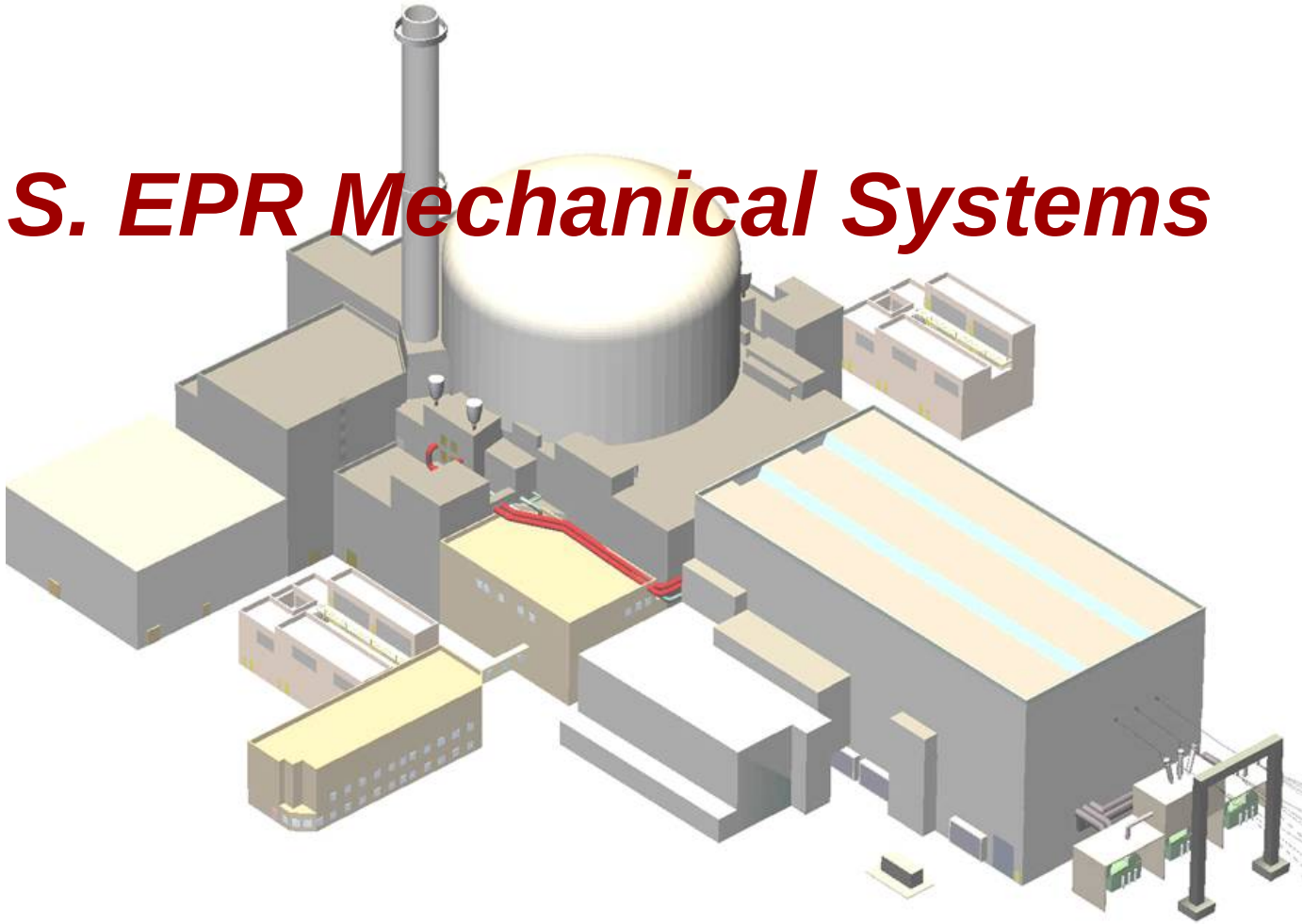
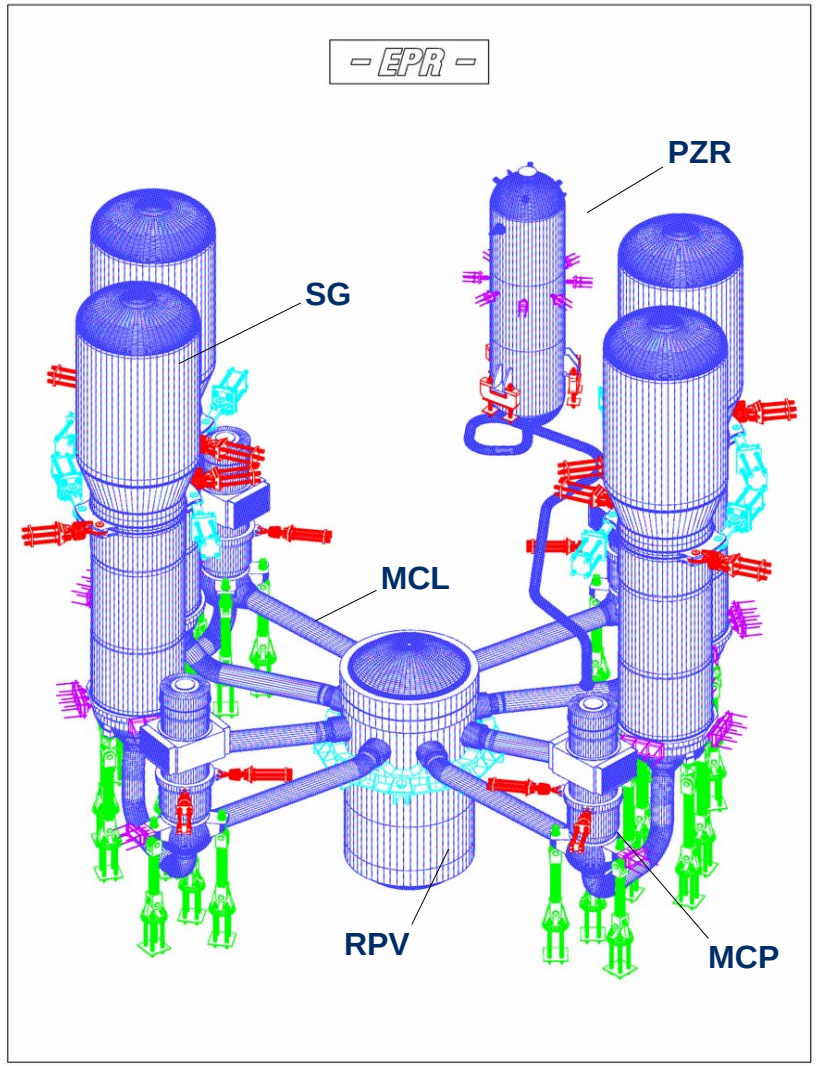
U.S. EPR Mechanical Systems



Tim Stack
Technical Integration
AREVA NP, Inc.

Reactor Coolant System General Arrangement



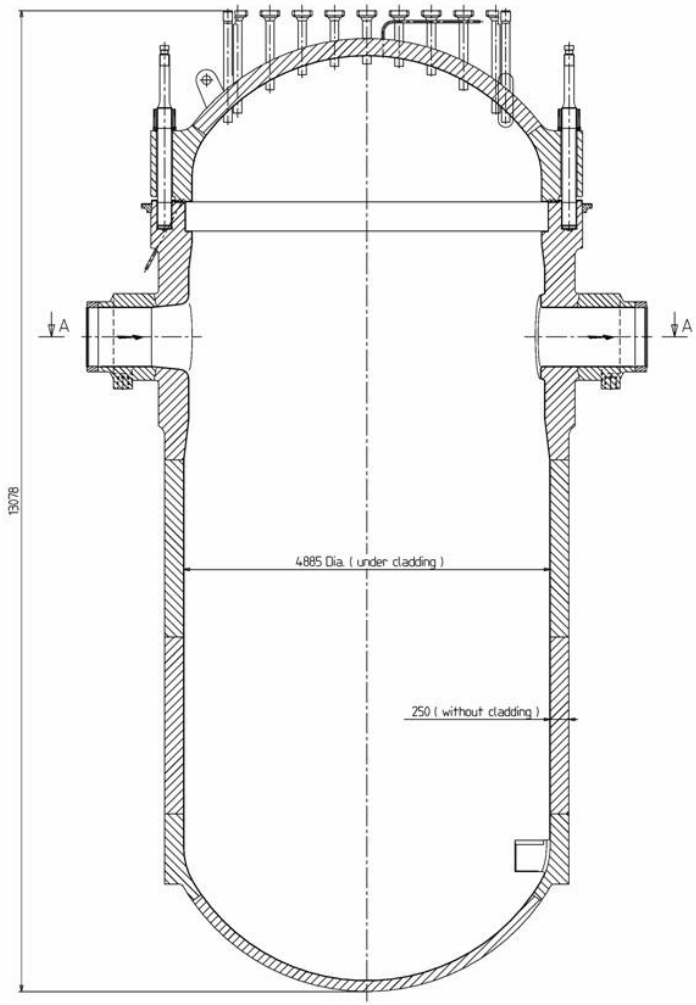
MCP - Main coolant pump
SG - Steam Generator
RPV - Reactor pressure vessel
PZR - Pressurizer
MCL - Main coolant line

Reactor Coolant System – Key Parameters

Parameter	Typical 4-Loop (Uprated)	U.S. EPR
Design Life	40	60
Thermal Power, MW	3587	4590
Electrical Power (Net), MW	1220	1600
Plant Efficiency, Percent	34	35
Hot Leg Temperature, F	619	624
Cold Leg Temperature, F	559	563
Reactor Coolant Flow Per Loop, gpm	100,500	125,000
Primary System Operating Pressure, psia	2250	2250
Steam Pressure, psia	1000	1109
Steam Flow Per Loop, Mlb/hr	4.1	5.17
Total RCS Volume, cu.ft.	12,265	16,245
Pressurizer Volume, cu.ft.	1800	2649
SG Secondary Inventory at Full Power, lbm	101,000	182,000

Reactor Pressure Vessel

Description	Technical Data
Design Life	60 years
Coolant volume	approx. 5300 ft^3
Vessel Outlet Pressure	2250 psia
Vessel Inlet Temperature	563 F
Vessel Outlet Temperature	624 F
Design pressure	2550 psia
Design temperature	664 F
Vessel Material	SA508 Gr3 Cl1
Cladding Material	308L/309L SS

