Sapienza Contribution to WGAMA International Standard Problem-52: PKL experiment on Multiple SG U-tube rupture

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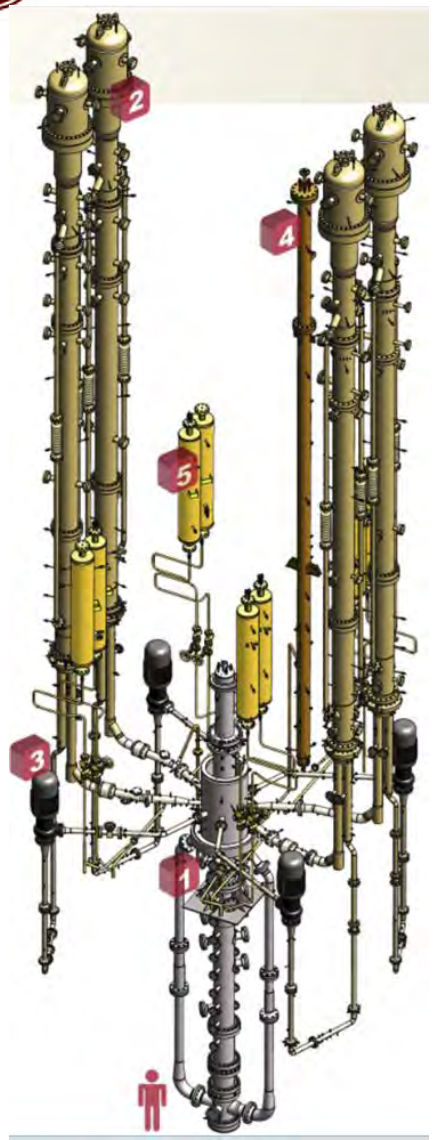
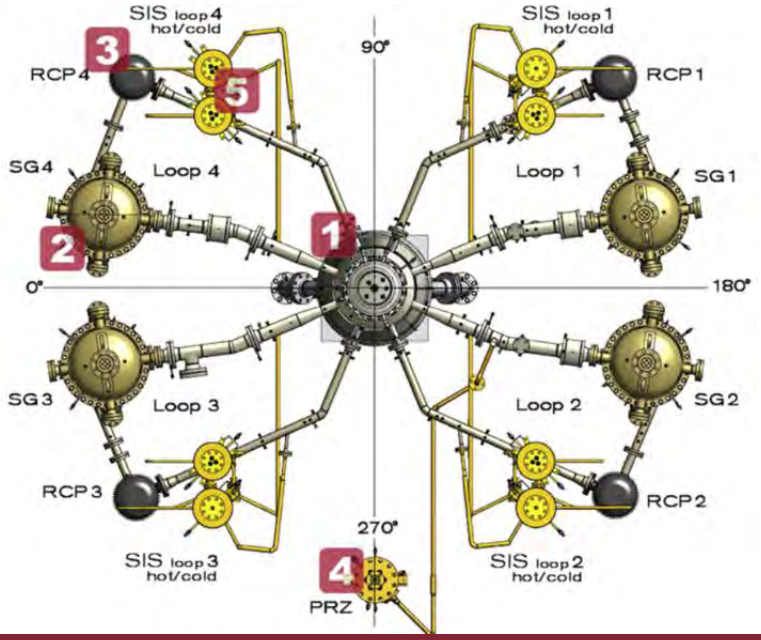
PKL Facility: Overview

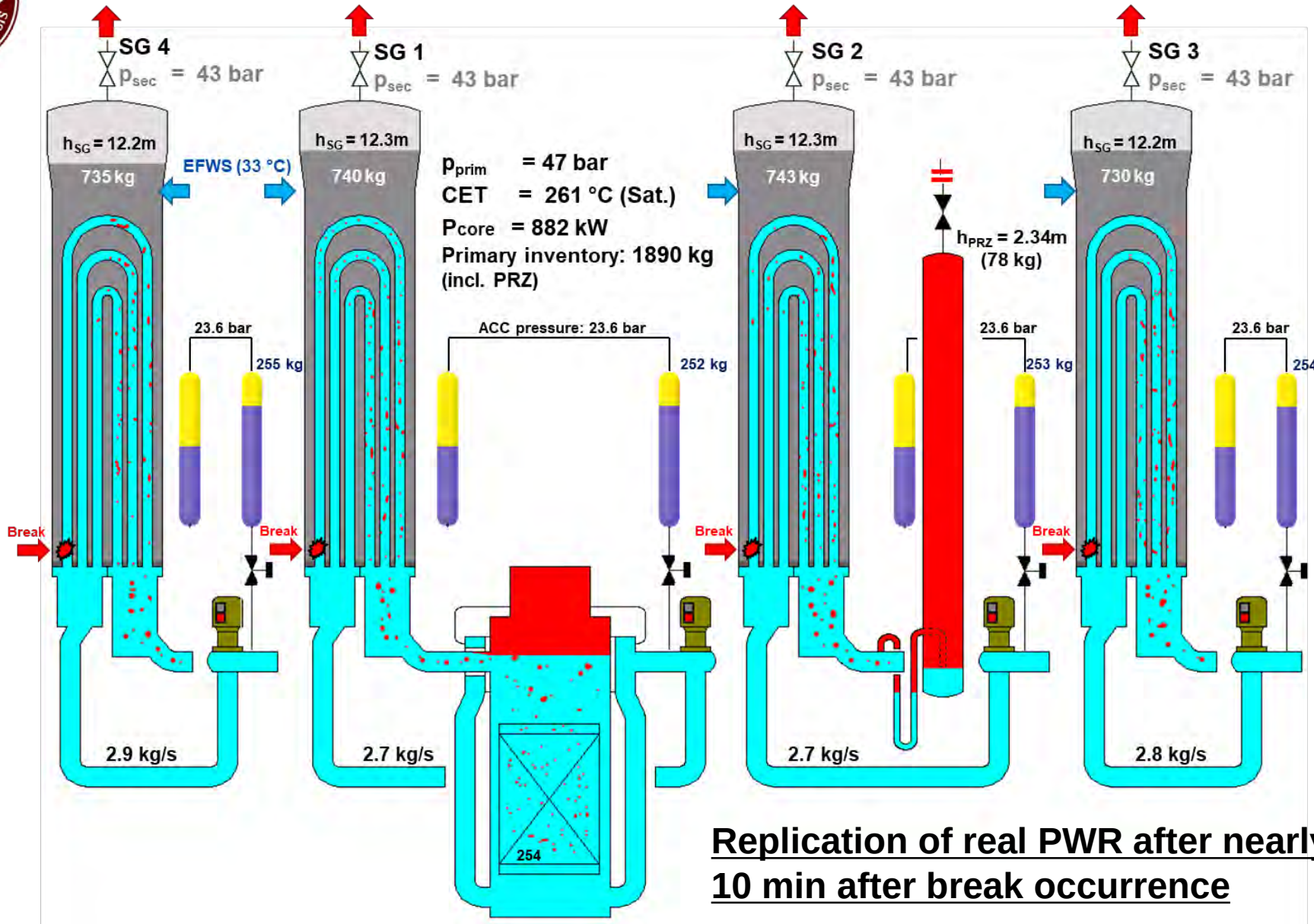


- Operated by Framatome GmbH in Erlangen, Germany.
- Replicates **PWR** primary system with reduced scale (1:145 in volume), preserving TH characteristics (pressure, temperature, flow distribution).
- Highly instrumented for data collection (temperature, pressure, flow rates, swelling levels).
- **Purpose**: experimentally study transient & accident conditions: LOCAs, Loss of RHR during shutdown; Secondary-side cooldown transients, etc.



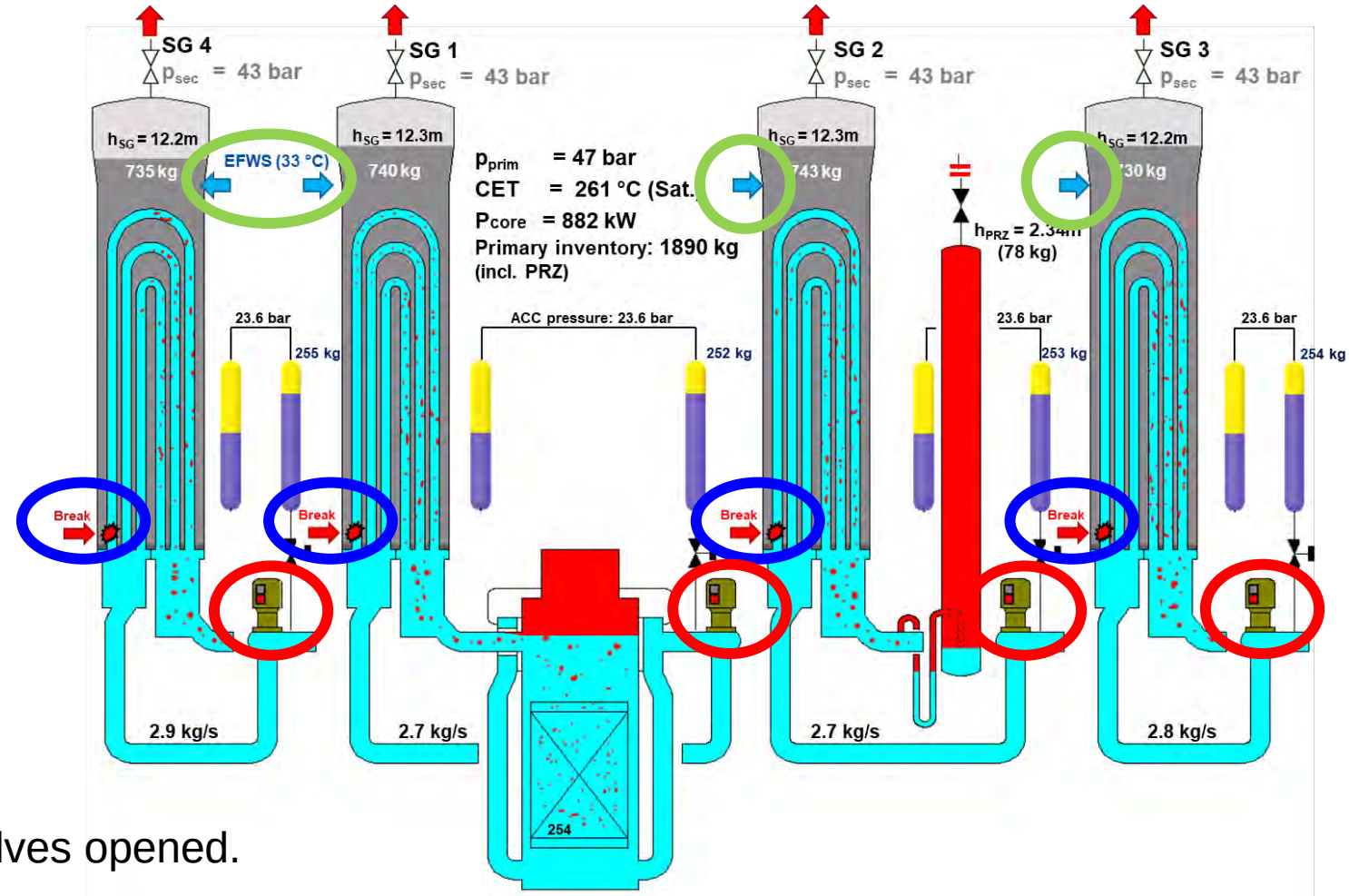
1. Reactor Pressure Vessel
2. Steam Generators
3. Reactor Coolant Pump
4. Pressurizer
5. Accumulators

