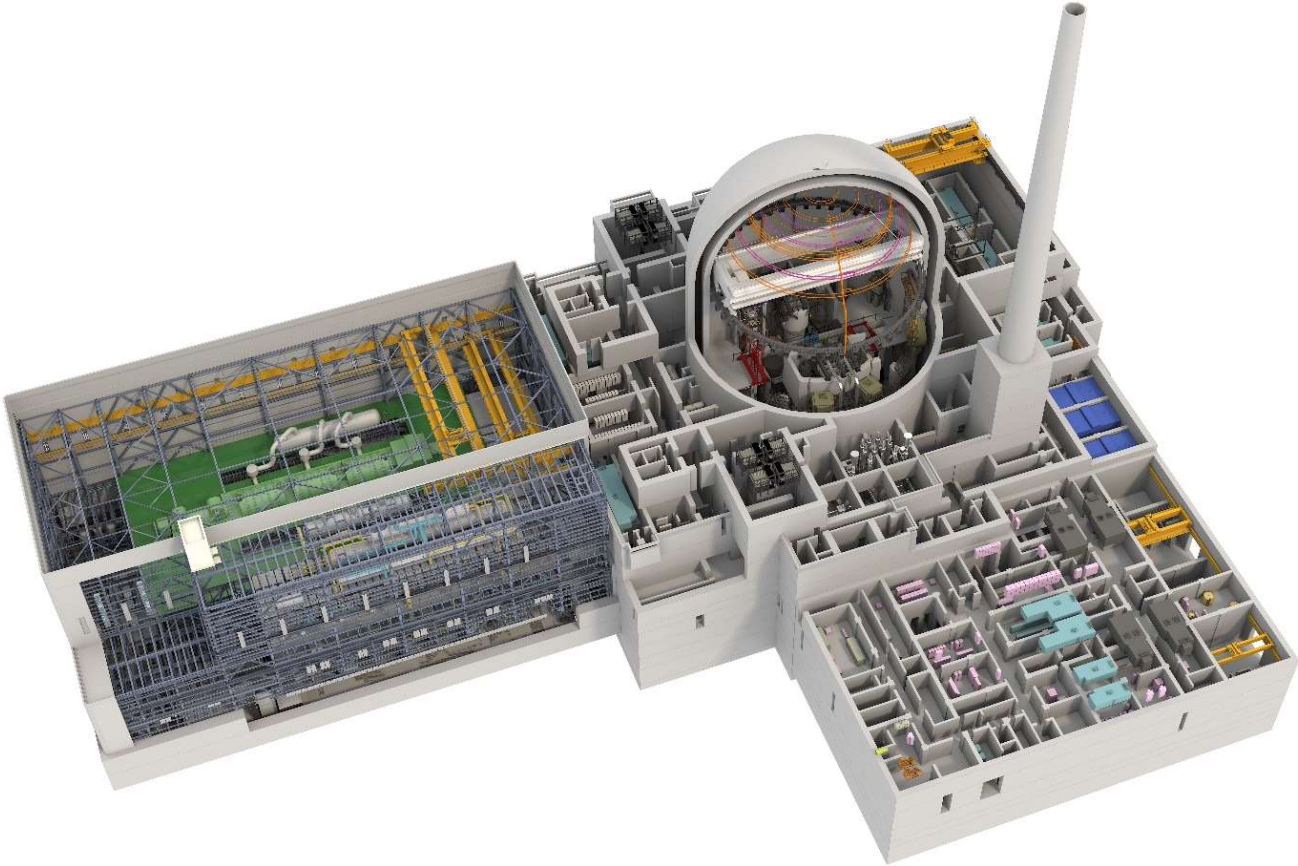
Special Session for APR1000 European Utility Requirement Assessment and Certification focusing on Lessons Learned

APR1000 NSSS Design and EUR Assessment



May 17, 2023

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NSSS Division

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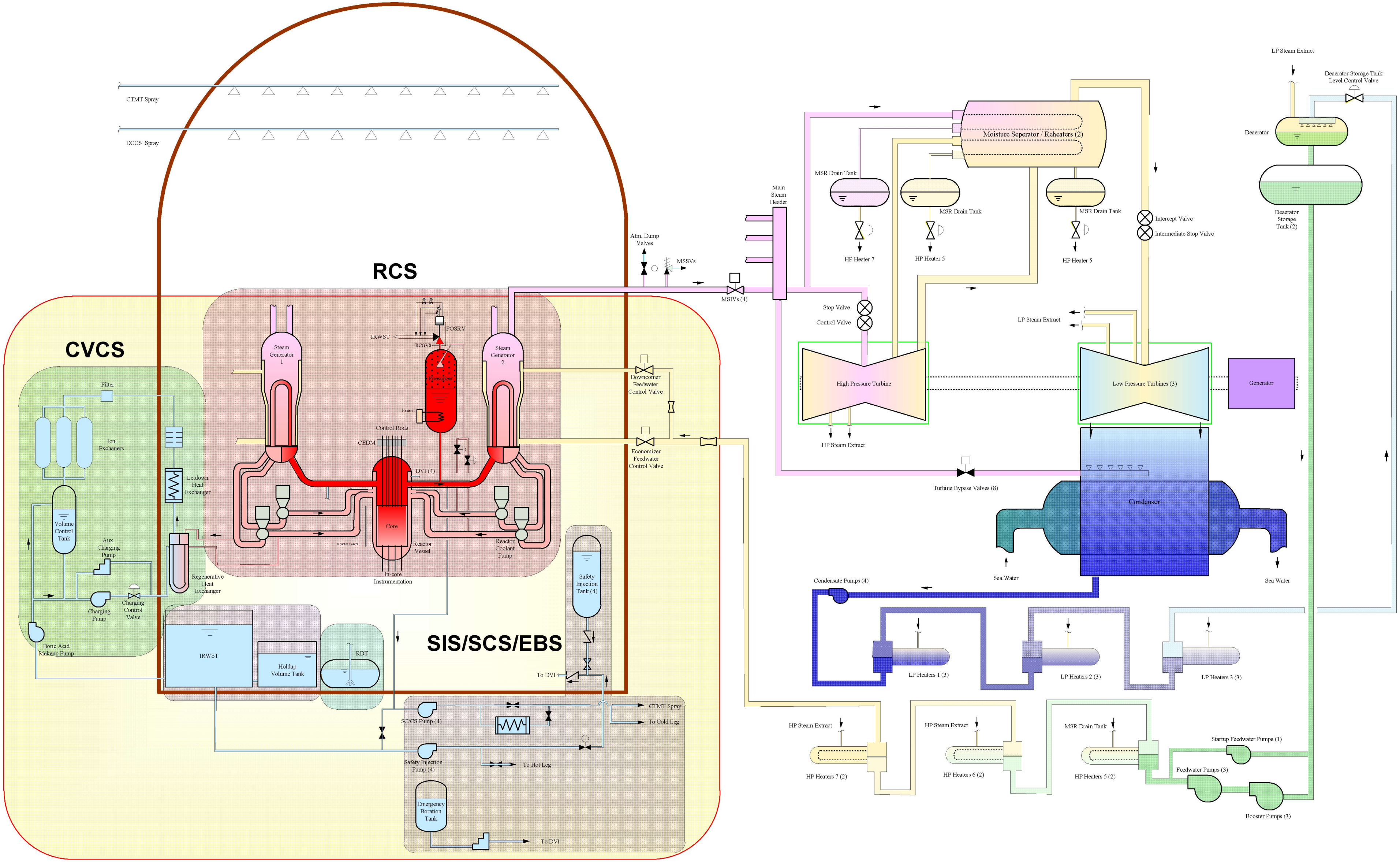
I.1 Nuclear Steam Supply System (NSSS)

