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MELCOR Simulation of SBO Scenarios of Fukushima-I-2 BWR within first 96 hrs

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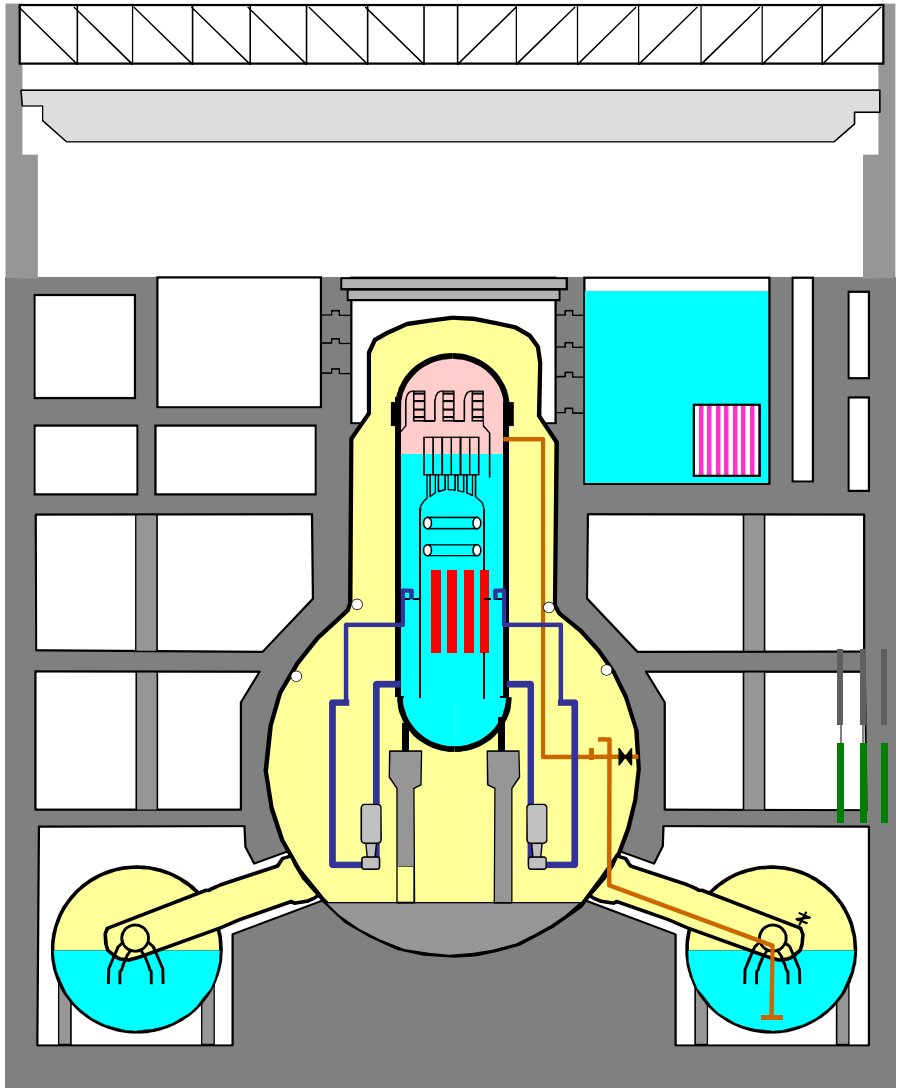
Outline of Content

- *Brief introduction of the plant and Initial conditions*
- *Modeling of systems and zones*
- *Highlighted SBO scenarios simulation results*
- *Discussion of analysis results*

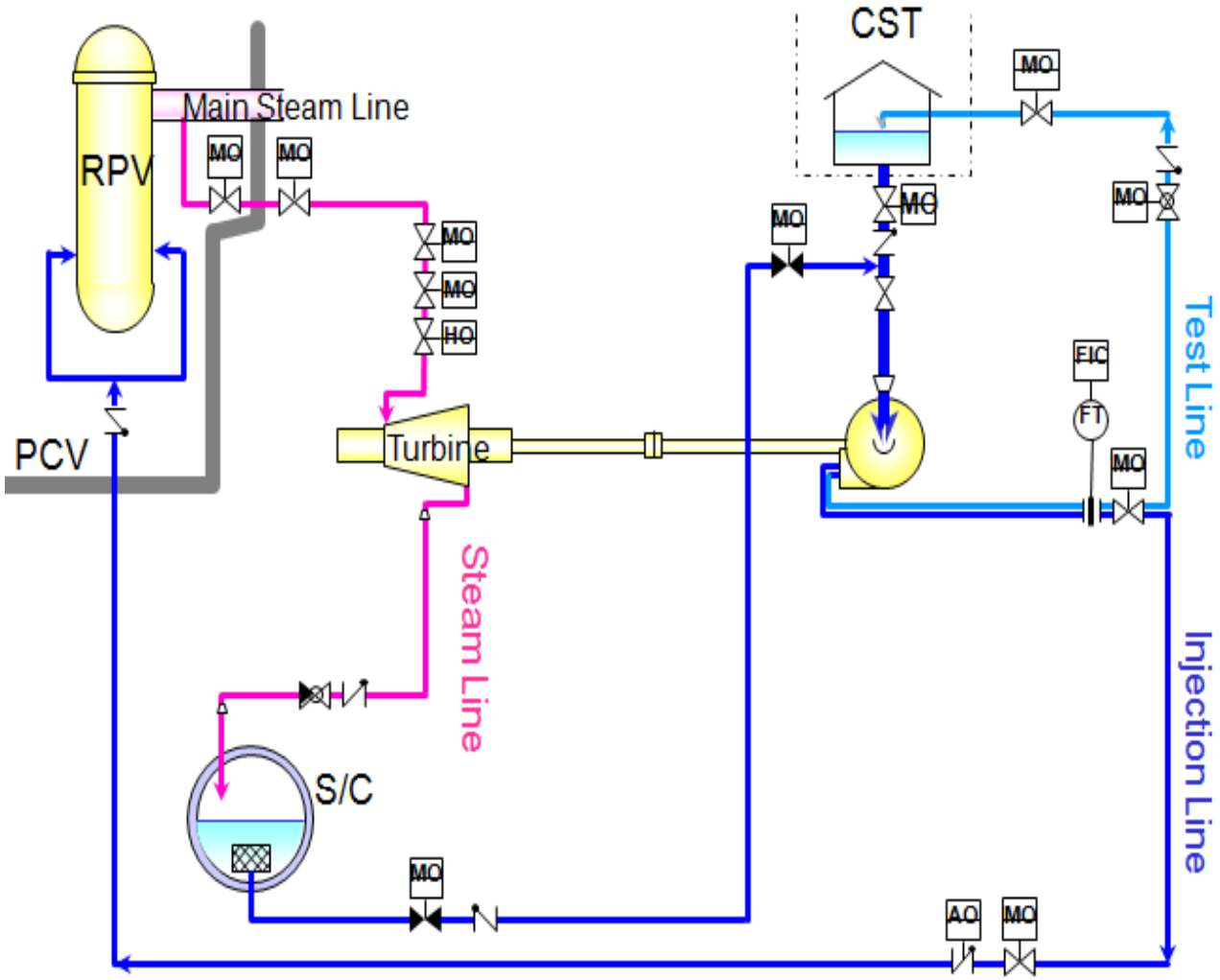
Brief introduction of F-I-2

Fukushima daiichi unit 2 is a BWR-4 NPP with MARK-1 type containment, which operated at power of 2381 MWth. It has 2 external recirculation loops and 4 steam lines. Operating pressure is 7.0 MPa. The core has 548 fuel assemblies and 137 control rods with B4C as absorber material. Each assembly has a fuel box to form an independent fluid channel. The reactor vessel is about 21.1 m high and has an inside diameter of 5.6 m. The reactor core has an active length of about 3.7 m.