PKL III J5.1 run 2: Initial Conditions



Replication of real PWR after nearly 10 min after break occurrence

PKL III J5.1 run 2: Test Boundary Conditions



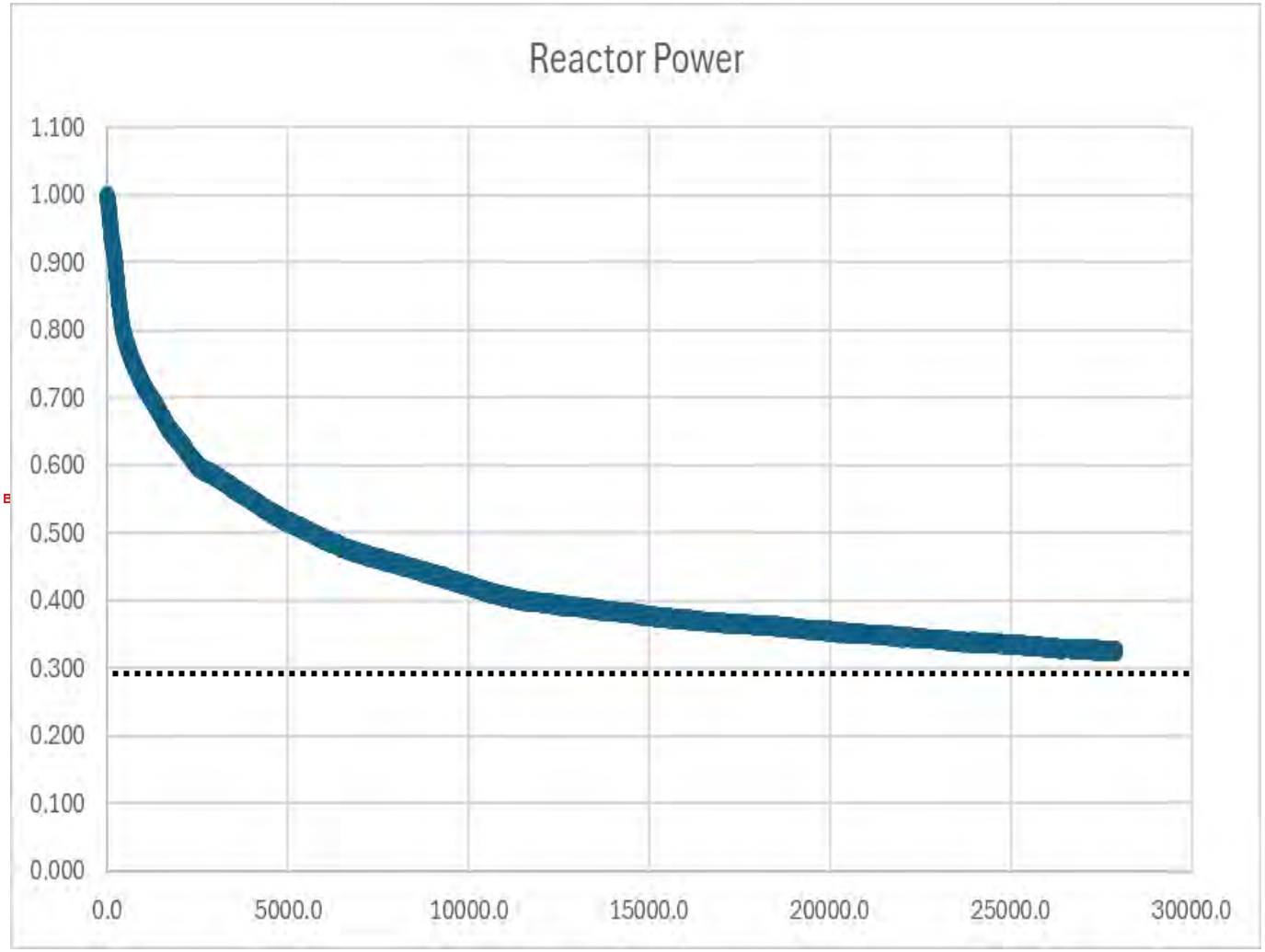
At SoT:

- Break lines valves opened.
- RCPs stopped.
- SGs sec. side main FW cutoff, No AFWS;

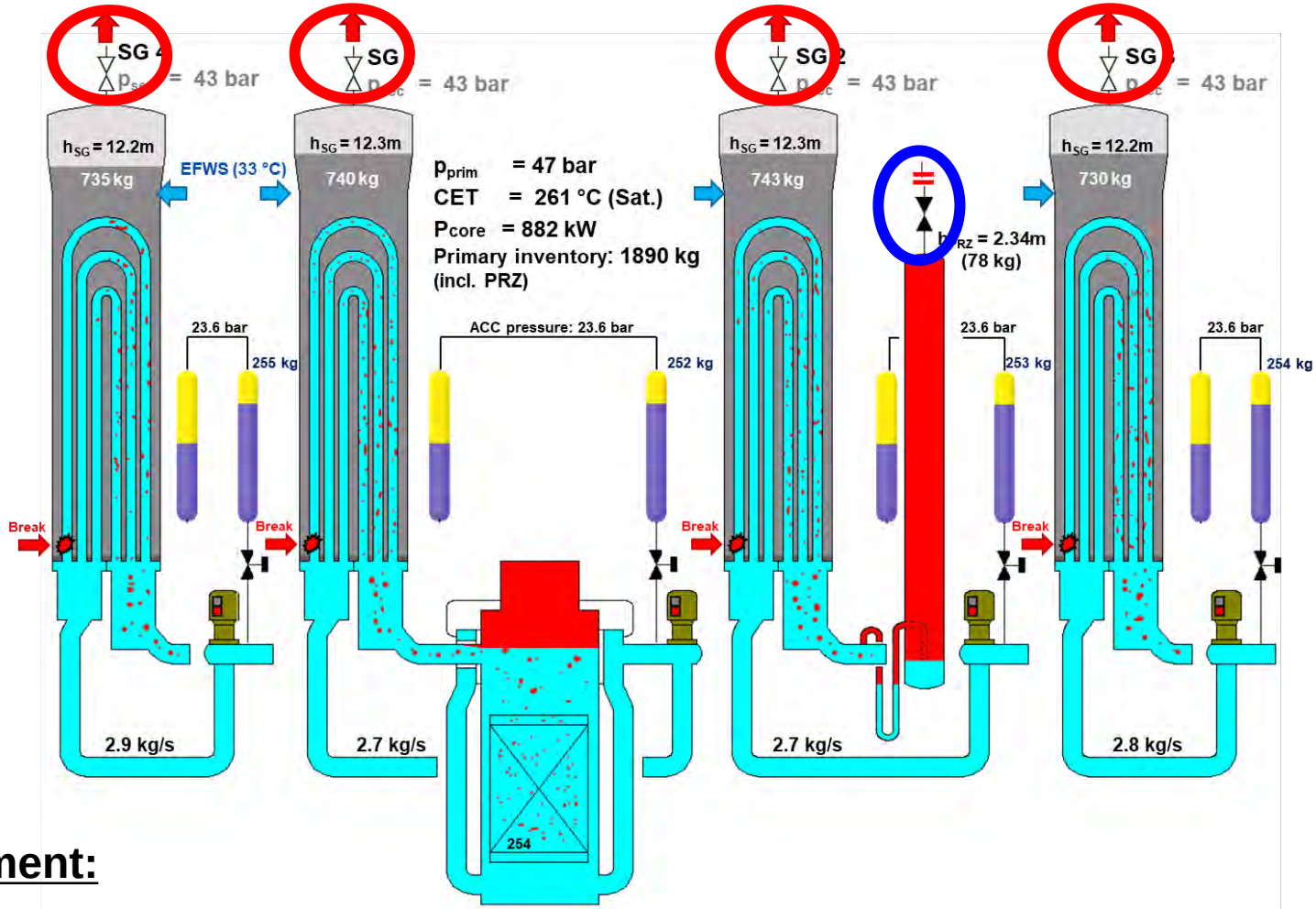
PKL III J5.1 run 2: Test Boundary Conditions (cont'd)

Power Source Terms:

- Core Power drops according to Decay Heat.
- PRZ Heaters active @ nominal power (8 kW).
- UH and UP Heaters active (3.1 & 1.3 kW).
- SGs Bypass Heaters active up to SGs dry-out (16.5 kW per component)



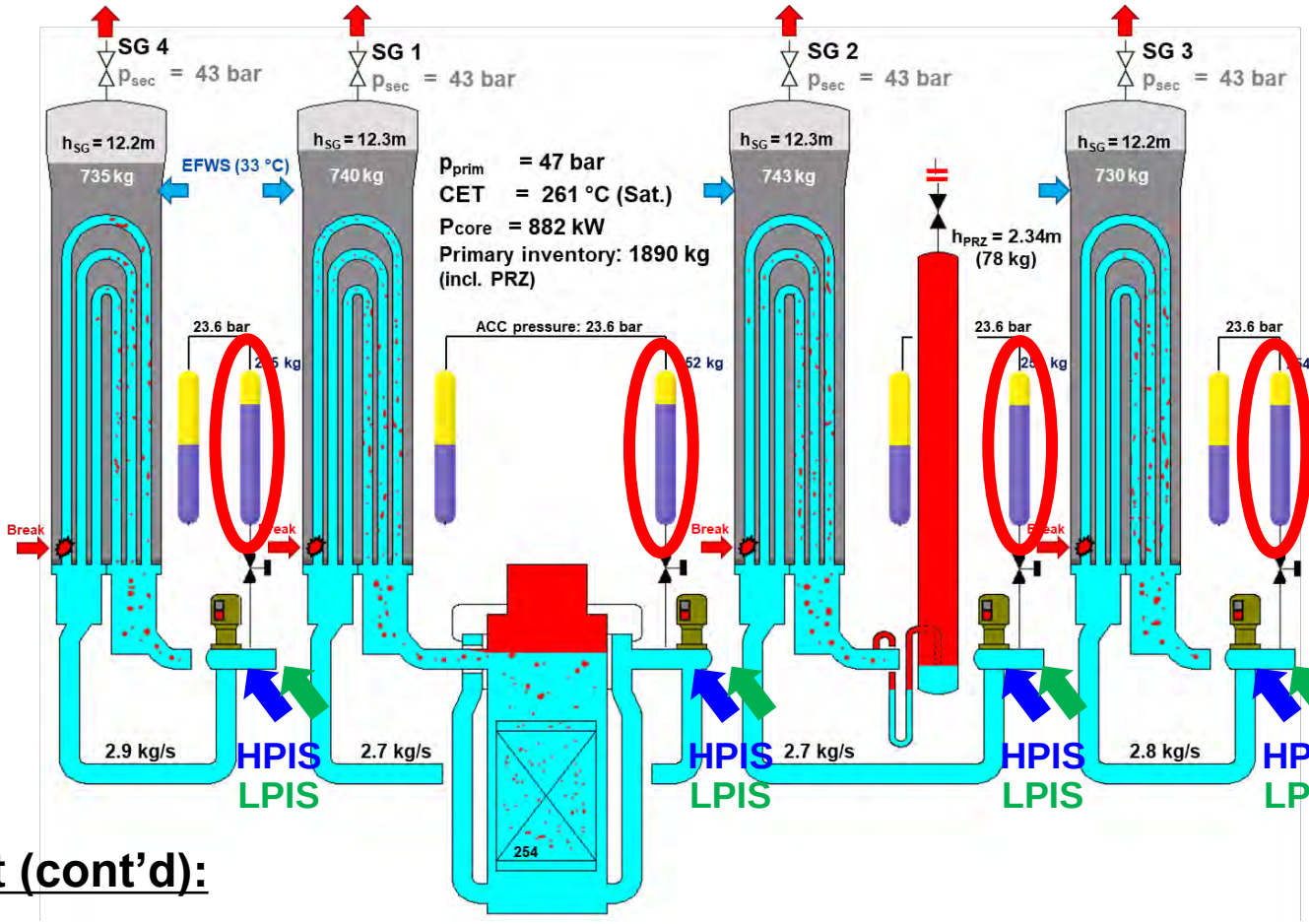
PKL III J5.1 run 2: Test Boundary Conditions (cont'd)



Accident Management:

- Primary System Depressurization (**PSD**) starts 1000 s after SoT.
- SGs sec. steam discharge system manually operated up to 9200 s after SoT.

