Reactor Pressure Vessel

- Reactor Vessel
  - Inner diameter: ~4.6 m, thickness: ~ 25 cm
  - Height: ~14.8 m
  - Material: manganese molybdenum steel
    - Surfaces that come into contact with reactor coolant are clad with stainless steel to increase corrosion resistance.

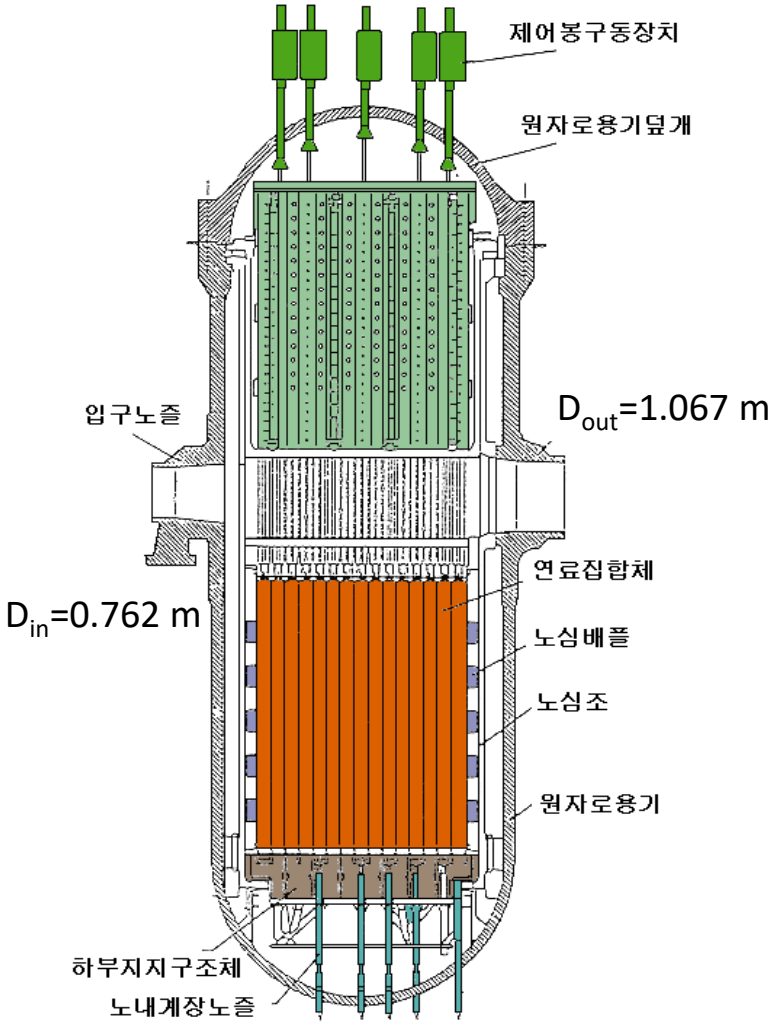
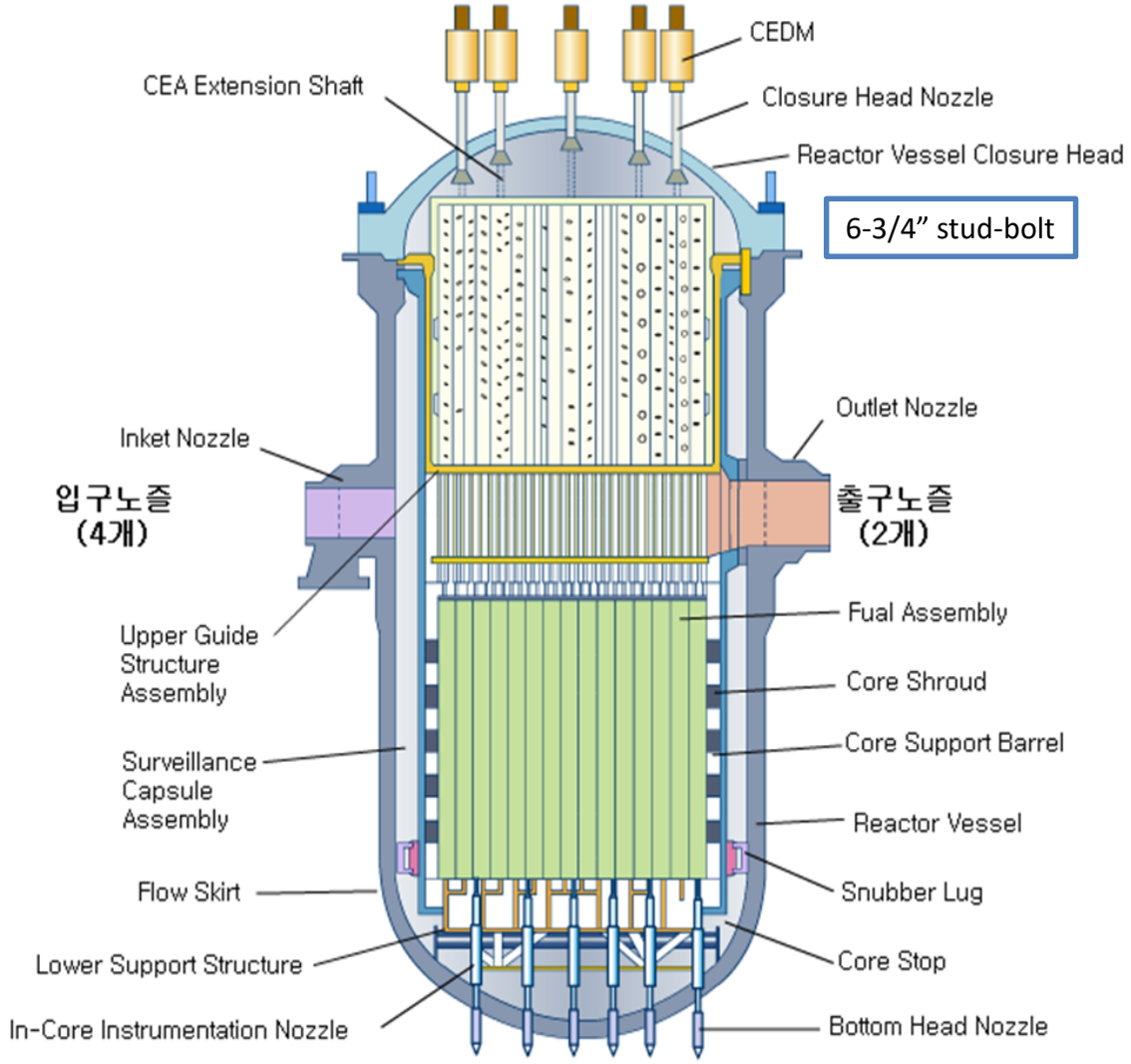