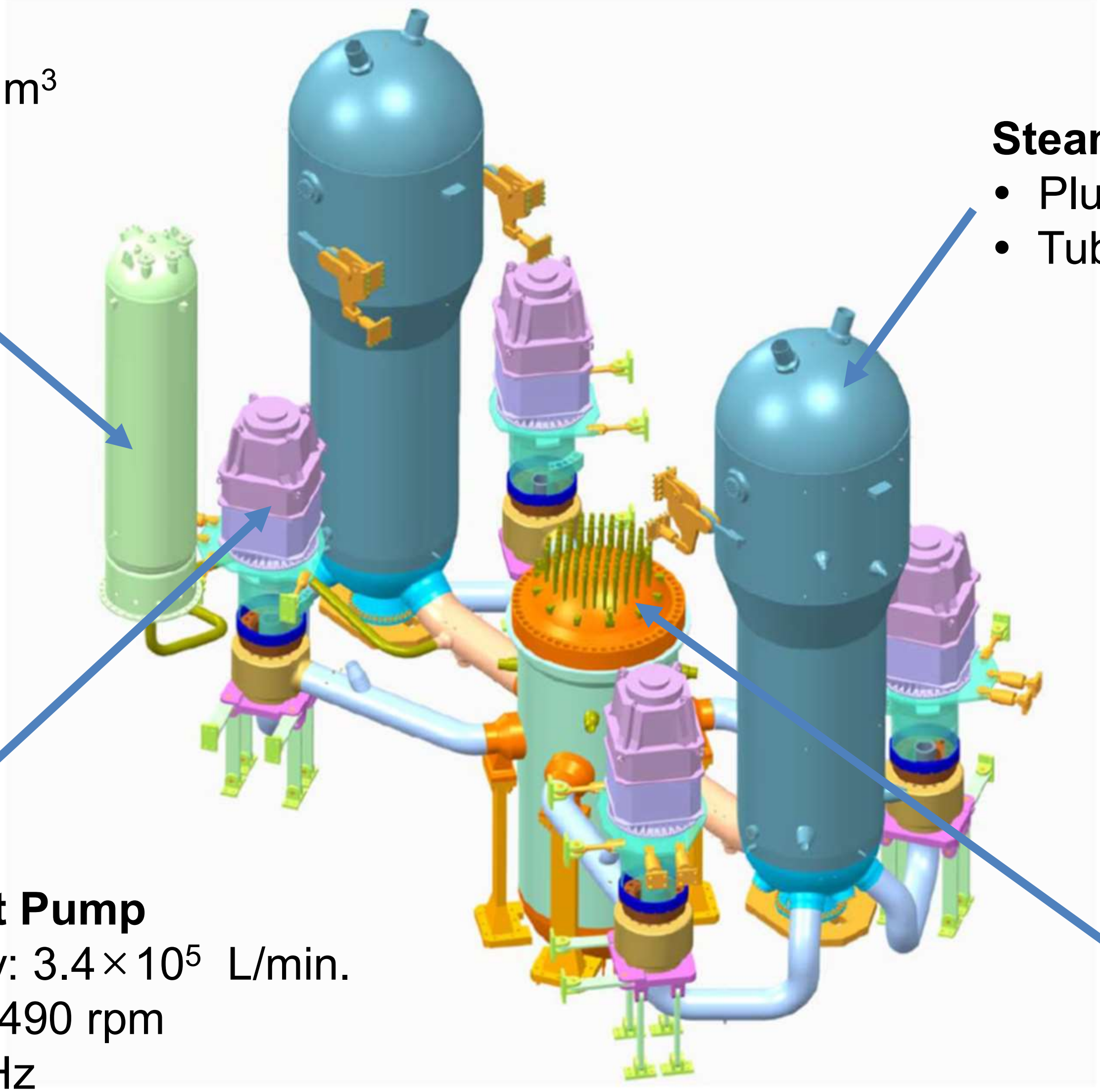


I.2 Reactor Coolant System (RCS)

- RCS Configuration

Pressurizer
- Free Volume: 51 m^3
- 158.2 kg/cm^2A
- POSRV
- ERDS

Steam Generator
- Plugging Margin : 10%
- Tube Material : Inconel 690



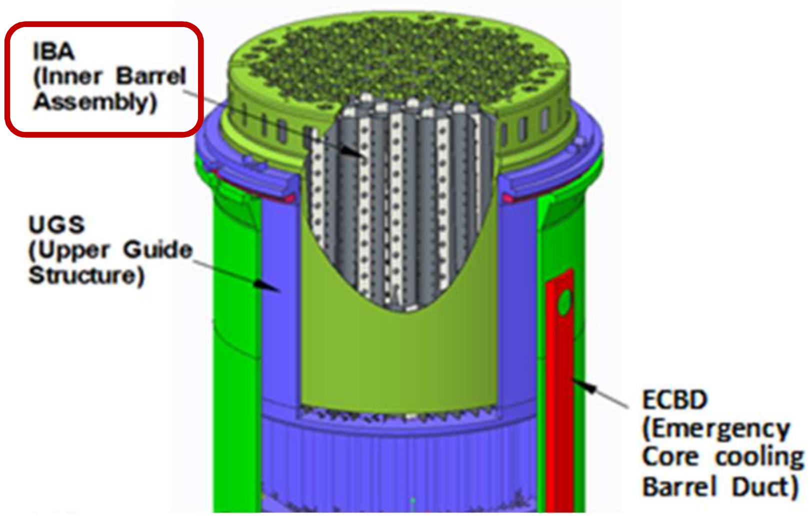
Reactor Coolant Pump
- Design Capacity: 3.4×10^5 L/min.
- Rated speed: 1,490 rpm
- Frequency: 50 Hz

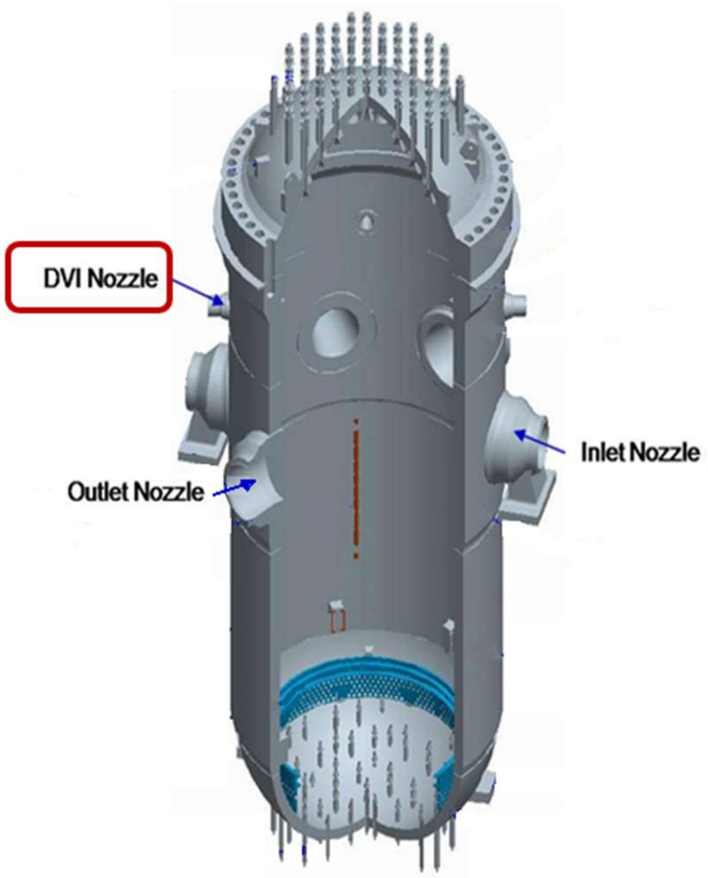
Reactor Vessel
- 4 train DVI
- 2 Hot Leg
- 4 Cold Leg