PKL III J5.1 run 2: Test Boundary Conditions (cont'd)

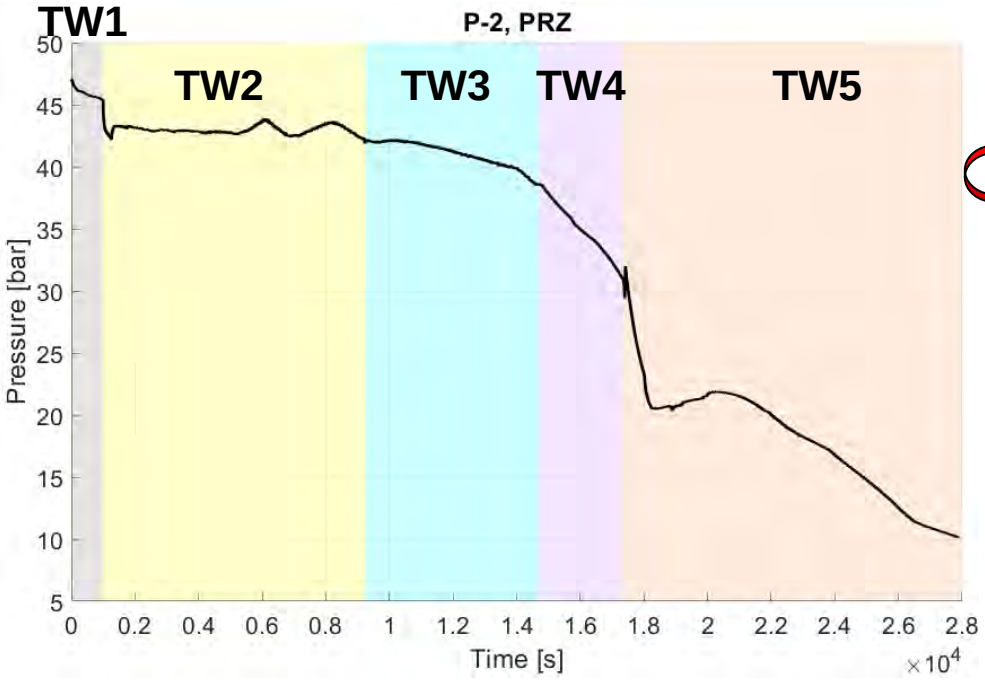


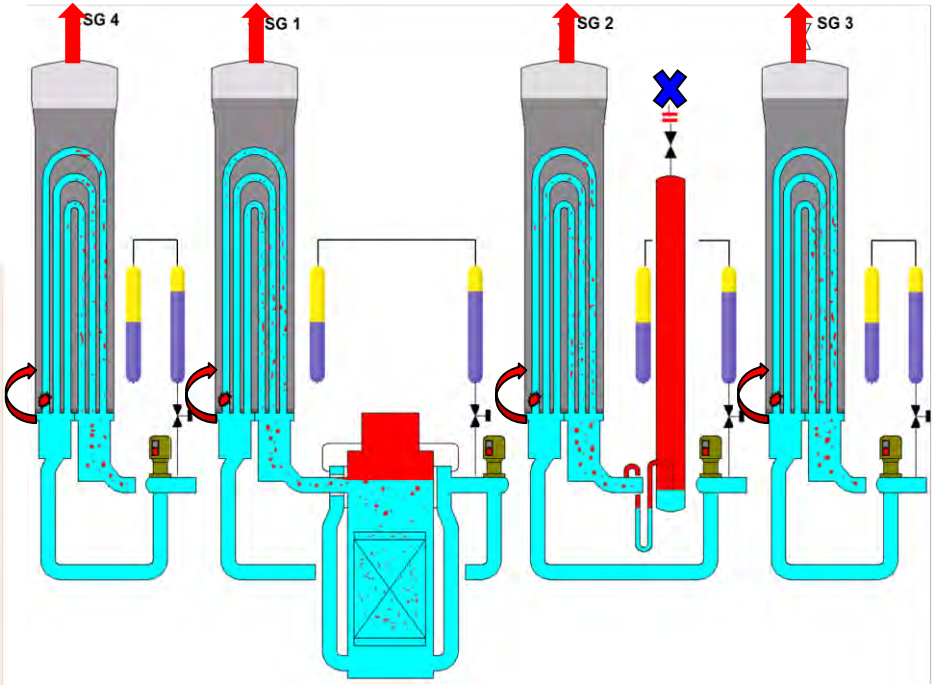
Accident Management (cont'd):

- HPIS on Core Exit Temperature (CET) > 350 °C;
- 4 CL Accumulators (ACC) triggered when p_{prim} < 23.6 bar. HL ACCs not available.
- LPIS triggered when p_{prim} < 12.4 bar.

PKL III J5.1 run 2: Time Windows

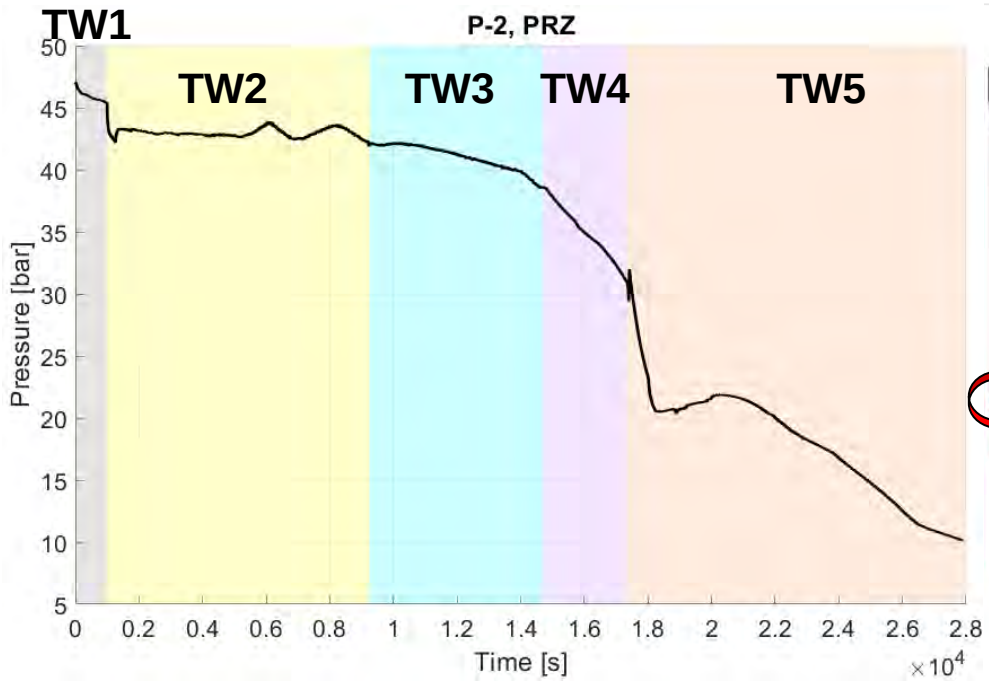
TWs	Timing [s]	Description	Main Phenomena
TW1	0 – 1000	SoT to Start of PSD	• P2S mass discharge through breaks; • SGs sec. side SRVs mass discharge.

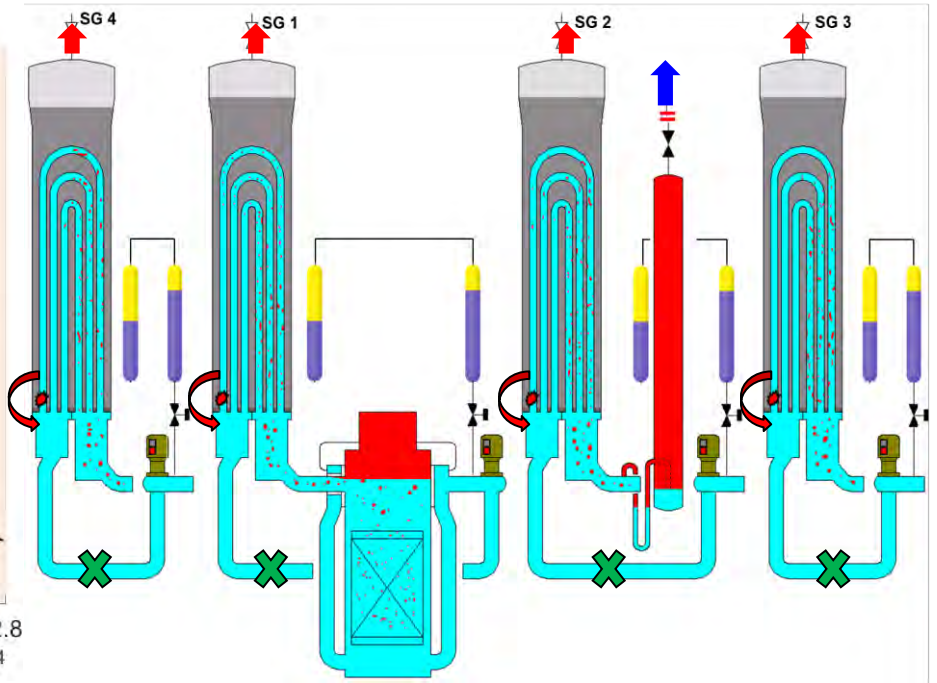




PKL III J5.1 run 2: Time Windows (cont'd)

