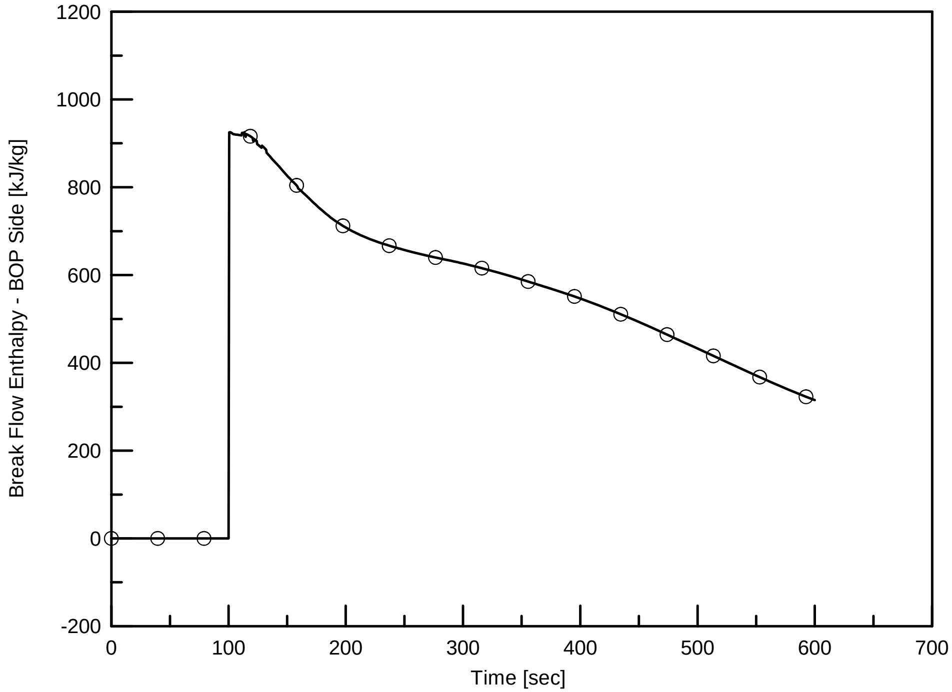
Extraction Steam Flow from Low Pressure Turbine