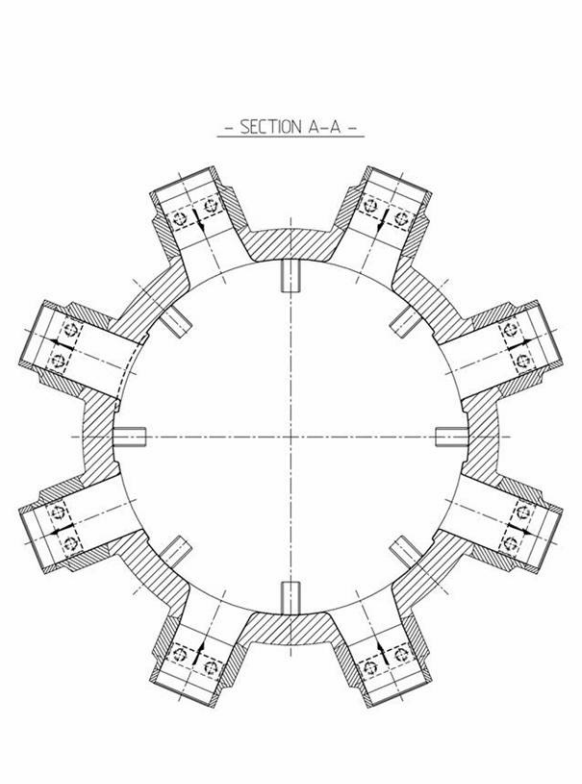


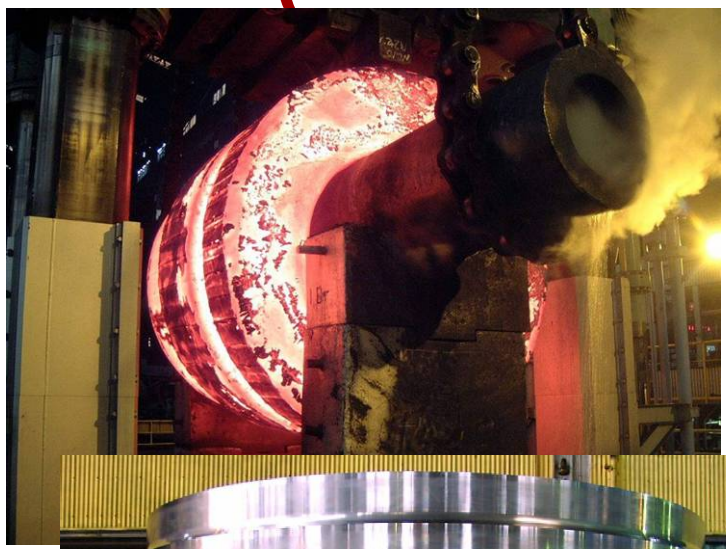
- **No penetrations in RV lower head**
- **No Alloy 600 in RCS applications**
- **Minimum number of welds in RV beltline region**

RPV Materials

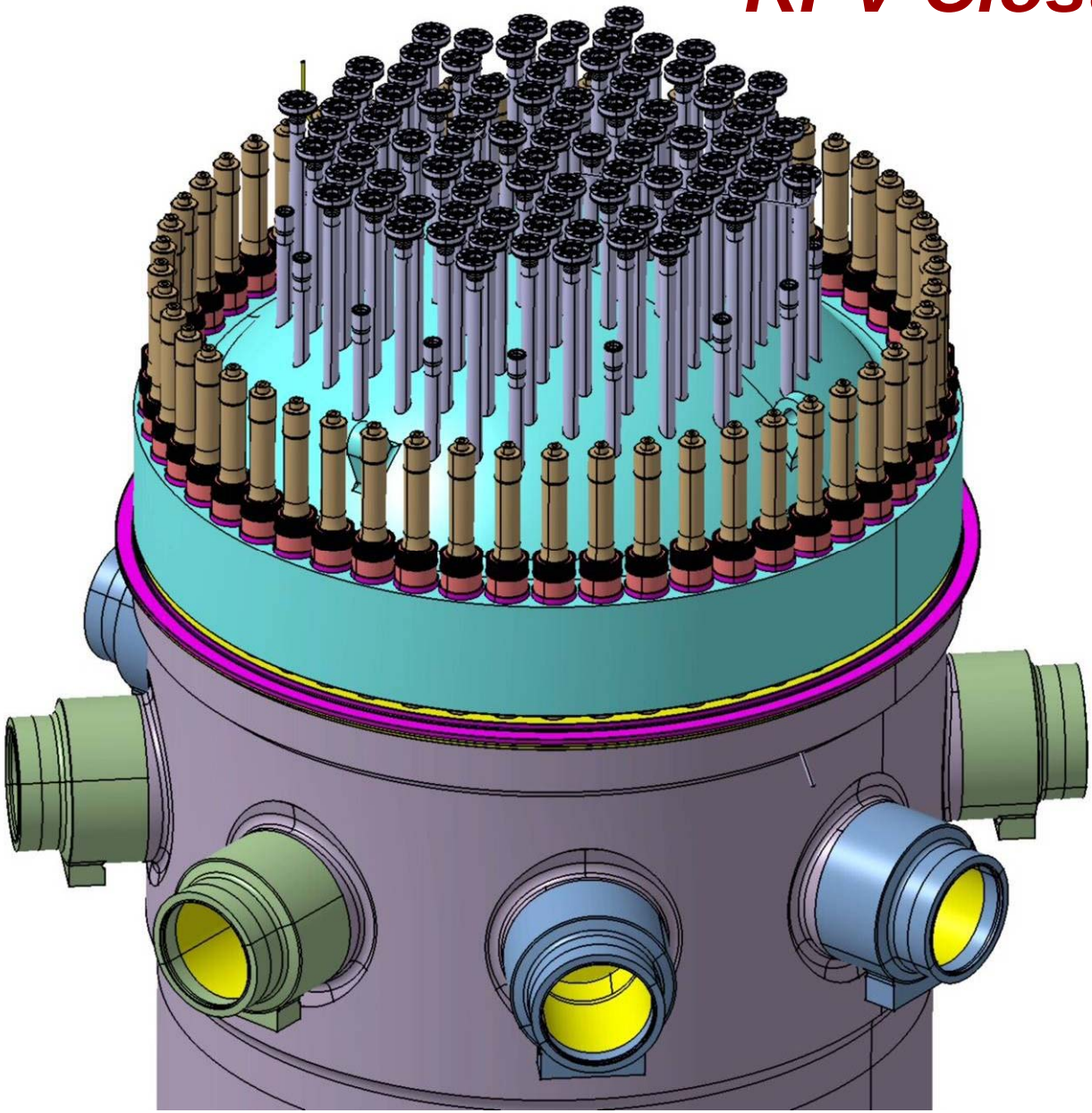
MAIN PART Sub Assembly	PRODUCT FORM Semi-finished Parts	MATERIAL FOR EPR
RPV Shells, Flange, Cover/Bottom Dome	forgings	16MND5, equivalent to: SA-508 Grade 3 Class 1 20 MnMoNi 5 5
RPV Nozzles	forgings	16MND5, equivalent to: SA-508 Grade 3 Class 1 20 MnMoNi 5 5
RPV Studs	forged bars	40NCDV7-03, equivalent to: SA-540 Grade B 24 Class 2 26 NiCrMo 14 6
RPV Nuts	forged bars or rings	40NCDV7-03 or 40NCD7-03 equivalent to: SA-540 Grade B 24 Class 2 34 CrNiMo 6 S
RPV Washers	forged bars or rings	40NCD7-03, equivalent to: SA-540 Grade B 24 Class 2 26 NiCrMo14 6
RPV Adapters (CRDM)	Tubes/ flange	Z2CN19-10+N2, alloy 690 20Mn 5 / X6 CrNiNb 18 10
Other RPV Adapters and Flange Heads	forged bars	Z2CN19-10+N2, Type 347, 316L X6 CrNiNb 18 10 S

Reactor pressure vessel (nozzle shell)