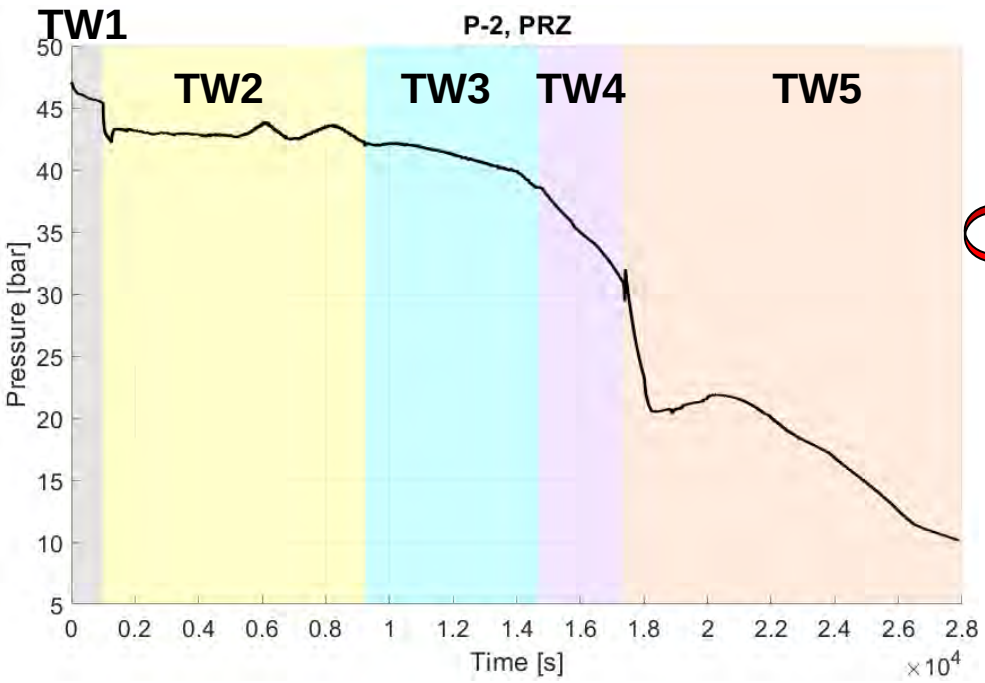
TWs	Timing [s]	Description	Main Phenomena
TW2	1000 – 9240	Start of PSD to SGs Sec. Side final isolation	• NC interruption; • P/S pressure equalization; • Break MF inversion (from P2S to S2P); • PRZ PORV mass discharge; • SGs sec. side SRVs pressure control.

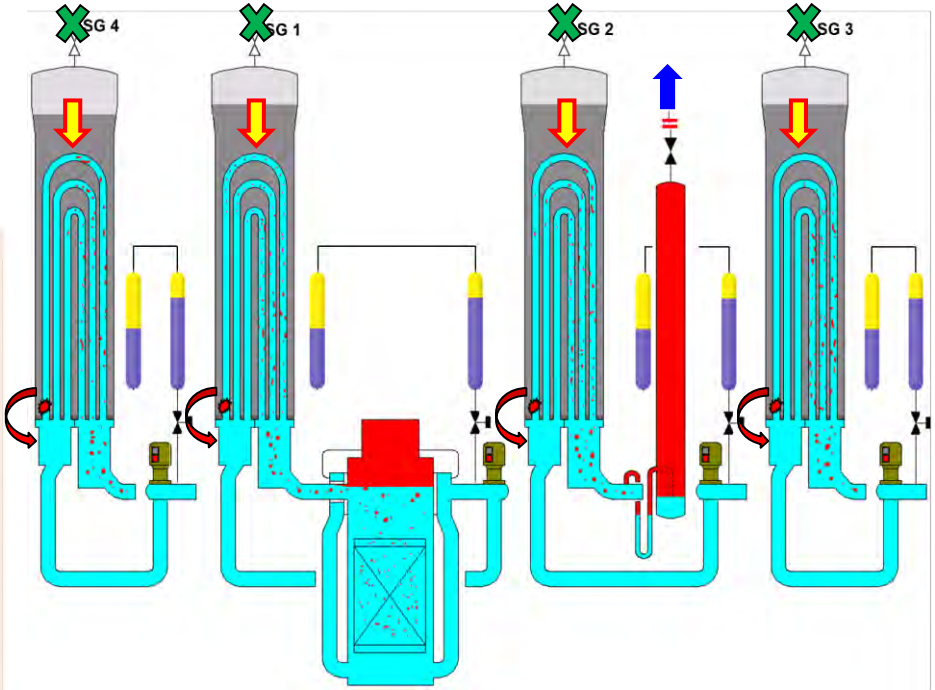




PKL III J5.1 run 2: Time Windows (cont'd)

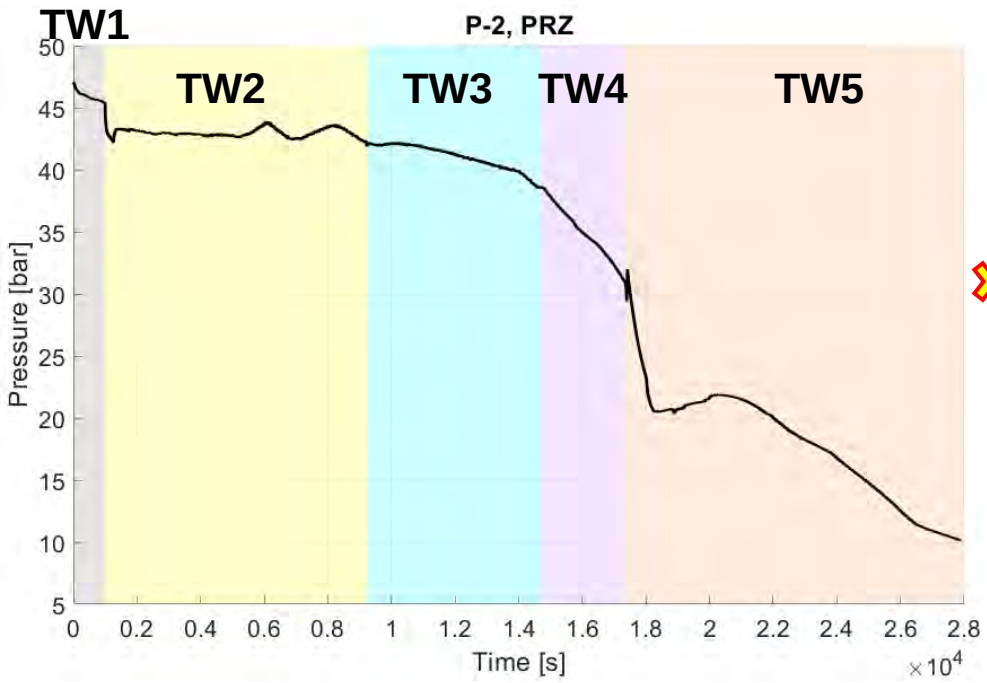
TWs	Timing [s]	Description	Main Phenomena
TW3	9240 – 14700	SGs Sec. Side final isolation to SGs dryout	• S2P mass discharge through breaks; • PRZ PORV mass discharge; • SGs gradually emptied.

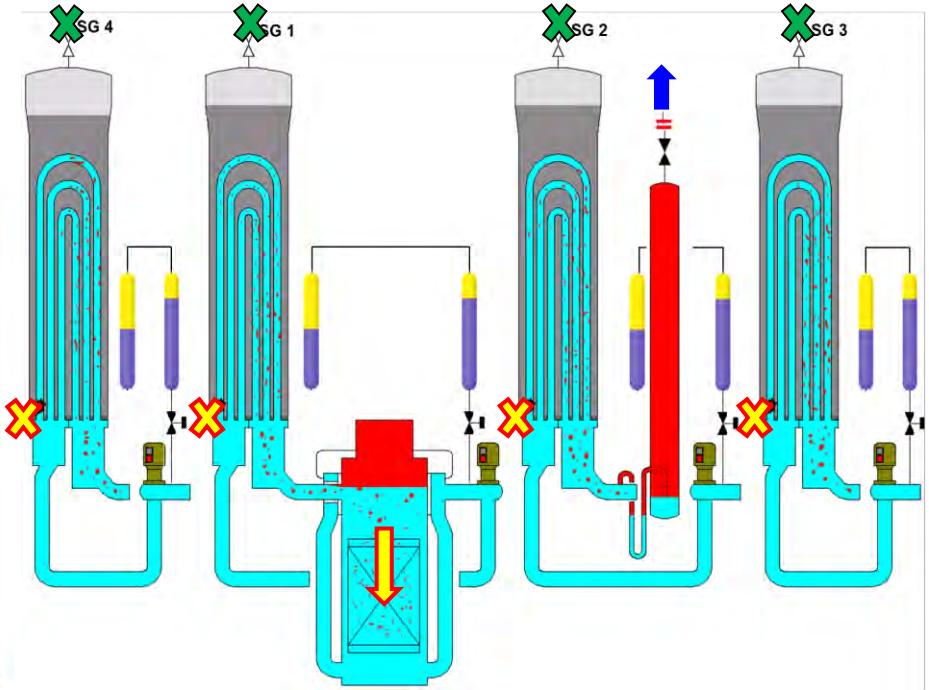




PKL III J5.1 run 2: Time Windows (cont'd)

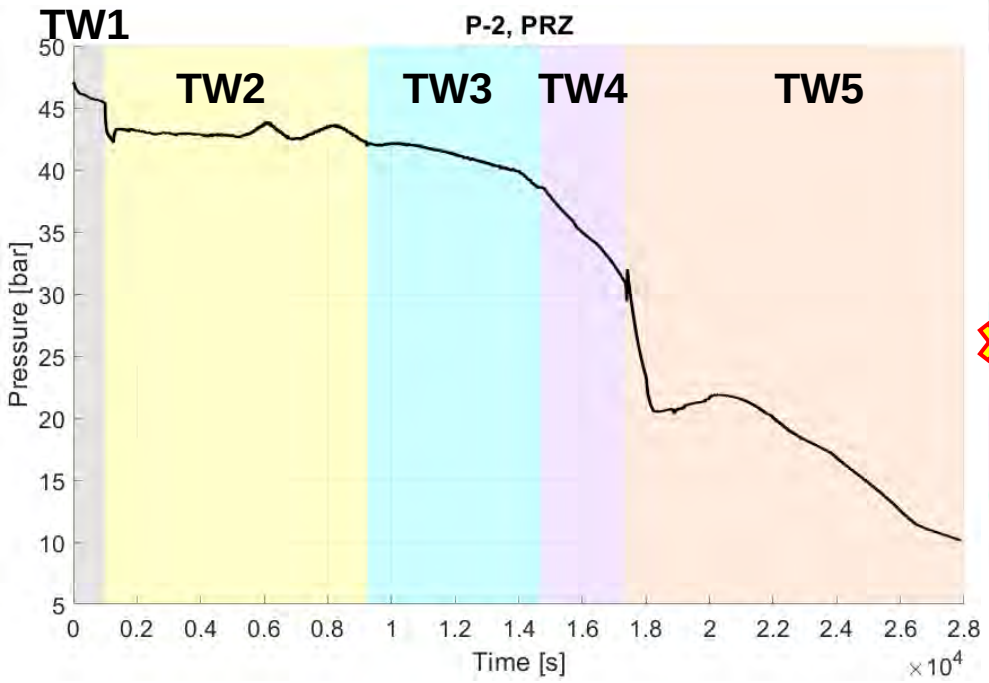
TWs	Timing [s]	Description	Main Phenomena
TW4	14700 – 17340	SGs dryout to Start of HPSI Injection	• PRZ PORV mass discharge; • PS mass reduction; • Core dryout; • CET & PCT peaks.