I.3 Reactor Pressure Vessel

Item	OPR1000	APR1400	APR1000
Direct Vessel Injection* Nozzle	None	4 EA	4 EA
Inner Barrel Assembly (IBA)	Top Hat + CEA Shroud Assembly (Bolting)	IBA (Welding)	IBA (Welding)

* **DVI for effective use of safety injection flow under cold leg break LOCA**



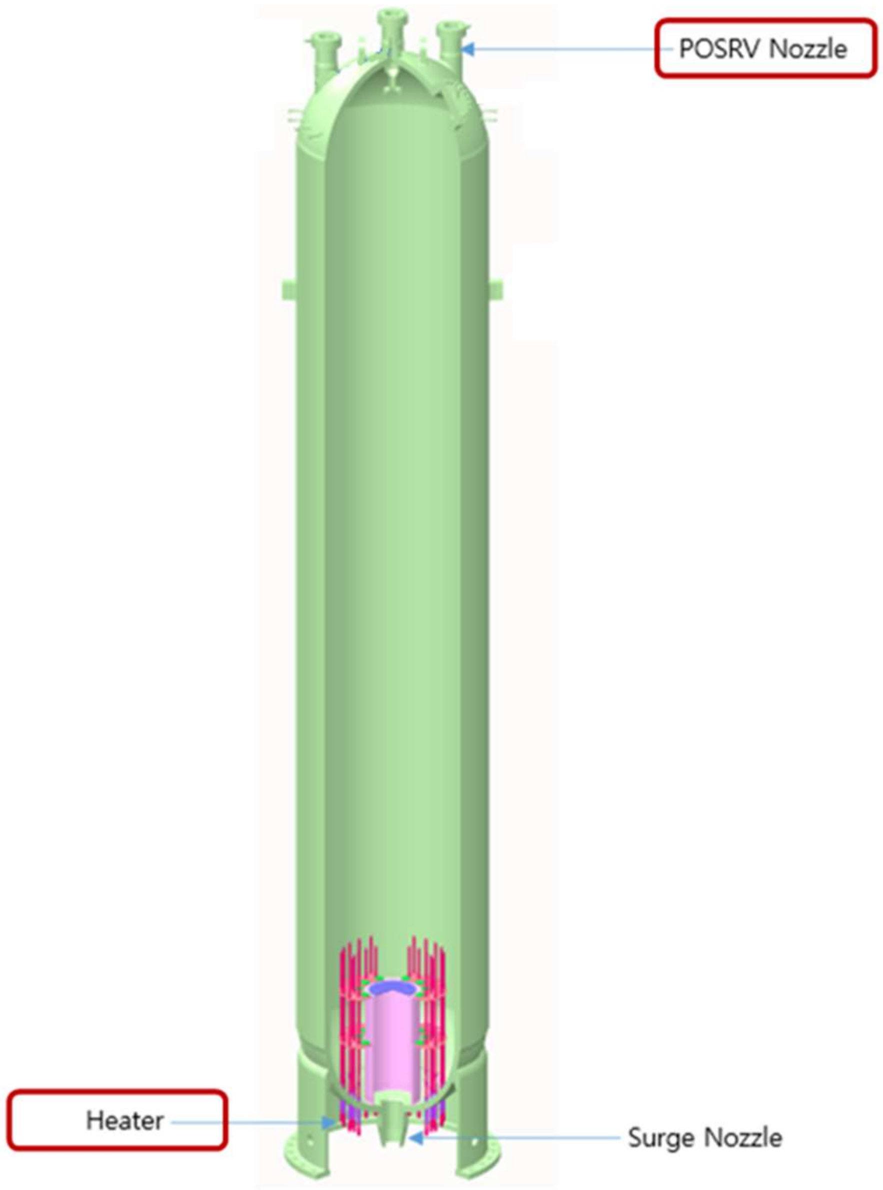


I.4 Pressurizer

Item	OPR1000	APR1400	APR1000
Q'ty of Safety Valve Nozzles	3 EA	4 EA	3 EA
Safety Valve	PSV / SDS	POSRV	POSRV
Q'ty of Heaters	36 EA	48 EA	48 EA
Free Volume (m^3)	51	68	68 *
Heater Capacity (kW)	1,800	2,400	2,400 *

*** Pressurizer Volume and Heater Capacity**

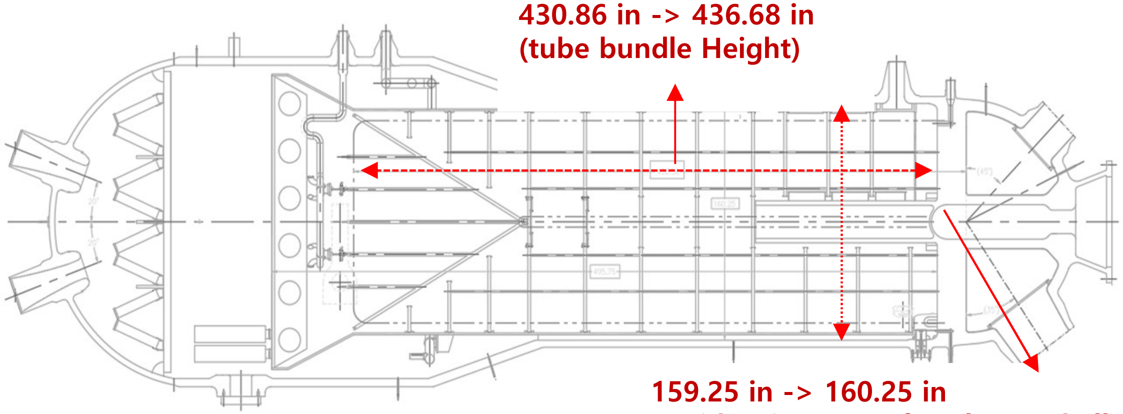
- Increased buffer volume as APR1400 considering POSRV response time during transient events

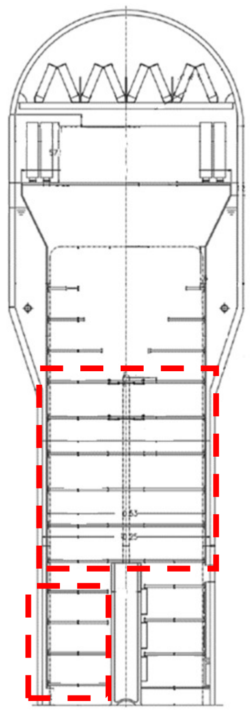


I.5 Steam Generator

- To meet the EUR Rev. E, 10 % tube plugging margin
  - SG U-Tube and Tube Support Design(Eggcrate) Changed

Steam Generator	OPR1000	APR1000	Remark
Quantity of Total Tubes	8,340	8,471	+131
Quantity of Tubes (For Design Plugging Condition)	7,635 (8% T.P.)	7,585 (10% T.P.)	-50

