MELCOR application to AP1000 SBO Simulation

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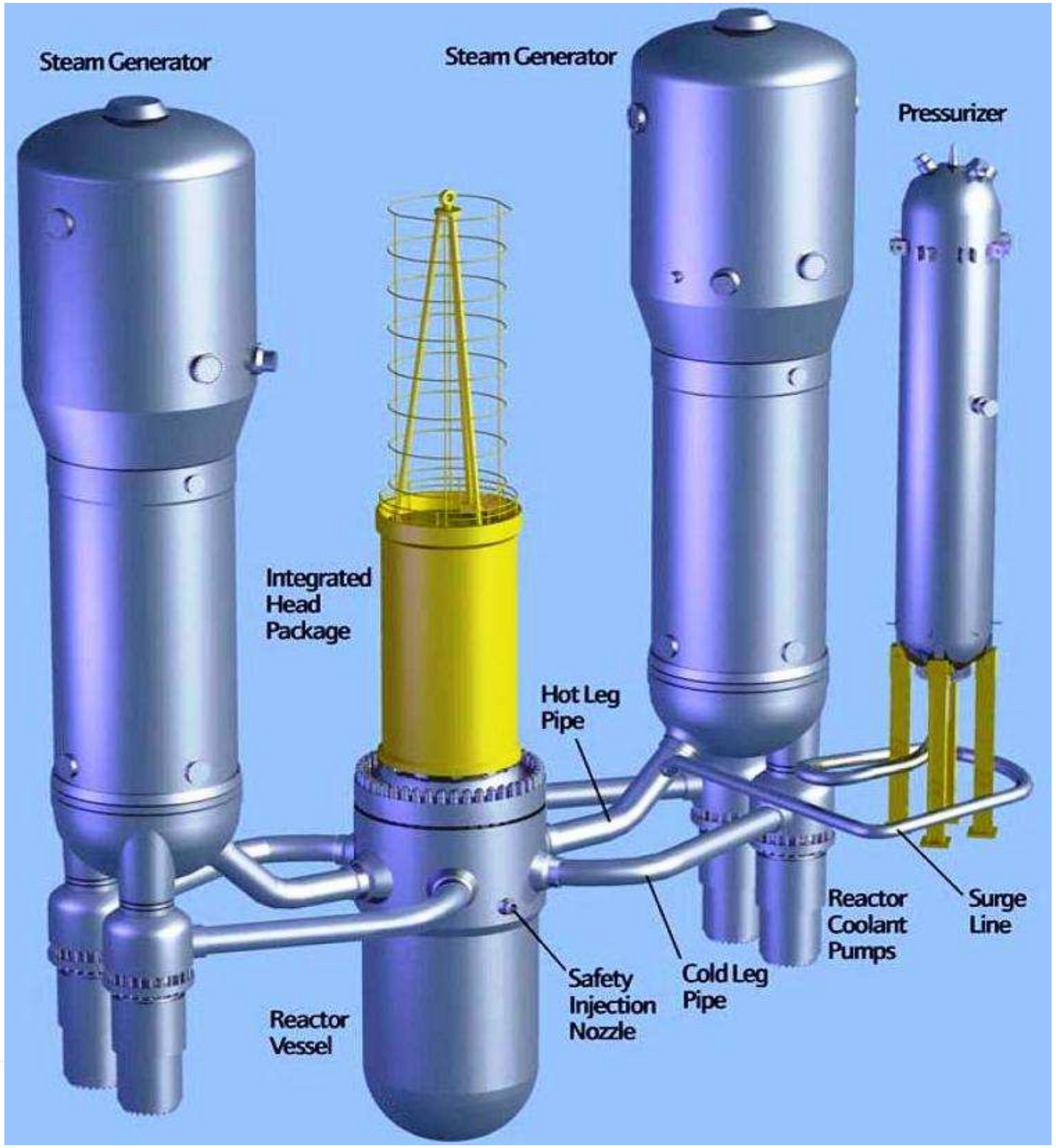
OUTLINE

- AP1000 overview
- MELCOR modeling of the plant
- Comparison of 2 SBO cases simulation results
- main finding and insight
- Future work

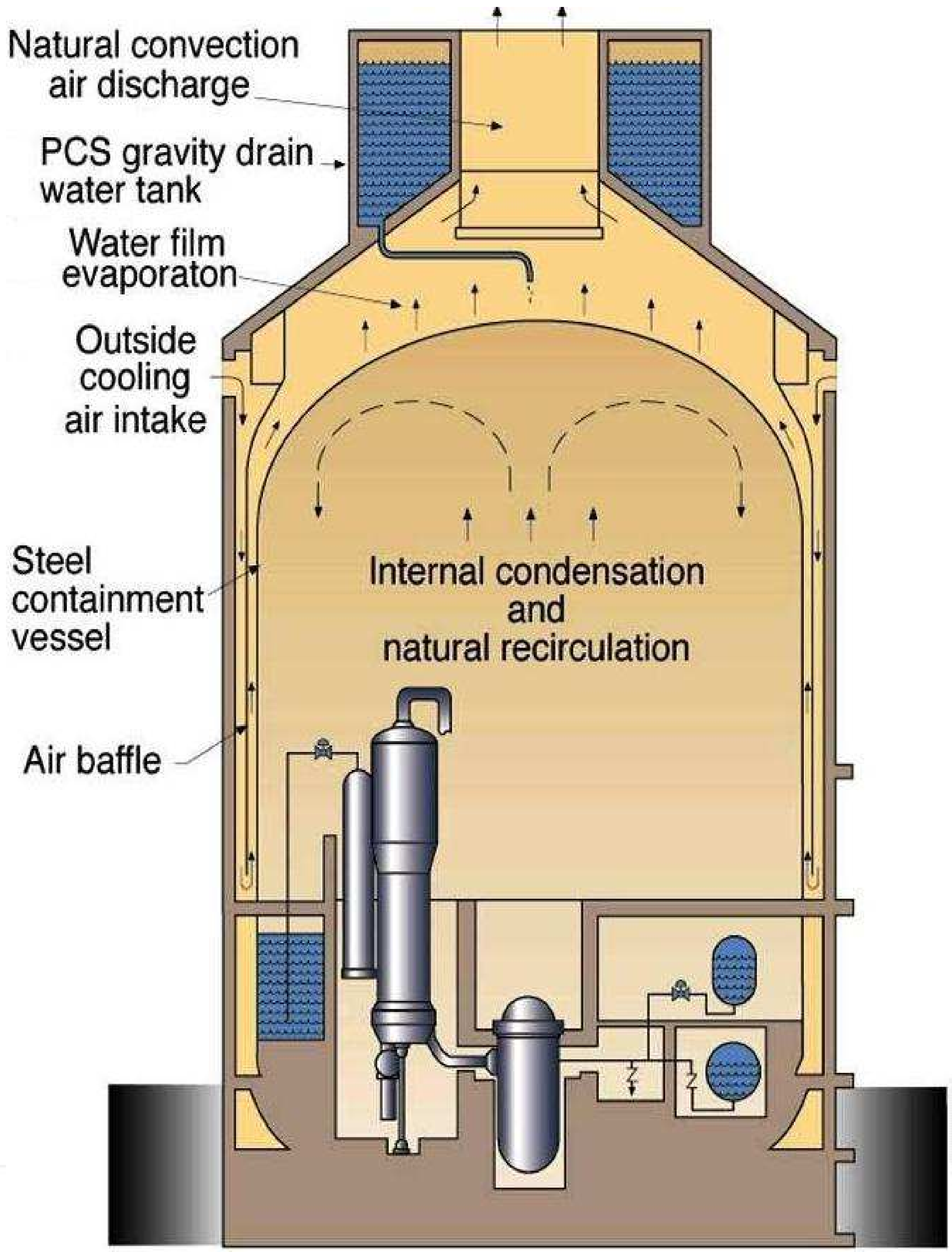
Plant overview: Reactor system

--157x14’ 17x17 FAs
-- No core lower plate
-- 2 hot legs/ 4 cold legs
-- No penetration in LH
-- Canned type MCP, no risk of shaft seal leakage
-- No intermediate section



Plant overview: PCS

- Steel containment vessel is part of passive safety system.
- PCS transfers heat from the shell to the environment.
- Water from Passive Containment Cooling Water Storage Tank (PCCWST) wets outer shell for > 72 hours.
- Natural convection air flow through containment annulus provides additional cooling.