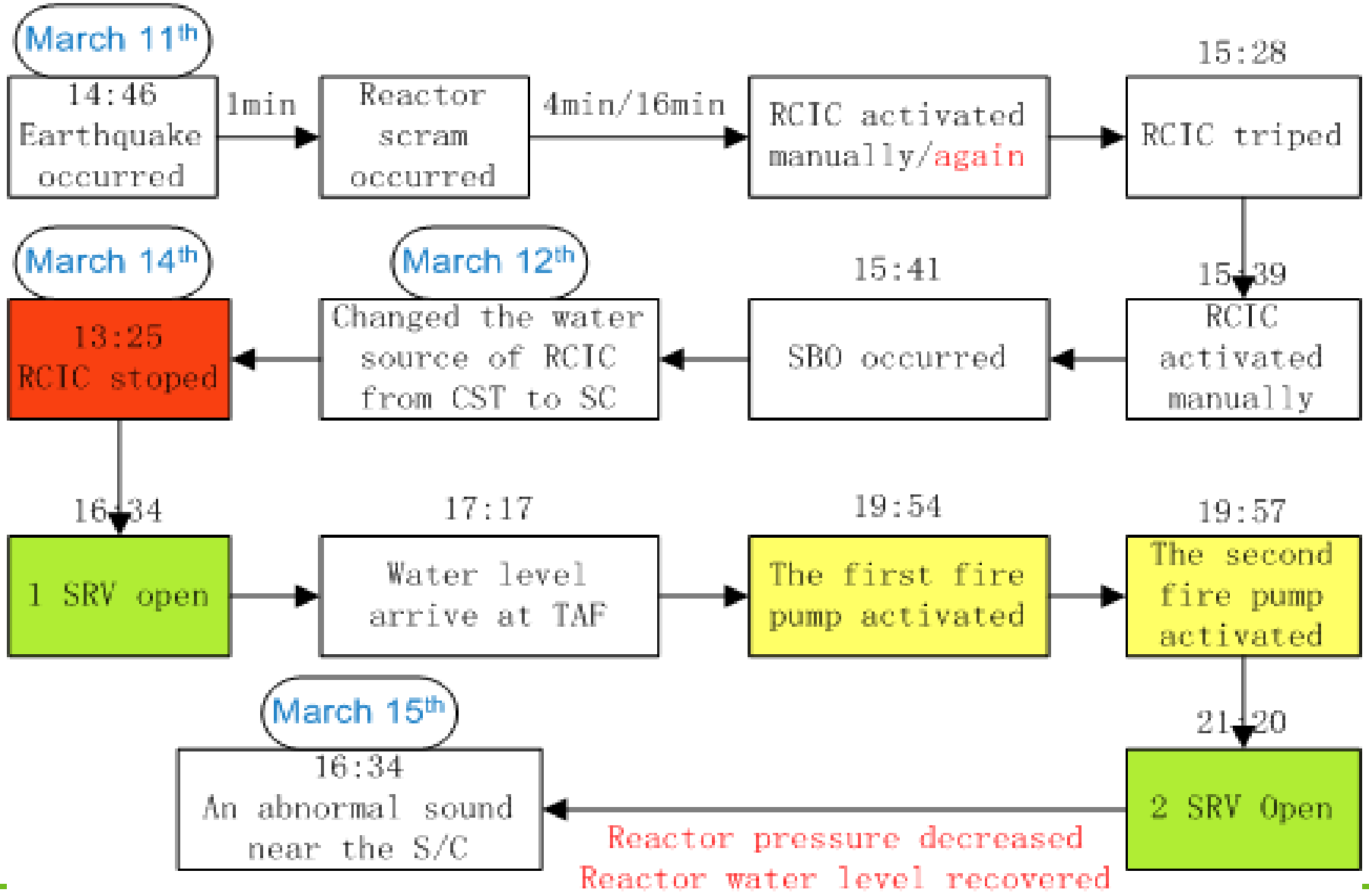


RCIC work condition in F2

- Rated Flow
  - √ About 95 ton/hr
- Work Pressure
  - √ 0.96~7.8MPa[gauge]
- Control(manual or automatic)
  - √ on/off between low water level(L-2) and high water level (L-8) automatically
- Water Source
  - √ Condensation Storage Tank (CST)
  - √ Suppression Pool



overview of main events



- Main assumption of plant initial state

  The plant is initially running at full power. The whole core has an inventory of around 94 tons of fuel, 38 tons of Zircaloy of claddings and other structures, and 1.5 tons of control rod poison(B4C).The bypass flow rate in the core zone is set at a fraction of 7.5% of total flow. the initial water level in the reactor vessel is kept at 13.125 m. The supression pool was kept at half level of SC.

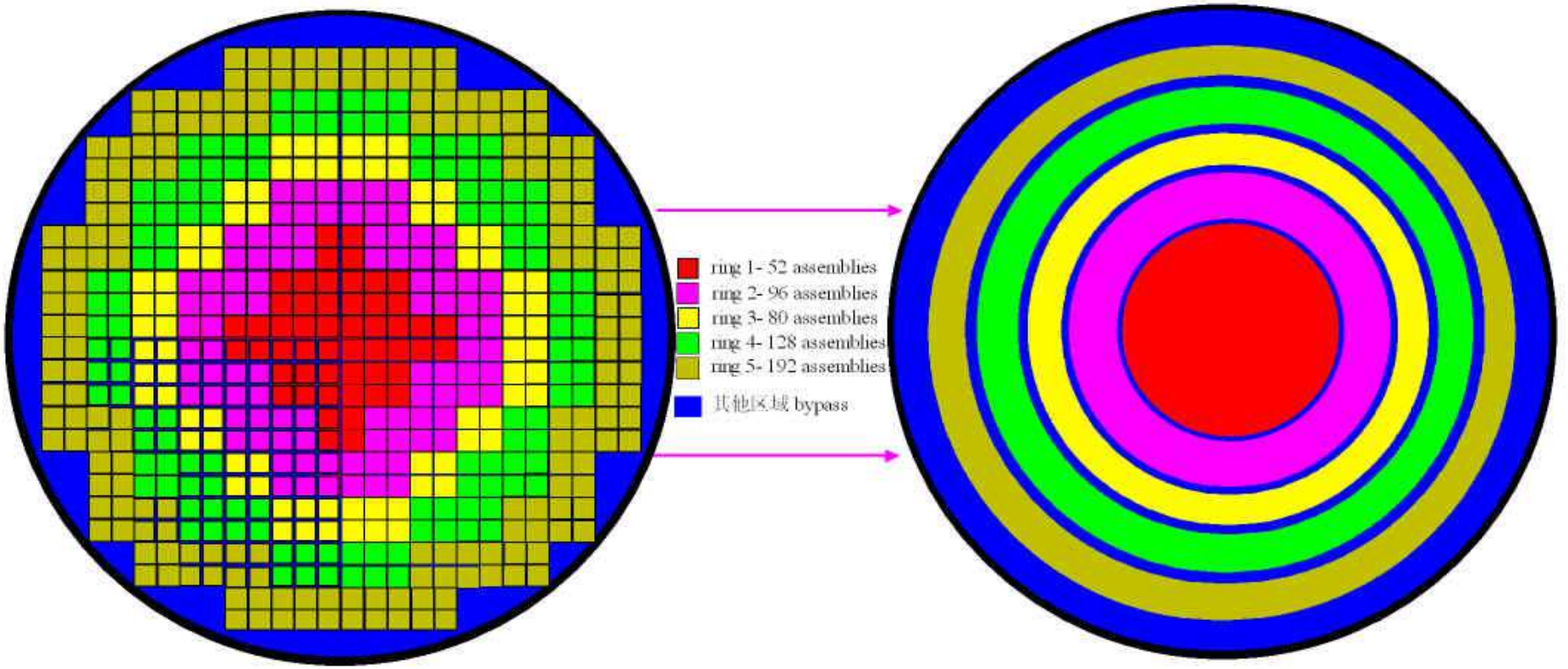
- Summary of nodalization scheme

  The MELCOR model for F2 comprises 38 control volumes, 69 flow paths and 100 heat structures, there are totally 77 core cells represent the core and lower plenum region; the elevations adopted in the input decks set the bottom of lower head inner surface as zero reference level, all the elevation data from drawings has to be adapted in relation: *z(MELCOR) = z(drawing) – 14.32 m.*

Main parameters of plant

Parameter（*unit*）	**value**
Reactor thermal power (MW)	2381
Reactor operation pressure (MPa)	7.0
Steam temperature(°C)	286
Initial RPV water level (m)	13.125
Active length of fuel (m)	~3.7
Number of control blade	137
Number of fuel assembly	548
UO_2 mass (t)	94
Internal diameter of RPV (m)	5.6
Height of RPV (m)	21.1
RCIC nominal flow rate (t/h)	95
HPCI nominal flow rate (t/h)	965
SRV opening pressure (MPa)	7.59/7.66/7.73
SRV discharge capacity (t/h)	2900
Dry well free volume (m^3)	4240
Gas volume of suppression chamber (m^3)	3160
Water volume of suppression pool (m^3)	2980
Water volume/temperature in spent fuel pool (m^3)	1440/40
Assumed Water temperature in CST (°C)	20