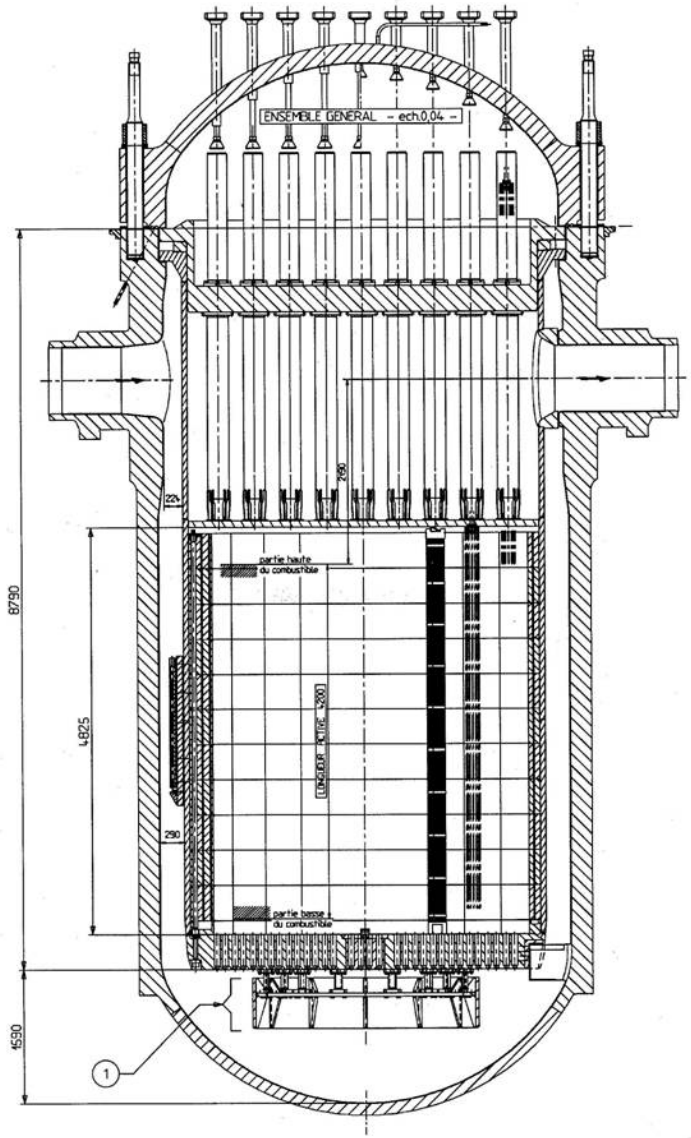




RPV Closure Head

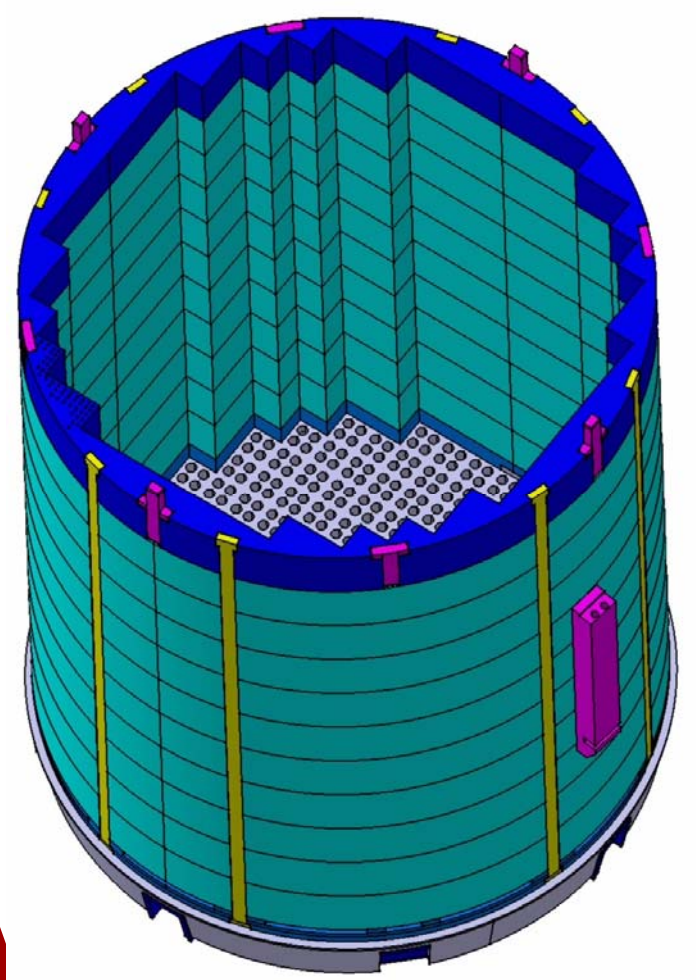


RPV Internals



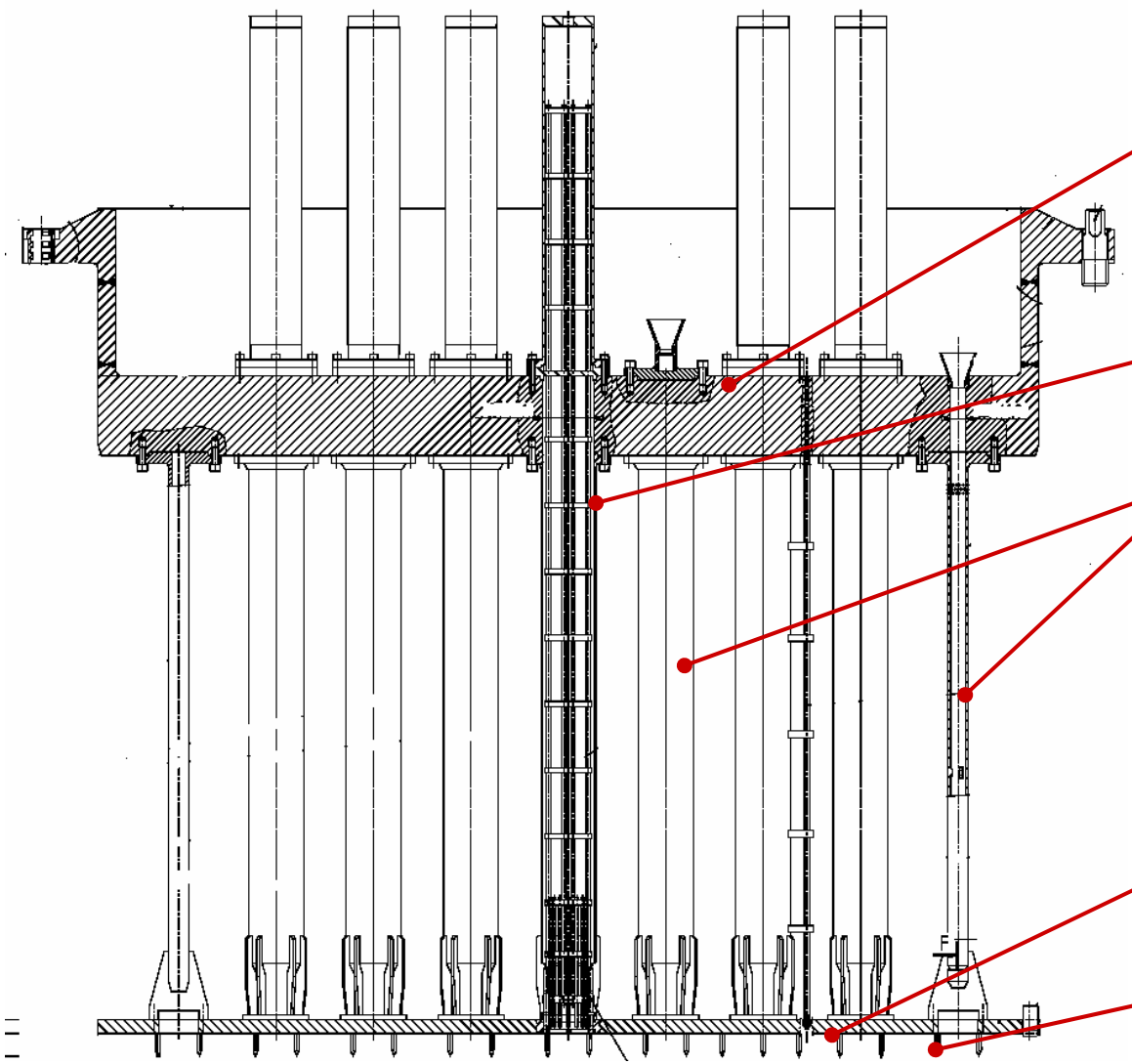
- **Requirements and functions:**
  - **Direct coolant flow in RPV**
  - **Shield RPV against excessive neutron irradiation**
  - **Maintain position and alignment of fuel assemblies**
  - **Align RCCAs, and absorb impact energy of RCCAs following shutdown**
  - **Support and guide instrumentation lances and RPV level measurement probes**
  - **Accommodate irradiation specimens for brittle fracture surveillance of RPV**

EPR Heavy reflector

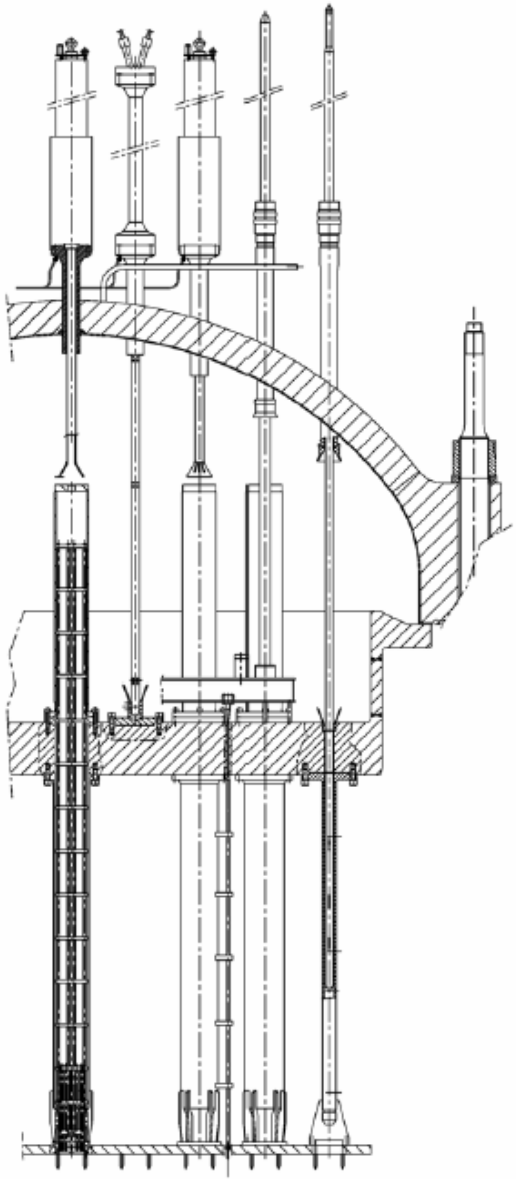


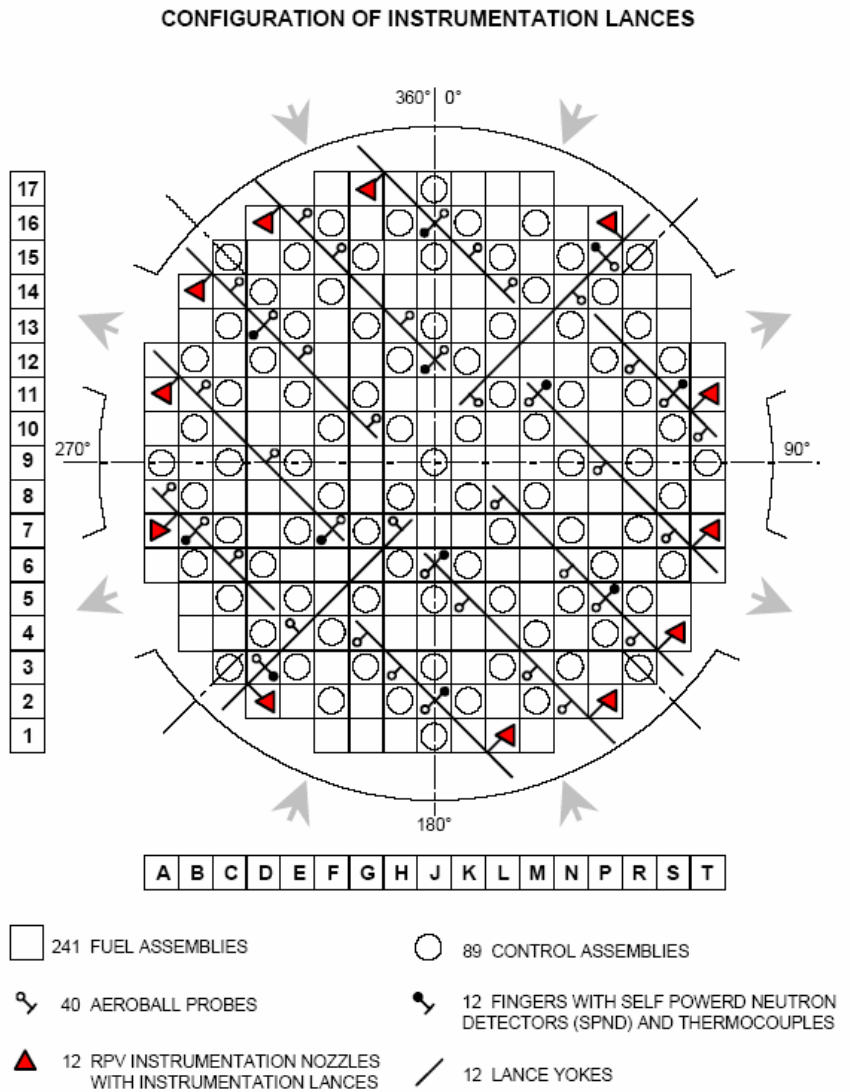
- **Replacement of core baffle assembly by a heavy reflector**
  - **Reduces fuel cycle cost**
  - **Improves long-term mechanical behavior of lower internals :**
    - No bolts or welds in the most irradiated areas
    - Temperature distribution in heavy reflector controlled via flow holes
    - No "baffle jetting"
    - Reduced LOCA hydraulic loads
  - **Protects RPV shell against radiation embrittlement**