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Plant overview: PXS

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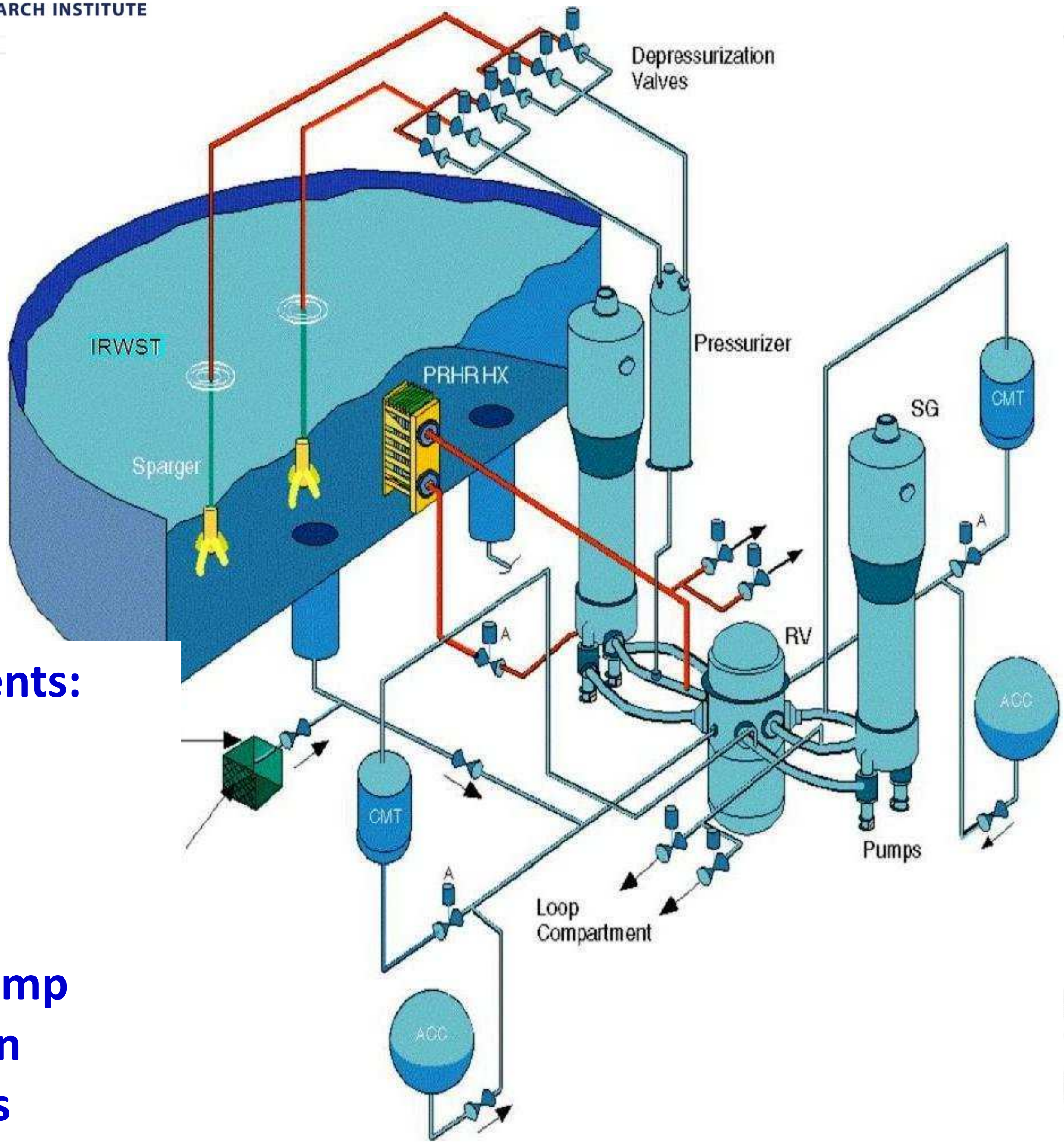


Major components:
CMTs
Accumulators
IRWST
PRHRHX
Containment sump
Depressurization (ADS) valves

PXS work condition

- PRHR remove decay heat in event of loss of SG function, transferring heat to IRWST
- CMTs provide coolant at full system pressure to downcomer through DVI line.
- ADS 1~3 actuates in order when CMT level decreases below 67.5%.
- Two accumulators provide coolant at high flow rates when RCS < 700 psia.
- IRWST supplies borated water to RCS once sufficiently depressurized.
- ADS 4 initiates with CMT Low-2 level (20%) + Low RCS pressure (1200 psig)

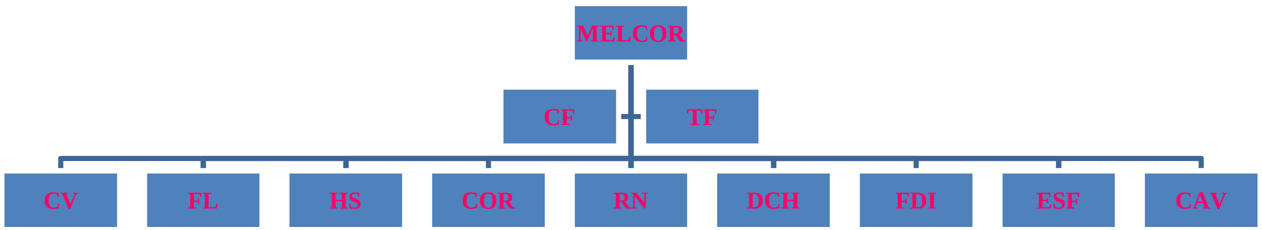
Main control signal of safety system

Signal group	A	B	C	D	E
SCRAM(1)	PZR high pressure 2460 psia	PZR level HI-3 76% range	Primary flow low 87% of nominal flow	RCP low speed 90% of nominal speed	CMT injection
SCRAM(2)	SG level Low-1 95000lbm	ESF activated	ADS onset	PZR low-1 pressure 1800 psia	
MCP trip	"S" signal	SG-NR HI-2 100% range	Tavg Low-2 542 F		
"S"signal	Pzr_pressure low2 1700 psia	Steam pressur low 535 psia	Tcold Low 500 F	Pcont Hi-2 8 psig	
ADS1~3 trigger	CMT low-1 67.5% vol	Hot leg lev low-2 0.072 m			
CMT injection	PZR level Low-2 7% range	"S"signal	ADS1~3 onset		
PRHR on	SG-NR Low+ startup feed failure	SG-WR Low 55000lbm	ADS1~3 onset	CMT injection	PZR level Hi-3 76% range
Turbine trip	SG-NR HI-2 100% range	"S" signal	scram		
MFW isolation	SG-NR HI-2 100% range	"S" signal	Tavg Low-1 542F		
ADS4 trigger	CMT low-2(20% vol) + Prcs<8.27 Mpa				
IRWST injection	ADS4 onset	Hotleg lev low2			

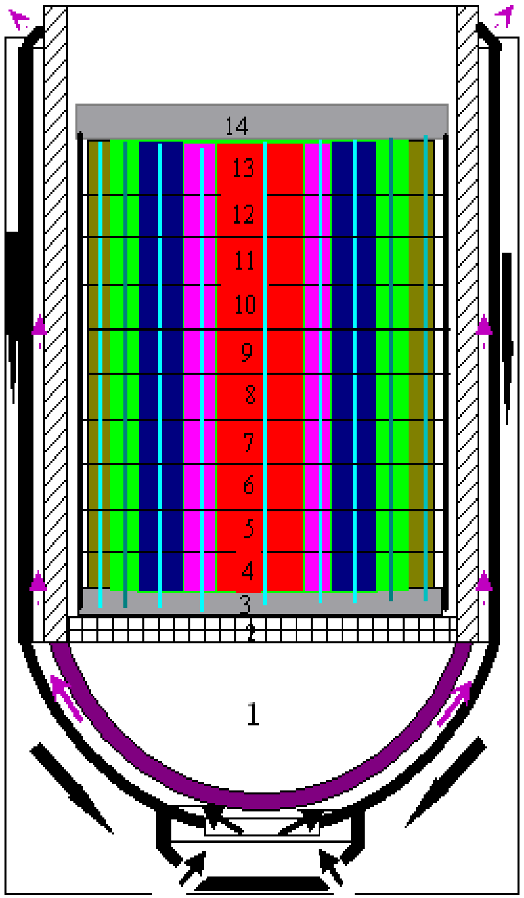
Main configuration of AP1000

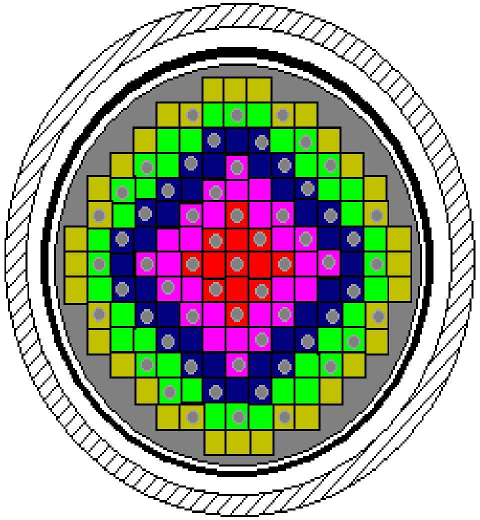
Equipment/ system	Medium/ str. Mass (ton)	Initial temp. (F)	Nominal pressure (MPa)	Water volume (m3)	Gas volume (m3)	Height (m)	Internal diameter (m)
Reactor							
core	/	2700*	15.5	/	/	4.267	1.59
cladding	/	650*	15.5	/	/	/	0.00836
RPV	72.55	301	2292/15.8	3510/99.4	0	12.2	4.04
RCS	199.4	301	2250/15.5	9620/273	1100/31.2	/	/
PZR	约15	345	2250/15.5	1000/28.3	1100/31.2	12.77	2.54
SG	84	271	814/5.61	148/5226	103/3637	19	4.19
PXS							
PRHR	2.88	49	15.5	1.55	0	11.55	0.01575
CMT	70.8	49	17.1	70.8	0	5.78	4.25
ACCU	39.6	49	4.9	39.6	17.1	7.5	4.76
CONT	/	49	0.1	/	58000	65.5	39.6
PCCWST	2592	49	0.1	2592	/	/	/
IRWST	2070	49	0.1	2070	238.1	9.69	/