Modeling of the core cells

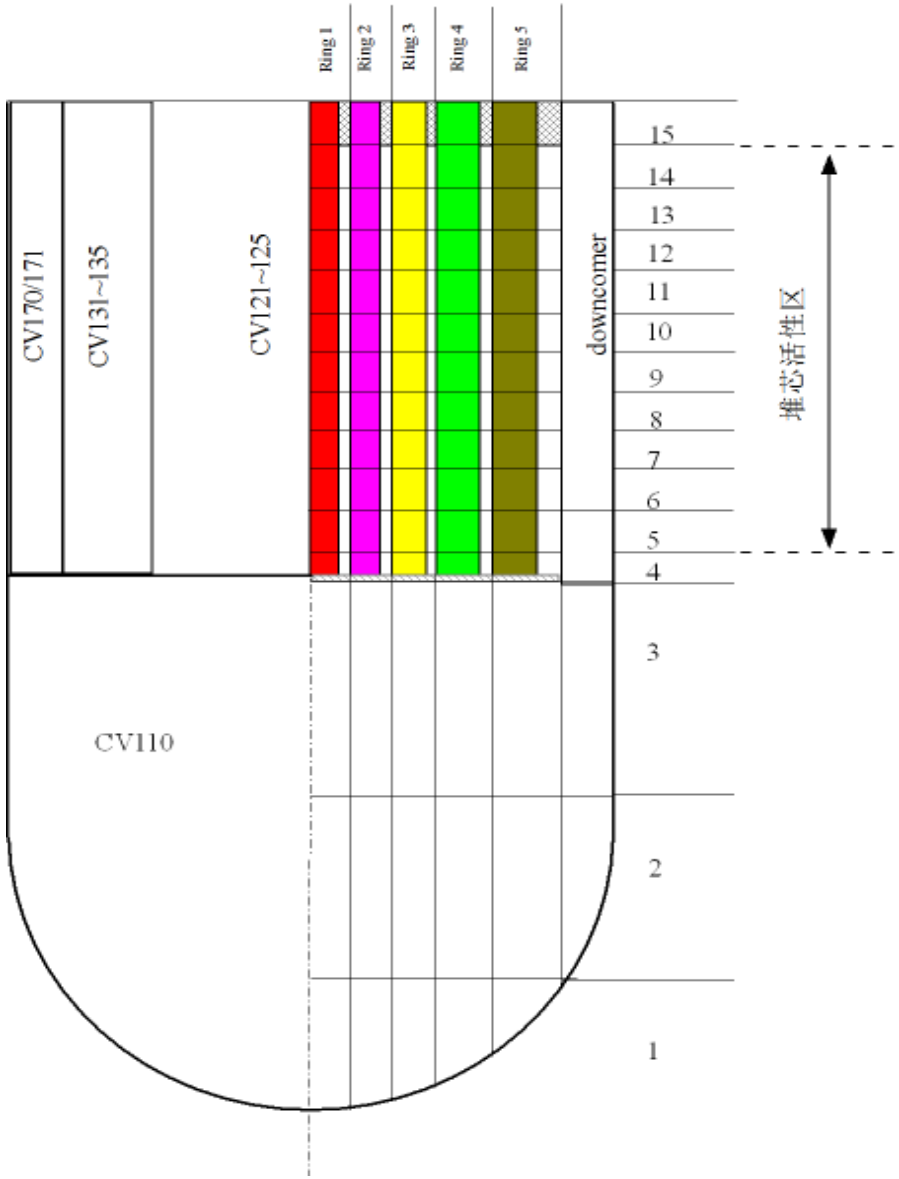


Ring No.	1	2	3	4	5	total
No of fuel assemblies	52	96	80	128	192	548
Flow area in fuel channels,m^2	0. 505	0. 932	0. 777	1. 243	1. 904	5.323
Flow area in bypass,m^2	0.229	0.424	0.354	0.566	3.268	4.841
Control rod number	13	24	20	32	48	137

Reactor core radial cell nodalization

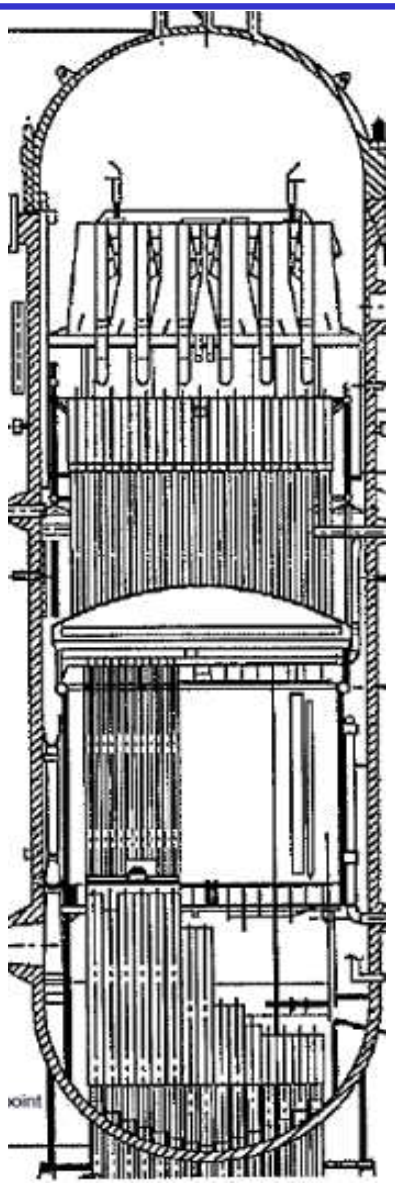
Nodalization of the core cells and CVs

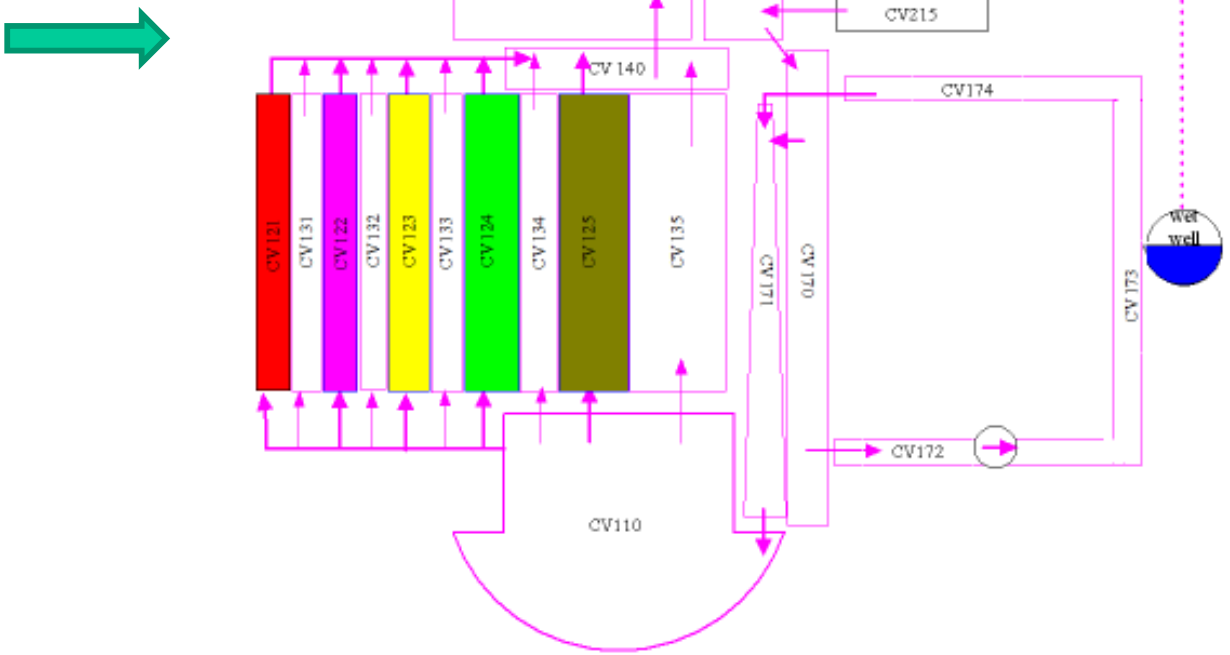
- 15 axial segment& 5 rings in MT
- 77 core cells in total
- 5 core channels& 5 bypass channels