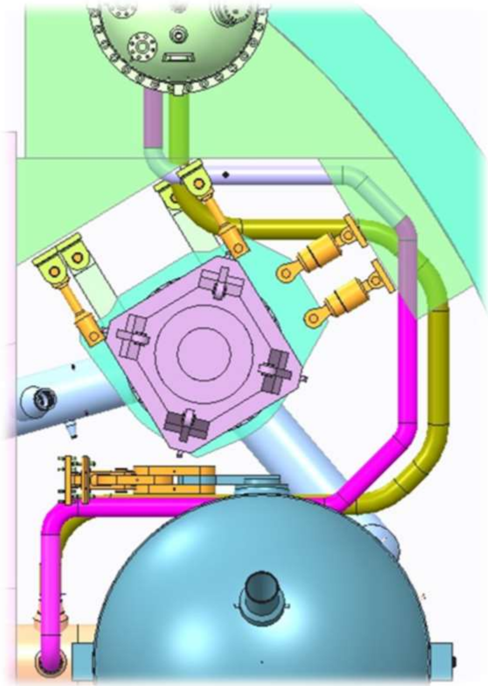


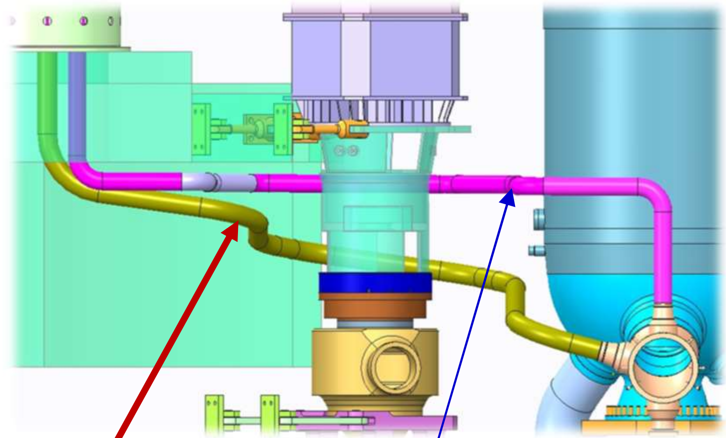


I.6 Surge Line

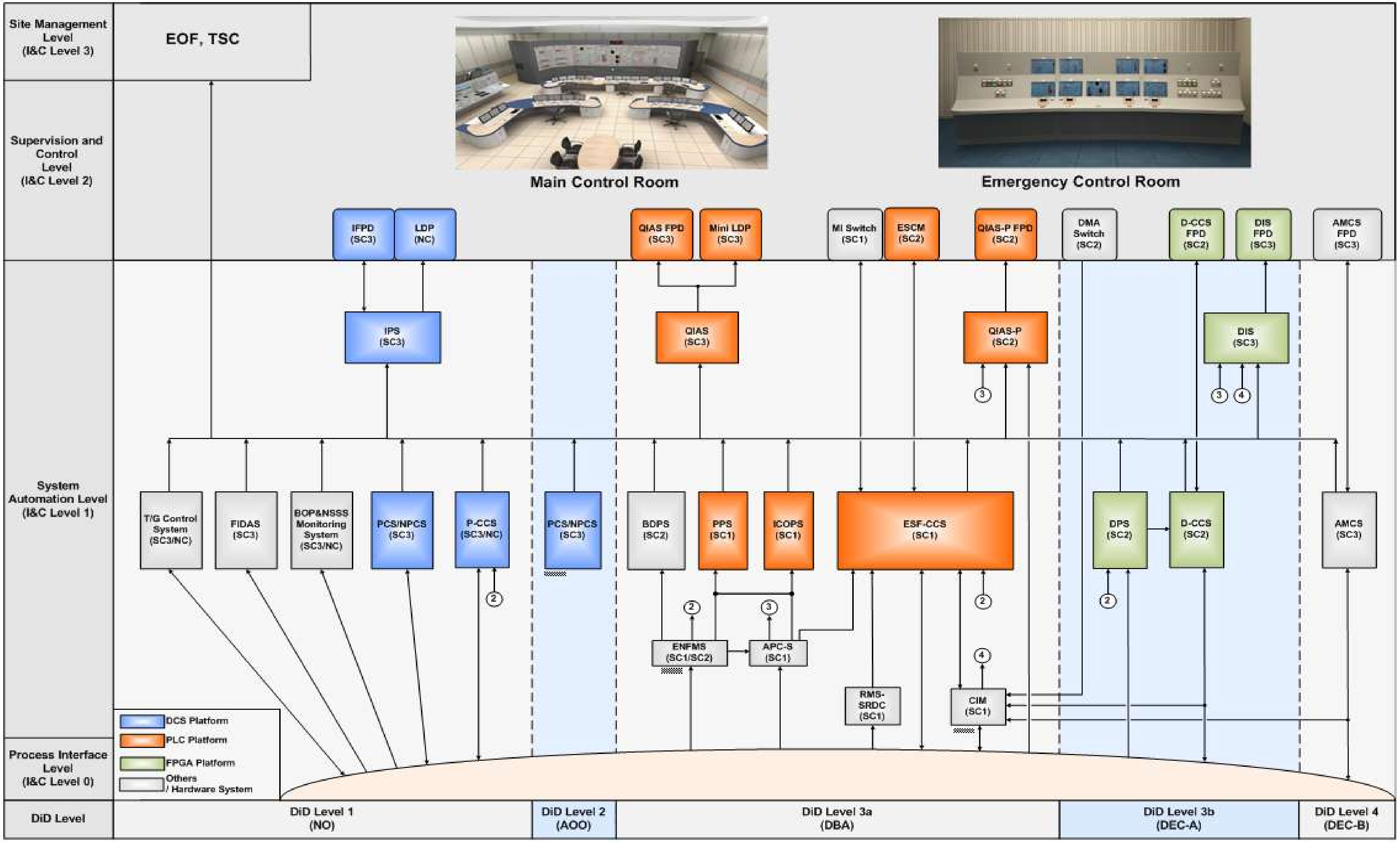
- Necessity for Design Changes of the Surge Line
  - To satisfy EUR Rev. E → Increasing slope
  - To satisfy LBB requirement and secure RCS safety margin → Increasing pipe size

- Major Design Changes of the Surge Line
  - Routing Slope and Curvature
    - ✓ Slope : 90°/ 0.3° → 15°/ 8°
    - ✓ Radius of Curvature: 1.5D → 3.0D
  - Increasing Pipe Size
    - ✓ Diameter: 12” SCH160 → 14” SCH160





I.7 I&C Architecture



NOTE

1) THE PCS/NPCS are used for normal operation and also handle some DiD Level 2 events for limitation function (mainly by RPCS, FWCS, SBCS).
2) The CIM related to the HVAC systems, hydrogen monitor isolation valves, and supporting system is only hardwired to the AMCS via the qualified isolators.
3) The ENFMS SC2 is interfaced with the BDPS.

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II.1 Event Categorization and Acceptance Criteria

Levels of DiD		Categorization		Event Frequency (/RY)	Physical Barrier Acceptance Criteria [1]			Radiological Acceptance Criteria
					Fuel	RCS	CTMT	
Level 1		NO		-	Maintain fuel integrity	$< P_{Design\_RCS}$	$< P_{design\_CTMT}$	0.1 mSv/yr
Level 2		AOO		$10^{-2} < F \le 10^{0}$	Maintain fuel integrity	$< 1.1\ P_{Design\_RCS}$	$< P_{design\_CTMT}$	0.1 mSv
Level 3	3a	DBA	DBA 1	$10^{-4} < F \le 10^{-2}$	Fuel failures accepted. Core coolable geometry retained	$< 1.1\ P_{Design\_RCS}$	$< P_{design\_CTMT}$	1 mSv
			DBA 2	$10^{-6} < F \le 10^{-4}$				5 mSv
	3b	DEC-A	Multiple failure	$10^{-6} < F \le 10^{-4}$	Fuel failures accepted. Core coolable geometry retained	$< 1.25\ P_{Design\_RCS}$	$< P_{FLC\_CTMT}$	10 mSv
Level 4		DEC-B	Severe Accident [2]	$F \le 10^{-6}$	N/A[3]	N/A[3]	$< P_{FLC\_CTMT}$	50 mSv (3km, 7d) 10 mSv (5km, 2d) 10 mSv (5km, 7d, I) 100 mSv (800m, 50y after end of release)

1) Applies to reactor accidents. (Only fuel and radiological criteria are applied for spent fuel accident. Only radiological criteria are applied for other accidents.)
2) Events that are practically eliminated shall demonstrate that their occurrence is either physically impossible or extremely unlikely.
3) No criteria is necessary since the core is in melting condition.