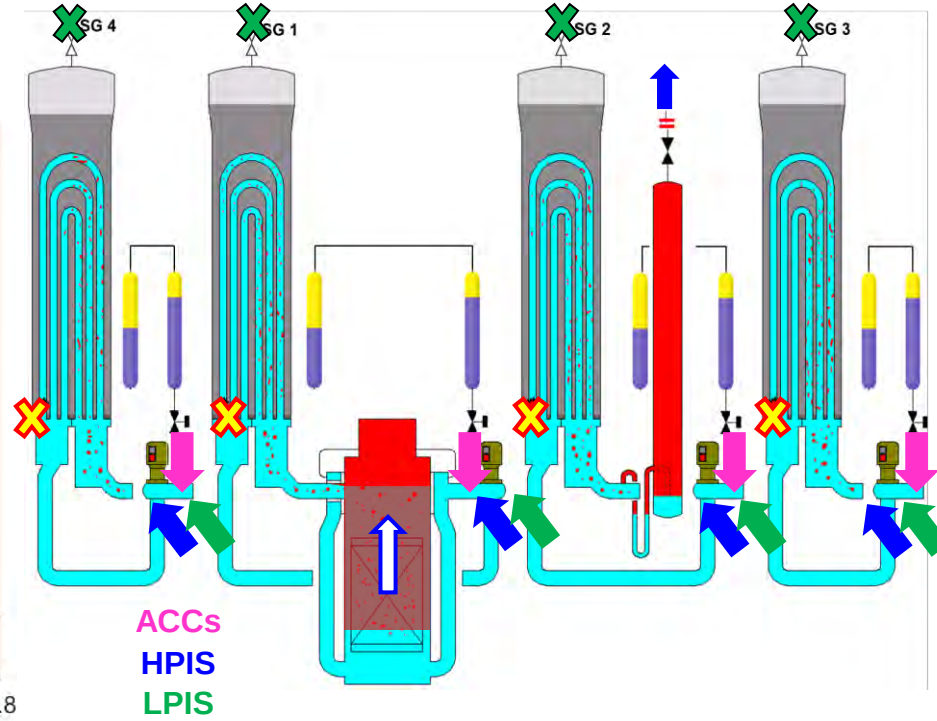




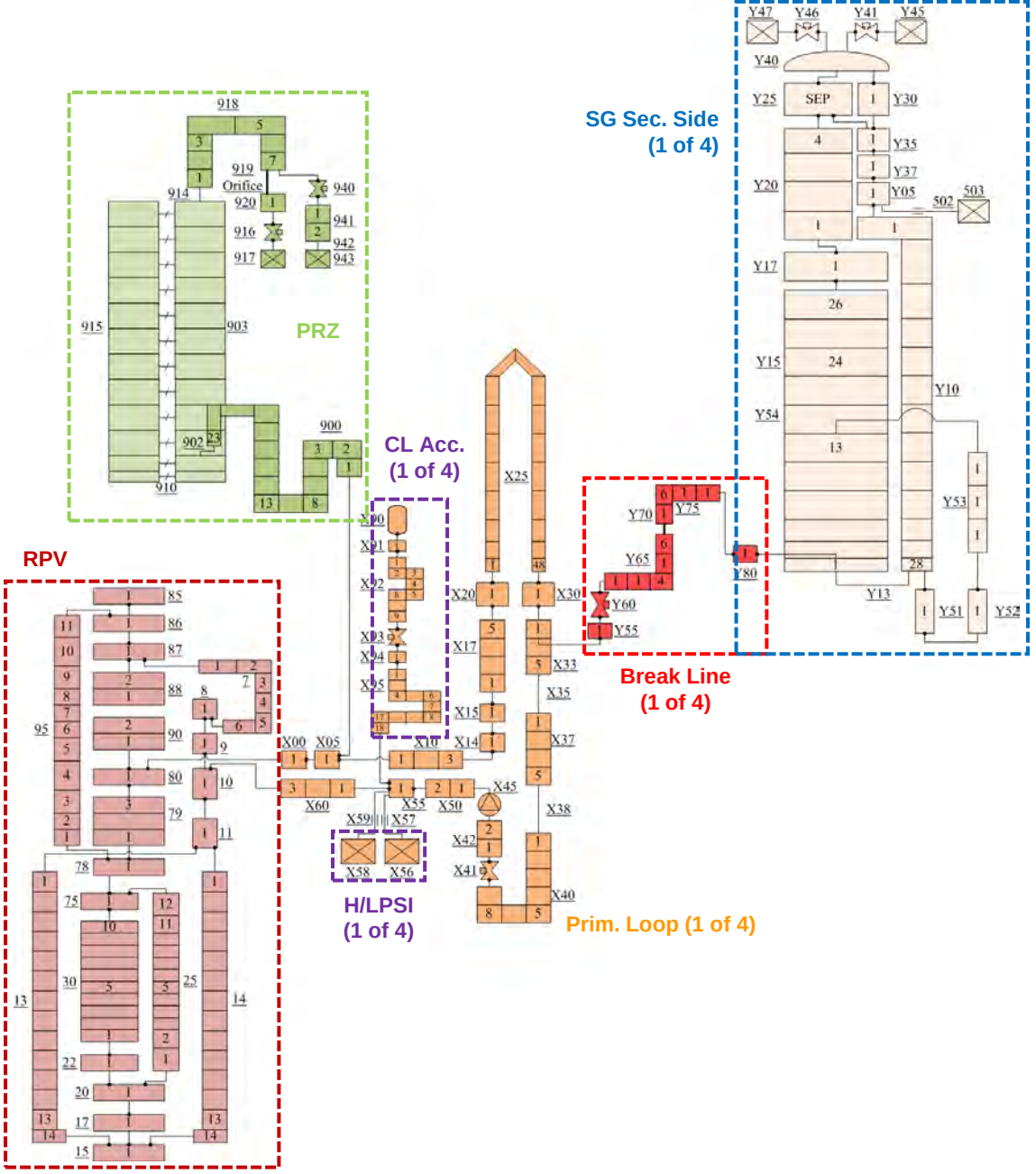
PKL III J5.1 run 2: Time Windows (cont'd)

TWs	Timing [s]	Description	Main Phenomena
TW5	17340 – 27500	Start of HPSI Injection To EoT	• PRZ PORV mass discharge; • HPSI injection ⟶ LS Clearing; Core quenching; • Acc. Injection ⟶ LS Filling; CET subcooled; • Solid PRZ; • LPSI injection.



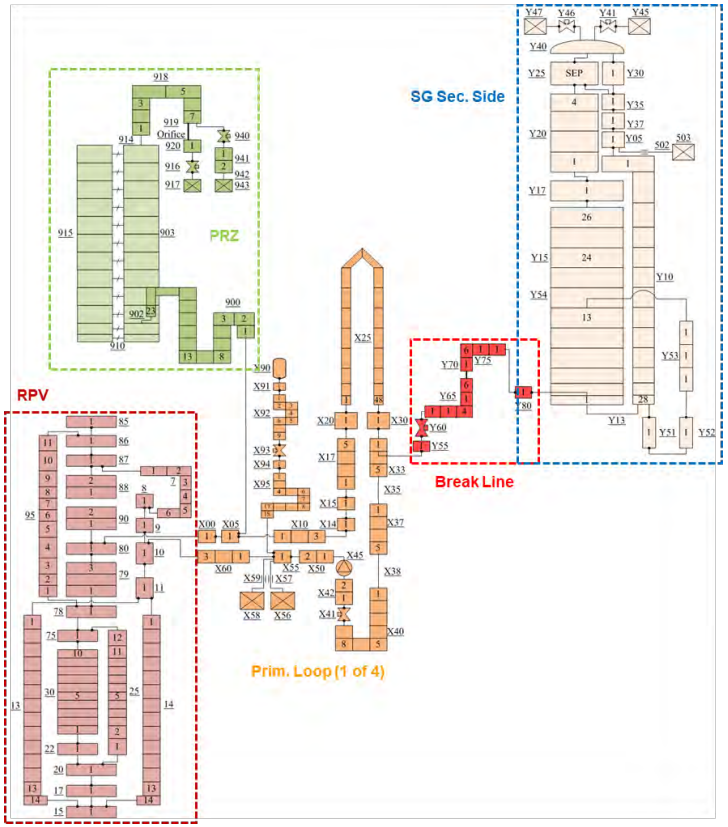


Nodalization



Nodalization Features

- Each loop (of 4) modelled with a dedicated batch of components.
- DC tubes within RPV (of 2) simulated separately.
- Core region modelled with 2 Eq. Pipes, i.e., active core & bypass.
- 10 Control Volumes (CVs) for the Core Active Region (0.39 m mesh length).
- 48 CVs for the U-tubes active length (0.35 m average mesh length).



Special Models

Chocked flow	Ransom-Trapp
SG separator/dryer models	R5 default model
PRZ specific models	NO
CCFL model	NO

Input @ a glance

Hyd. Vol.	1203
Jun N°	1225
HSs	999
Temp Points	7976

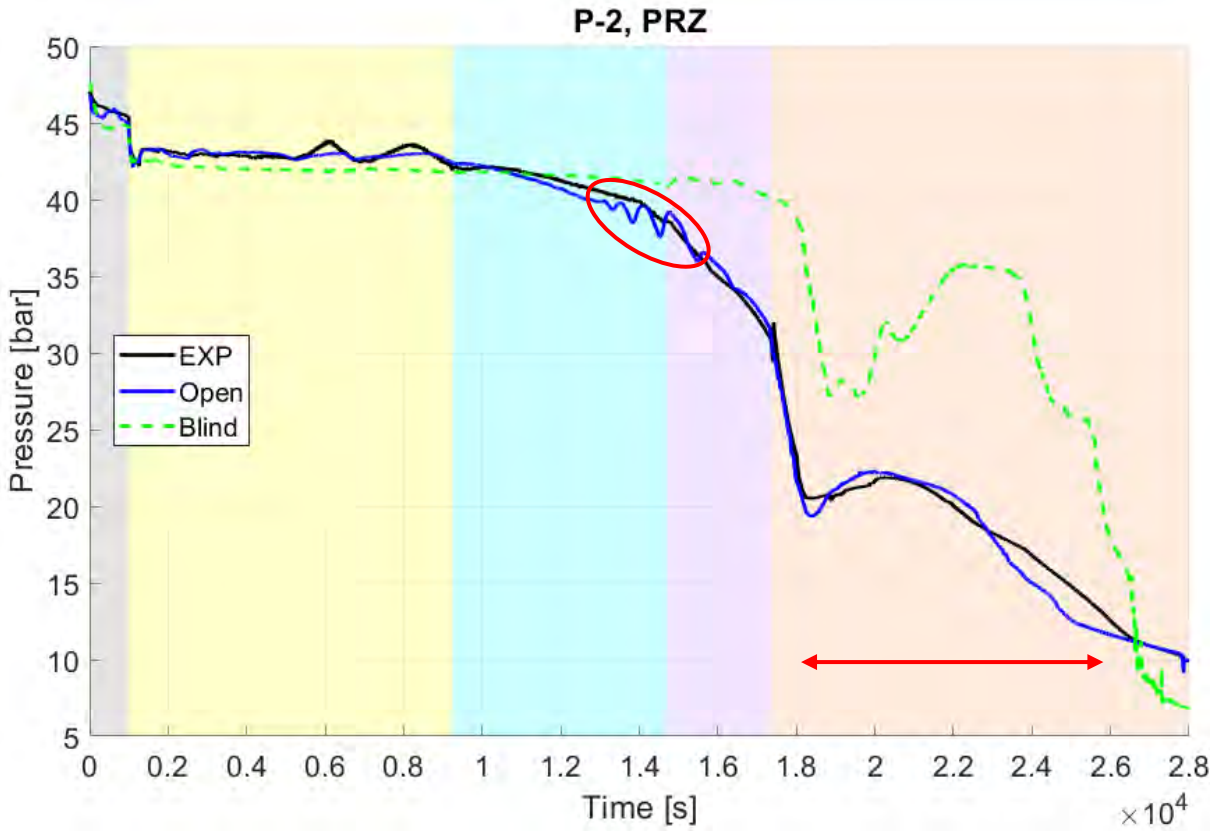
Simulation results: Initial Conditions

System	Parameter	Unit	Exp.	Open
Prim. Power Bal.	Core	kW	880	881.4
	PRZ Heaters	kW	8.0	8.0
	USP Heaters	kW	1.24	1.37
	RPV Heaters	kW	**Defective**	2.7
Primary System	Pressure	bar	47.0	47.0
	Core Inlet Temp.	°C	254	255.6
	CET	°C	261 (Sat.)	261.1 (Sat.)
	Inventory	m^3	1890	1827
	PRZ Inv.	m^3	78	67
	MassFlows (L1-L4)	kg/s	2.8/2.7/ 2.8/2.9	2.60/2.60/ 2.66/2.84
	PRZ Level	m	2.34	2.39
	RPV Level	m	7.35	7.30
	Core Level	m	6.00	5.64