Axial nodalization of Reactor core and lower plenum

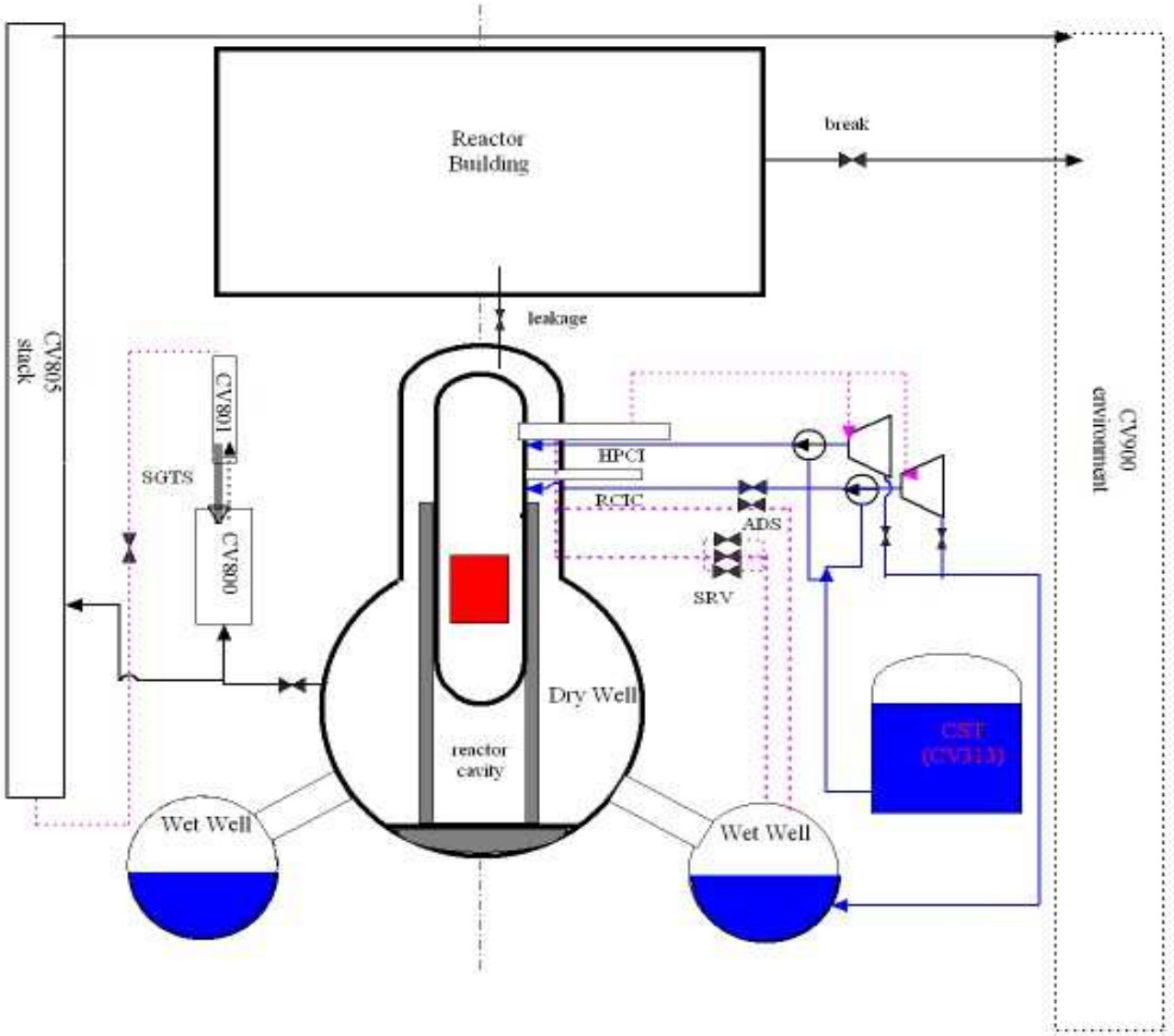
Modeling of the Reactor system





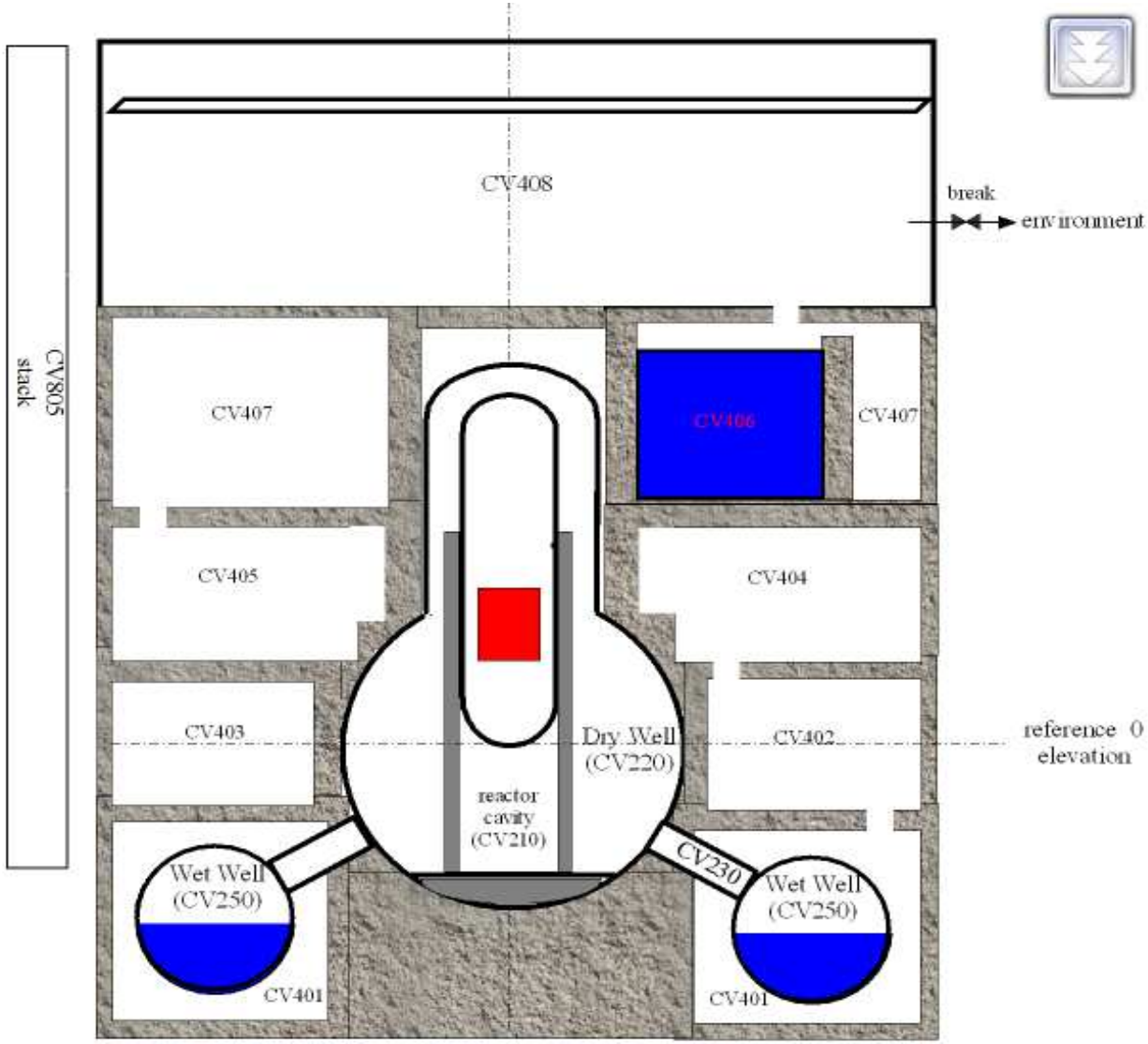
Reactor vessel and primary circuit control volume nodalization

Sketchmap of safety systems



Modeling of safety system which available for action

Modeling of the Reactor Building



Primary&secondary containment nodalization

Specific assumptions for FUKISHIMA I-2 SBO scenario

- Reactor scram completed within 10 s since accident, steam turbine isolated in 2 minutes
- RCIC was active to take steam to drive turbine and pump, and inject cooling water into core during 16~42 min&53min~70.65hr since earthquake
- On march 12th 4:20 am (13.55hr) ,the cooling water source of RCIC changed from CST to wet well
- The first SRV was opened manually at 75.32 hr, and the second SRV was opened manually at 78.55 hr, and closed at 80.22 hr.
- At About 77.12 hr, the fire pump started kept injection into the reactor vessel at flow rate of 10kg /s in case when reactor pressure is lower than 0.60MPa.
- Steam discharge into the wet well through SRV, and no discharge into dry well
- The leakage ratio of containment is set at its design level, when pressure in the containment exceeded its design pressure(0.48 MPa), the leakage ratio will increase 10 times.
- There is an opening between atmosphere of SC and the TORUS room, sensitive analysis will be made depending on different size of opening area.
- No containment vent operation were assumed during first 96 hr