그림-3 한국표준형경수로의 원자로

[자료] Korea Electric Power Corporation : KOREAN STANDARD NUCLEAR POWER PLANT(KSNP), p.41

Reactor Pressure Vessel

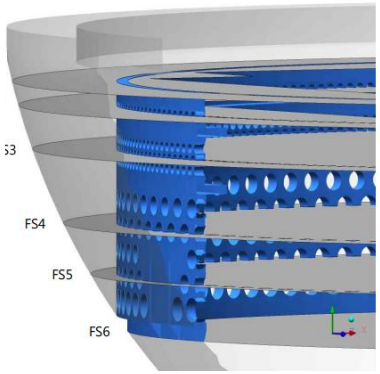
❖ Reactor Vessel



Closure head assembly

- 108 nozzles for CEDMs
- 54 studs and 2 O-rings

Flow skirt: 유량분배환, 유량 분배 균일화



Reactor Pressure Vessel

- Reactor Vessel

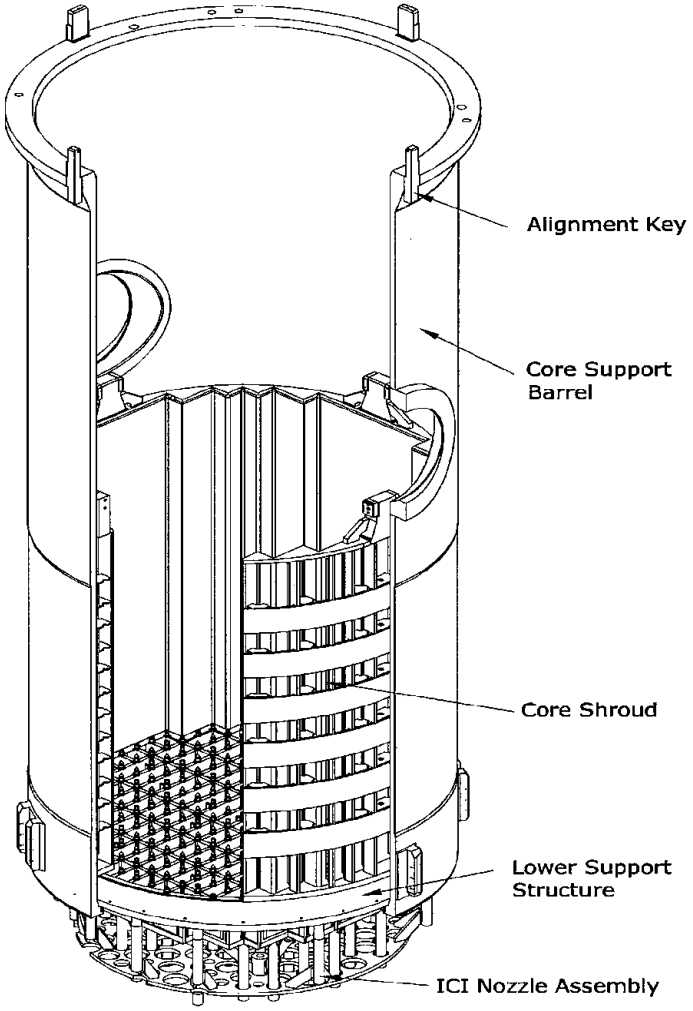
Doosan heavy industry

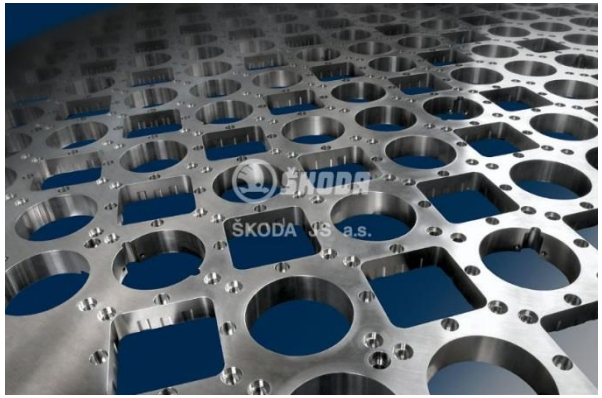
Ring Forging

Cladding

Reactor Pressure Vessel

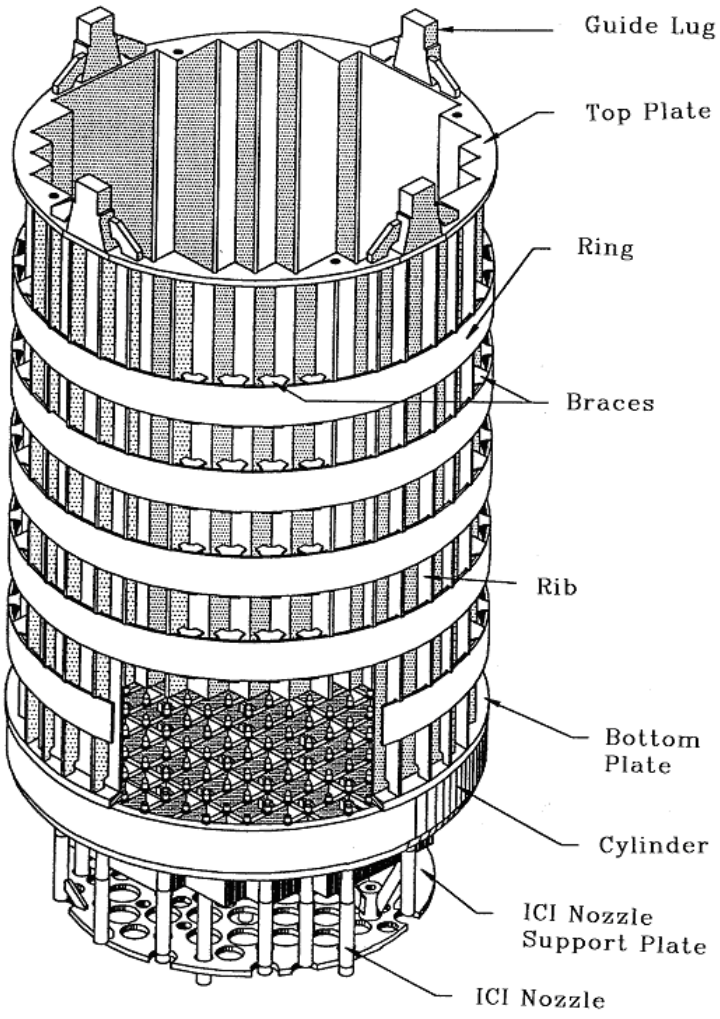
Core Support Barrel contains and supports the fuel assembly, core shroud and lower support structure, and shields from radioactivity along with coolant. Linked with reactor vessel's exit nozzle, the nozzle attached to the cylinder minimizes the coolant leakage.