II.2 Event List of Anticipated Operational Occurrence (AOO)

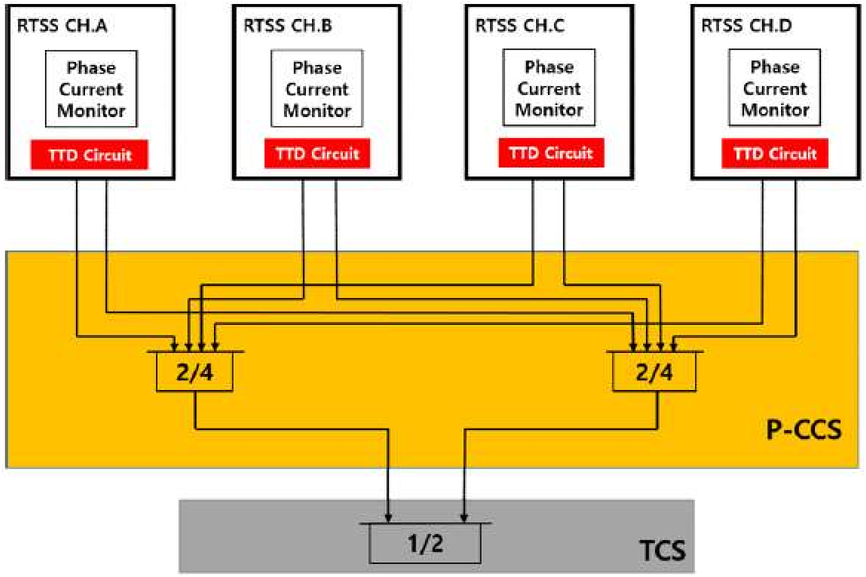
- AOO (20)

No.	Event List
1	Decrease in Feedwater Temperature
2	Increase in Feedwater Flow
3	Increase Main Steam Flow
4	Inadvertent Opening of a SG Relief or Safety Valve
5	Loss of External Load
6	Turbine Trip
7	**Loss of Condenser Vacuum**
8	Main Steam Isolation Valve Closure
9	Loss of Non-Emergency AC Power to the Station Auxiliaries
10	Loss of Normal Feedwater Flow
11	Loss of Reactor Coolant Flow
12	Single Control Element Assembly Drop

No.	Event List
13	**Single Control Element Assembly Withdrawal**
14	Uncontrolled Control Element Assembly Withdrawal From Subcritical or Low Power Conditions (with Loss of Offsite Power)
15	Uncontrolled Control Element Assembly Withdrawal at Power (with Loss of Offsite Power)
16	Start-up of an Inactive Reactor Coolant Pump
17	Inadvertent Loading of a Fuel Assembly into the Improper Position
18	Inadvertent Operation of the Emergency Core Cooling System (ECCS)
19	Pressurizer Level Control System (PLCS) Malfunction (with a Loss of Offsite Power)
20	**Inadvertent boric acid dilution**

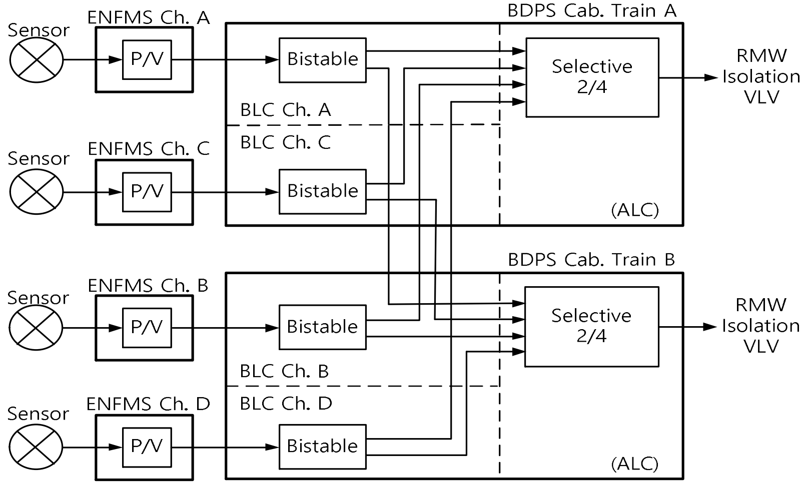
II.2-1 Turbine Trip Delay System (TTDS)

- Function
  - Safety system to cope with single Control Element Assembly (CEA) withdrawal event
  - The RTSS consists of four (4) independent channels each of which includes the Control Element Drive Mechanism (CEDM) phase current monitoring devices and the turbine trip delay function circuitry for turbine trip delay function.
  - The three (3)-second TTD signal is generated through the TTD circuit in each channelized RTSS cabinet when the status of the phase current monitoring becomes “low” following a reactor trip.
  - The TTD signal is then transmitted to the Turbine Control System (TCS) via the Process-Component Control System (P-CCS) where the 2-out-of-4 logic is performed.

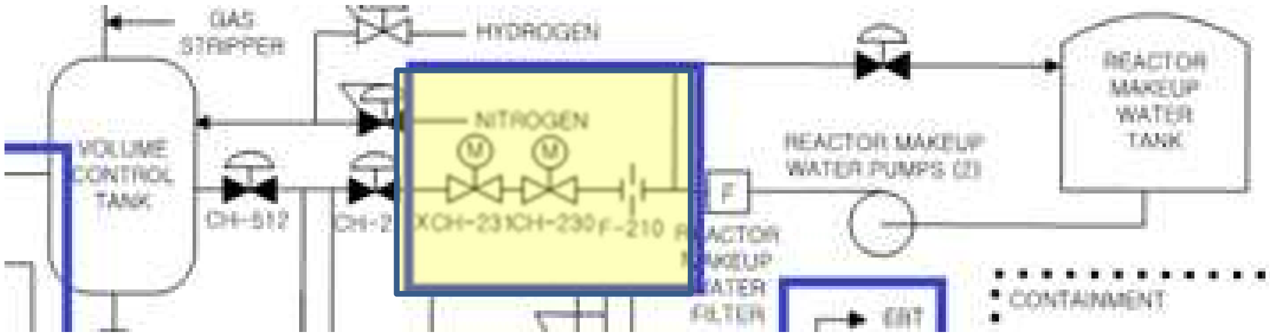


II.2-2 Boron Dilution Prevention System (BDPS)

- Function
  - Detect an inadvertent boron dilution event by monitoring Excore Neutron Flux Monitoring System (ENFMS) neutron flux signal.
  - When this neutron flux signal increases to equal to or greater than the calculated trip setpoint, boron dilution prevention signal is generated to isolate reactor makeup water which flows into charging pumps.