Additional Assumptions in SBO multi-cases simulation

- ***Sensitive study are performed on the impact of :***

1) opening area between SC and TORUS room

2) RCIC stop time

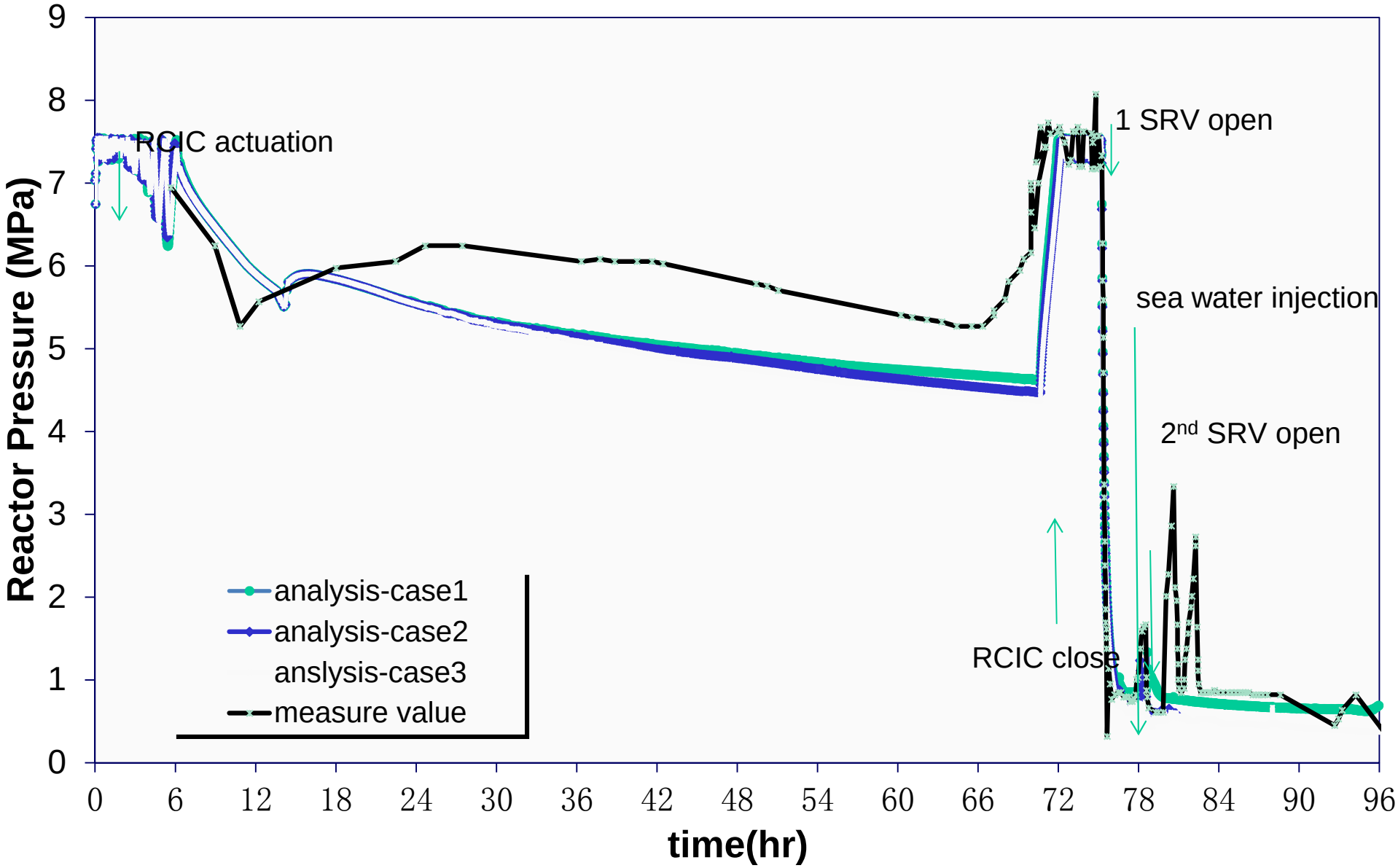
to evolution of severe accident and radioactive source term released

RCIC status / opening size	RCIC stop time=70.65 hr	RCIC stop time=66.80 hr
D=1in	Case 1	Case 4
D=2in	Case 2	Case 5
D=3in	Case 3	Case 6

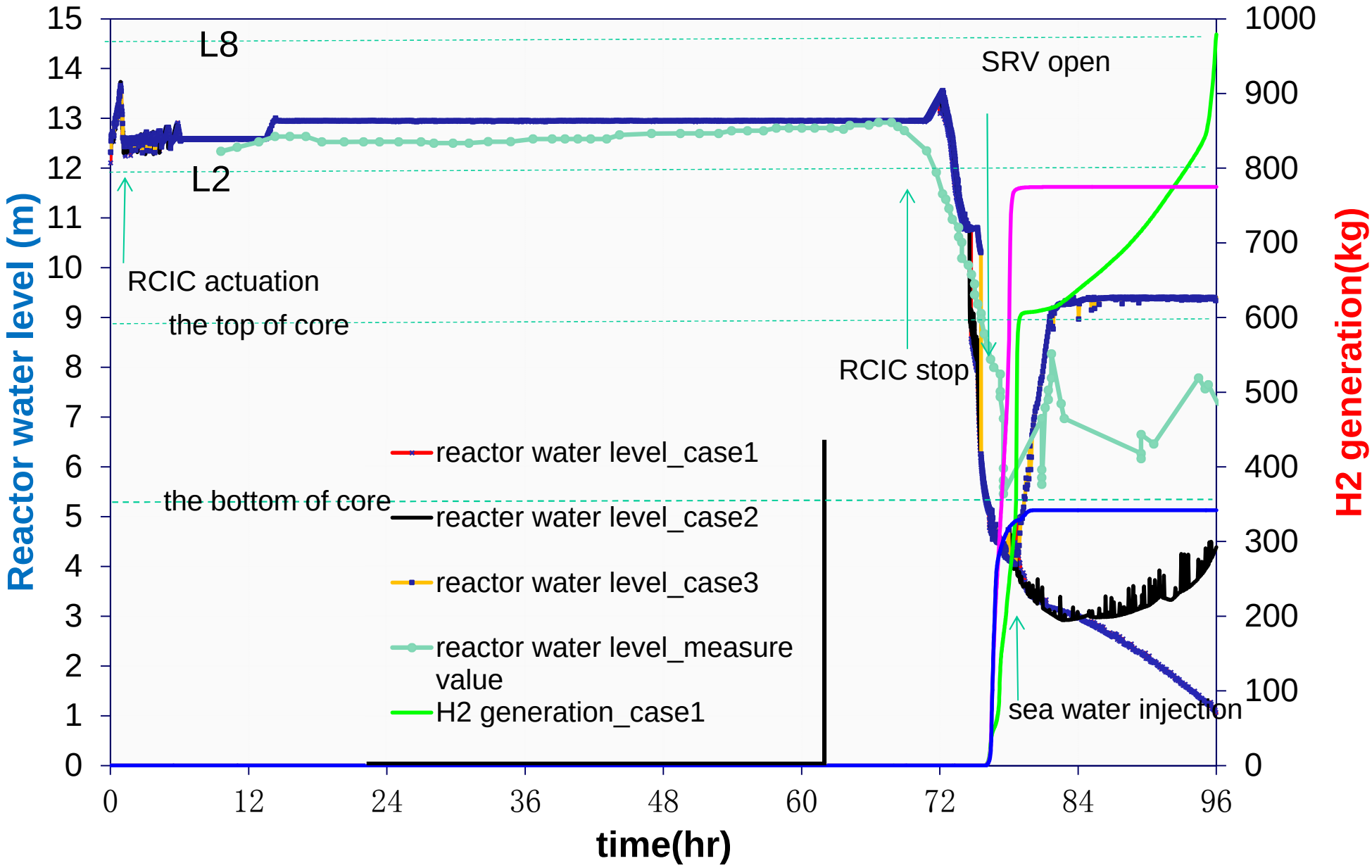
Benchmark of simulated SBO events

LOCAL TIME		Real Time table (hr)	Simulated Time table (hr)	SIMULATION EVENT
3月11日	14:46	0.0	0	EARTHQUAKE
	14:47	0.017	0.003	REACTOR SCRAM
	14:50	0.27	0.27	RCIC manually turned on
	15:28	0.68	0.68	RCIC trip
	15:39	0.87	0.87	RCIC starts
	15:41	0.92	0.9	Station blackout
3月12日	NA	NA	13.55	RCIC suction-wetwell
3月14日	11:36	66.80	70.65/66.80	RCIC stops
	17:17	67.5	72.7	Reactor water level reach TAF
	16:34	73.6	74.4	SRV 1 opens
	NA	73.7	75.8	Water level reach BAF
	NA	NA	76	Zr-steam reaction initiate
	NA	NA	76.03	Repture of fuel claddings
	19:54	77.12	77.12	Seawater injection starts
	21:00	78.55	78.55	SRV 2 opens
	21:20	80.22	80.22	SRV 2 closes