EPR upper internals



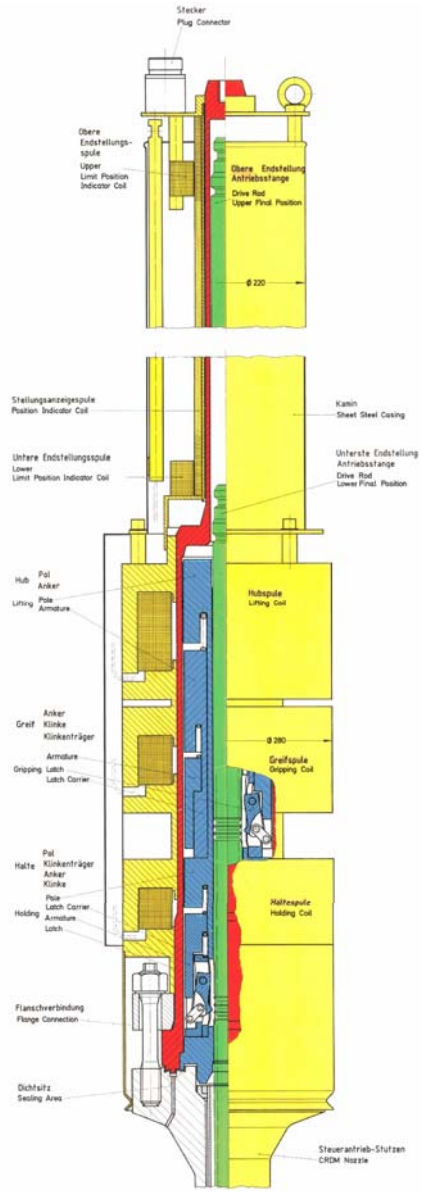
EPR RPV Upper Internals/Core Instrumentation





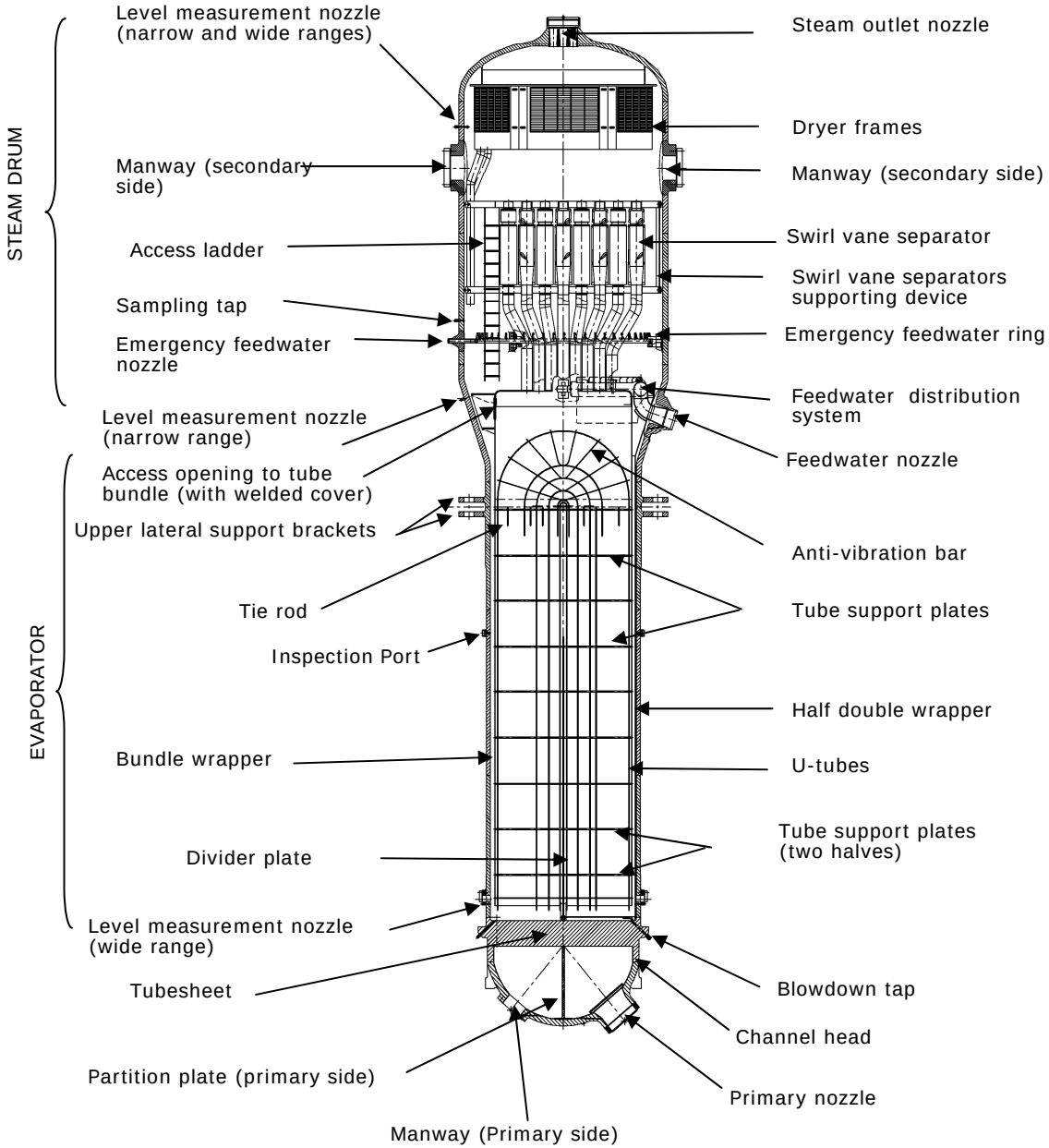
EPR Control Rod Drive Mechanisms

Description	Technical Data
Type of CRDM	Electromagnetic jack
Type of installation	Vertical, flanged
Quantity	89
Scram time max. allowed (preliminary)	3.5 s
Step increment	10 mm (0.394 inch)
Maximum stepping speed	75 s/min

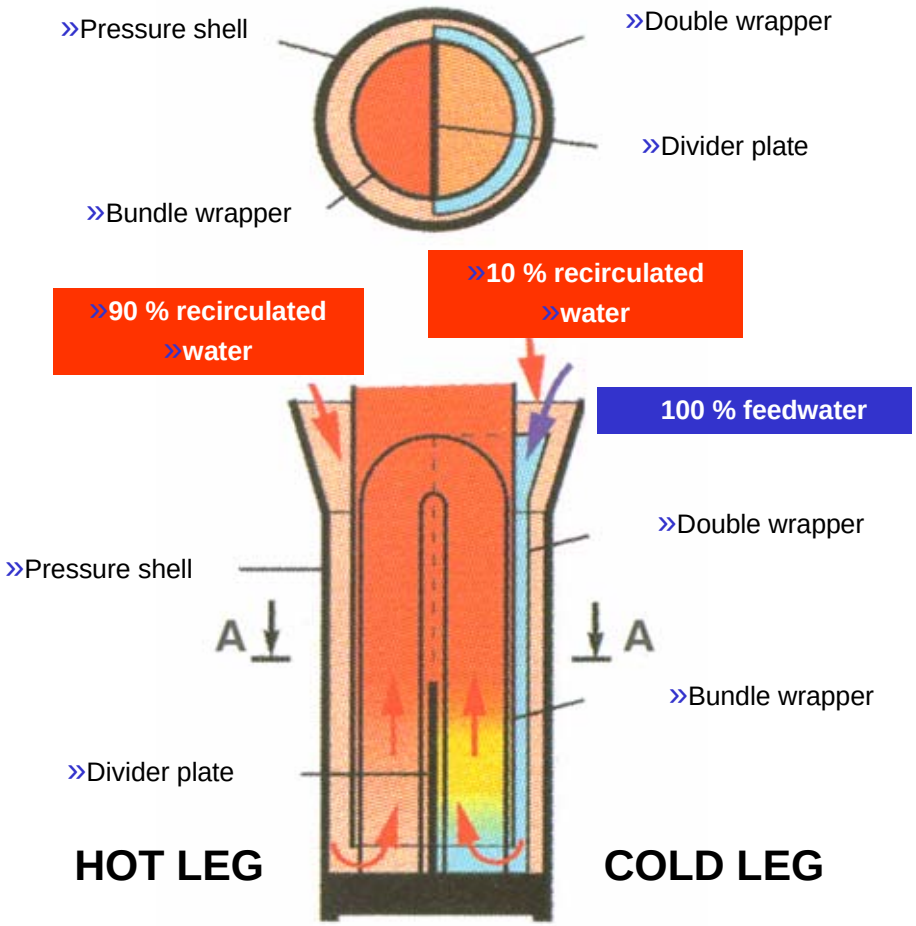


- **CRDM functions:**
  - **RCS pressure boundary**
  - **Insert and withdraw RCCAs over entire height of core, and hold RCCAs in any selected step position.**
  - **Trip RCCAs on demand by interrupting power to coil circuit.**
  - **Provide RCCA position indication via digital and analog position indicating systems.**