ALC: Actuation Logic Circuit
BLC: Bistable Logic Circuit



II.2-3 Safety Analysis Results for AOO

- Loss Of Condenser Vacuum (LOCV) selected as a limiting event in AOOs with regard to system peak pressure and radiological consequences
- Conclusion
  - The RCS & SG peak pressure: <110% of design pressure
  - Fuel Integrity: No DNBR
  - Radiological consequence: < 0.1 mSv

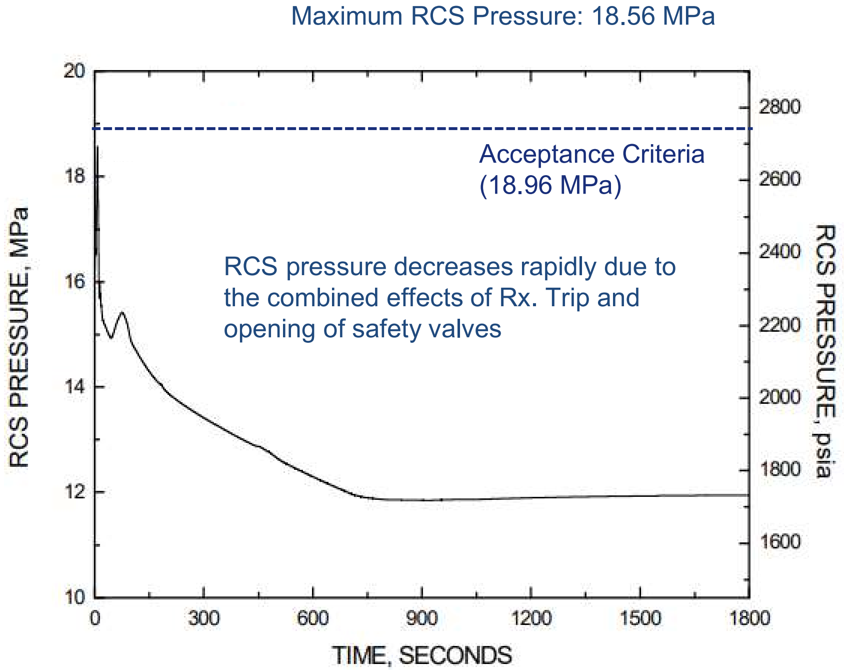


Fig. 1 RCS Pressure vs Time

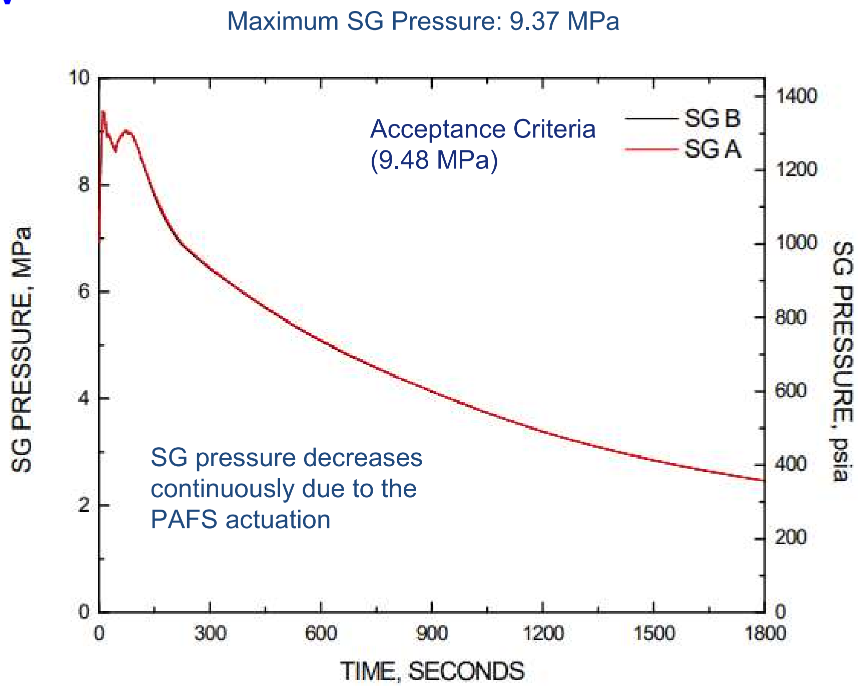


Fig. 2 SG Pressure vs Time

II.3 Event List of Design Basis Accident (DBA)

- DBA 1 (10)

No.	Event List
1	Inadvertent Opening of a Pressurizer Safety Valve
2	One Steam Generator Tube Rupture (with simultaneous Loss of Off-site Power)
3	Double-Ended Break of a Letdown Line Outside Containment
4	Loss of reactor coolant (small pipe break)
5	Small secondary pipe break
6	Rupture of volume control tank
7	Rupture of gaseous waste hold-up tank
8	Failure of liquid waste effluent tank
9	Total loss of off-site power (up to 72 hours)
10	**AOO event with delayed scram**

- DBA 2 (8)

No.	Event List
1	Main Steam-line break
2	**Main Feedwater line break**
3	Reactor Coolant Pump locked rotor or shaft break
4	Single CEA Ejection
5	Loss of reactor coolant up to and including double-ended guillotine failure of largest RCS pipe
6	Fuel Handling Accident
7	Two Steam Generator Tube Ruptures (SGTR) with previous iodine spiking with a simultaneous Loss of Off-site Power
8	Spent fuel cast drop accidents

II.3-1 Safety Analysis Results for DBA 1

- LOCV with delayed scram Selected as a limiting event in DBA 1 with regard to system peak pressure
- Conclusion
  - The RCS & SG peak pressure <110% of design pressure