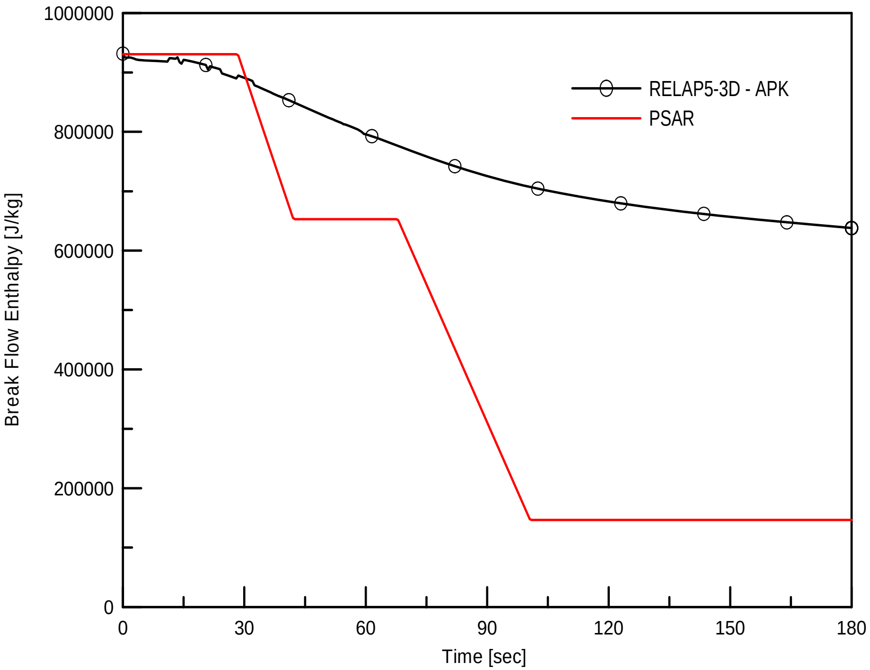
Feewater Heater Shell Side Pressures

Results

❑ *BOP Short-Term Inboard Break*



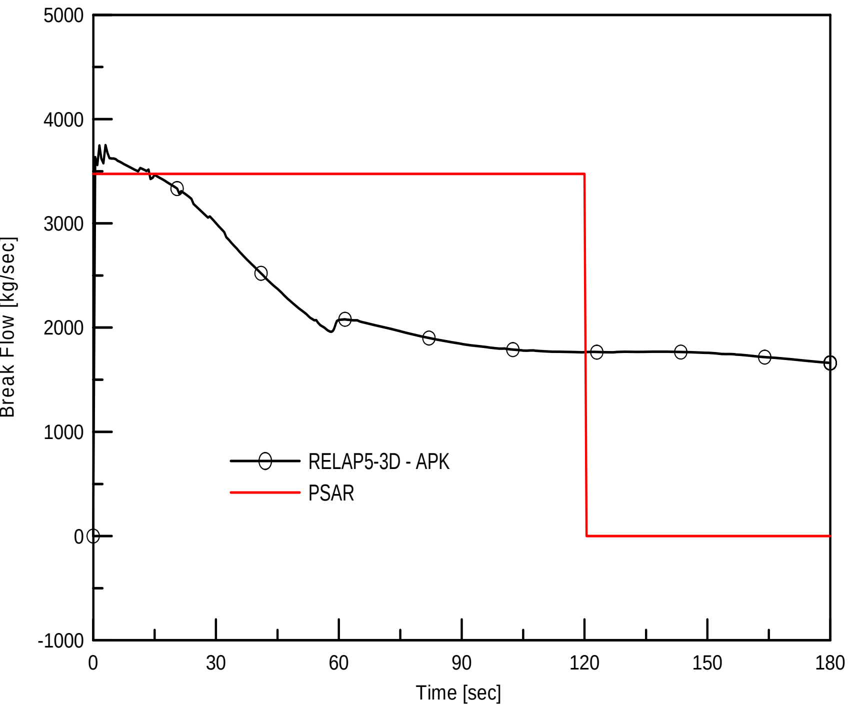
BOP Blowdown Enthalpy



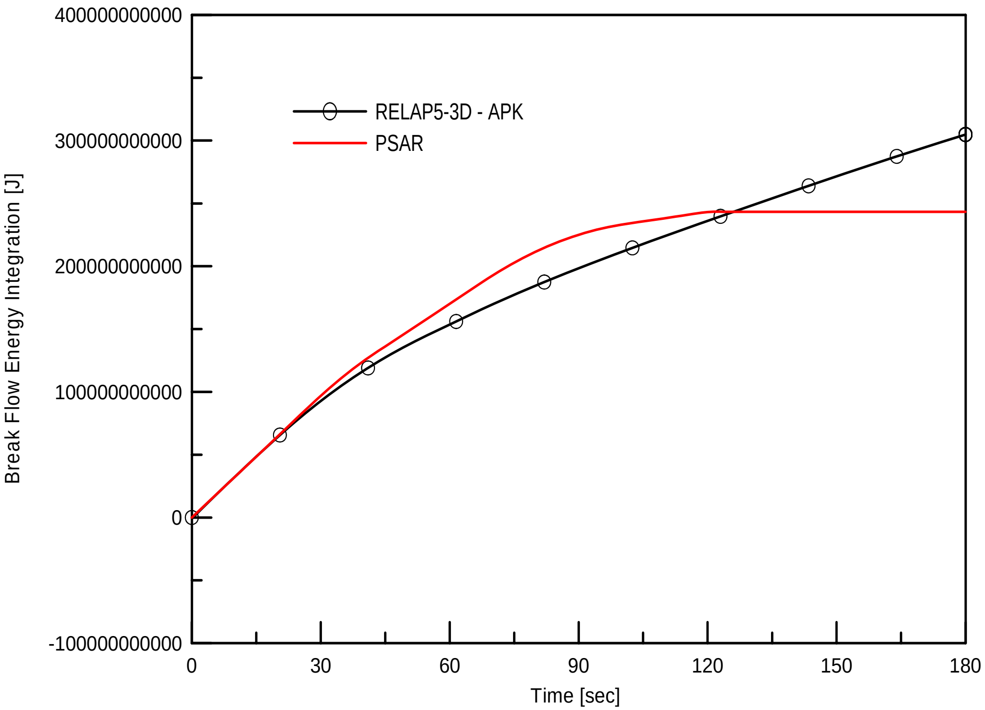
Comparison BOP Blowdown Enthalpy against PSAR Curve