MELCOR modeling of AP1000



COR module





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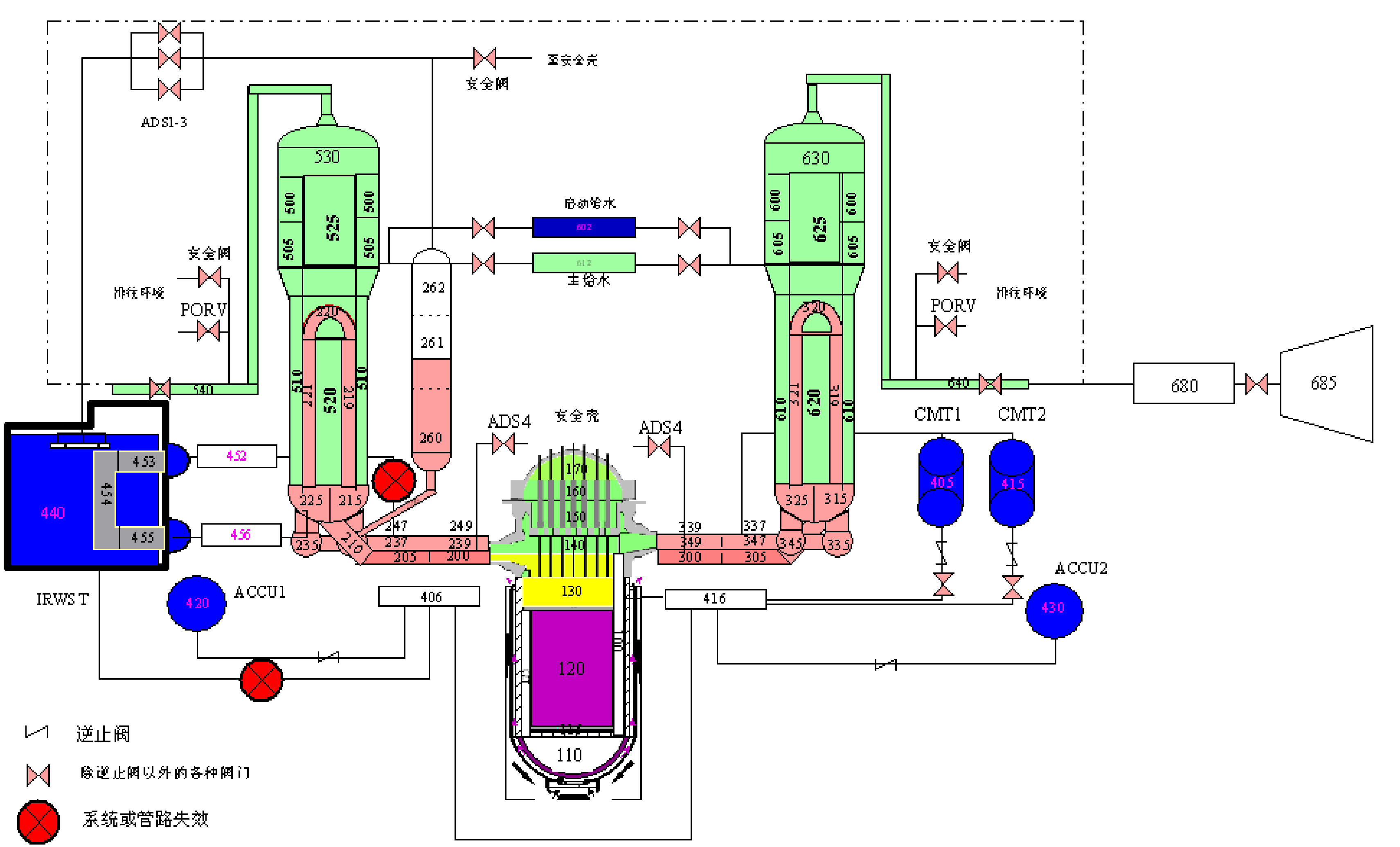
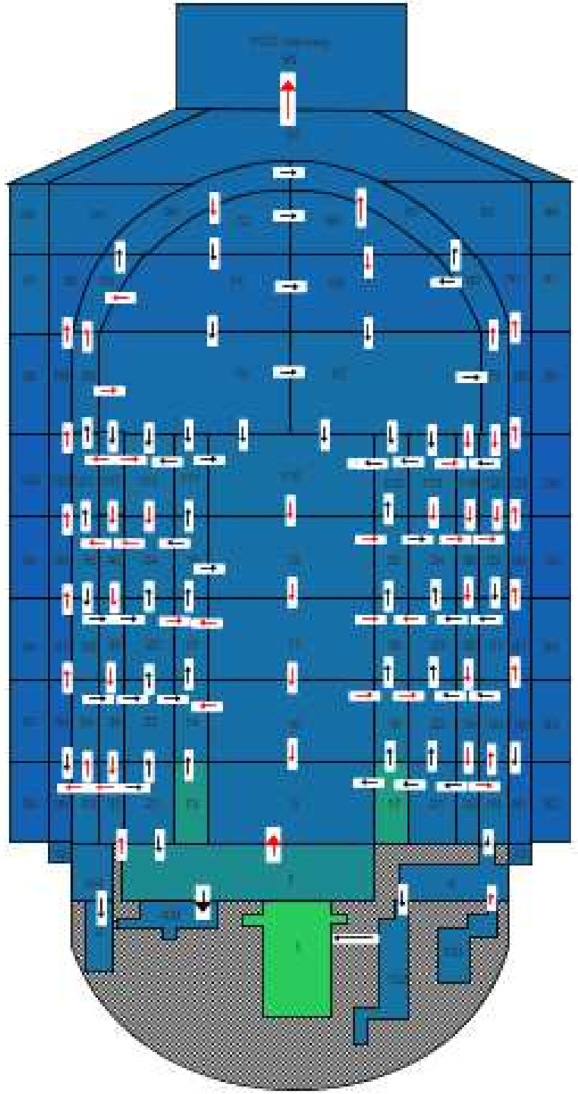
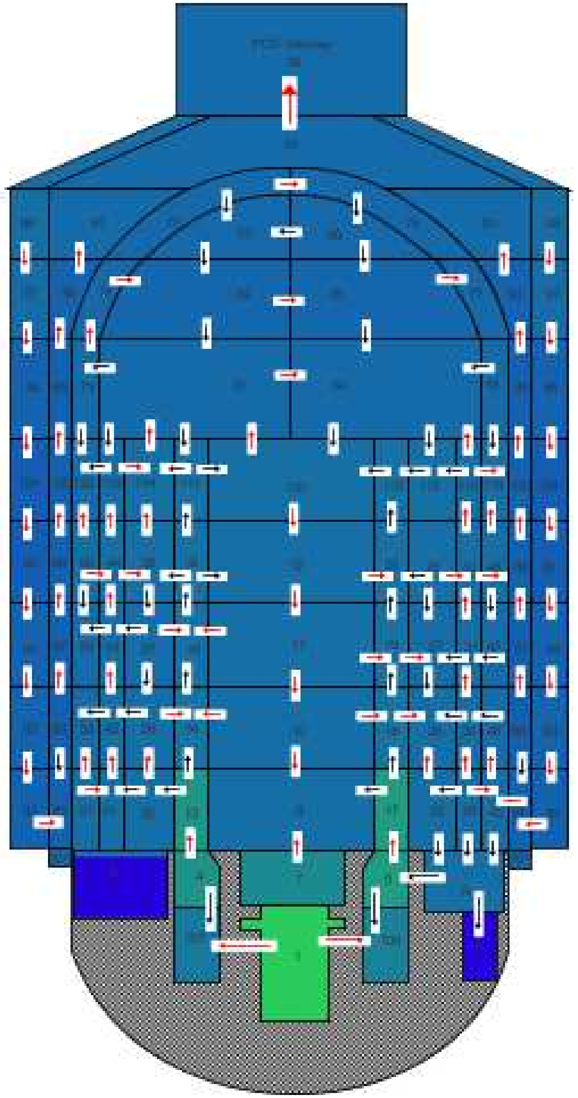
Nodalization of primary&secondary and PXS system