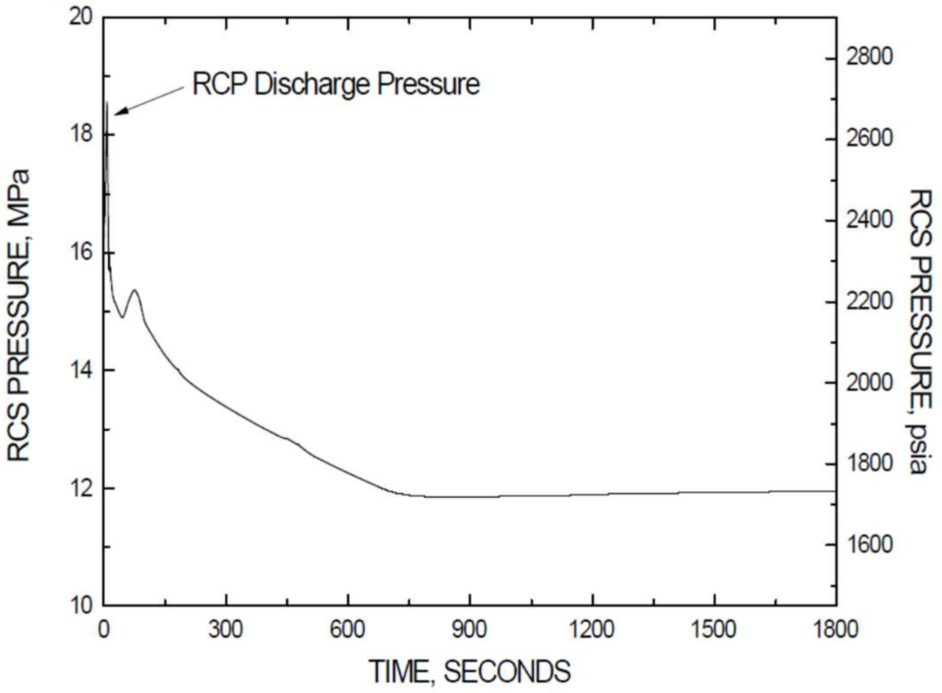


Fig. 1 RCS Pressure vs Time

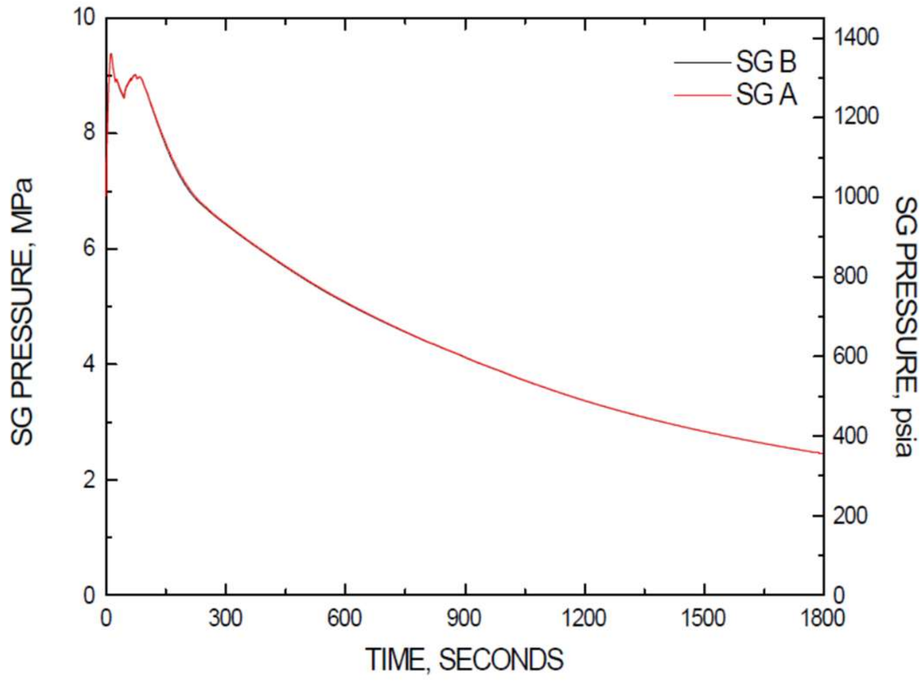


Fig. 2 SG Pressure vs Time

II.3-2 Safety Analysis Results for DBA 2

- FLB selected as a limiting event in DBA 2 with regard to system peak pressure
- Conclusion
  - The RCS & SG peak pressure <110% of design pressure
  - Minimum DNBR > SAFDL of 1.25