Results

❑ *BOP Short-Term Inboard Break*



Comparison of the Blowdown Flow against PSAR Curve



Comparison of the Accumulated Blowdown Energy against PSAR

Conclusions

- The blowdown licensing analysis of FWLB have been successfully analyzed by the advanced RELAP5-3D/K, which include
  - Inboard & Outboard break
  - RPV & BOP blodwodn
  - Short term & long term
- All essential processes involved can be adequately simulated by RELAP5-3D/K:
  (1) critical flow at the break ends or the internals,
  (2) flashing of RPV inventory and FW near the break,
  (3) run out and coast down of the FW pumps;
  (4) steam extractions to FW heaters and FWP turbines;
  (5) flashing of saturated water initially stored inside systems;
  (6) energy release from saturated water and system metal,
  (7) cold water transportation from condenser to the break; and
  (8) ECC injections and associated level variations.

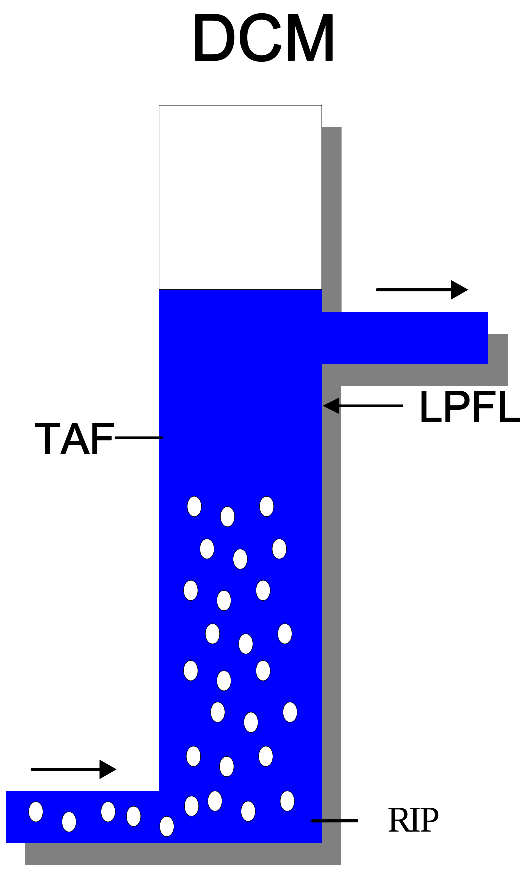
Conclusions

- Through comparisons against the PSAR curves for the inboard break, it was observed that
  - The revised accumulated blowdown mass can be bounded in the first 180 seconds,
  - The revised accumulated blowdown energy can only be bounded in the first 120 seconds.