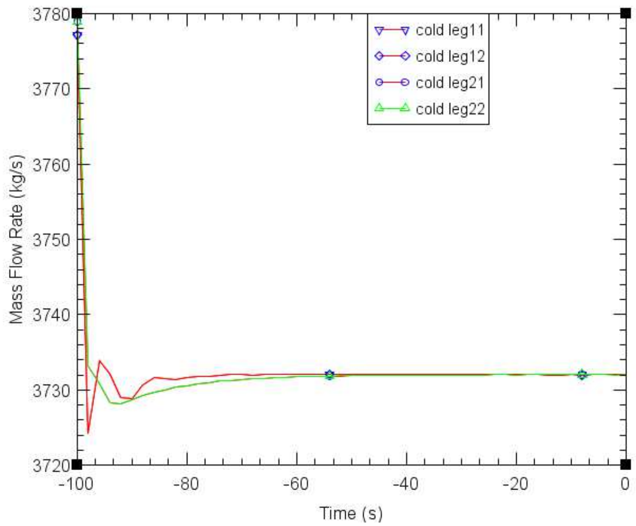
Detailed PCS nodalization scheme



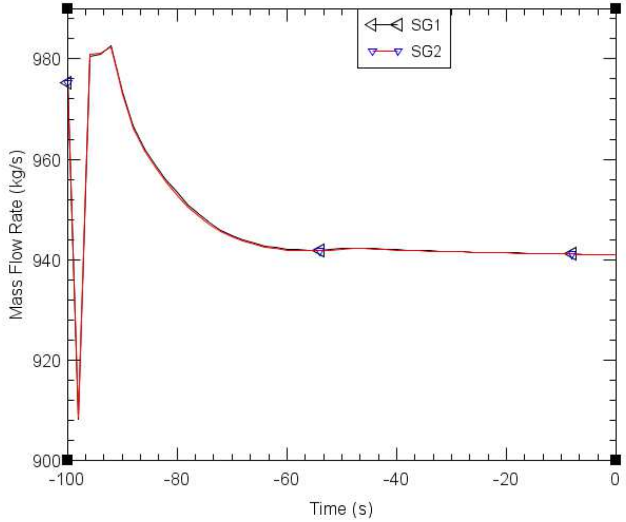


Configuration:
122 CVs
316 FLs
257 HSs

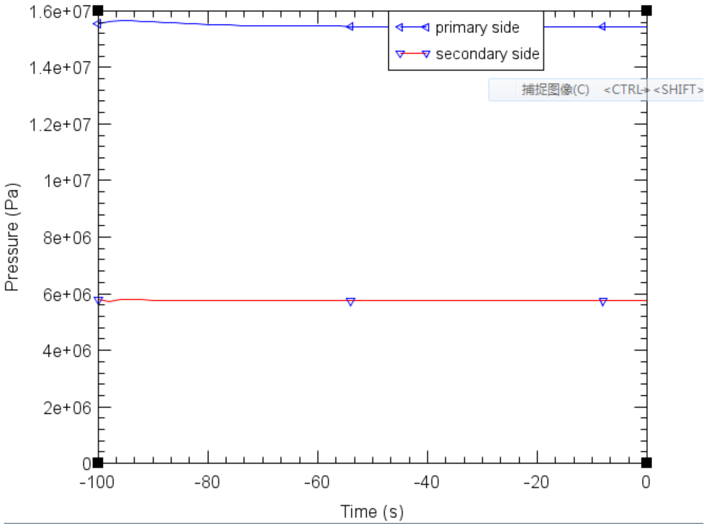
Plant Steady State Initialization



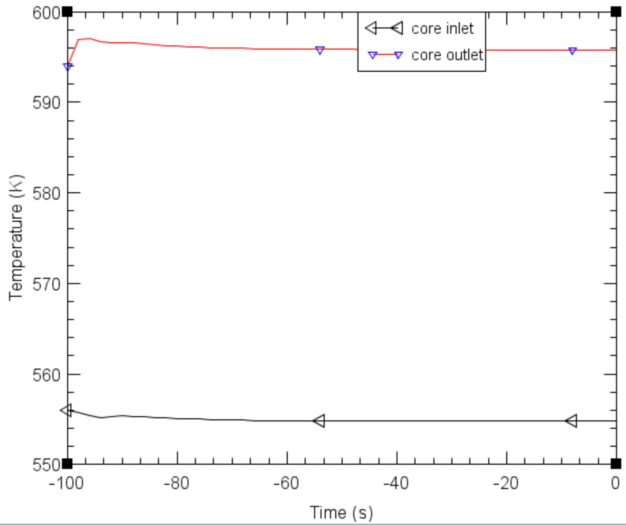
Primary coolant flow rate



Secondary steam flow rate



Primary&secondary pressure



Core inlet&outlet temperature

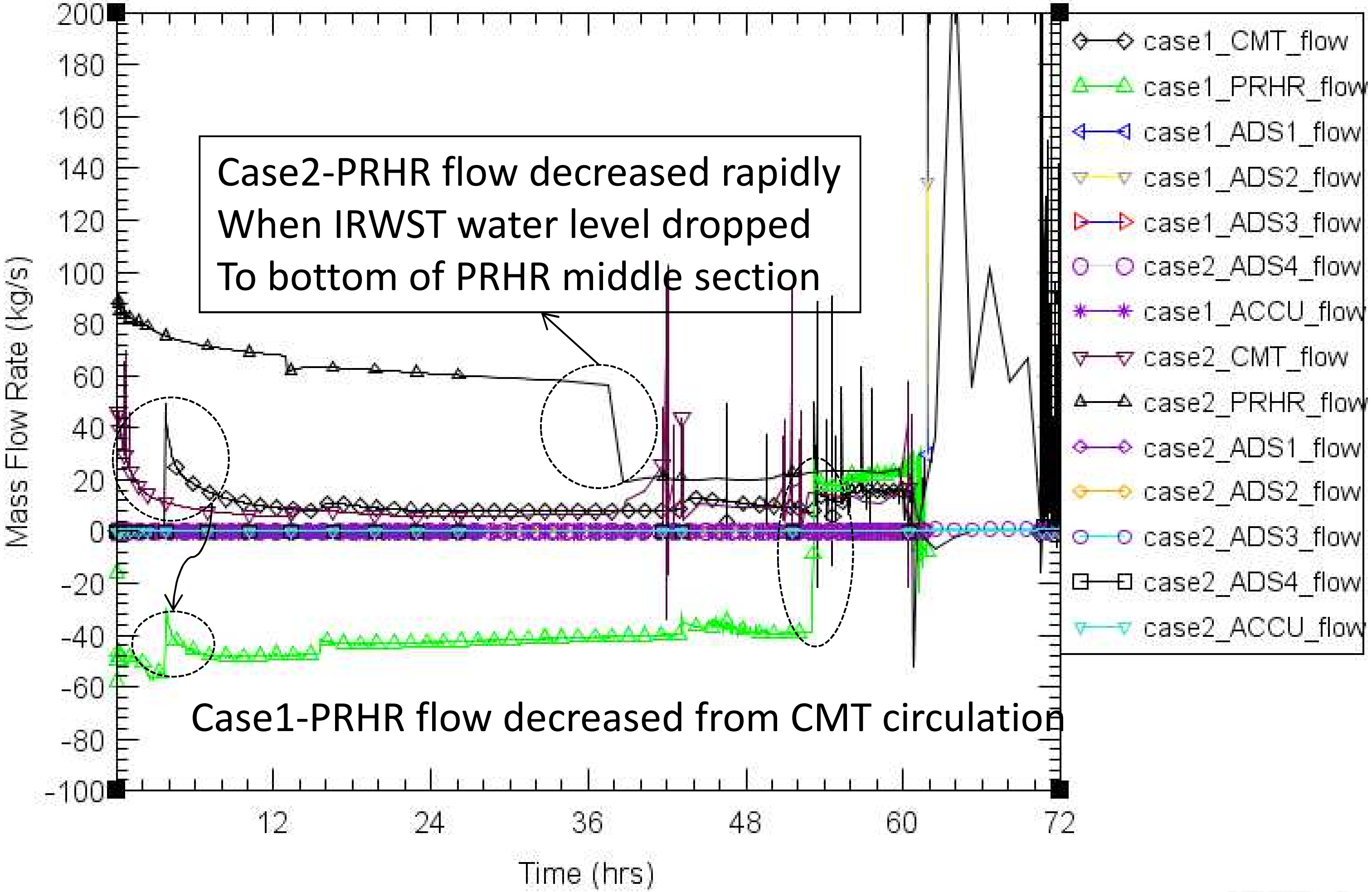
Main assumptions:

- The reactor initially operated at full power
- All PXS and PCS system could work except the ERVC measure considered failed
- Cooled water droplet draining down along the containment shell inside wall will not return to IRWST directly
- the containment shell surface area is down scaled to account for partial coverage of water film on the outer surface
- 2 cases are simulated