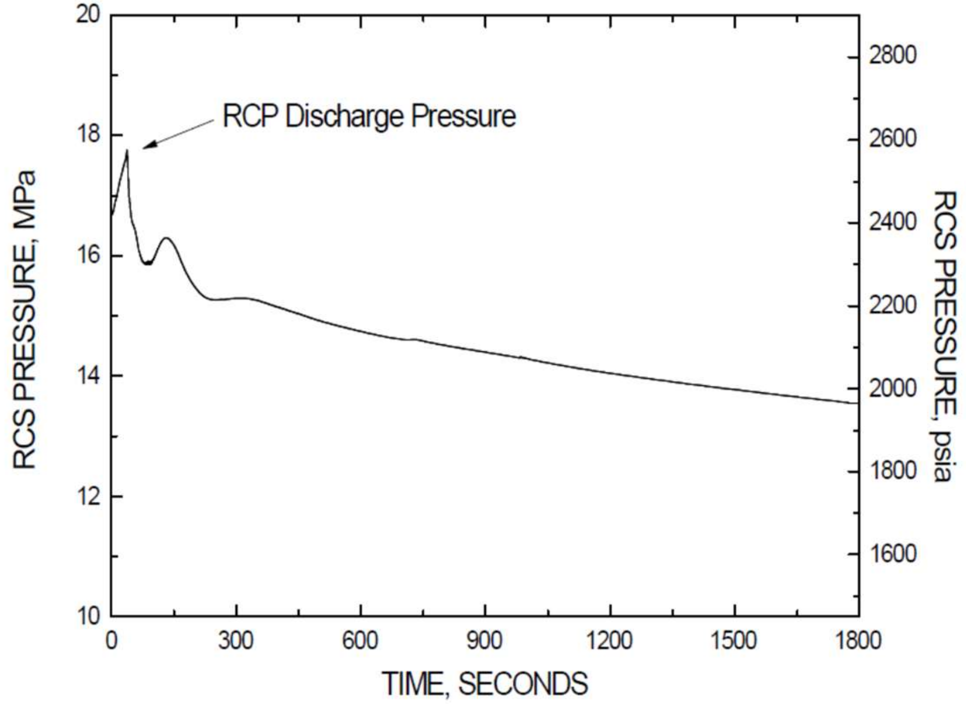


Fig. 1 RCS Pressure vs Time

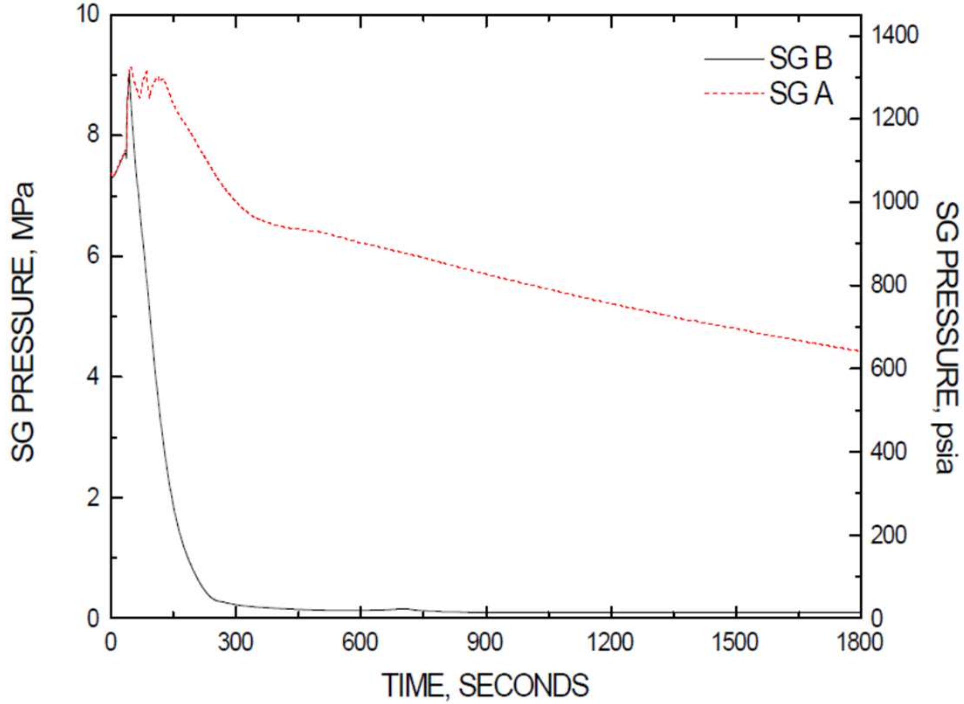


Fig. 2 SG Pressure vs Time

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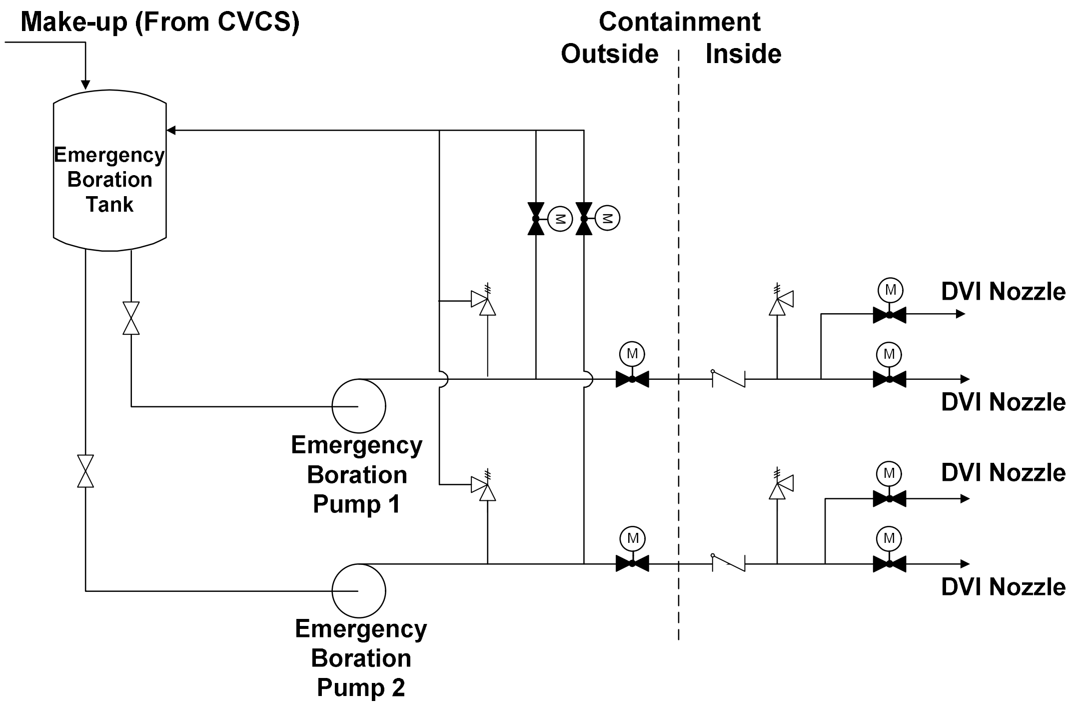
II.4 Event List of Design Extension Condition (DEC)-A

- DEC-A (13)

No.	Event List
1	**Anticipated Transient Without Scram (ATWS) due to mechanical blocking of rods**
2	Anticipated Transient Without Scram (ATWS) due to failure of reactor protection system
3	Station Blackout (SBO)
4	Total Loss of Feedwater (TLOFW)
5	LOCA with loss of safety injection
6	Uncontrolled boron dilution
7	Total Loss of Ultimate Heat Sink during Normal Operation (LOUHS)
8	Total Loss of Cooling Chain during Normal Operation (loss of CCWS + ESWS)
9	Total Loss of Spent Fuel Cooling Functions during Normal Operation (LOSFPC)
10	Multiple steam generator tube rupture (MSGTR)
11	Main steam-line break (MSLB) with consequential SGTR
12	Loss of Reactor Residual Heat Removal System (LORHR)
13	Interfacing system LOCA (ISLOCA)

II.4-1 Emergency Boration System (EBS)

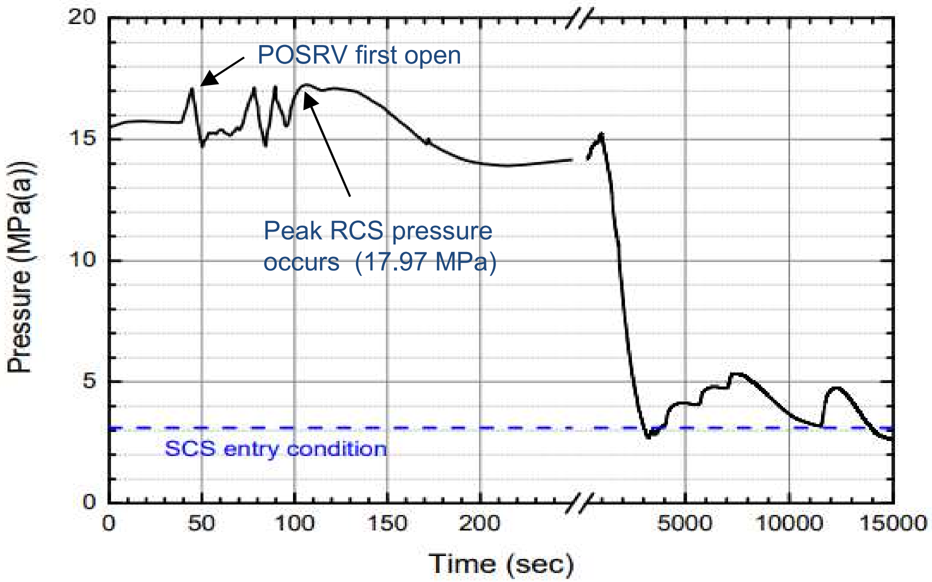
- Function
  - To supply the diverse means for reactor shutdown
  - Emergency Boration Actuation Signal (EBAS) by RTSS Phase current (low) and ENFMS Reactor Power low level
  - Injects highly concentrated borated water into RCS through 4 DVI nozzle .
  - Maintains reactor in a subcritical condition



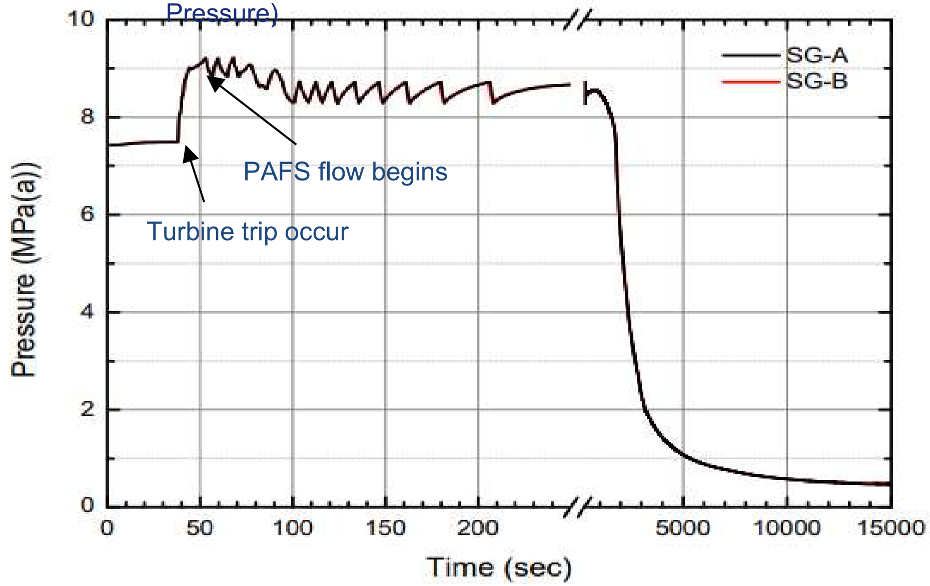
- Design Features
  - 2 Trains
    - ✓ 2 Emergency Boration Pumps
    - ✓ 1 Emergency Boration Tank

II.4-2 Safety Analysis Results for DEC-A

- ATWS due to Mechanical Blocking Rods selected as a limiting event in DEC-A with regard to the system peak pressure and radiological consequences (ATWS-LONF)
- Conclusion
  - The RCS and SG peak pressure: below 125% of design pressure
  - Fuel Integrity: No DNBR
  - Radiological consequence: below 10 mSv



Pressurizer Pressure vs Time



SG Pressure vs Time

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III. Lesson Learned for EUR Rev. E Certification

- Due to the inconsistency between the requirements of Ch. 2.1 (Safety Re and Ch. 2.10 (I&C) during the initial evaluation, the requirements of Ch. 2.10 were judged as NOC, but an objection was raised and recognized as the final COM.
  - (TR 2.1.5..1.5.C. a) The Single Failure Criterion is not required to systems Identified to support DEC scenarios and designed as a backup of a safety class 1 system (safety class 2) which provides an alternative means to accomplish the safety function…..
  - (TR 2.10.6.4.2.2.2 A) No Single Failure* of an I&C system or a subsystem shall result in the loss of a category 1 and category 2 Function

➔ When issuing EUR Rev.F, revisions are planned to resolve the above discrepancies

Thank you