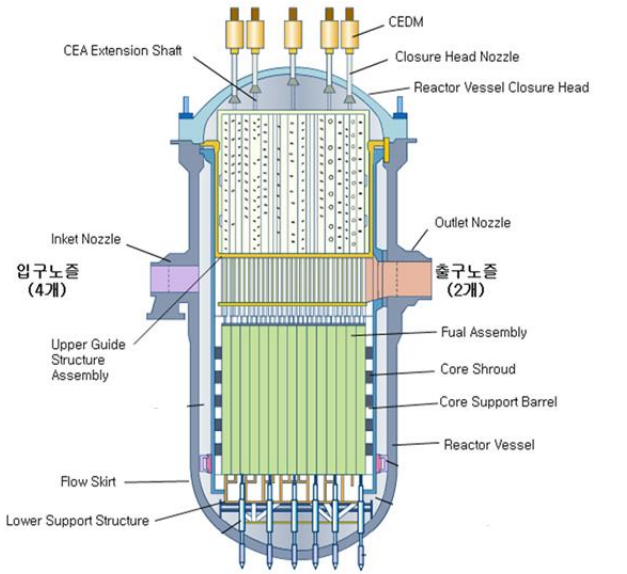


Reactor Pressure Vessel

Core Shroud shelters the reactor fuel and stabilizes the flow of coolant.

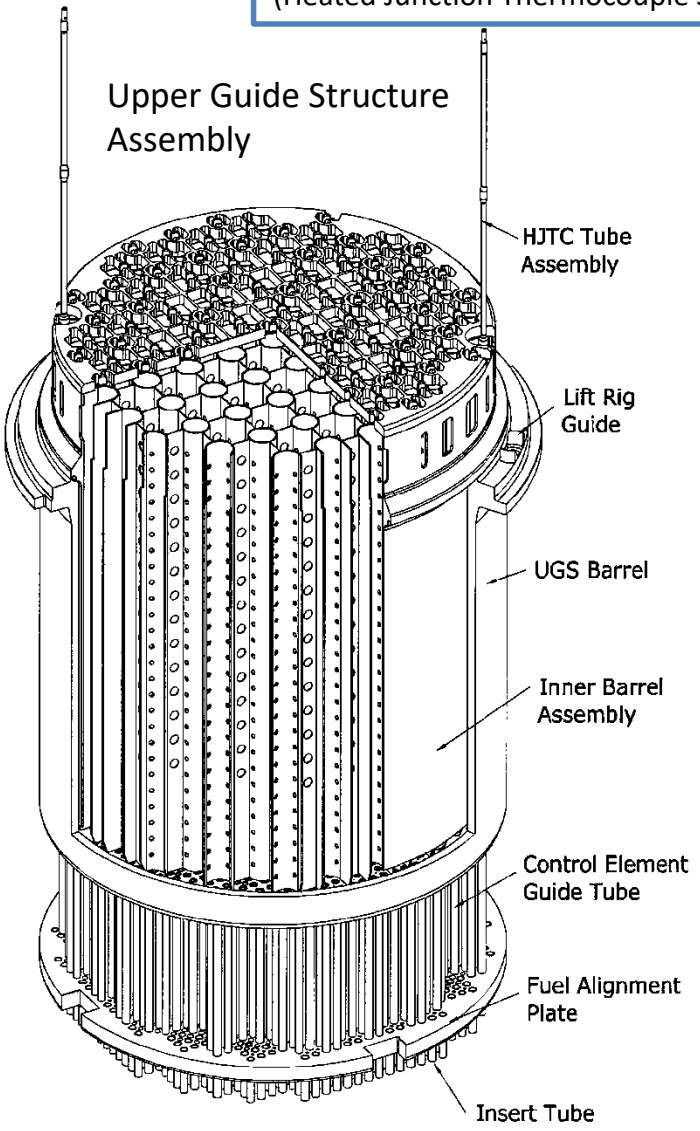


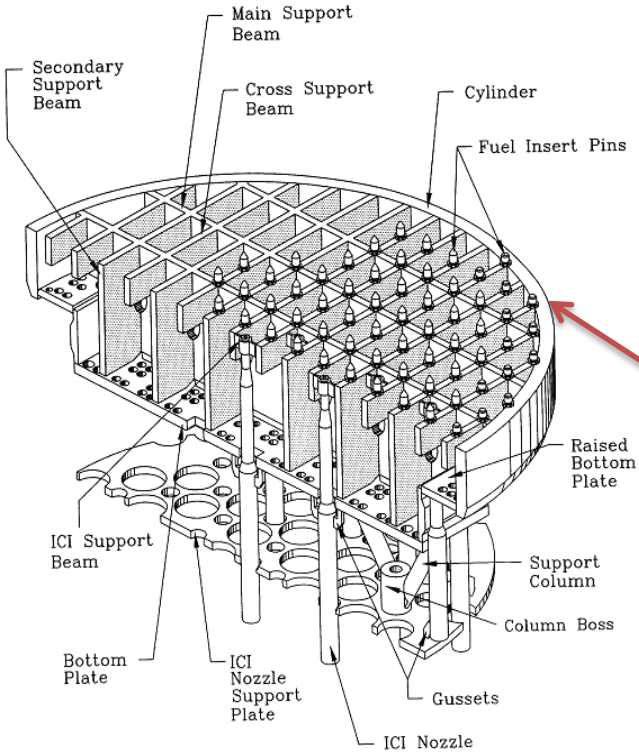
Reactor Pressure Vessel



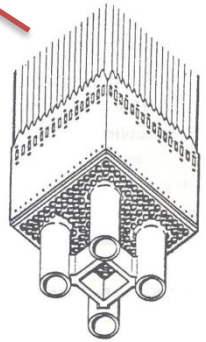
가열접점 열전대
(Heated Junction Thermocouple System)