1)PRHR started with 1 min delay after SG low level signal true

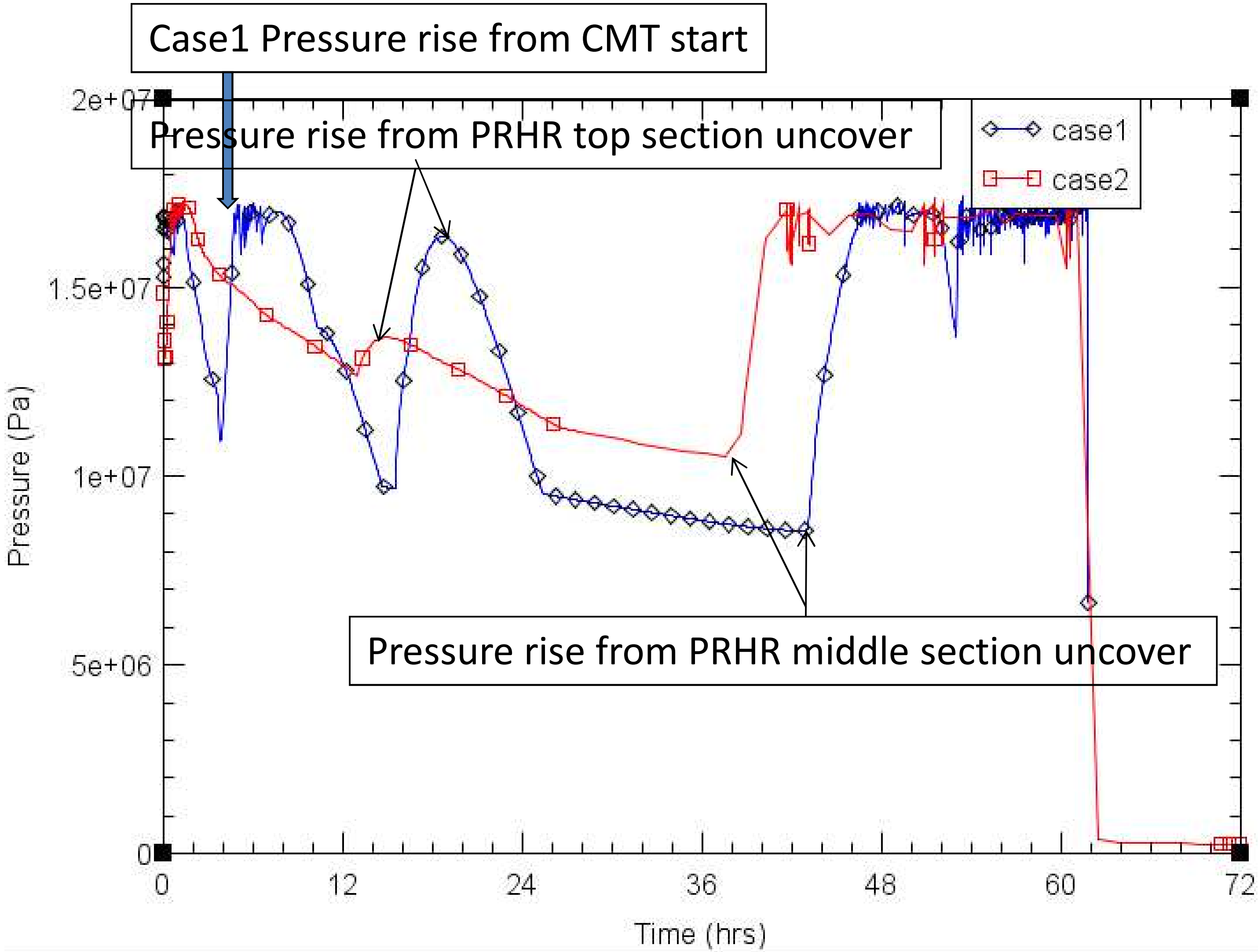
2)PRHR started immediately after reactor scram