Steam generator: Layout

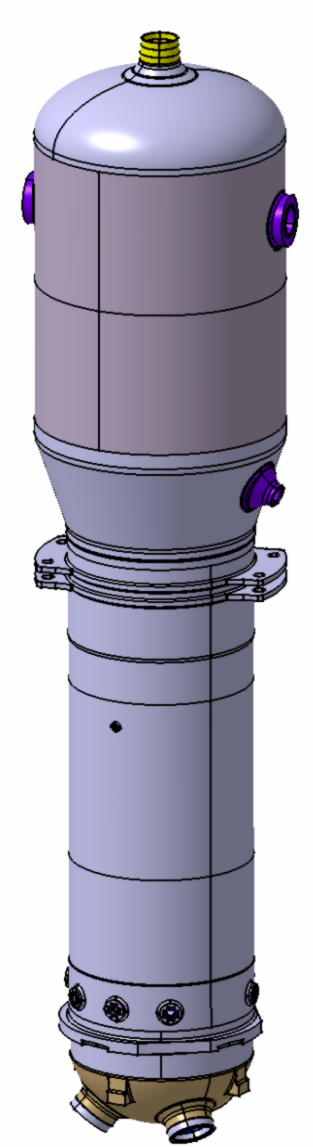


Steam Generator Axial Economizer



EPR STEAM GENERATORS

Primary Side Parameters	
• Thermal Power per SG	1131.5 MWth
• Thermal Design Flowrate	12250 lbm/s
• Temperature at SG Inlet	625.6ºF (329.8ºC)
• Temperature at SG Outlet	563.7ºF (295.4ºC)
• Average SG Temperature	594.7ºF (312.6ºC)
• Reactor Coolant Pressure	2250 psia (155 bar)
• Primary Design Pressure	2550 psia
Secondary Side Parameters	
• Outlet Steam Static Pressure	**1118 psia (77.1 bar)**
• Secondary Design Pressure	1450 psia
• Steam Flowrate	1407.4 lbm/s (638.4 kg/s)
• Feedwater Temperature	446ºF (230ºC)
• Overall Circulation Ratio	3.6
• Water Mass	85.1 Tons (77.2 Metric Tons)
• Steam Mass	6.06 Tons (5.50 Metric Tons)
• Total Mass	**91.2 Tons (82.7 Metric Tons)**
Selected Materials	
• Tubing	**Alloy-690 TT**
• Shell & Channel Head	SA508 Gr3 Cl2
• Channel Head Cladding	308L / 309L SS
• Tube Sheet Cladding	Ni Cr Fe Alloy
• Tube Support Plates	410 SS
• Anti-Vibration Bars	405 SS

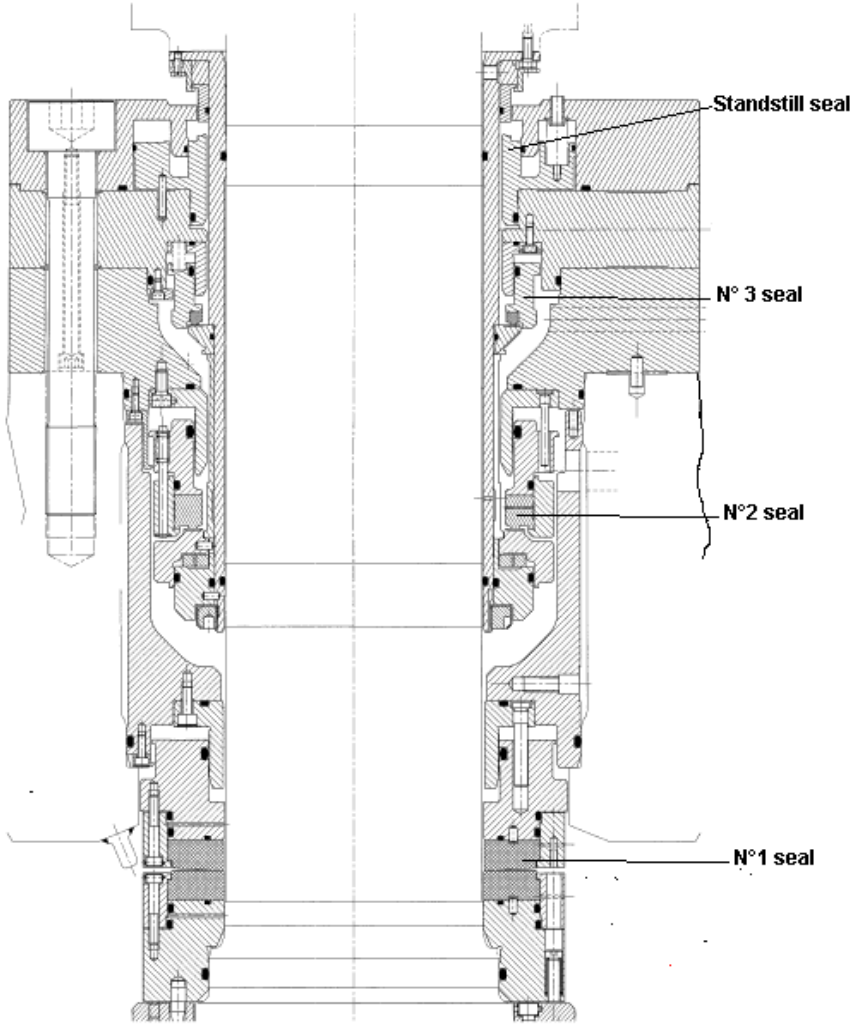


EPR Reactor Coolant Pump

RCP UNIT	
- Design Pressure	2550 psia (*17.6 MPa*)
- Design Temperature	664 ^{0}F (*351 ^{0}C*)
- Unit overall height	30.7 ft (*9.362 m*)
- Number of Seal Stages	**3**
- Seal water injection	**7.9 gpm (*1.8 m^3/h*)**
- Seal water return	**2.99 gpm (*0.680 m^3/h*)**
- Cooling water flow (thermal barrier)	**39.63 gpm (*9 m^3/h*)**
- Maximum continuous cooling water	113 ^{0}F (*40.5 ^{0}C*)
PUMP	
- Best estimate flowrate	125000 gpm (*28320 m^3/h*)
- Best estimate manometric head	330 ft (*100.6 m*)
- Thermalhydraulic flowrate	120000 gpm (*27185 m^3/h*)
- Mechanical flowrate	135000 gpm (*30585 m^3/h*)
- Suction temperature	564.6 ^{0}F (*295.7 ^{0}C*)
- Pump discharge nozzle, inside	2.56 ft (*0.78 m*)
- Pump suction nozzle, inside	2.56 ft (*0.78 m*)
- Speed (approximately)	1185 rpm

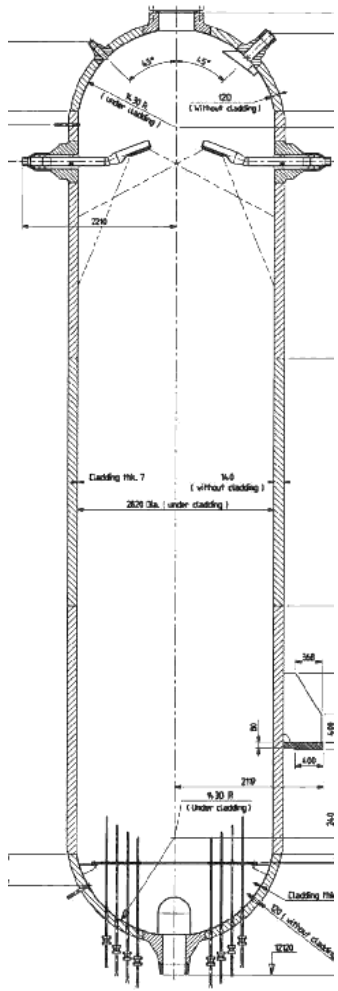
Shaft sealing system

- Standstill seal (4th seal) provided to ensure RCP shaft sealing during SBO conditions.
- Standstill seal is manually actuated when RCPs have stopped and RCP seal return is isolated.
- Ring seal moves upwards against landing on rotor via nitrogen pressure. This provides metal-to-metal contact, and seals shaft.