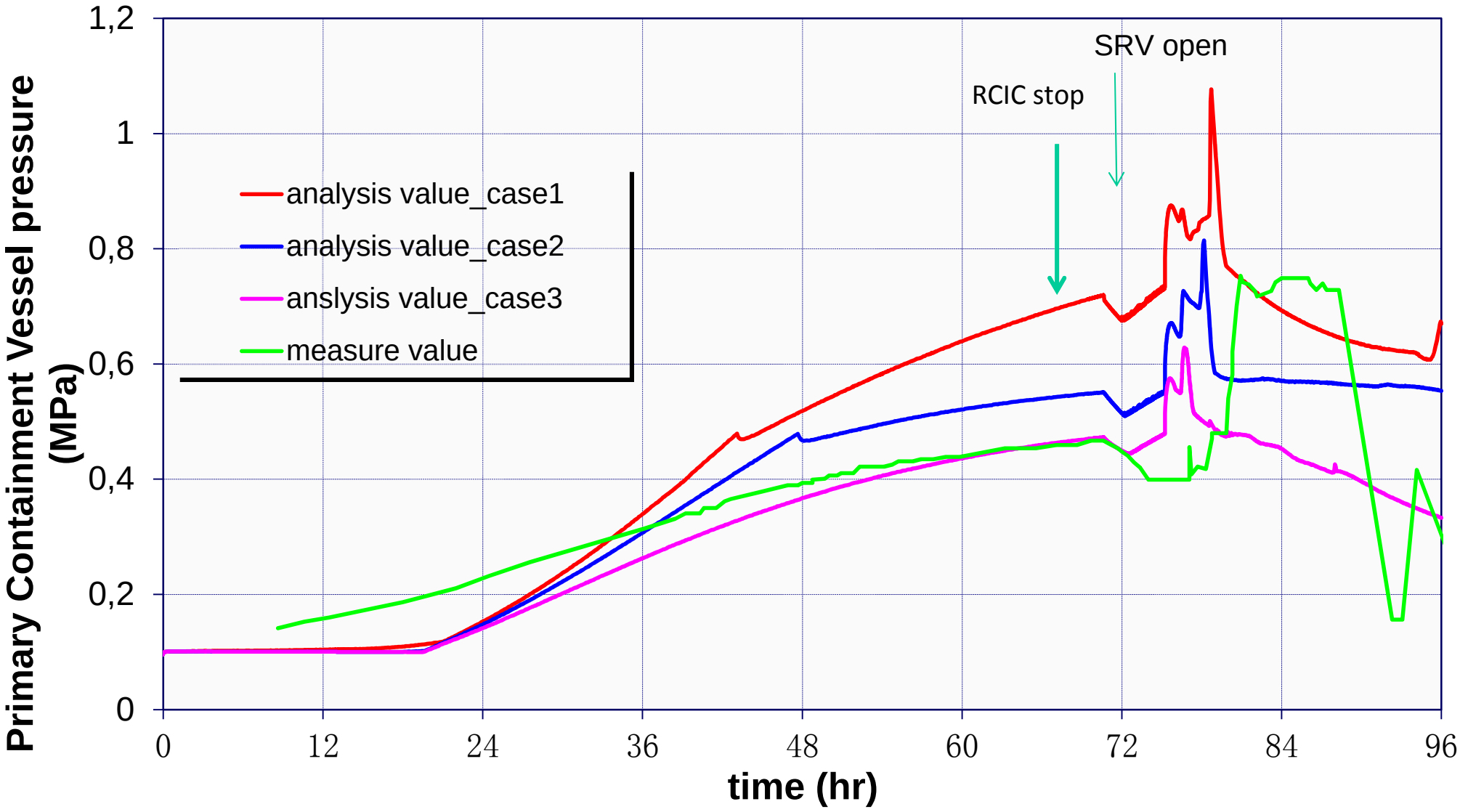
Reactor pressure(case1~3)



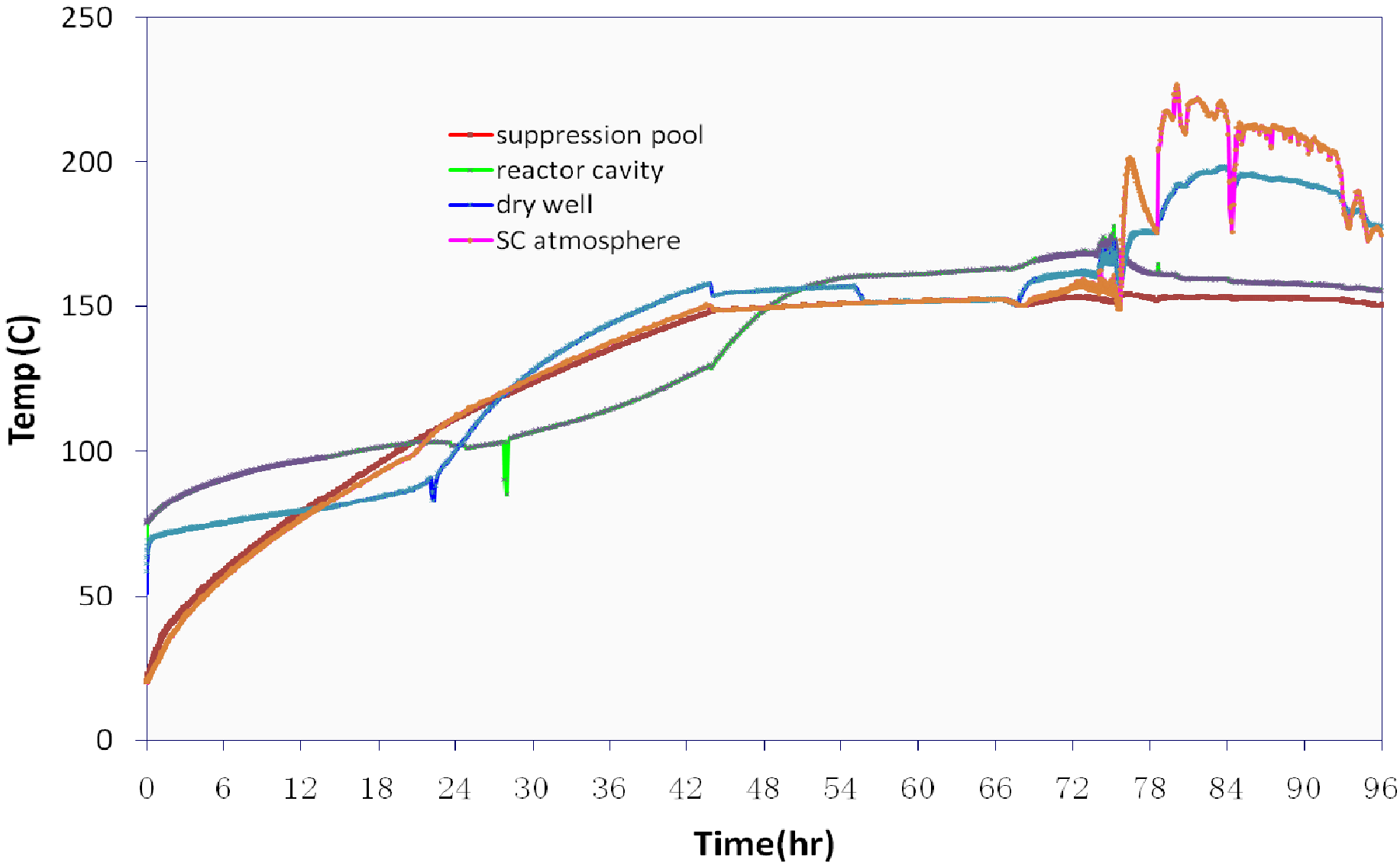
Water level&H2 mass from metal-steam reactor(case1~3)