72 hr SBO simulation and analysis



Comparison of PXS flow rate

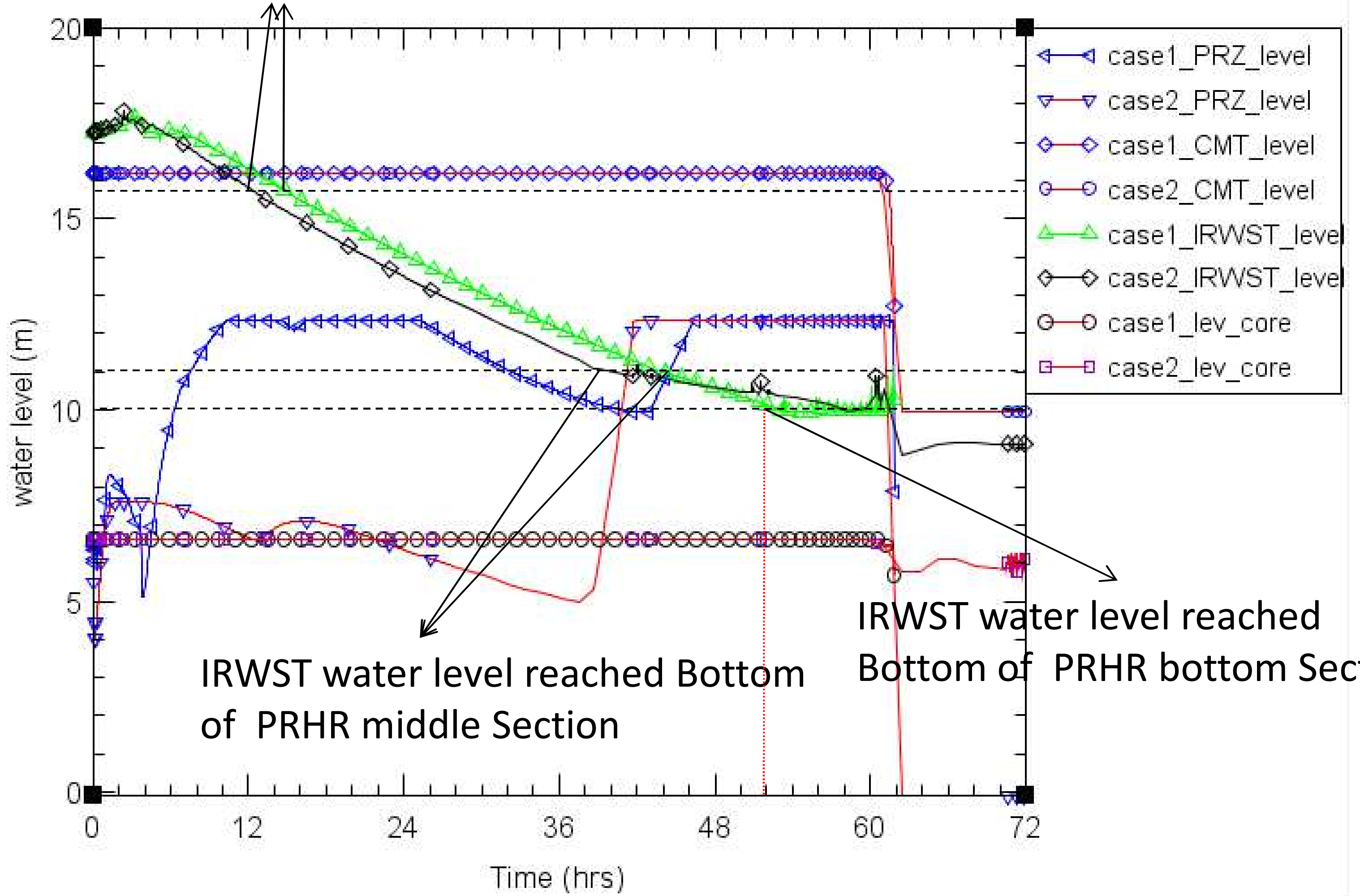
72 hr SBO simulation and analysis



Comparison of primary pressure trend

72 hr SBO simulation and analysis

IRWST water level reached Bottom of PRHR top Section

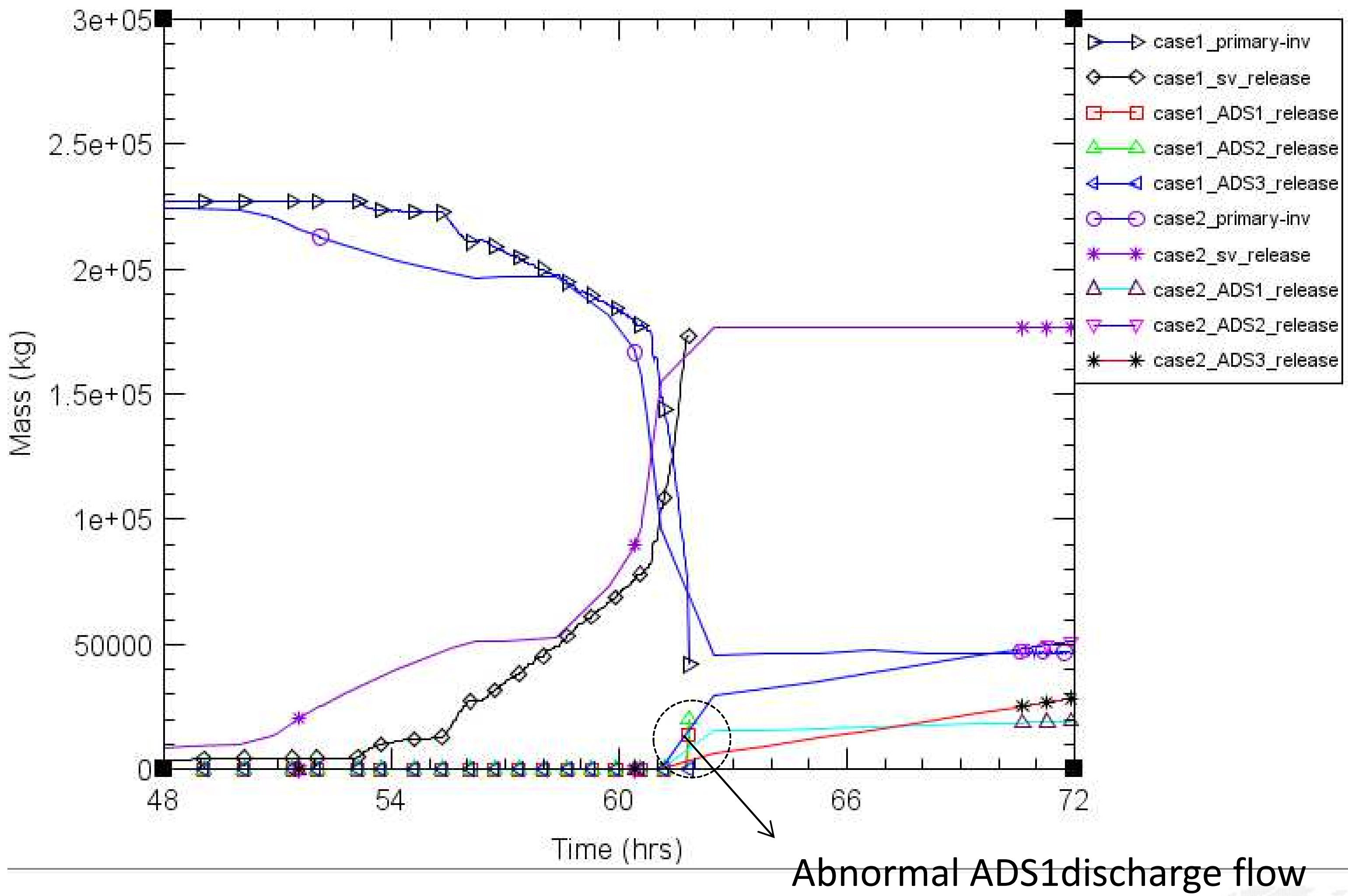


IRWST water level reached Bottom of PRHR middle Section

IRWST water level reached Bottom of PRHR bottom Section

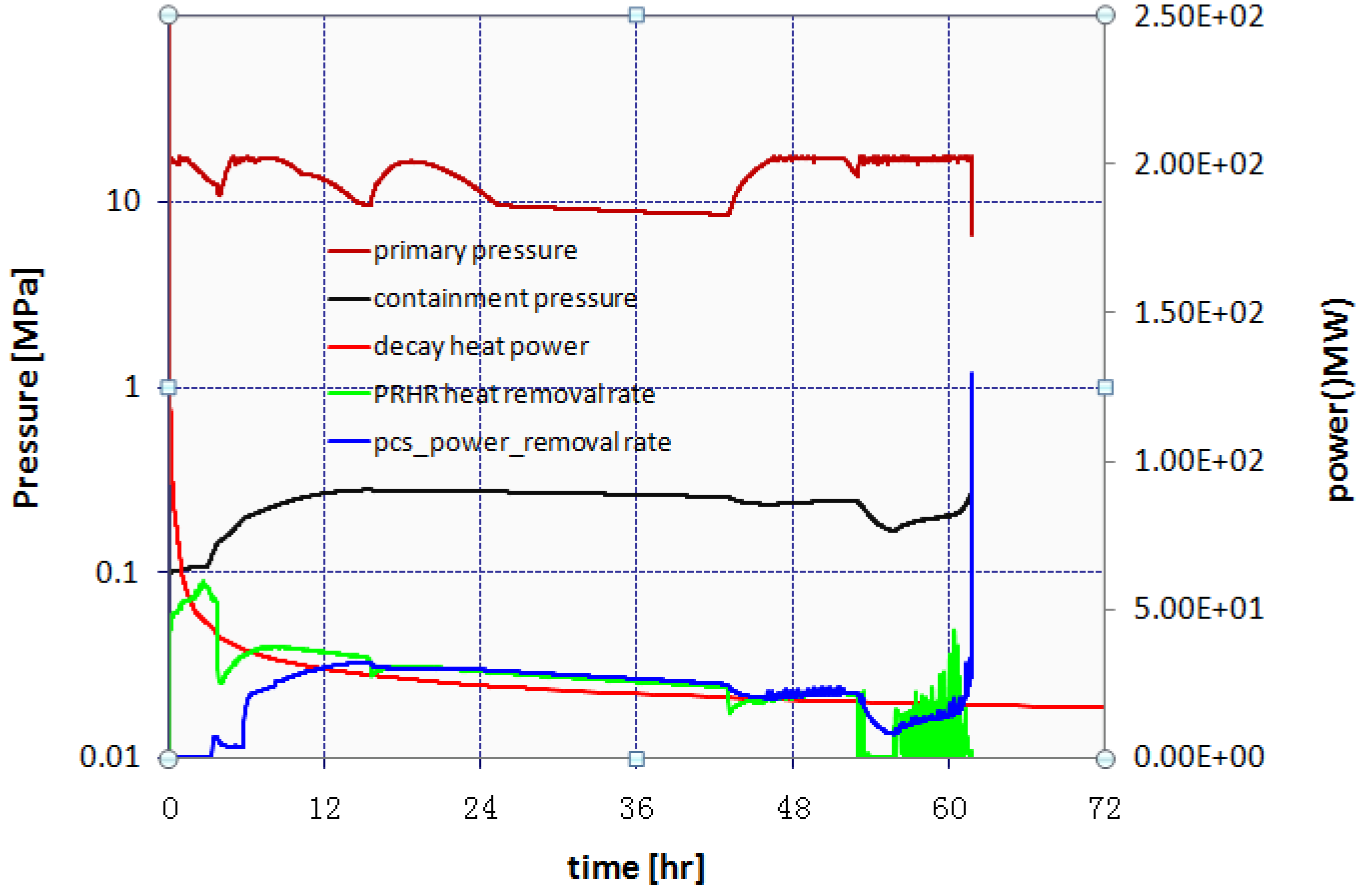
Comparison of water level in PXS tank and RCS

72 hr SBO simulation and analysis



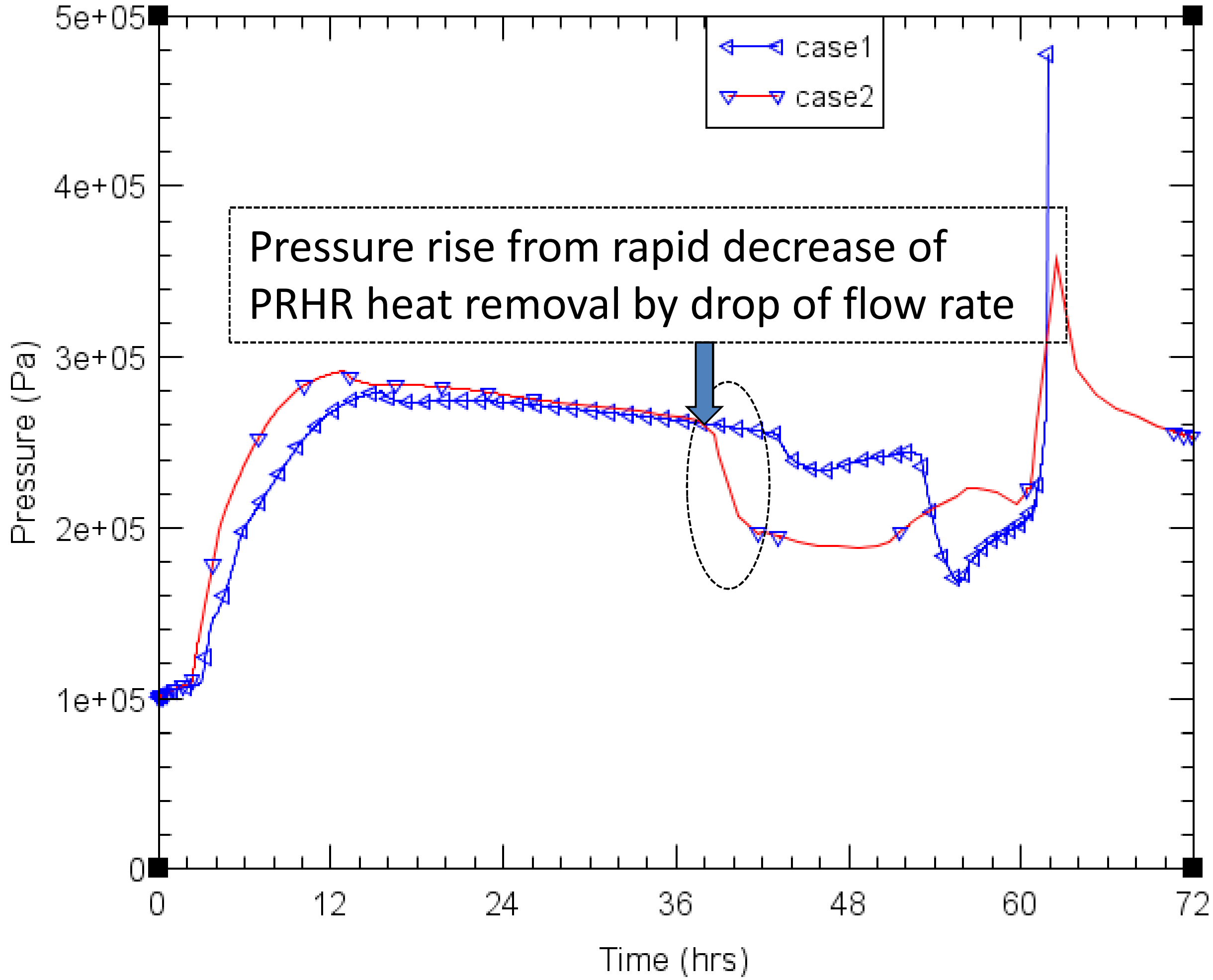
Comparison of RCS water inventory and discharge mass