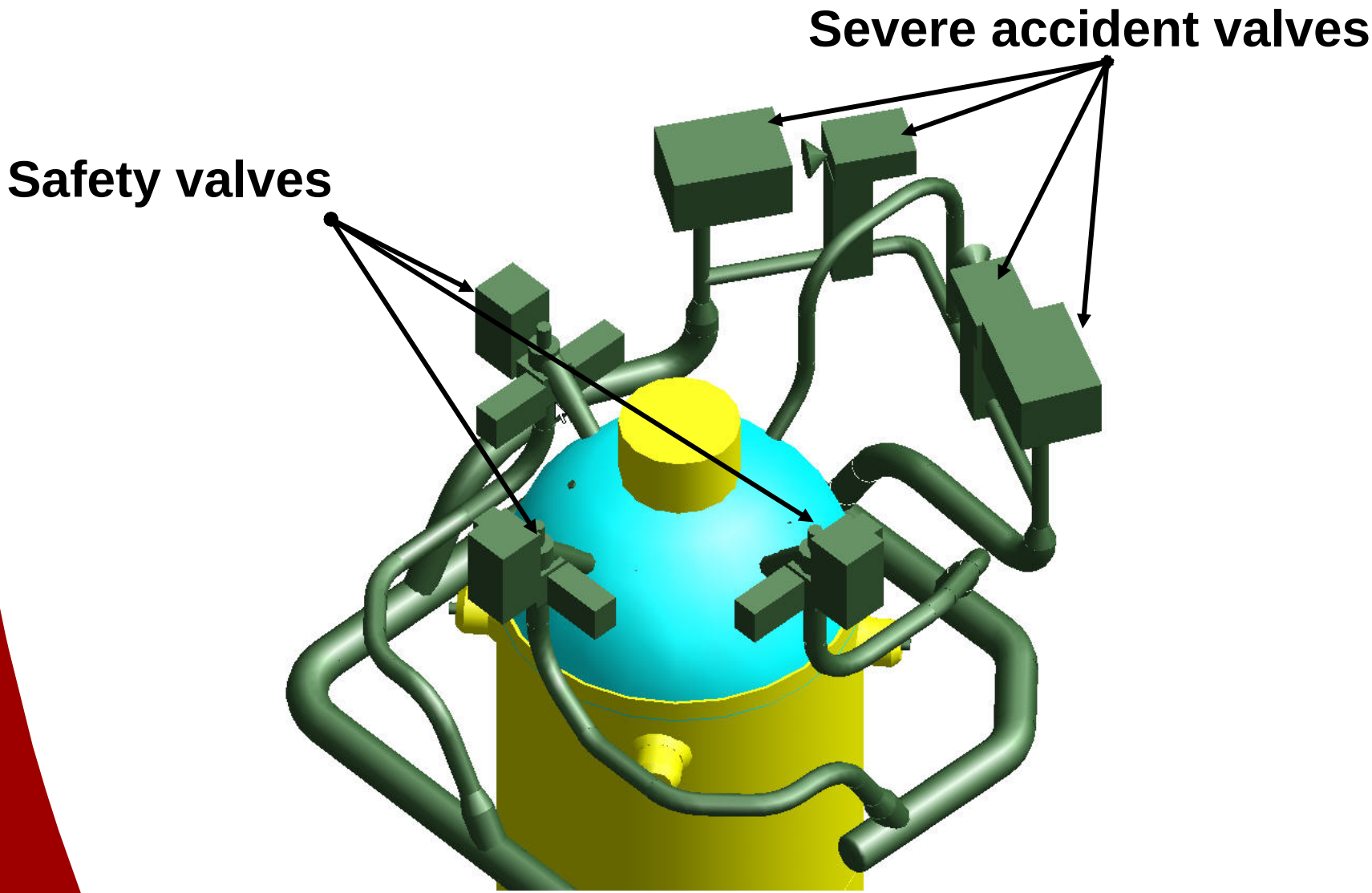
Pressurizer - Technical Data

DESCRIPTION	TECHNICAL DATA
Quantity	1
Design Life	60 Years
Design Pressure	2550 psia (17.6 MPa)
Design Temperature	684ºF (362ºC)
Total Free Volume	**2650 ft^3 (75 m^3)**
Water Volume at Full Load	1410 ft^3 (40 m^3)
Steam Volume at Full Load	1240 ft^3 (35 m^3)
Operating Temperature	653ºF (345ºC)
Operating Pressure	2250 psia (15.4 MPa)
Number of Operational Spray Lines	**2 from RCPs**
Number of Auxiliary Spray Lines	**1 from CVCS**
Number of Safety Valves	**3**
Number of Severe Accident Valves	**4 (2 pathways)**
Installed Heater Power (approx.)	**2600 kW**
Number of Heater Rods	108 + 8 Spare
Dry Weight (approx.)	165 t ($15x10^4$ kg)
Vessel Material (Ferritic Steel)	SA 508 grade 3 class 2
Heater Sleeves (Austenitic Stainless Steel)	**Type 316 LN**
Cladding	308L / 309L SS



Surge line

Pressurizer Discharge Valves Arrangement

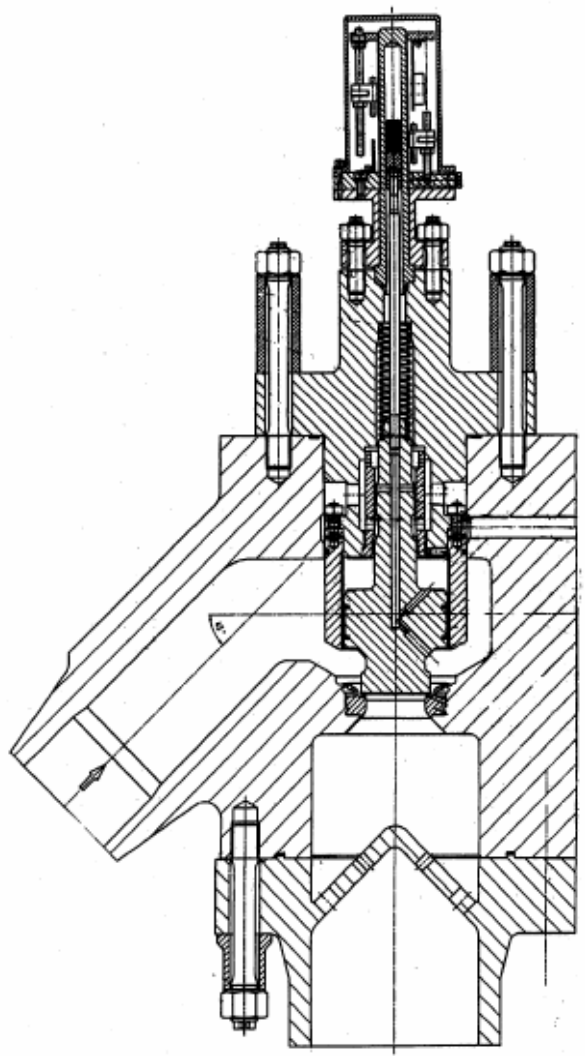


Safety Relief & Severe Accident Valves

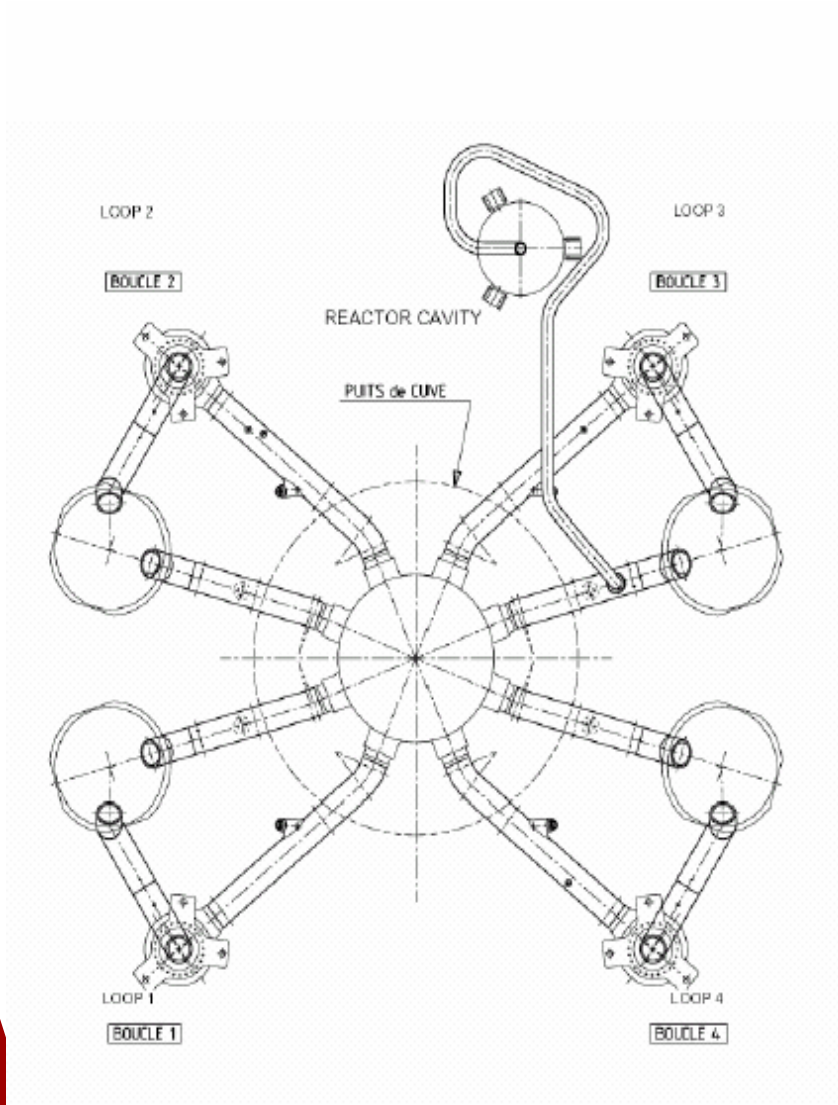
Description	Technical Data
Pressurizer Safety Valve Stations	
System Design Data under Normal Conditions	
• **Number**	**3**
• Design Pressure	2550 psia (176 bar)
• Design Temperature	684ºF (362ºC)
• Relieving Capacity at 2550 psi (176 bar), each	330 Tons/hr (300 Metric Tons/hr)
Functions	
• **RCS overpressure protection**	
• **LTOP during shutdown modes**	
• **Feed & Bleed cooling with MHSI**	
Severe Accident Bleed Valve Station	
System Design Data	
• **Number**	**4 (arranged in 2 paths)**
• Design Pressure	2550 psia (176 bar)
• Design Temperature	684ºF (362ºC)
• Relieving Capacity at 2550 psia, each	992 Tons/hr (900 Metric Tons/hr)
Functions	
• **RCS depressurization during severe accident**	

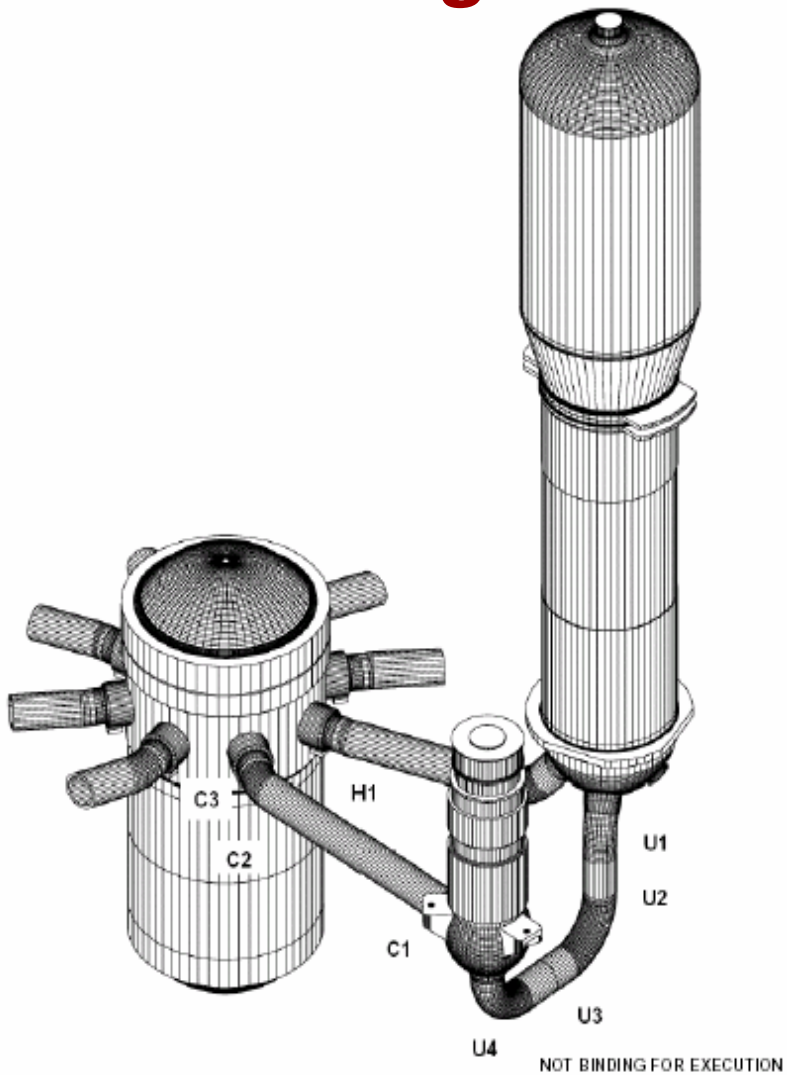
Pressurizer Safety Valves

Design Parameters	Technical Data
Number	3
Relieving capacity at 2550 psia (176 bar), each	66×10^4 lbm/hr
Design Pressure	2535 psia (176 bar)
Design Temperature	684ºF (362ºC)
Operating Characteristics •Dead Time •Opening Time	 0.5 s 1.5 s
Fluid	Saturated Steam
Back Pressure •Minimum •Maximum during discharge	 17.4 psia (1.2 bar) 740 psia (51 bar)