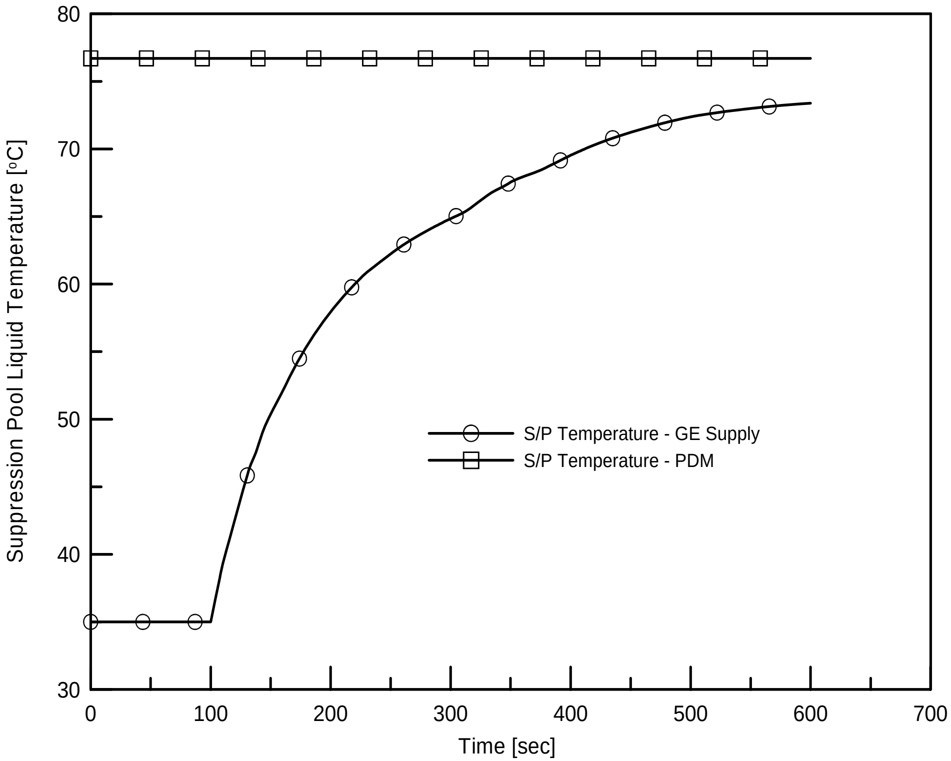
Special Issue of LPFL Injection Bypass

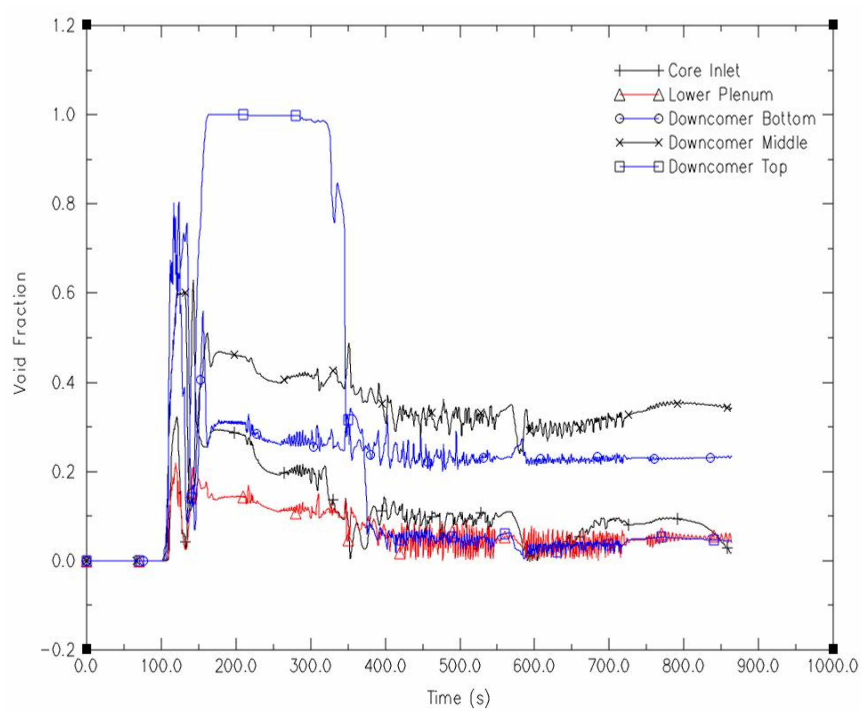
❑ What is the LPFL Injection Bypass?