Upper Guide Structure Assembly

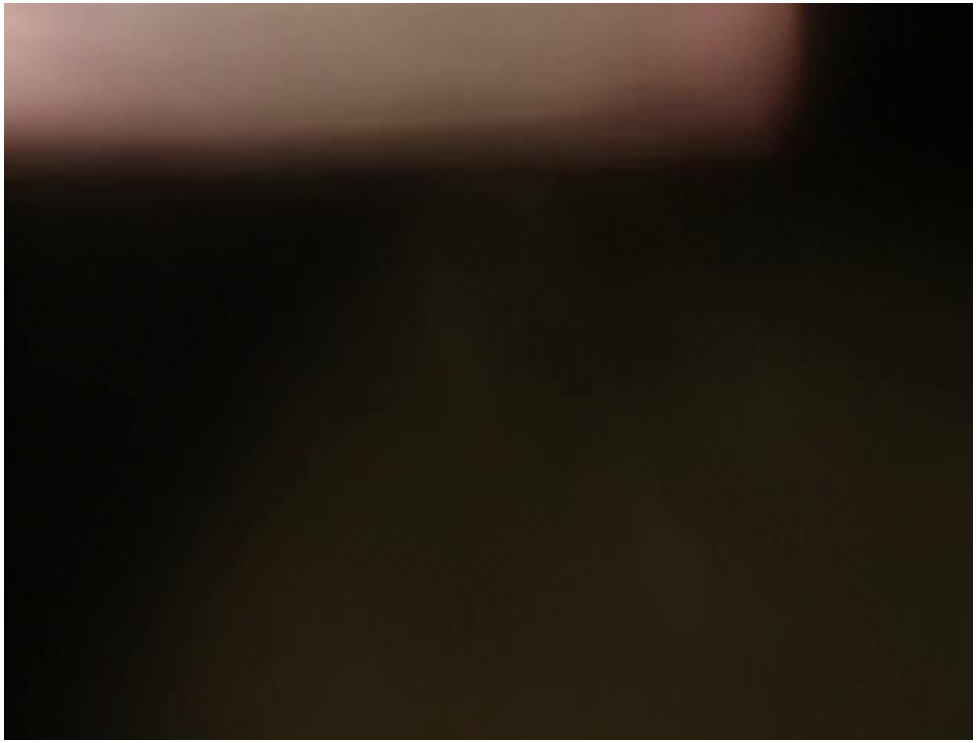




Lower support Structure



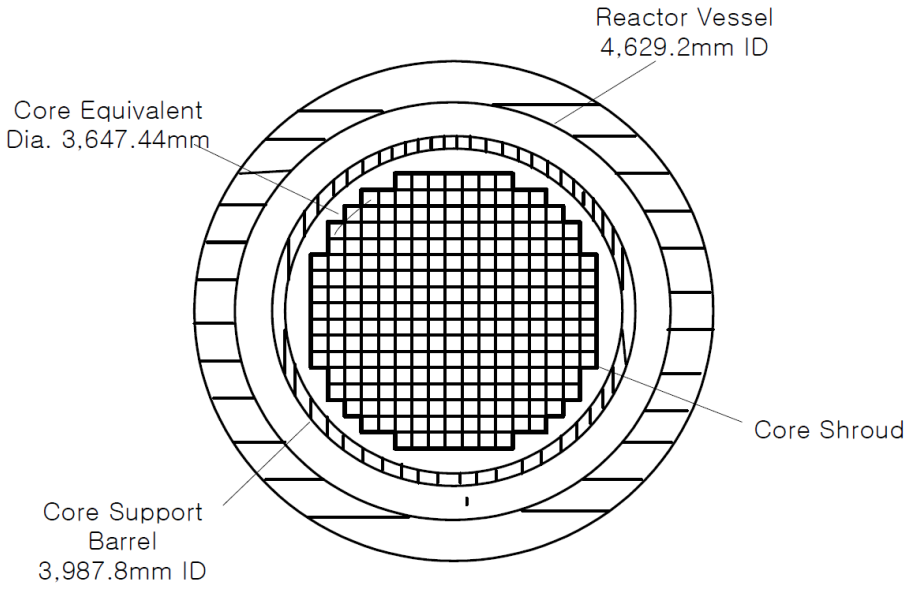
Reactor Pressure Vessel



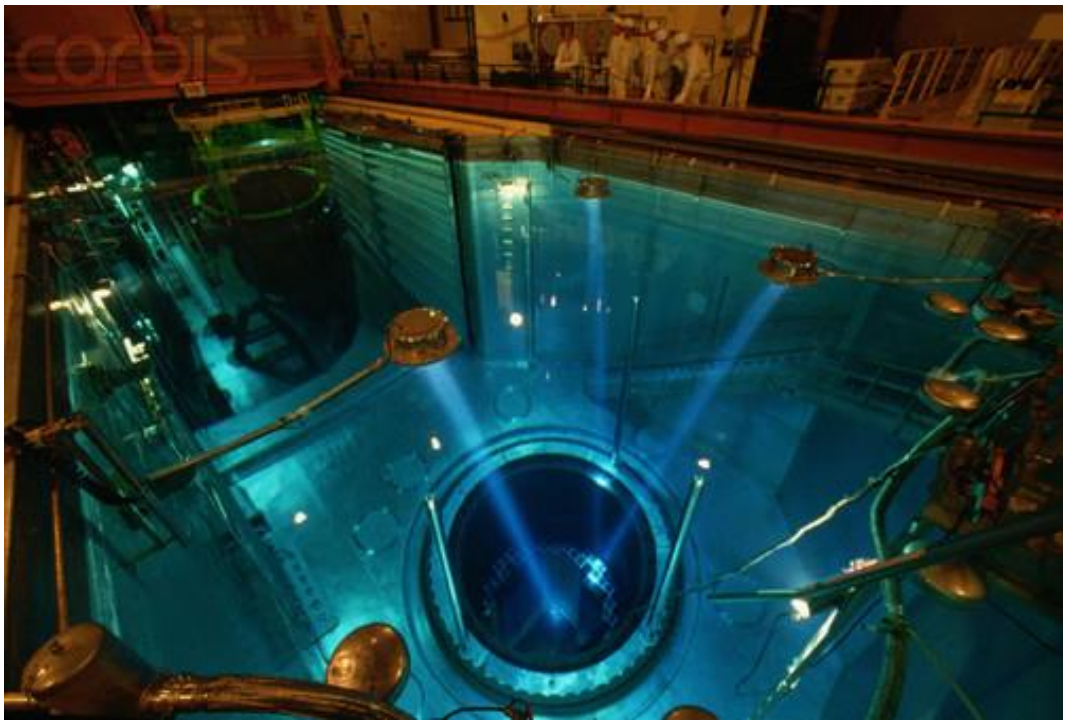
Reactor Pressure Vessel

*) 원자로 노심

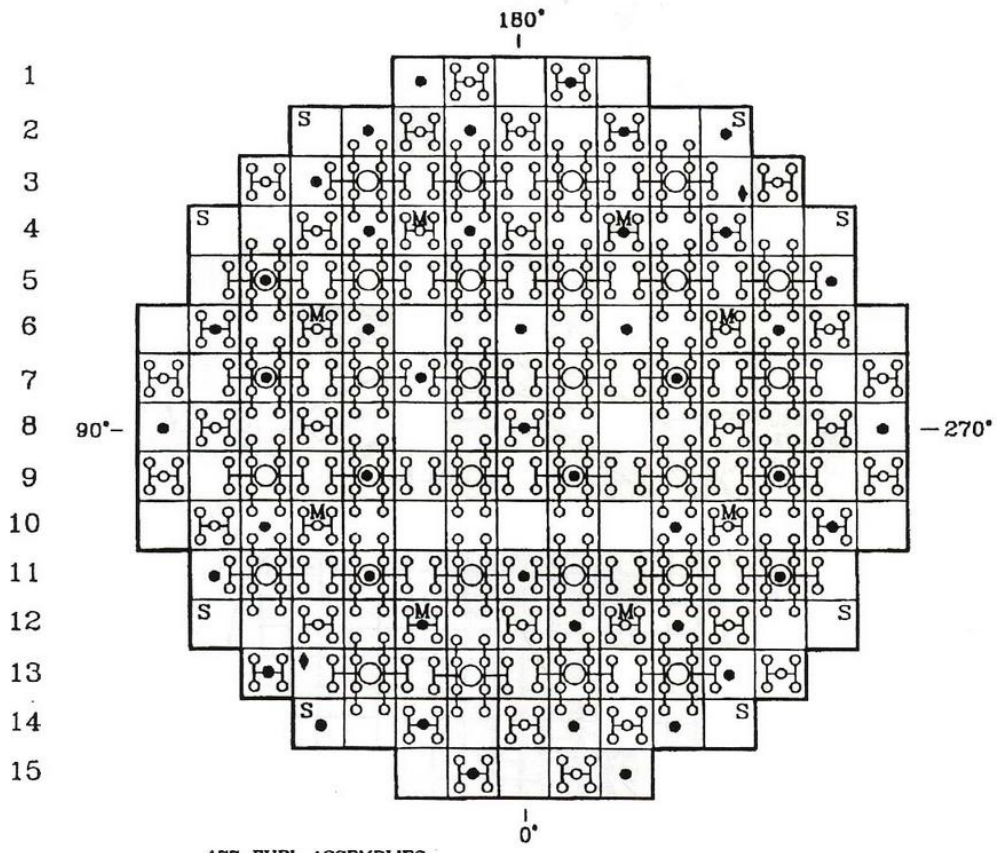
- Reactor core
  - At the nuclear power plant, the fuel assemblies are inserted vertically into the reactor vessel (a large steel tank filled with water with a removable top).