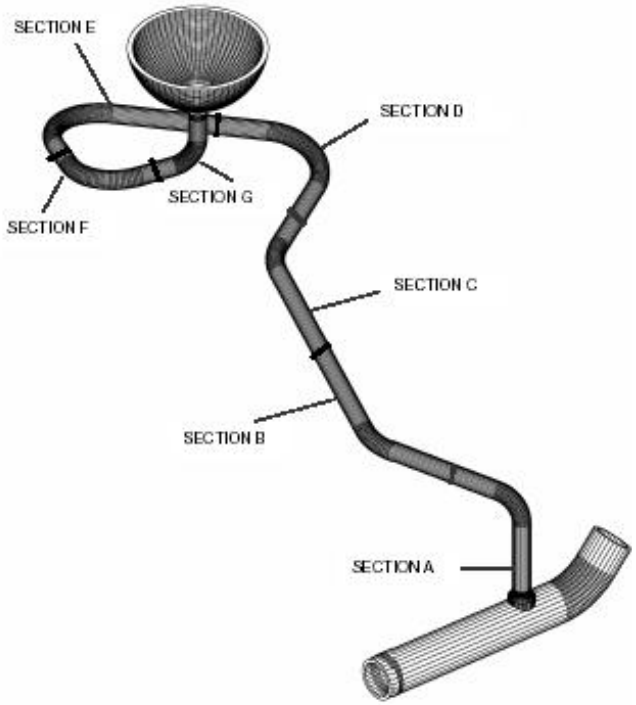
JEC/JEF - Main Coolant Lines and Surge Line

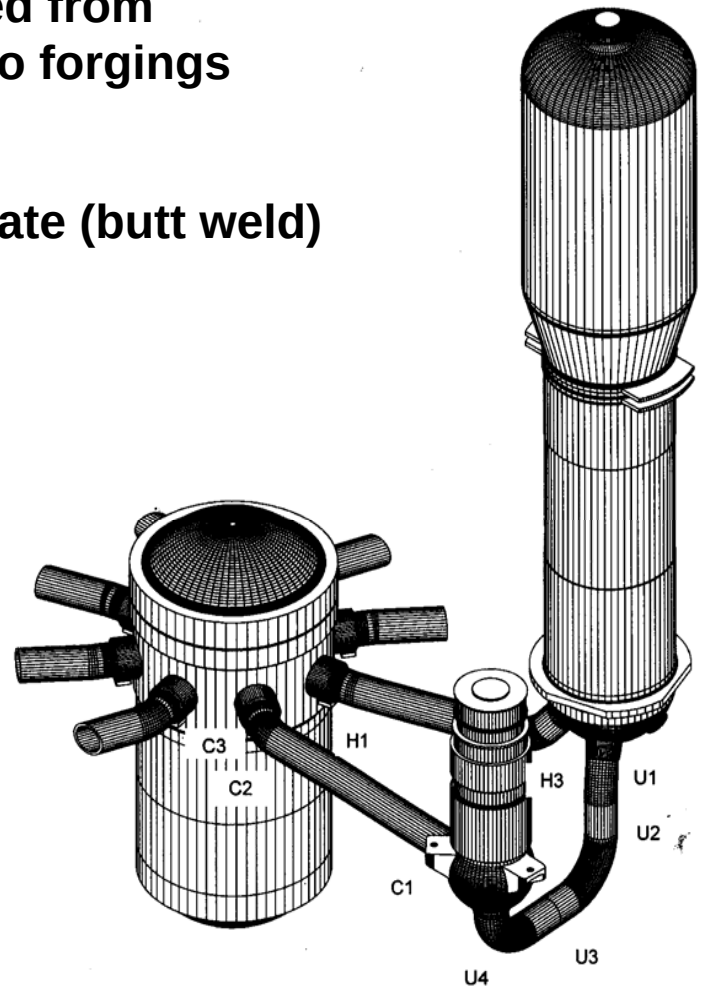




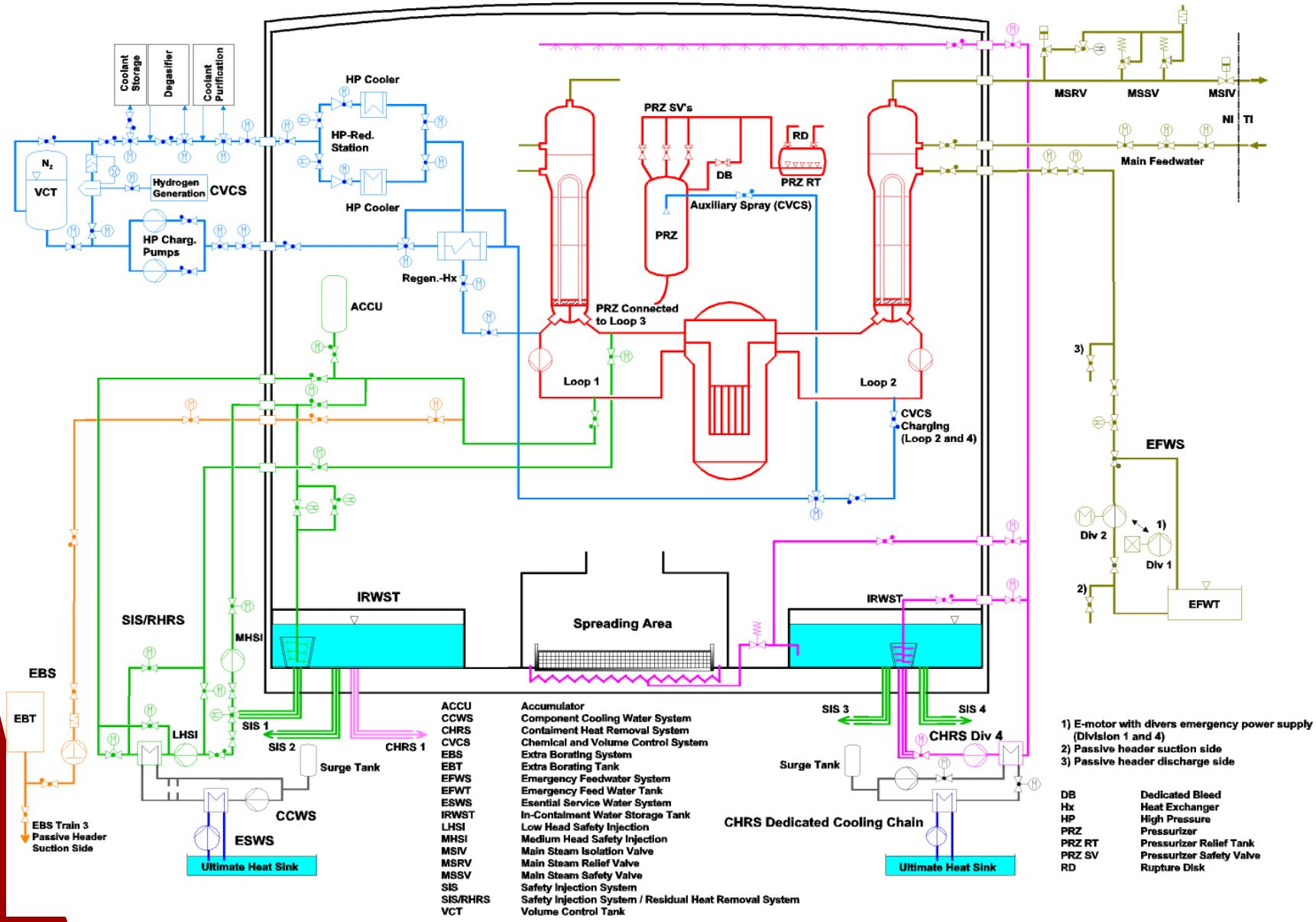
Main Coolant Lines

- Reactor coolant piping is manufactured from forgings with nozzles incorporated into forgings (eliminates need for thermal sleeves).
- Other nozzles are welded on a base plate (butt weld) to simplify welding and inspections.
- Fabricated of 304LN stainless steel.