- **A two-phase mixture water column with cold ECC water above might exist in the DCM during a FWLB event.**
- **The effective hydraulic head of this mixture water is not enough to bring the DCM water into the core core.**
- **Once DCM water level ascends to the FW rings, all the LPFL injection water will be directly driven to the break without entering the core shroud.**



Special Issue of LPFL Injection Bypass





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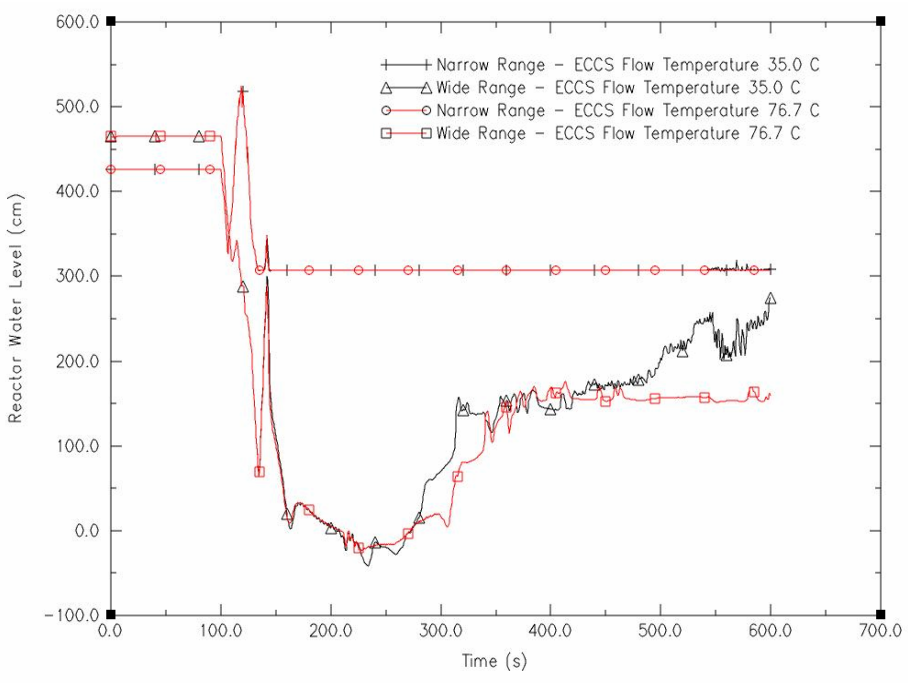
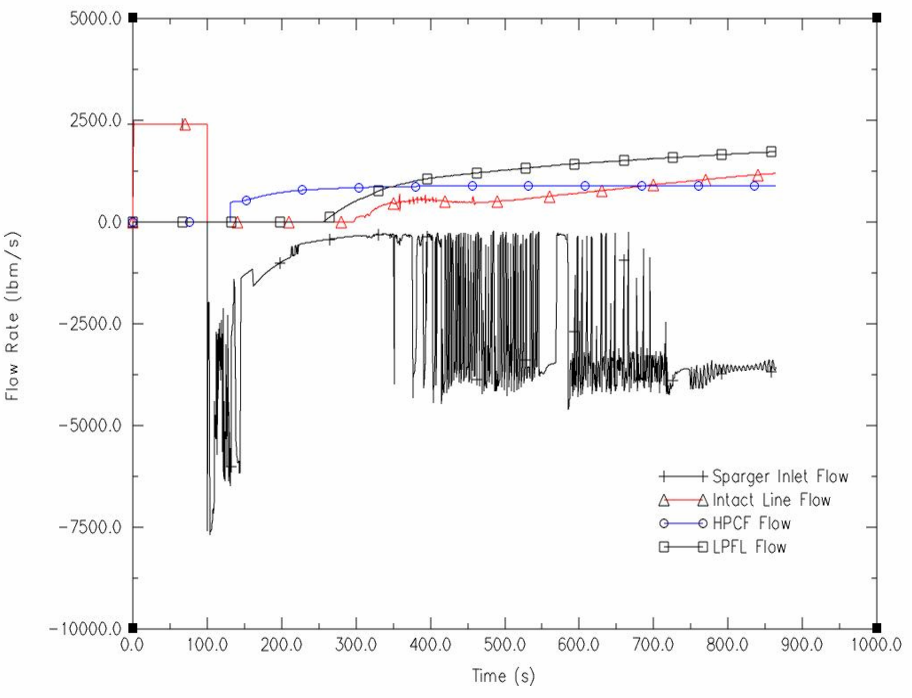


RPV Water Level Responses



Balance of RPV Boundary Flows