72 hr SBO simulation and analysis



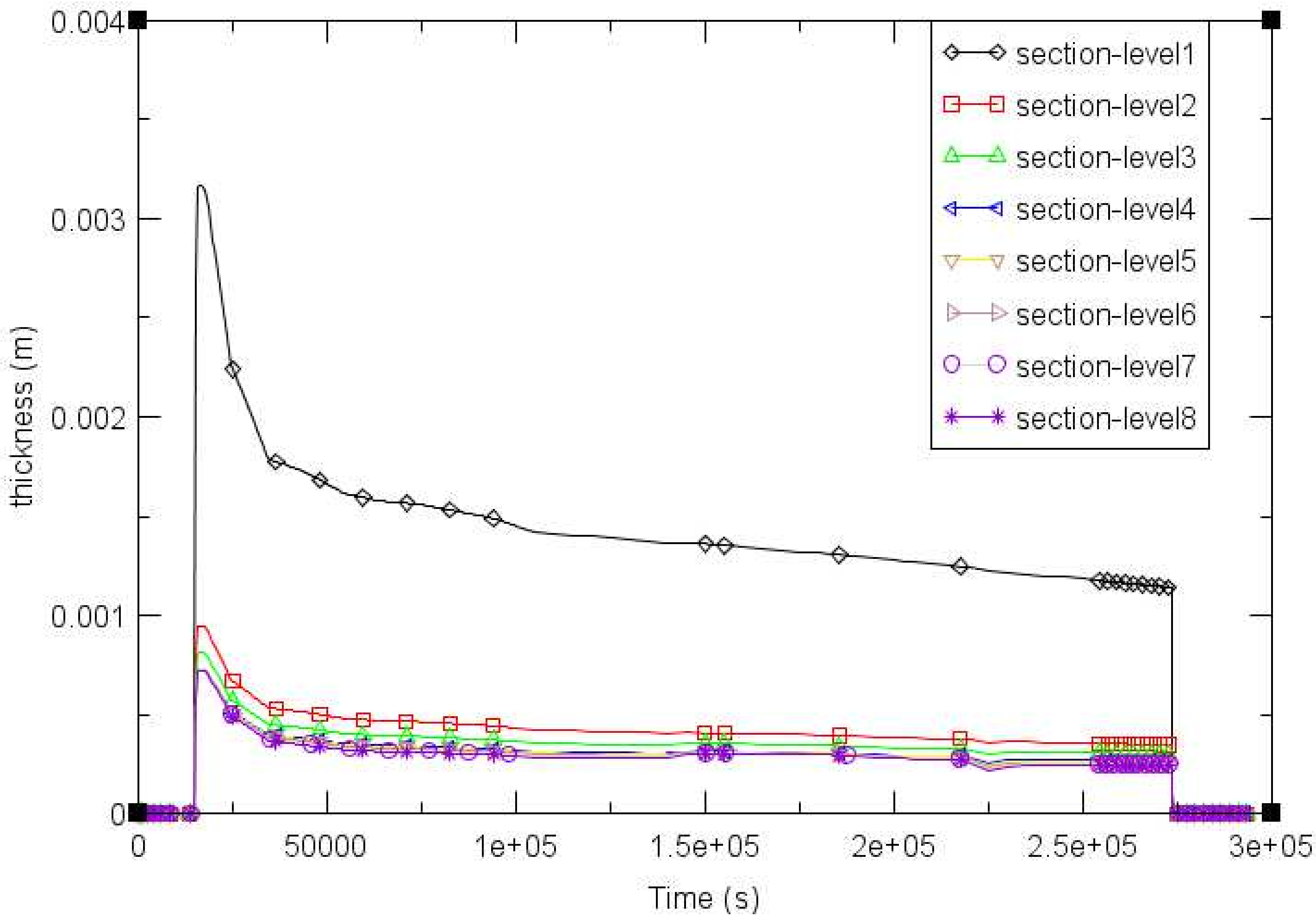
Primary side&containment pressure V.S. heat removal trend(case1)

72 hr SBO simulation and analysis



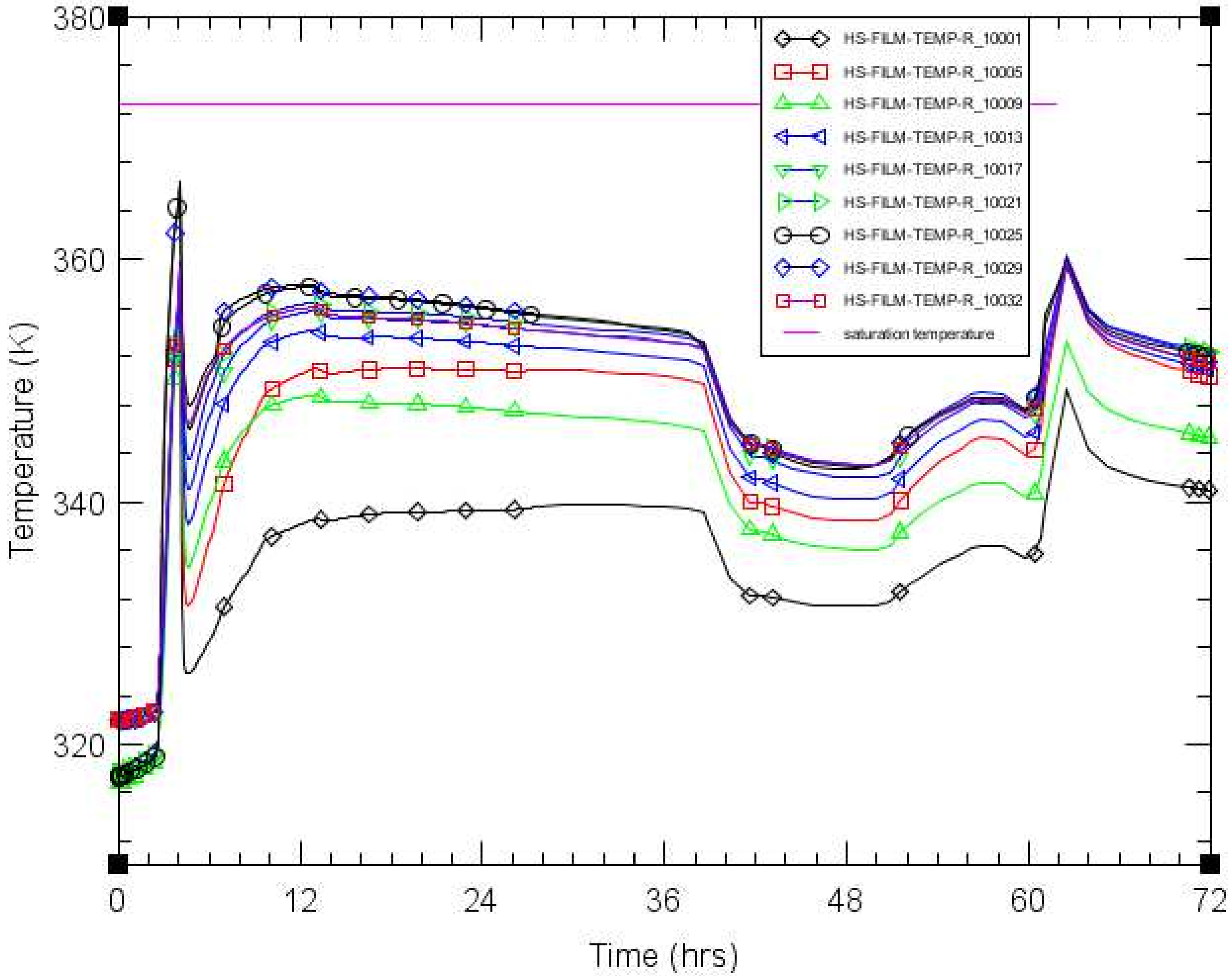
containment pressure trend

72 hr SBO simulation and analysis



Water film thickness along the containment shell outside(case2)

72 hr SBO simulation and analysis



Water film temperature along the containment shell outside(case2)

Main events of SBO Progression within 72 hrs

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timing（s/hr） Sequences	case1		case2	
	second	hour	second	hour
SBO initiated	0		0	
Reactor scram	2		2	
SG narrow range water level low	25		25	
Steam line stop valve closed	62		62	
PRHR line open	85		25	
primary low-2 true T-averagee	274		120	
CMT line started circulation	11711	3.3	260	
Pressurizer low-2 pressure	13380	3.7	88538	24.6
PCS started by containment high pressure	20066	5.6	14448	4.0
PRHR tubes uncovered	158000	43.9	151500	42.1
CMT level low-1，ADS1~3 triggered	222400	61.8	220620	61.3
Hotleg low level true, IRWST injection signal activated	222573	61.8	220757	61.3
ADS4 triggered	222573	61.8	220757	61.3
ACCU started injection	n/a	n/a	220787	61.3
Core exit temperature exeeded 1200 F	n/a	n/a	228605	63.5
Cavity –flooding activated	n/a	n/a	228605	63.5
PCCWST exhausted	n/a	n/a	273649	76.0
Calculation terminated	222600	61.8	290000	80.6