Simulation results: Initial Conditions (cont'd)

System	Parameter	Unit	Exp.	Open
Sec. System	Exch. Power (SG1-SG4)	kW	-	217.6/216.9 223.2/225.7
	Bypass Heat. (SG1-SG4)	kW	17.8/17.7/ 18.0/17.8	17.5/17.5 17.5/17.5
	Pressure (SG1-SG4)	bar	43	43.0/43.0/ 43.0/43.0
	Inventory (SG1-SG4)	m^3	735/740/ 743/730	734/734/ 734/734
	Level (SG1-SG4)	m	12.2/12.3 12.3/12.2	12.1/12.1/ 12.1/12.1
Parameter	**PKL section**	**Unit**	**Ref. Data**	**Open**
Heat Losses	RPV	kW	51.5	49.5
	LOOPs	kW	24.3	27.0
	MCP (Cooling)	kW	-20.3	-20.3
	PRZ and surge line	kW	10.0	11.7
	SGs (vessel) SS	kW	71.4	75.2

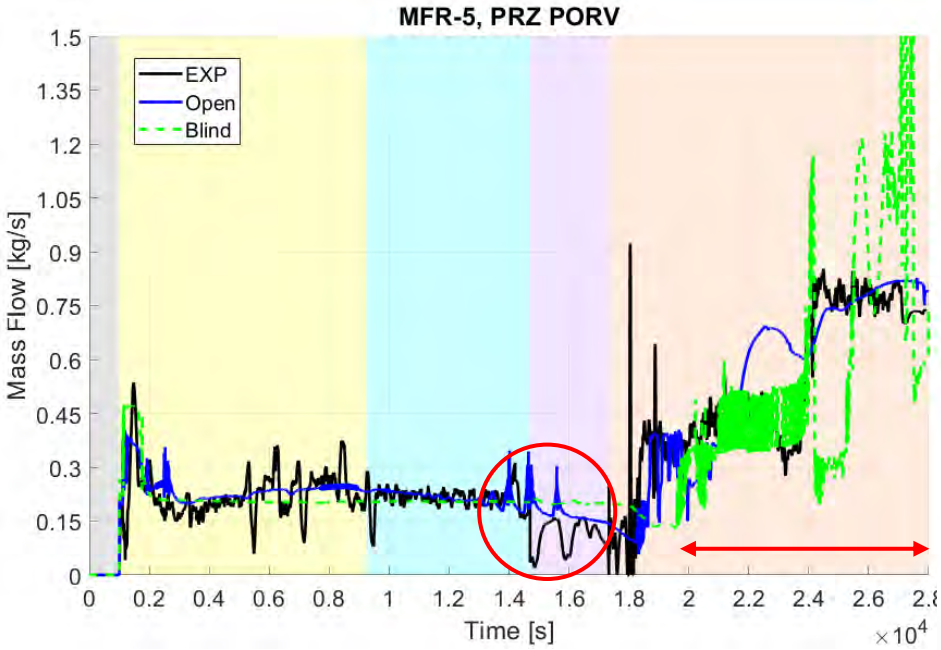
PKL III J5.1 run 2: Results



Deviations between numerical results and experimental data:

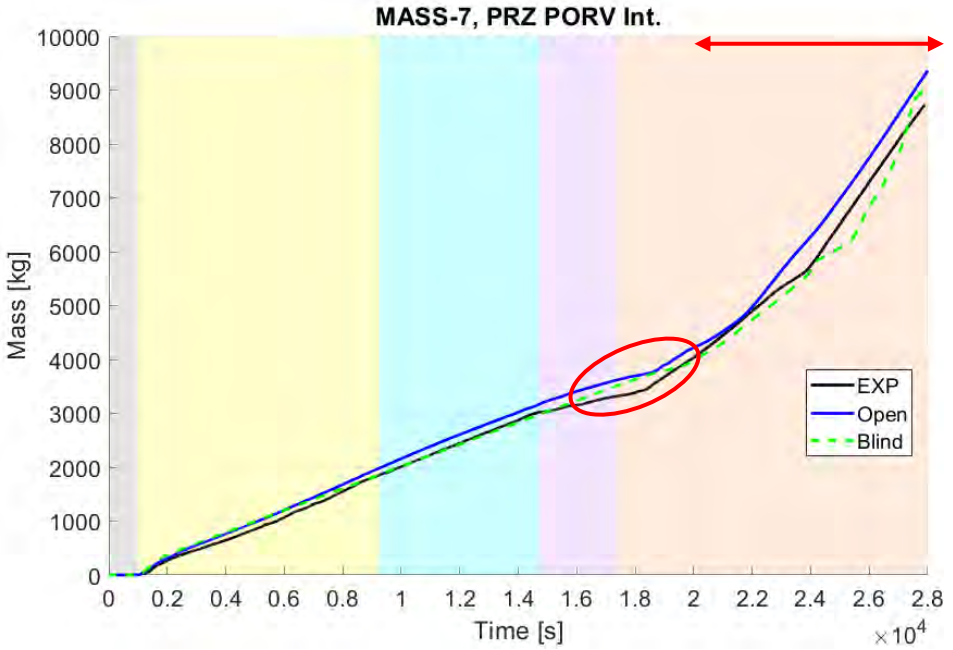
- Oscillations at the edge of TW3/TW4
- Misalignment in TW5

PKL III J5.1 run 2: Results

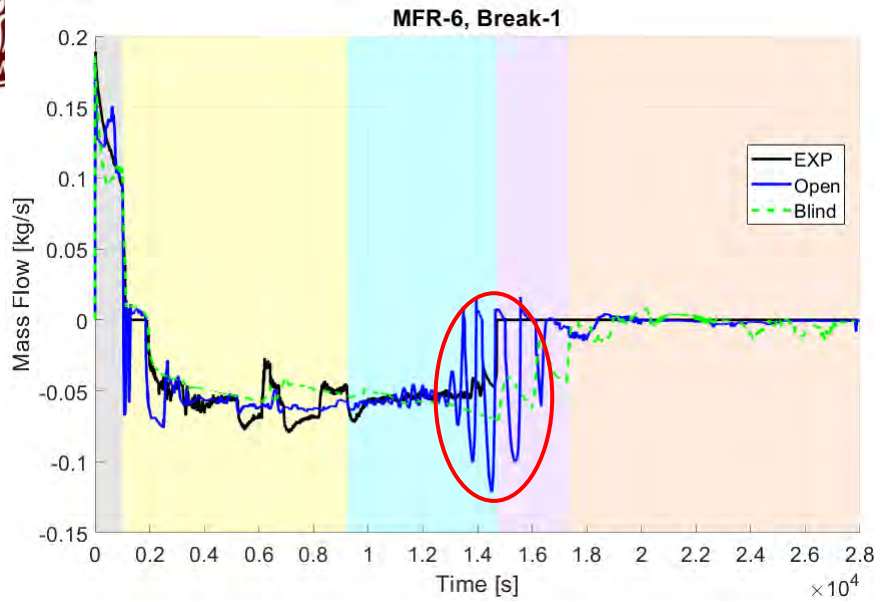


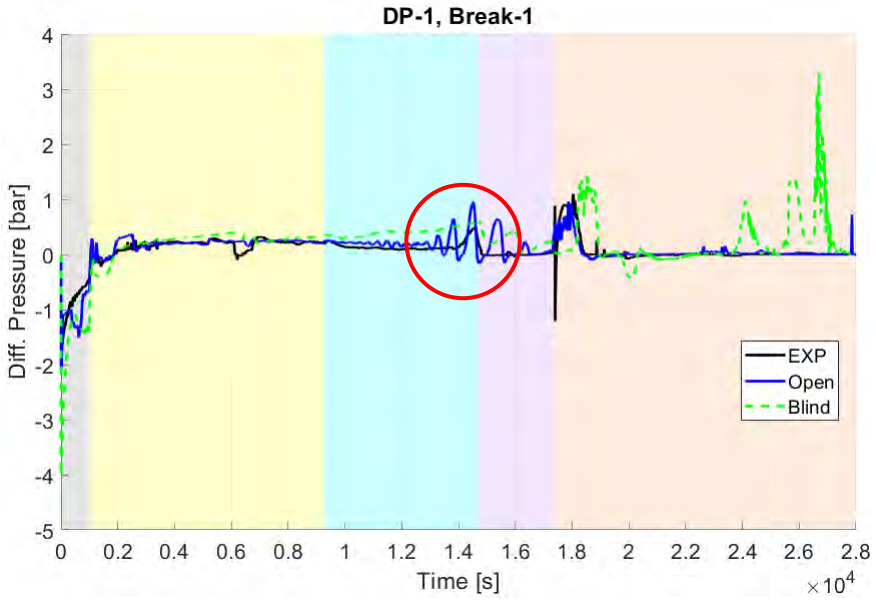
Ransom-Trapp model:

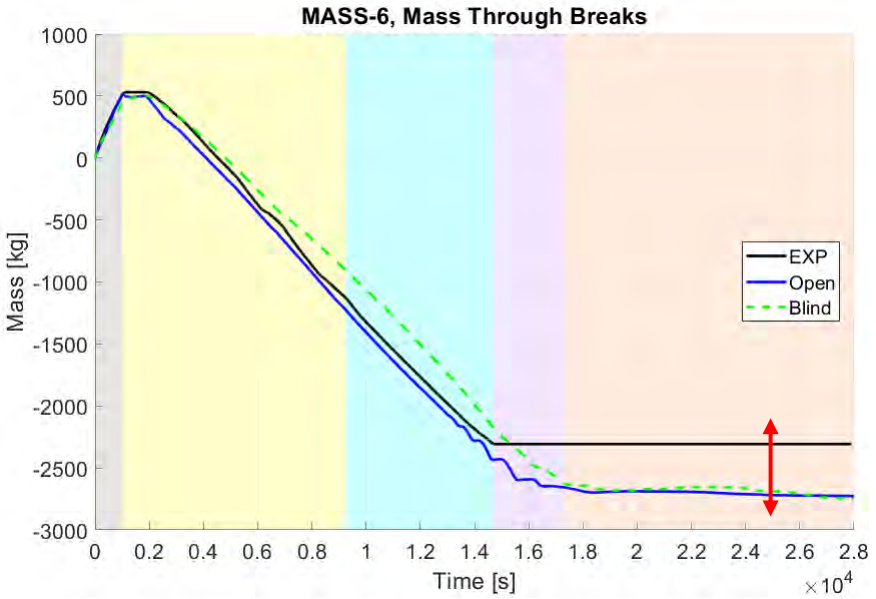
- Seems to overestimate the discharged mass flow when core dryout occurs (steam flow @ the vapor)
- Does not properly simulate the subcooled water flow in TW5, producing the pressure misalignment