  - The fuel is placed in a precise grid pattern known as the “reactor core.”
  - 241 assemblies in APR1400 (3983 MWt), 177 in OPR1000 (2815 MWt)
    - 15.9~16.5 MWt/assembly



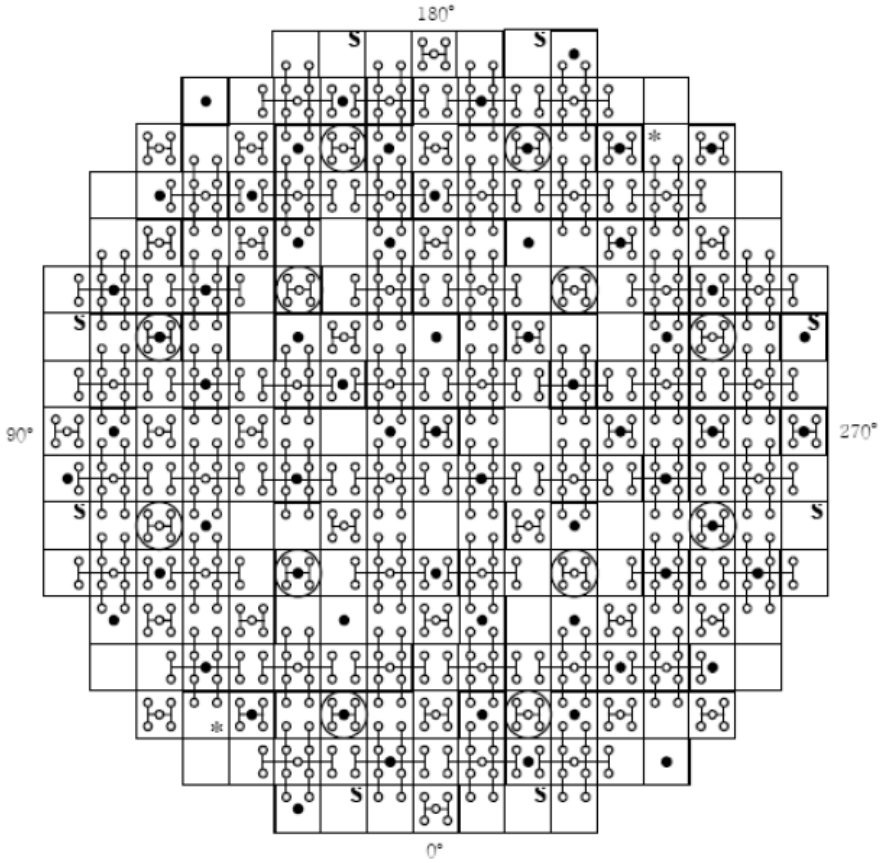
APR1400 Reactor Core



Reactor Pressure Vessel



177 FUEL ASSEMBLIES
73 CEA's AND CEDM's
8 MANEUVERING CEA's (M)
8 ADDITIONAL LOCATIONS FOR SHUTDOWN CEA's (S)
45 FIXED IN-CORE DETECTOR ASSEMBLIES (●)
2 NEUTRON SOURCE ASSEMBLIES (M-3 AND D-13) (♦)