Main findings and insights

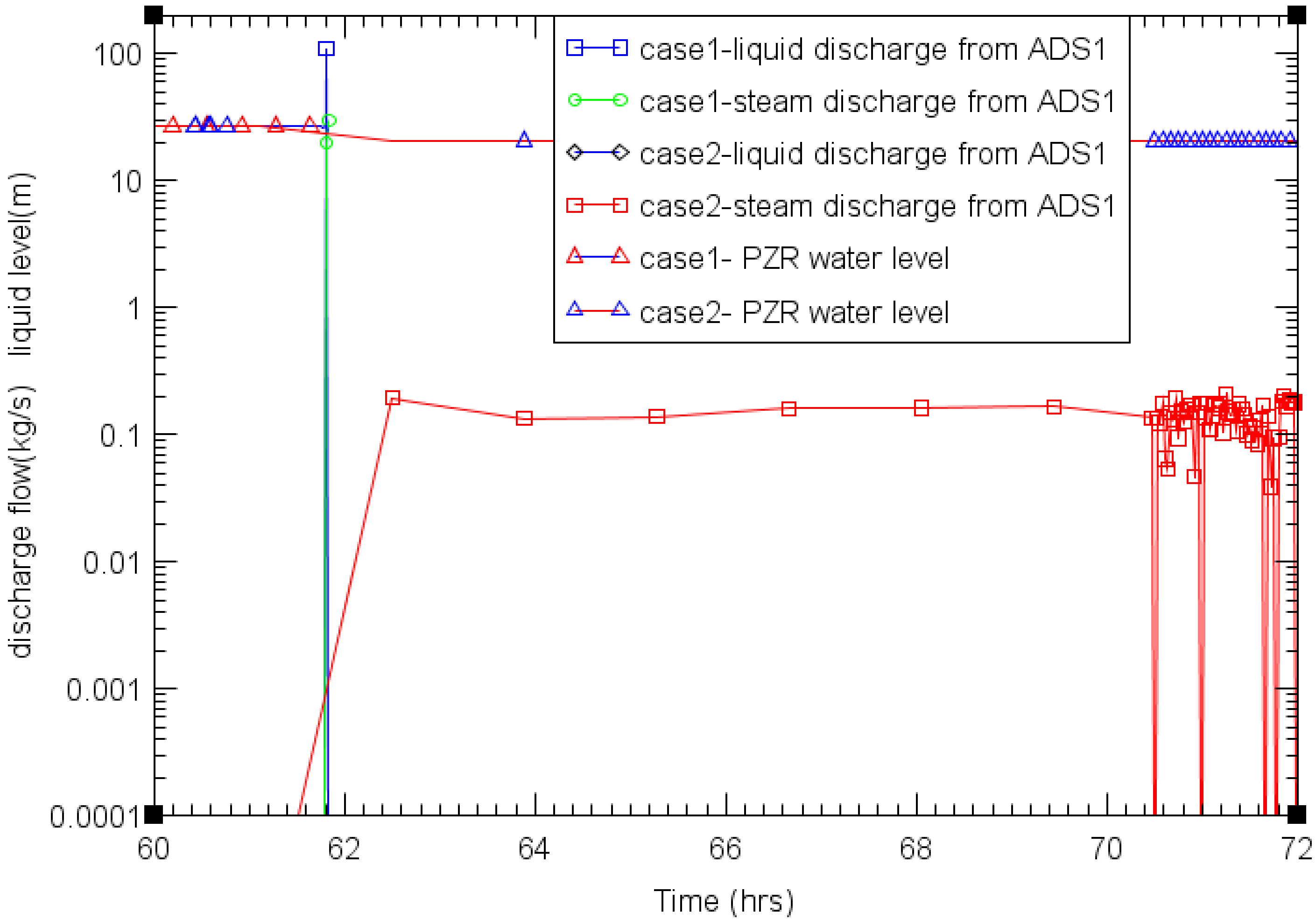
- Under LOOP and SBO accident condition, to avoid PRHR reverse flow, the PRHR Line should be opened as soon as the reactor scram. To study such complex phenomena, more detailed PRHR thermal-hydraulic nodalization scheme is needed. Earlier start of CMT will counter-act the cooling efficiency of PRHR.
- SBO lasted up to 72 hrs for AP1000, will not result in severe core degradation, As long as decay heat could be transferred from coolant to PRHR and IRWST, And then removed by PCS in a well coupled way, as demonstrated in the simulation.
- MELCOR seems to be overestimating the film thickness draining down from Dome top.
- In the phase of ADS discharge simulation, 2 version of MELCOR 186 generated quite big difference, the old version seems to have predicted more reasonable ADS flow rate.

Planned future work

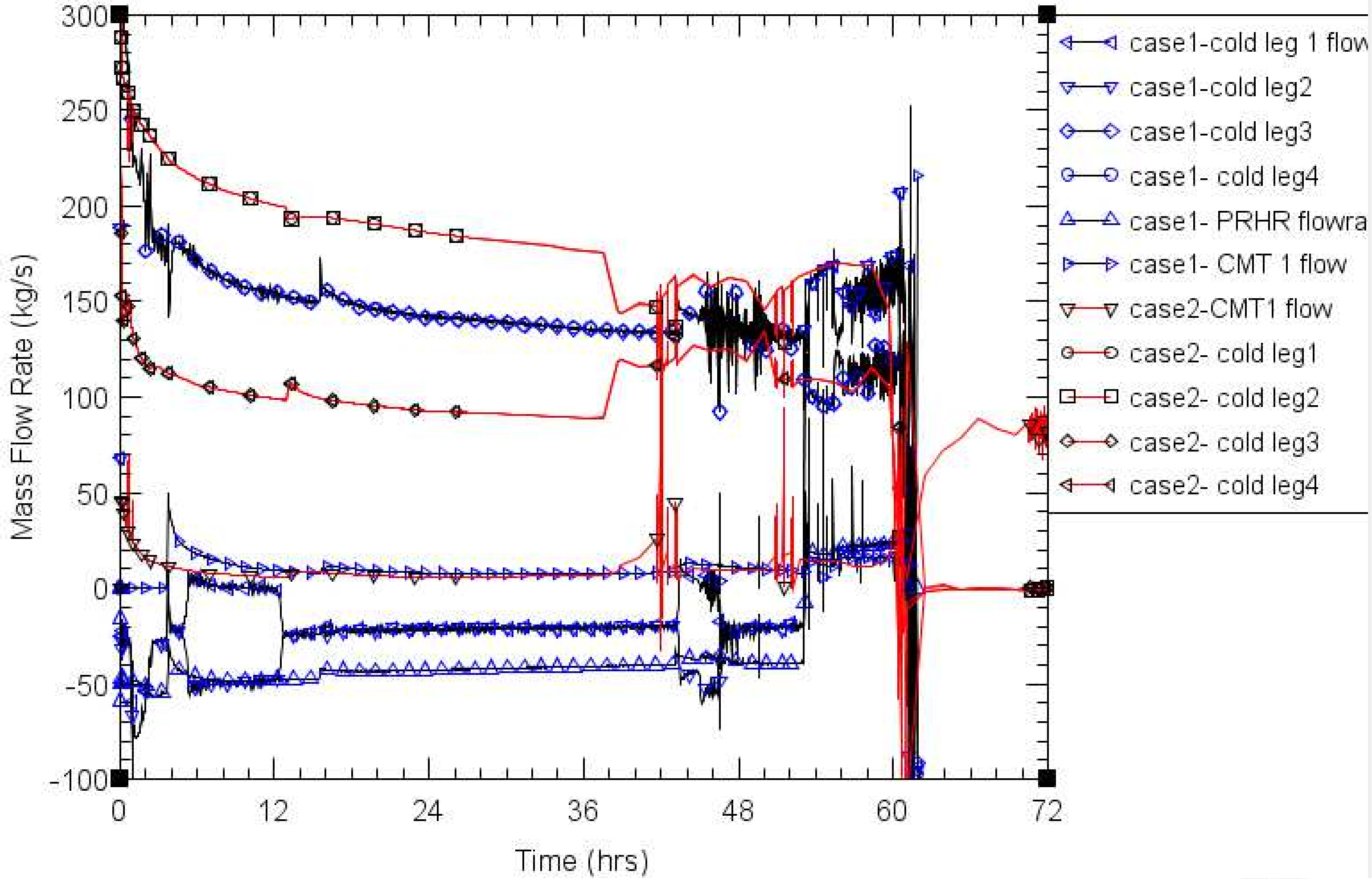
- Severe accident simulation of long-term SBO extended to 1 week, as well as SA scenario from other extreme external events
- Validation of HSFT model against data from SNPTC containment validation test
- Detailed CVs and FLs for ERVC simulation will be added to current input deck, to study the effectiveness of IVR measures
- Transformation of current input model to larger passive NPP.
- Study on alternate SA mitigation measures for AP1000.
- Validation and improvement of current AP1000 SAMG

谢谢观赏

Thank you



Comparison of water level of PZR V.S. discharge rate of ADS 1



Comparison of CMT&PRHR&cold leg flow