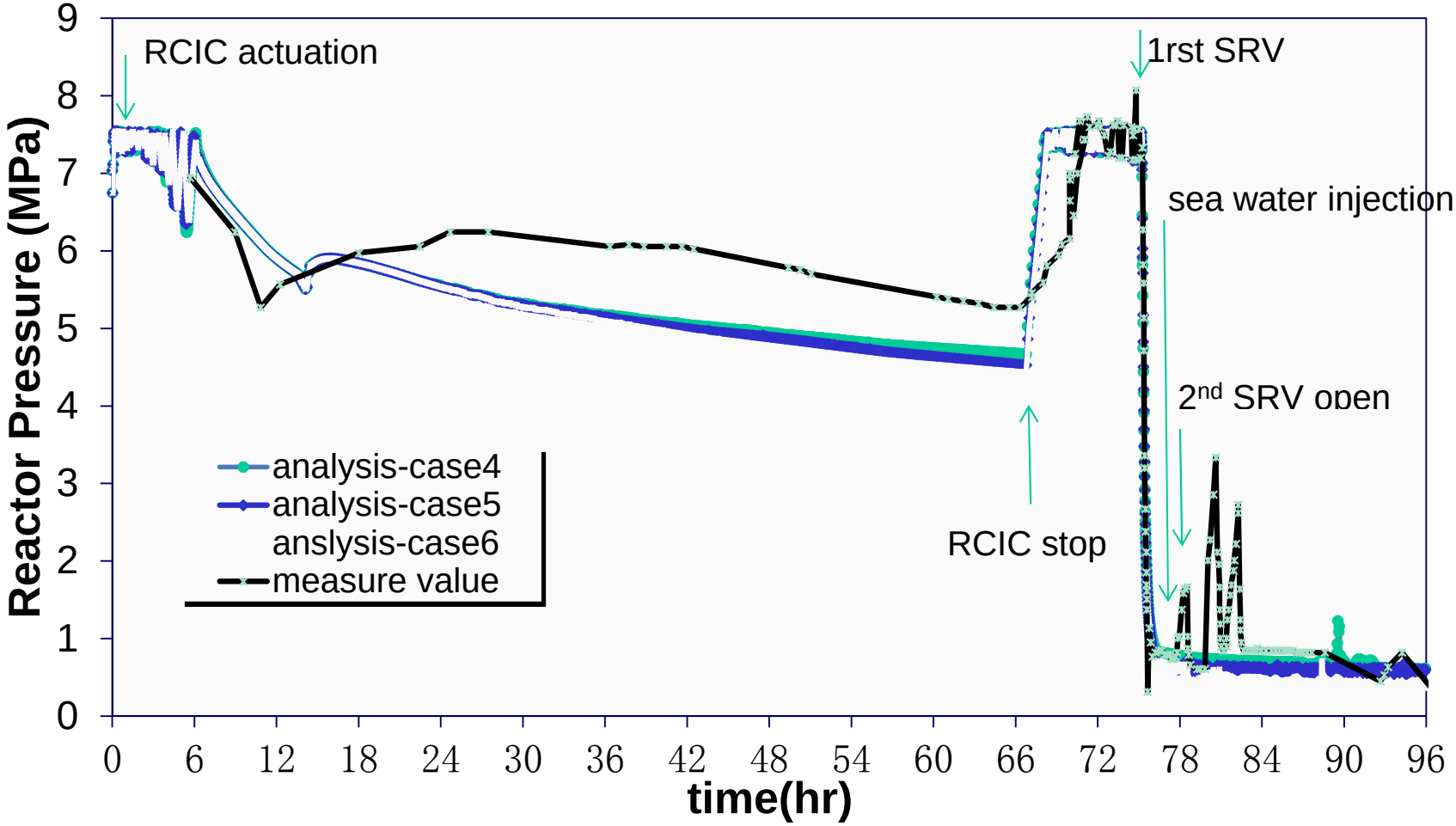
Containment pressure(case1~3)



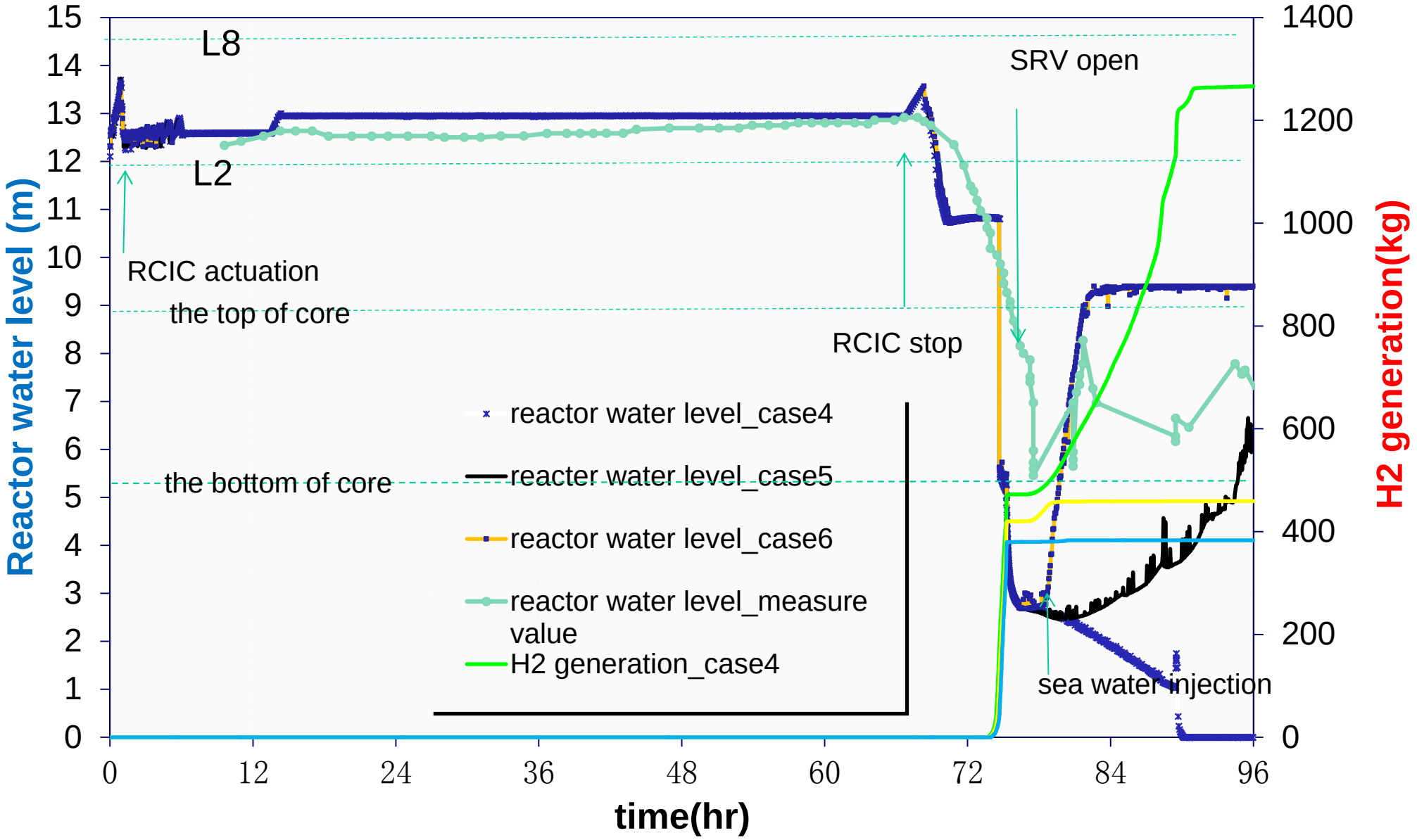
Containment temperature(case1)