Reactor Pressure Vessel

❖ Reactor Core: Thermal and Hydraulic Parameters

Reactor Parameters	Ulchin 3&4	SKN 3&4
Core Average Characteristics at Full Power:		
Total core heat output, MWt	2815	3983
Total core heat output, 10^6 kcal/h (MBtu/h)	2421 (9608)	3425 (13,590)
Average fuel rod energy deposition fraction	0.975	0.975
Hot fuel rod energy deposition fraction	0.975	0.975
Primary system pressure, kg/cm^2 A (psia)	158 (2250)	158 (2250)
Reactor inlet coolant temperature, °C (°F)	296 (564.5)	291 (555)
Reactor outlet coolant temperature, °C (°F)	327 (621)	324 (615)
Core exit average coolant temperature, °C (°F)	328 (623)	325 (617)
Average core enthalpy rise, kcal/kg (Btu/lb)	45.3 (81.5)	46.7 (84.1)
Design minimum primary coolant flow rate, L/min (gpm)	1,249,000 (330,000)	1,689,000 (446,300)
Design maximum core bypass flow, % of primary	3.0	3.0
Design minimum core flow rate, L/min (gpm)	1,211,000 (320,000)	1,639,000 (432,900)
Hydraulic diameter of nominal subchannel, cm (in.)	1.196 (0.471)	1.265 (0.498)
Core flow area, m^2 (ft^2)	4.165 (44.83)	5.825 (62.7)
Core average mass velocity, million kg/h-m^2 (million lb/h-ft^2)	12.84 (2.63)	12.60 (2.58)
Core average coolant velocity, m/s (ft/s)	5.10 (16.7)	4.94 (16.2)
Core average fuel rod heat flux, Kcal/h-m^2 (Btu/h-ft^2)	487,660 (179,750)	517,361 (190,735)
Total heat transfer area, m^2 (ft^2)	4840 (52,100)	6454 (69,470)
Average fuel rod linear heat rate, W/cm, (kW/ft)	172.6 (5.26)	179.2 (5.46)
Power density, kW/L	96.6	100.5
No. of active fuel rods	41,772	56,876

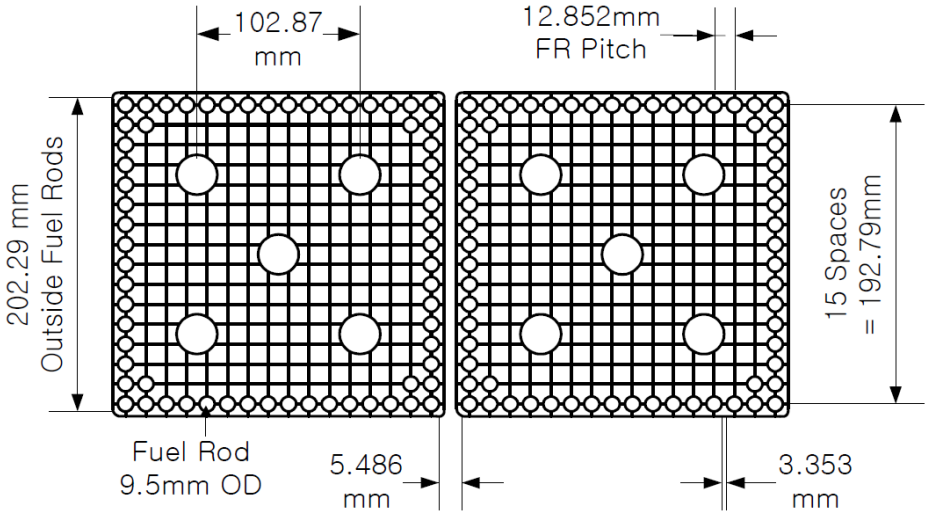
APR1400: 109.7m 461.3㎥/min

OPR1000: 102.7m, 323.3㎥/min

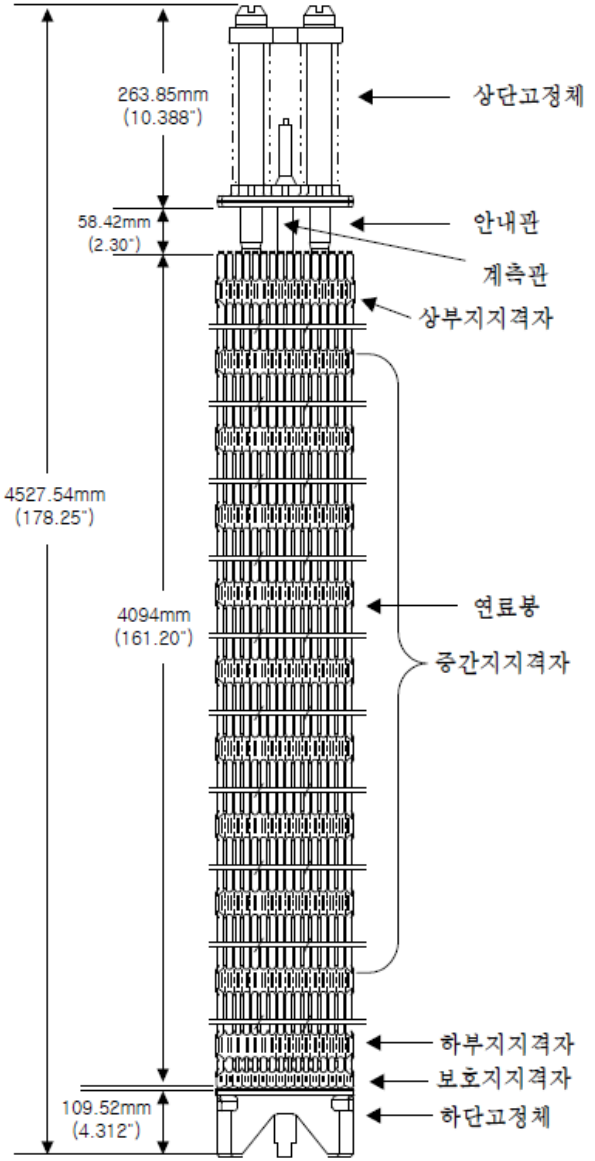
Reactor Pressure Vessel

Reactor Core

- Equivalent diameter: ~3.647 m, active core height: 3.81 m
- APR1400: 241 Fuel assemblies (16×16)
- Coolant temperature: Inlet (~291°C), outlet: (~324 °C)
- Flow rate: 1,639,000 lpm ≈ 27.3 m^3/s ≈ 4.94 m/s
- Linear power density of each rod: 17~18 kW/m