PKL III J5.1 run 2: Results

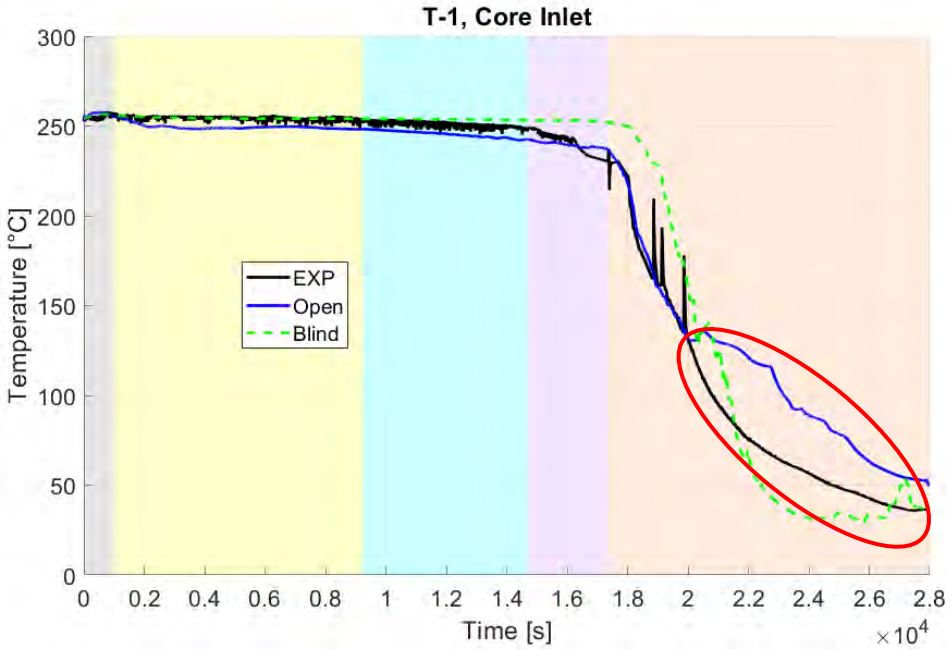




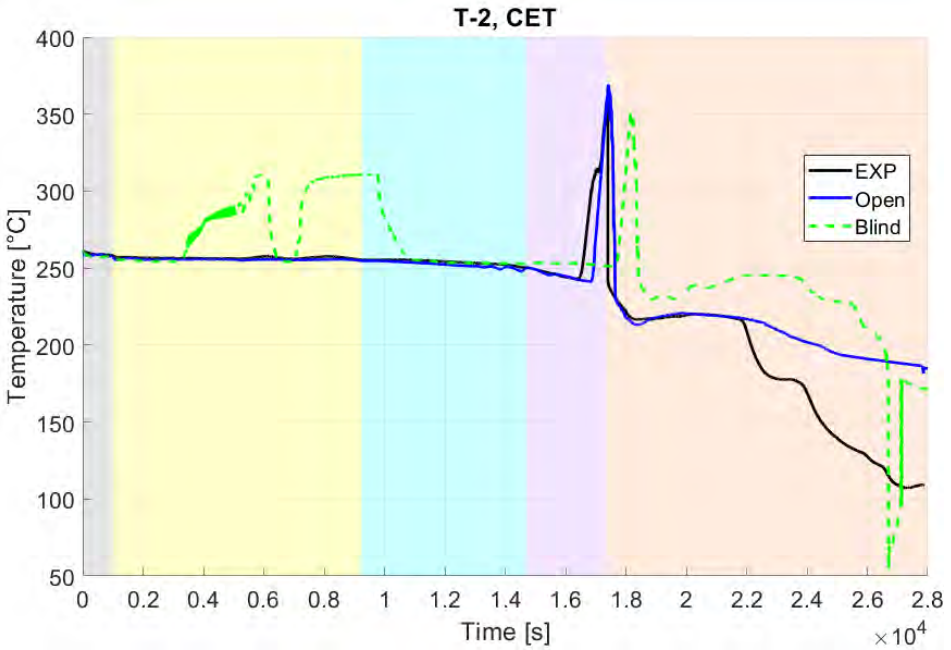


This oscillations @ the break produce the PS pressure oscillations

PKL III J5.1 run 2: Results

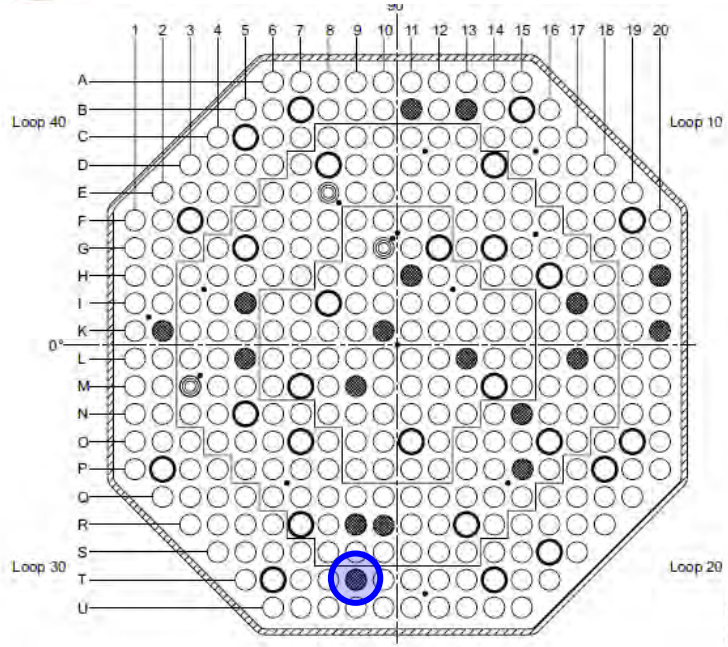


Still under investigation (higher heat losses?)



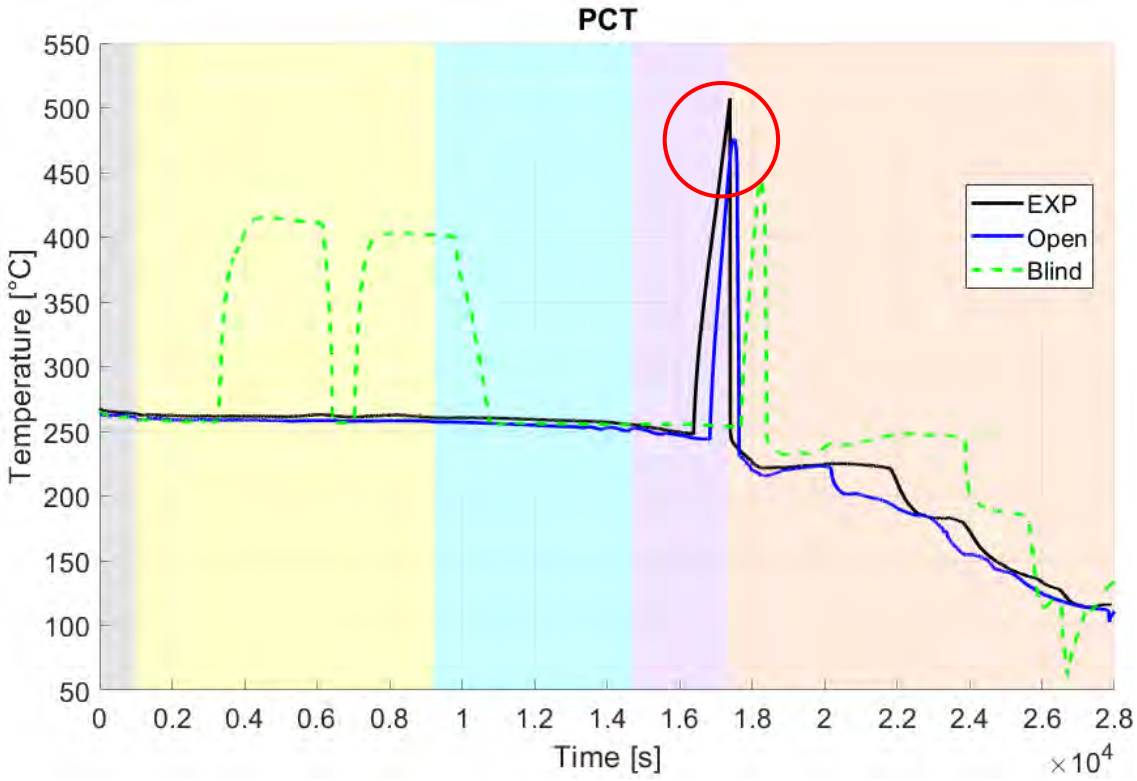
Only post-processing issue. 'Tempg' is plotted in this figure, while CET is subcooled @ the end of TW5.

PKL III J5.1 run 2: Results

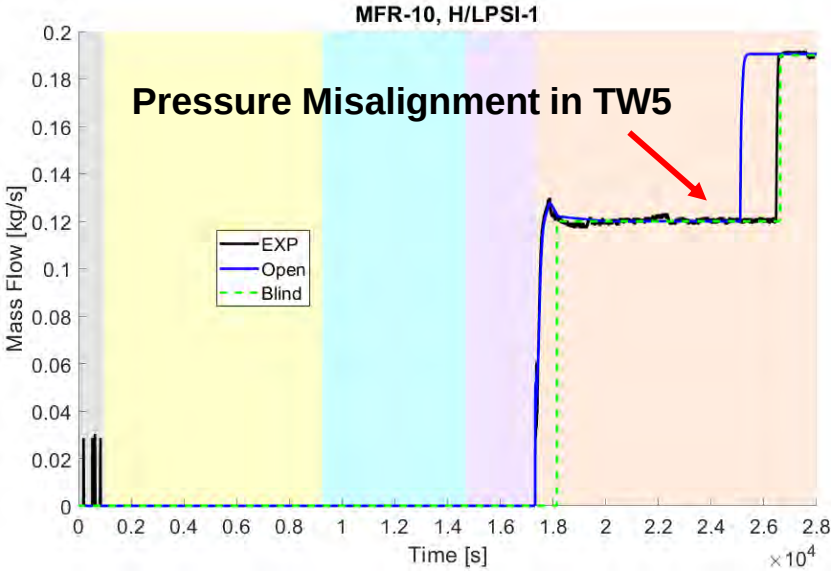


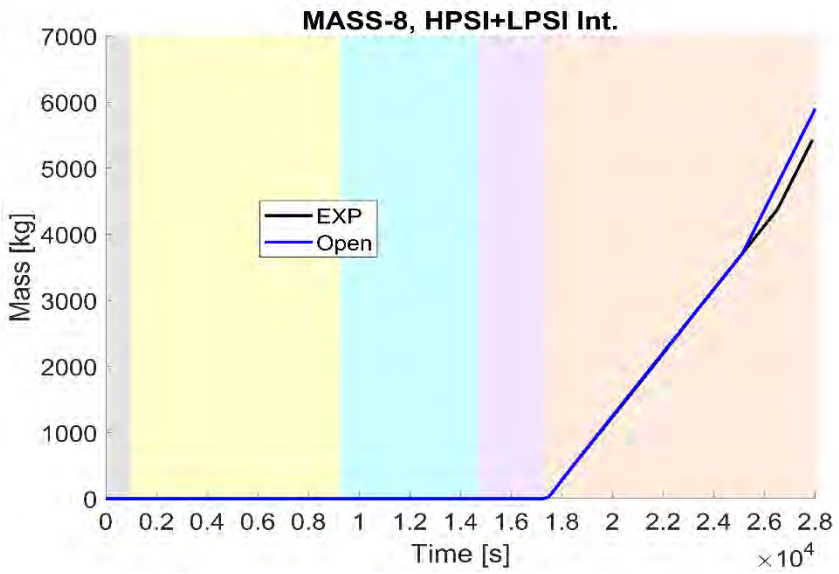
Slight underestimation. Possible causes:

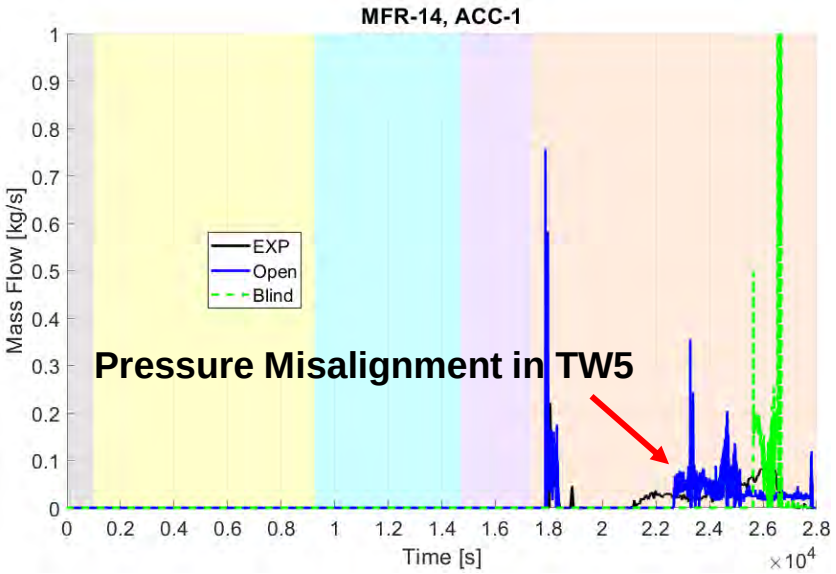
- **Power distribution between inner/middle/outer zones**
- **Pin thermal conductivity values**

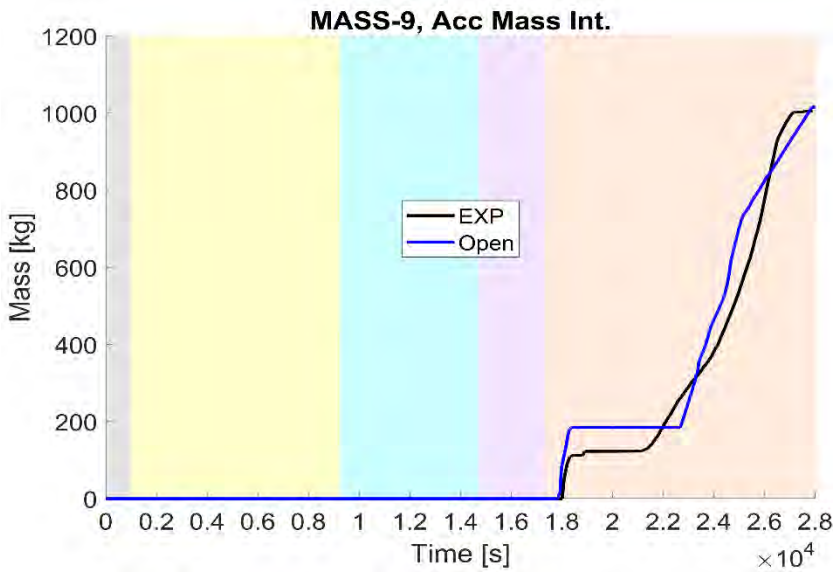


PKL III J5.1 run 2: Results

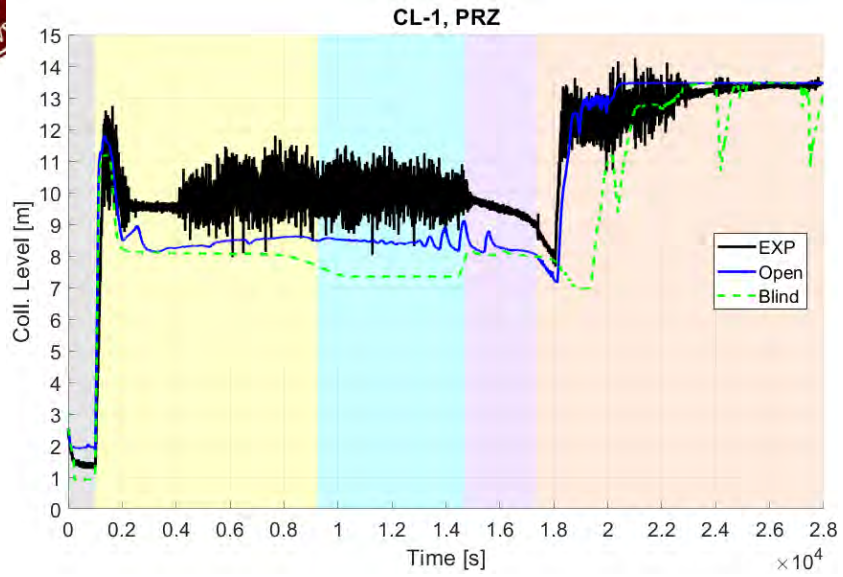


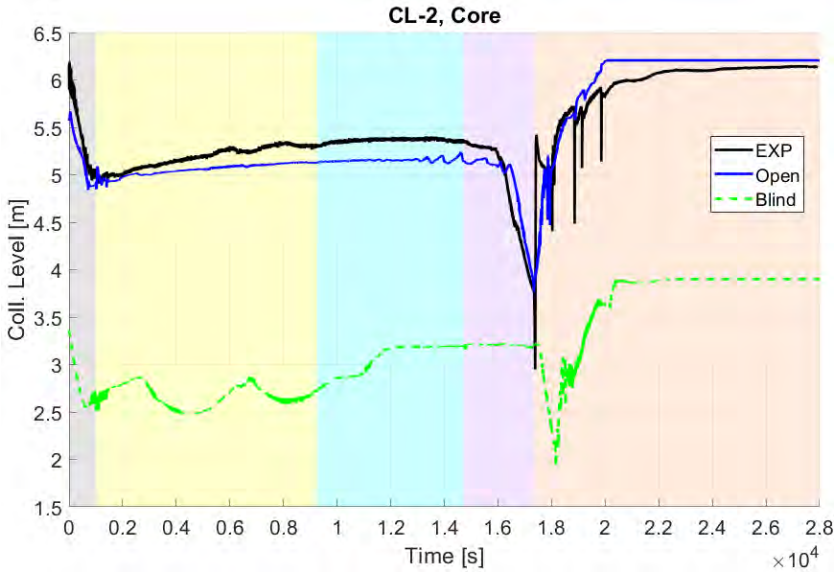


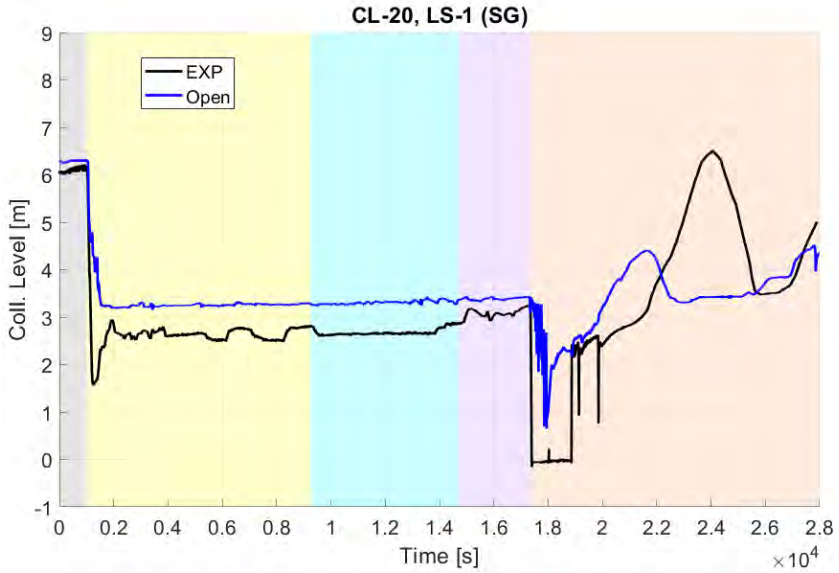


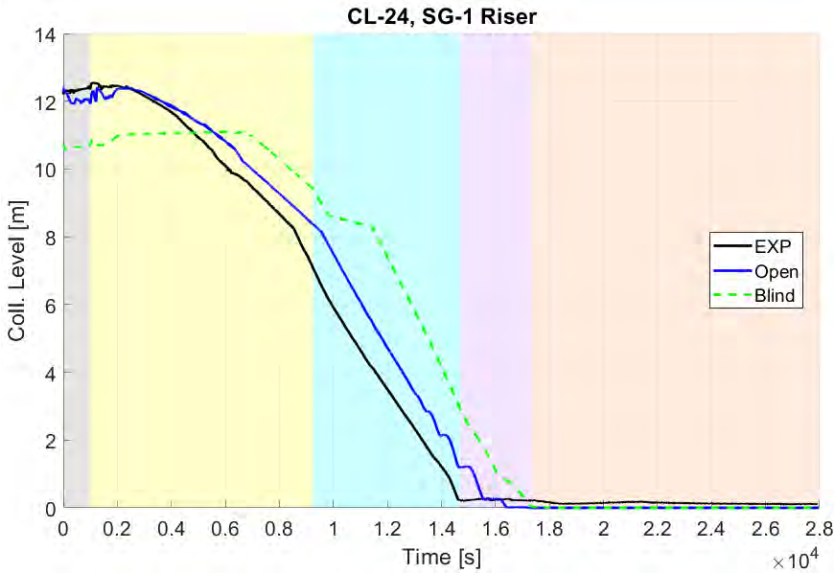


PKL III J5.1 run 2: Results









PKL III J5.1 run 2: Conclusions

- RELAP5-3D© predictions of the selected PKL test are in good agreement with the experimental data.
- RELAP-3D© demonstrated to be able to well simulate complex 2D phenomena: choked flow through the PRZ PORV, primary-secondary systems pressure equalization, loop seal clearing, core dryout and quenching, etc.
- Only some minor aspects have still to be investigated (core inlet temperature in TW5, etc.);
- Sensitivity analysis is planned about some selected parameters (pin th. cond., heat losses, etc.)
- PKL III J5.1 run 1 simulation is planned for the prosecution of the activity.

Thanks for your attention

Any questions?