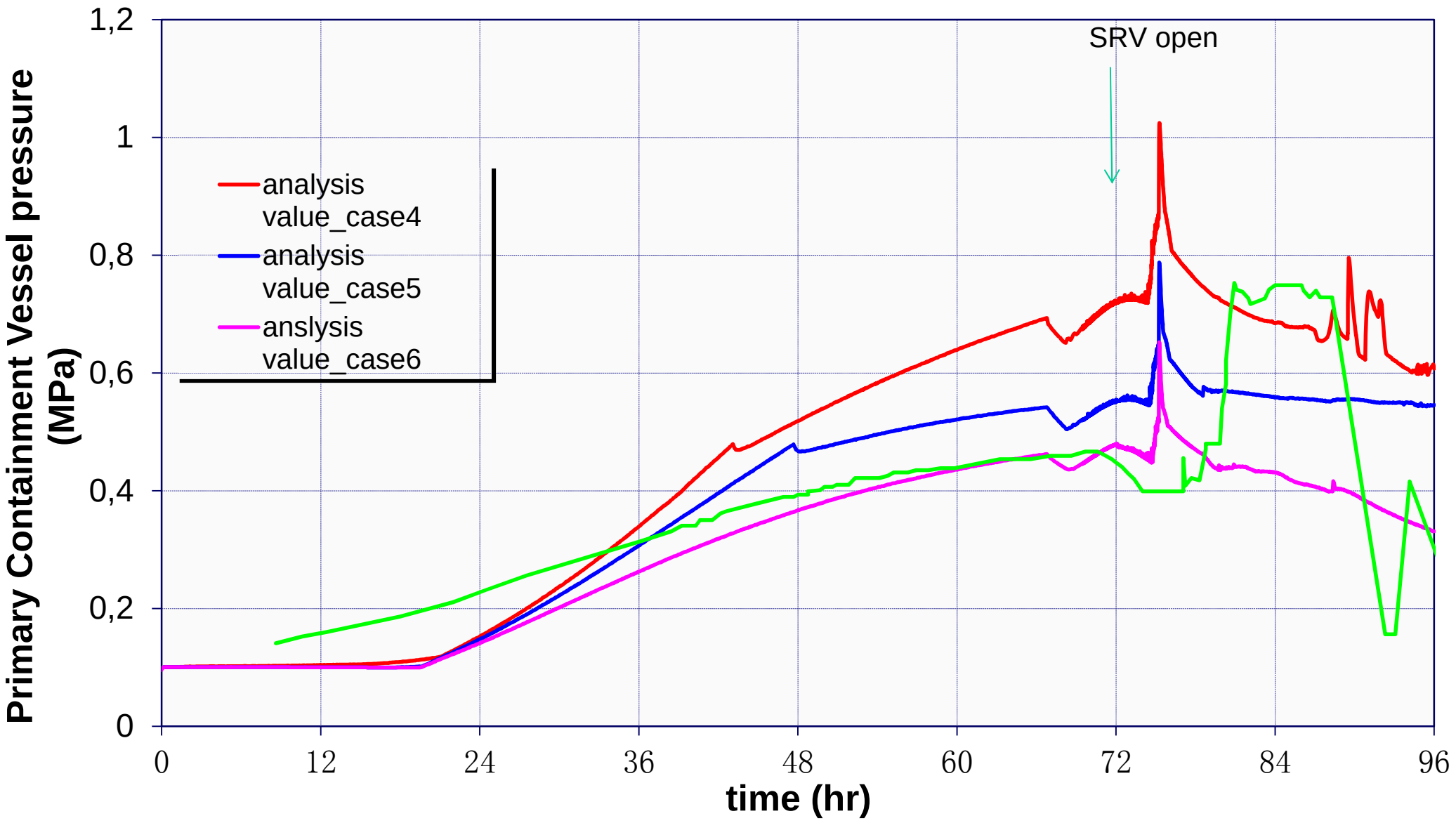
Reactor pressure(case4~6)



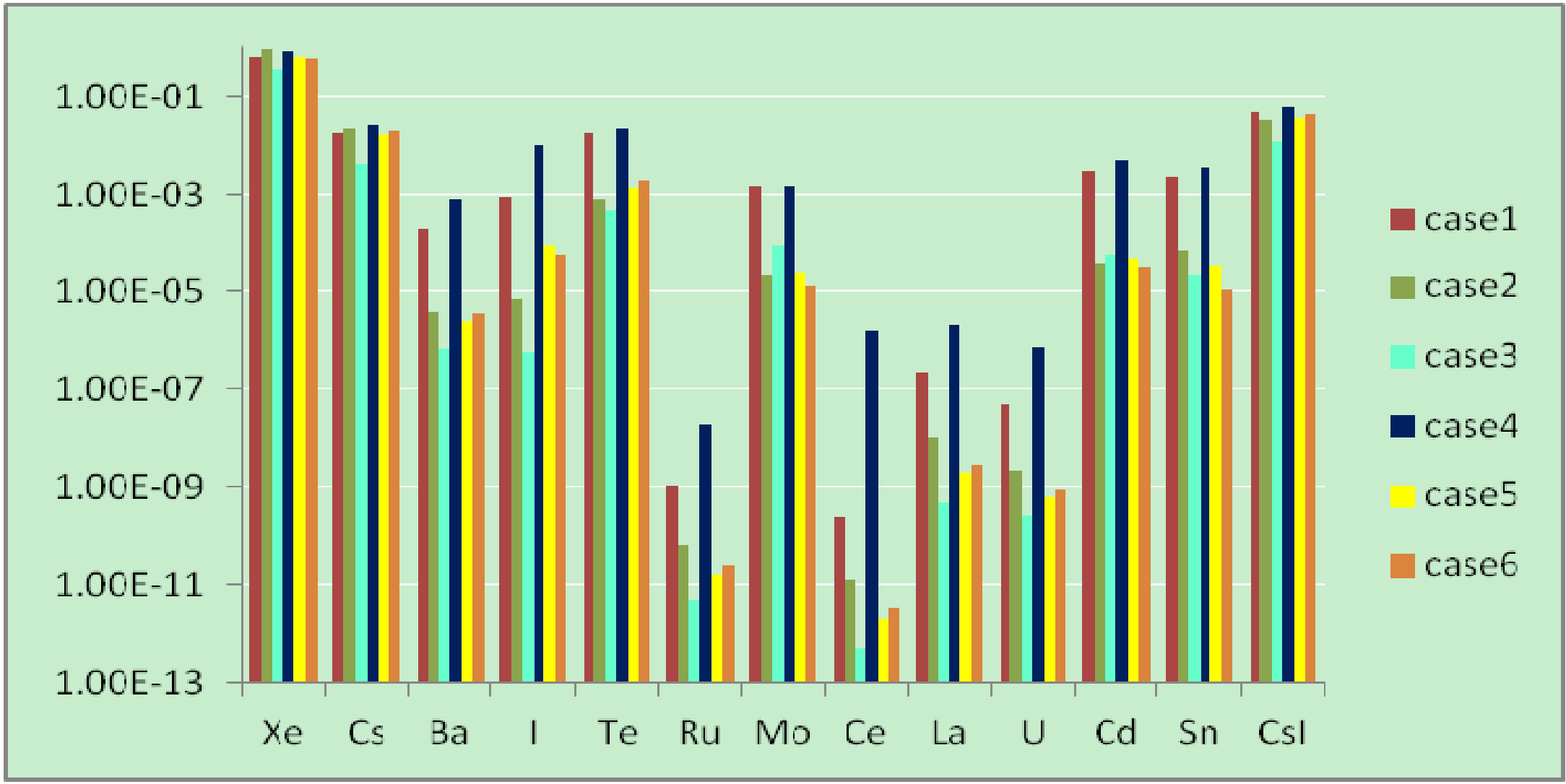
Water level&H2 mass from metal-steam reactor(case4¬6)



Containment pressure(case4~6)



Fraction of Radioactive radionuclide released into environment by 96 hr(case1~6)



Highlighted results of simulation

Value Parameter(unit)	case1	case2	case3	case4	case5	case6
Oxidization fraction of zircaloy(%)	53	44	18	64	25	21
Time of deflagration occurred	80.6	90.3	N/A	79.7	76	80.1
First release time of FP from clading	76	76.1	76.1	73.8	73.9	74
Total mess of H2 generaction	970	775	340	1279	460	380
Failure time of vessel(hr)	N/A	N/A	N/A	90.8	N/A	N/A
Failure time of support plant(hr)	N/A	N/A	N/A	80	N/A	N/A

Discussion and Outlook

- the MELCOR has generally good performance on simulation of full range of accident evolution trend, except for its limitation on modeling of bubble physics in subcooled pool and work & condensing process of steam in RCIC system.
- The early exhaust of CST water make RCIC cooling water source switch to Suppression Pool, and become gradually unavailable when SC water turned saturated, finally lead to core uncovered from boiling off.
- Around 2 hrs before the cooling water by fire pump was able to be injected into the reactor, the core damage started at around 75 hr and get degraded severely within 2 hrs.

Discussion and Outlook(cont'd)

- The containment has high possibility of connected to the environment with big opening area from the beginning, but most of the FP aerosol phase was discharged through SRV and retained within suppression pool successfully. And owing to this reason, the mitigation of the radioactive risk to environment was fulfilled.
- Fukushima accident event progression and plant response could be a very good reference example and have higher requirements for PSA people to make improvement on current studies (f.e. extend accident progression analysis from 24 hours to several days, screening of external events more carefully)
- With more information of plant details available, more complex nodalization will be employed in the SA simulation, and more sensitive and uncertainty analysis will be performed, to reproduce the plant severe accident evolution in a more reasonable way.