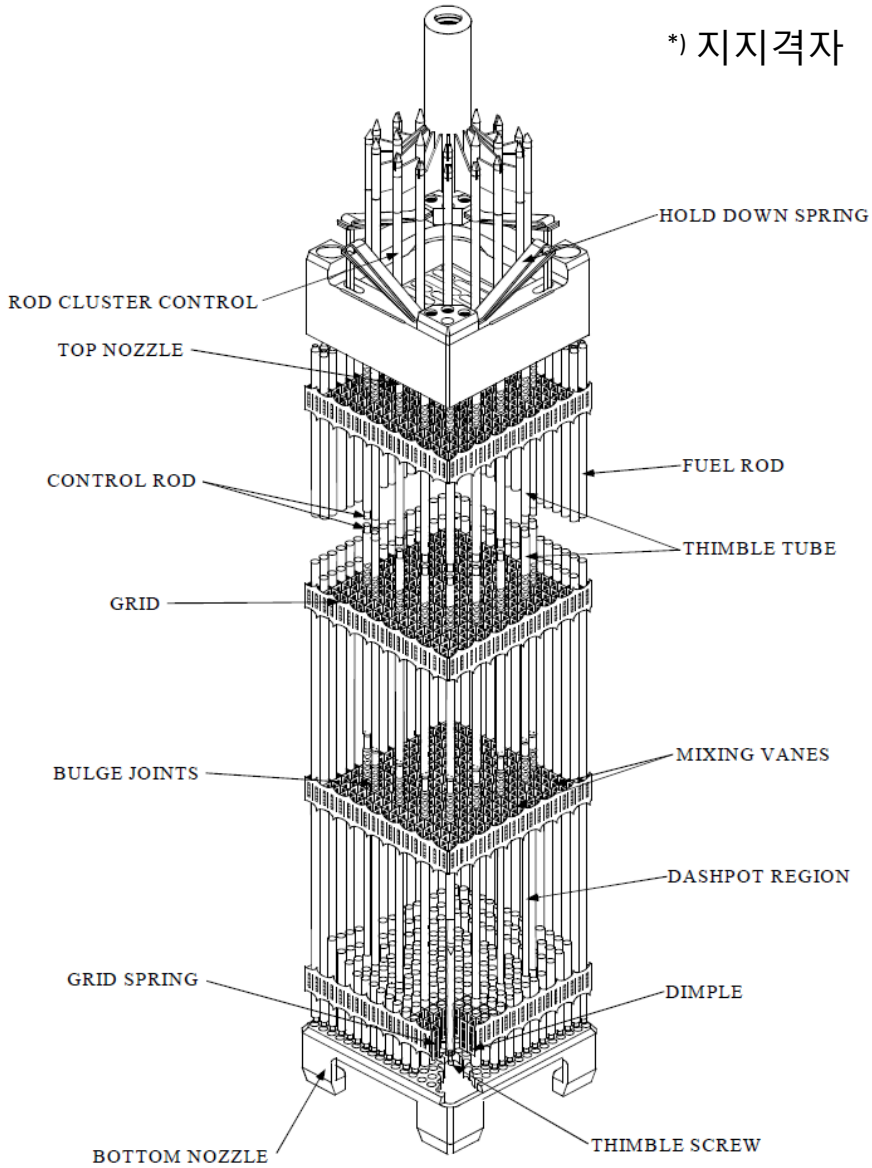
15 % 이용률 (3.5 시간)



Reactor Pressure Vessel

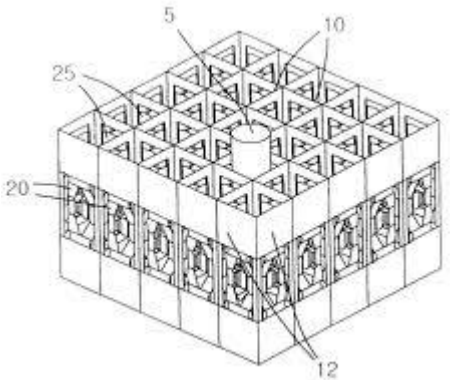
- Reactor fuel assemblies
  - Major components
    - Fuel rods
    - Spacer grids
    - Upper and lower end fittings
  - Fuel rods
    - Ceramic fuel pellets
    - Length: 3.81 m (APR1400)
    - Contain a space at the top for the collection of any gases produced by the fission process
      - For example, xenon and krypton
    - Arranged in a square matrix
      - 16×16 or 17×17 for PWRs
        - 236 in APR1400, why not 256?
      - 8×8 for BWRs
    - APR1400: 241 Fuel assemblies (16×16)
      56876 fuel rods