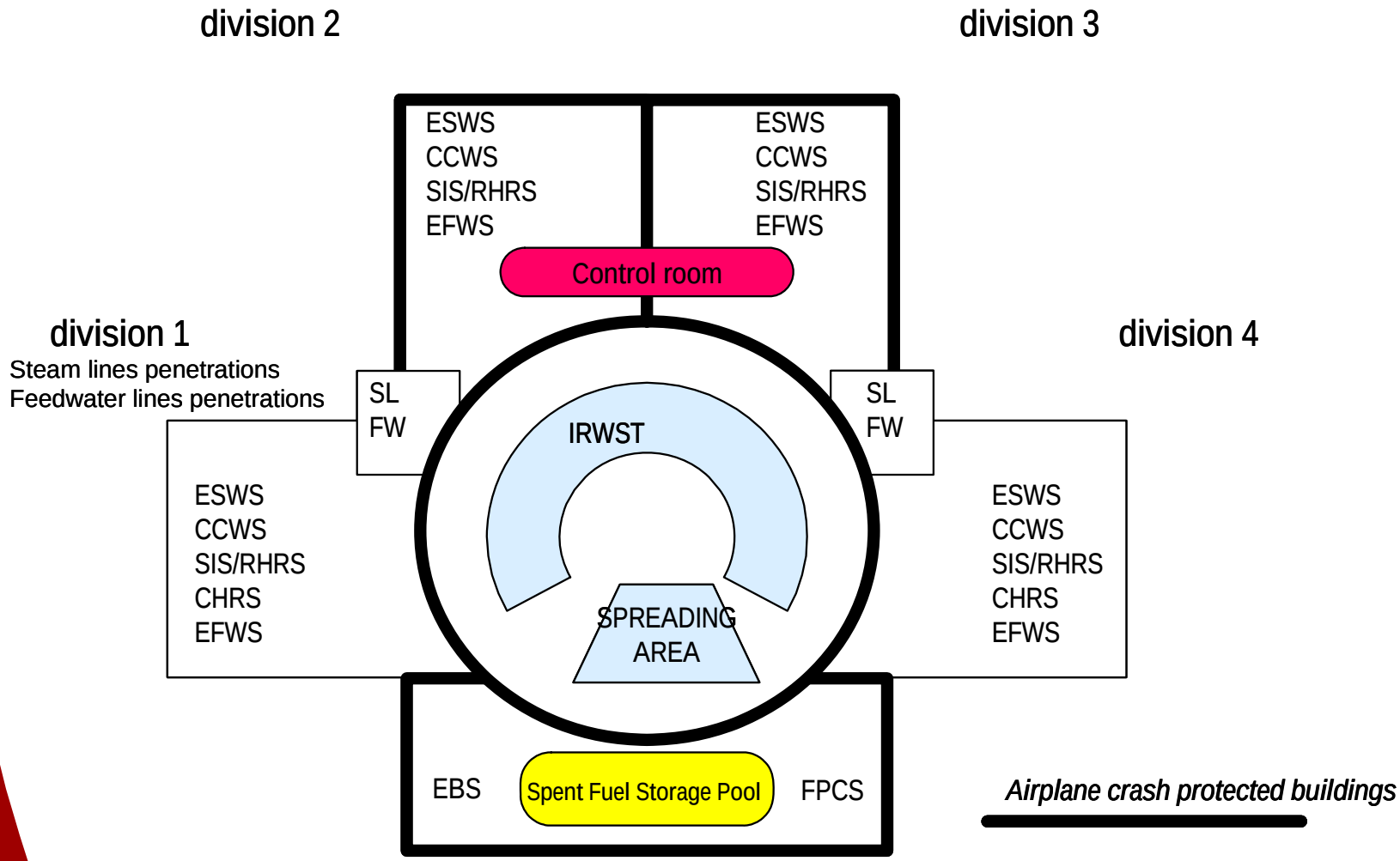




MAIN FLUID SYSTEMS



Installation in the Safeguard Buildings



Section A-A

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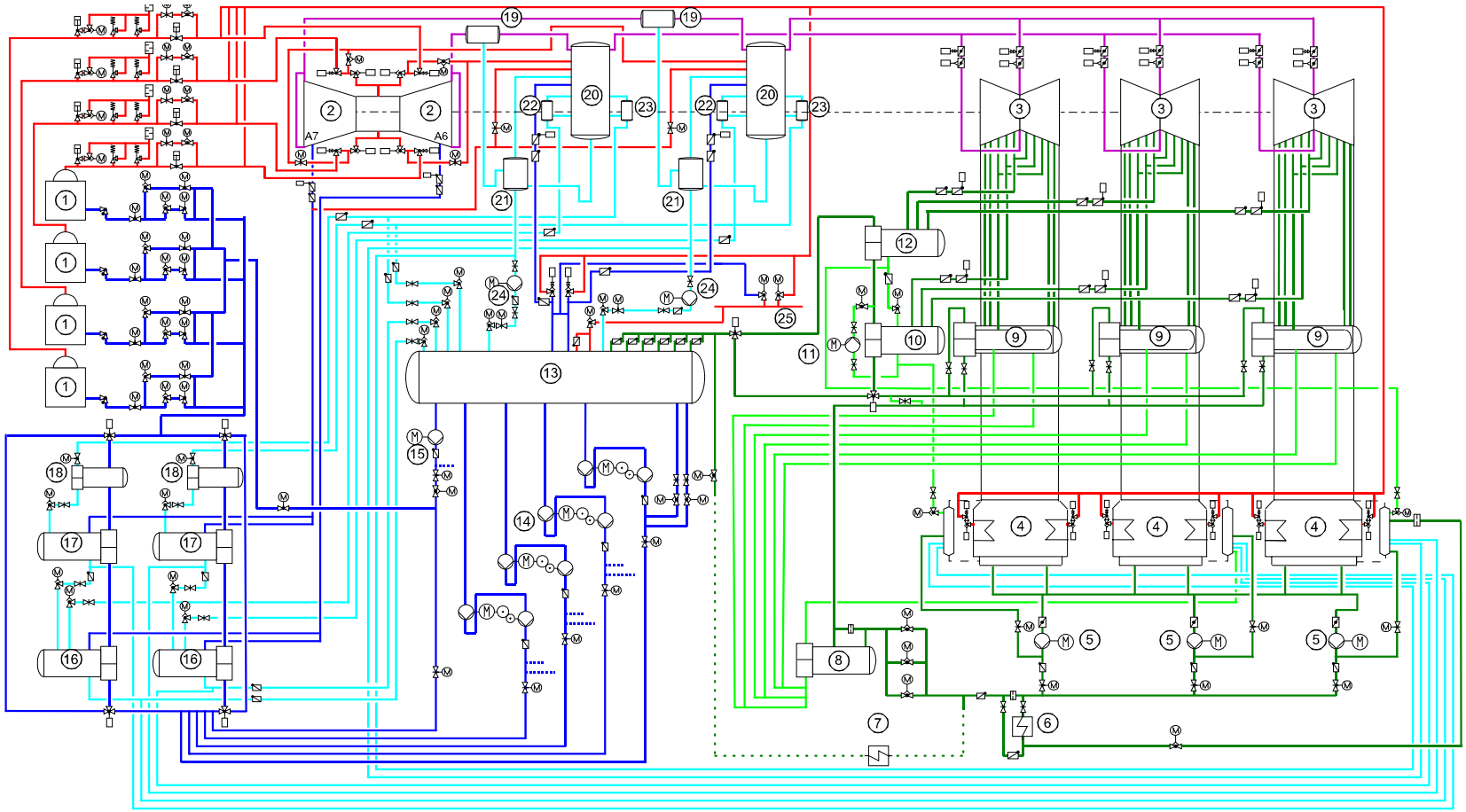
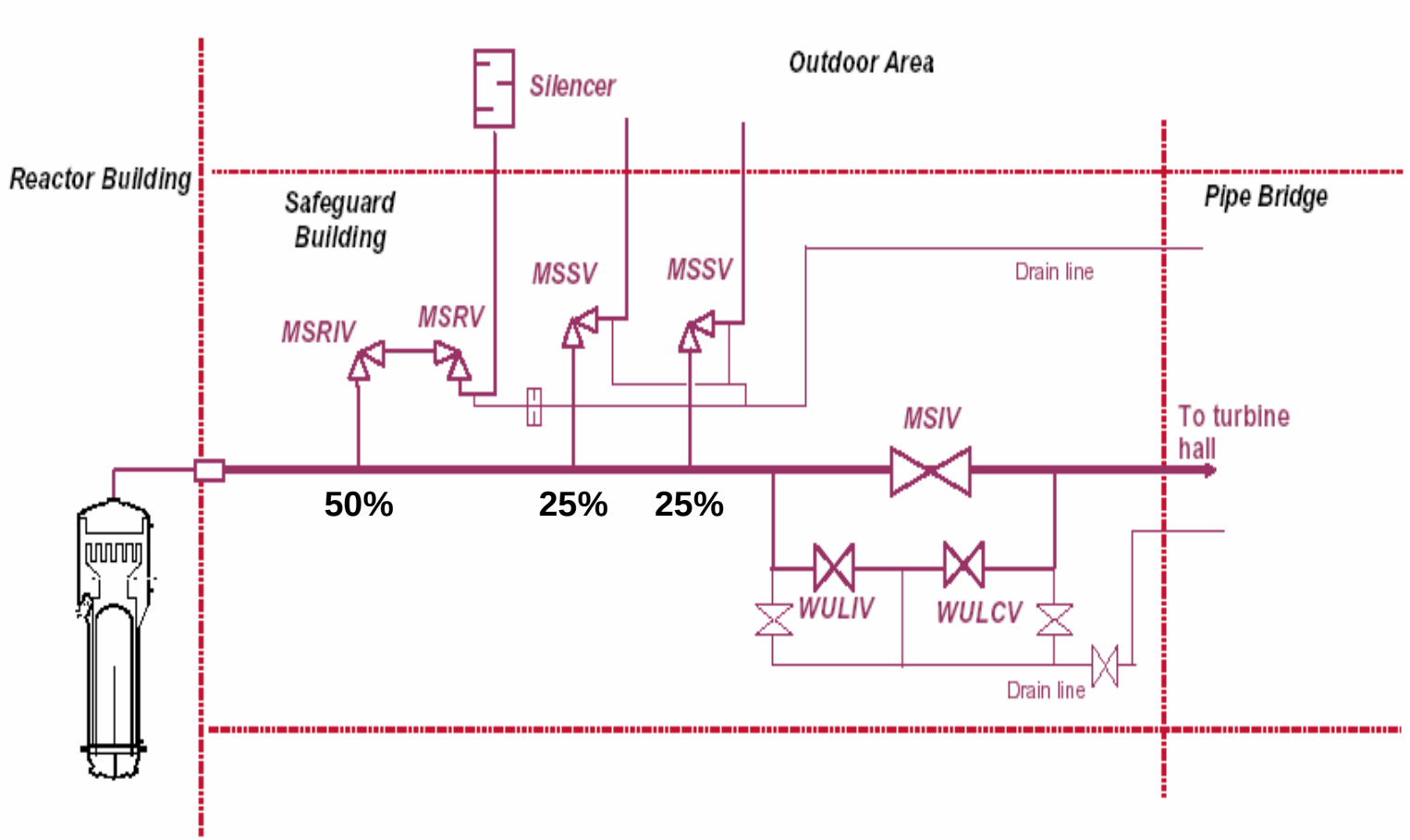
Main Steam/Main Feed Water Systems



1. Steam Generator
2. HP Turbine
3. LP Turbine
4. Condenser
5. 3x50% Condensate Extraction Pumps
6. Gland Steam Condenser
7. Blowdown Cooler (Nuclear Island)
8. Simplex LP Heater Drains Cooler
9. Duplex LP Heater A1/A2
10. LP Heater A3
11. LP Heater Drains Pump
12. LP Heater A4
13. Deaerator/Feedwater Storage Tank
14. 4 x 33% Feedwater Pumps
15. Startup and Shutdown Pump
16. HP Heater A6
17. HP Heater A7
18. Reheater Stage 2 Drains Cooler
19. Moisture Pre- Separator (Powersep)
20. Moisture Separator / Reheater
21. Moisture Separator Drains Tank
22. Reheater Stage 1 Drains Tank
23. Reheater Stage 2 Drains Tank
24. Moisture Separator Drains Pump
25. Auxiliary Steam Header

Main Steam System Overpressure Protection



Overview – EPR Mechanical Systems