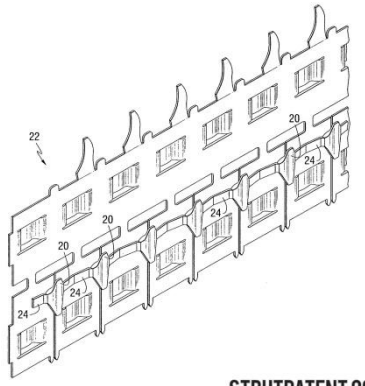
*) 지지격자

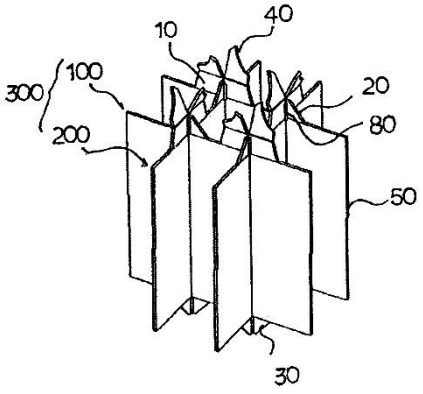


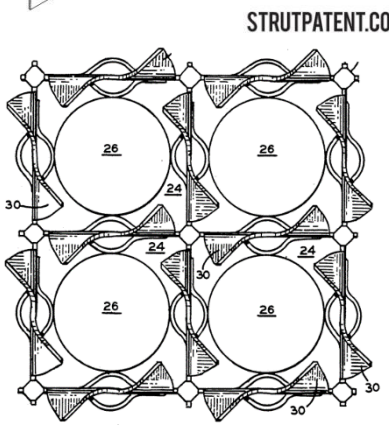
Reactor Pressure Vessel

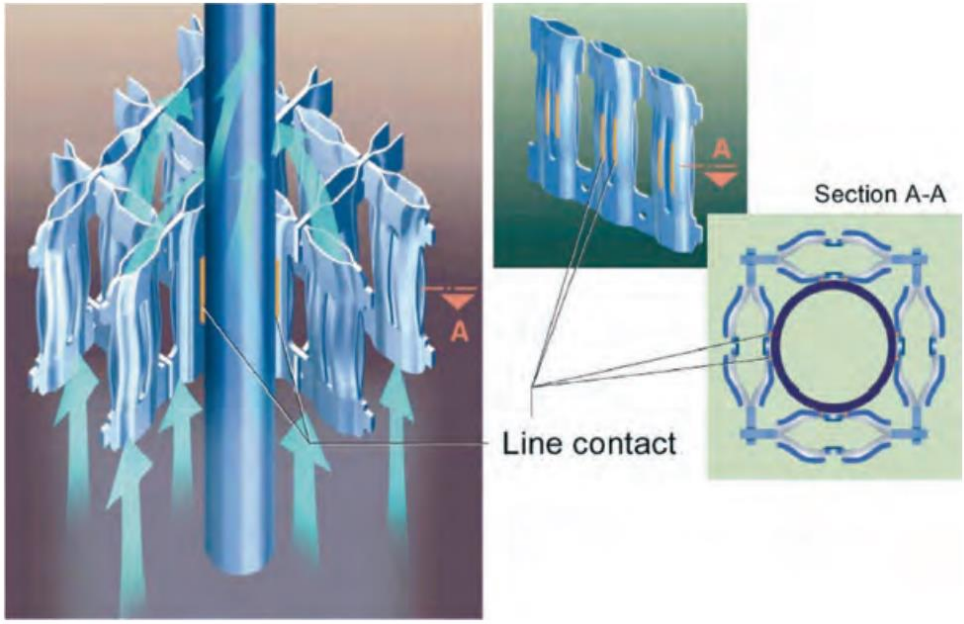
- Reactor fuel assemblies
  - Spacer grids*)
    - Separate the individual rods with pieces of sprung metal.
    - Provide the rigidity of the assemblies.
    - Allow the coolant to flow freely up through the assemblies and around the fuel rods.
    - Some spacer grids may have flow mixing vanes (or swirl vane) that are used to promote mixing of the coolant as it flows around and through the fuel assembly.



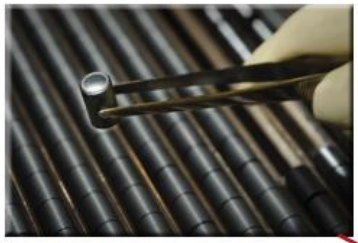






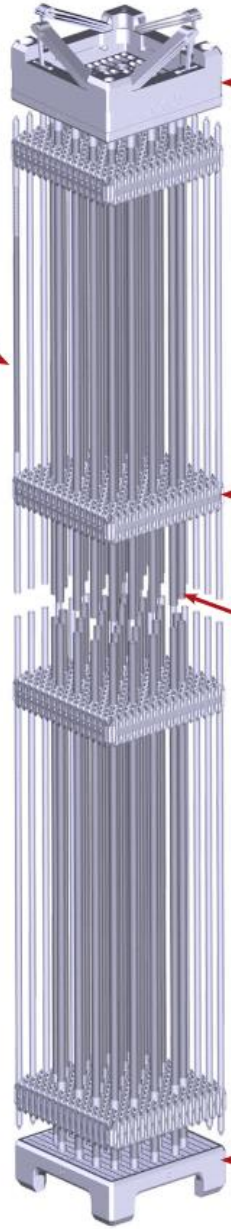


Reactor Pressure Vessel



Ceramic Fuel Pellet

Sealed
Fuel Rod



End Fitting

Spacer Grid

Structural Guide Tube

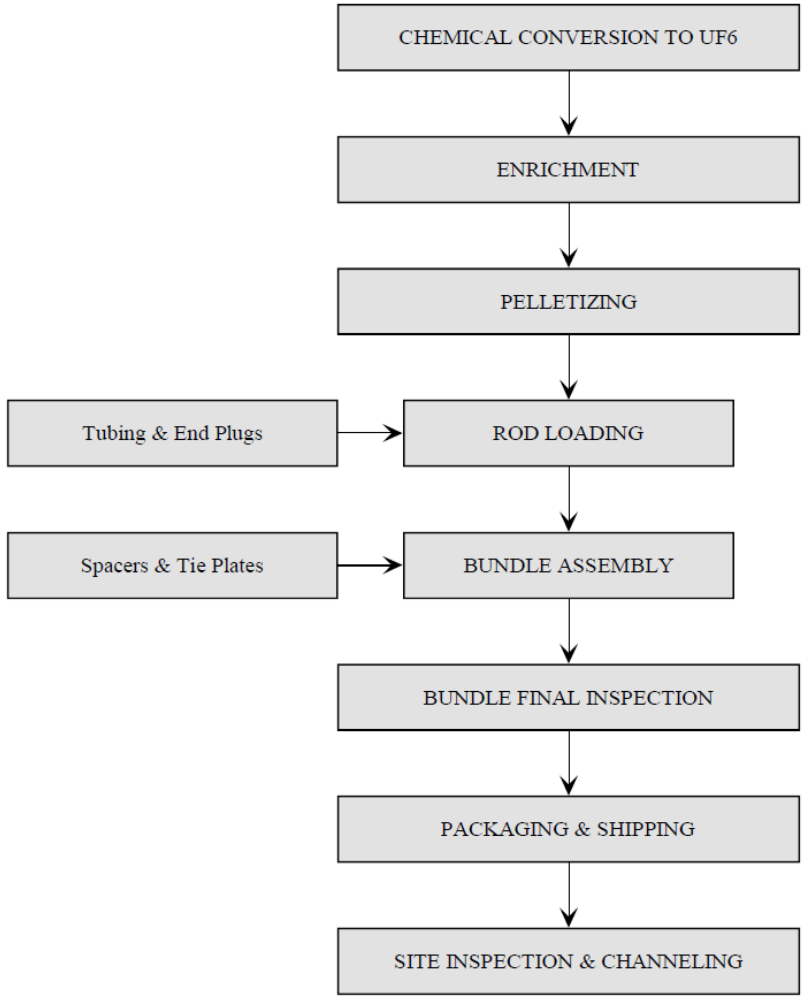
End Fitting

Reactor Pressure Vessel

Fuel Assemblies (Cont'd)	
Pellet diameter (nominal), cm (in)	0.819 (0.3225)
Pellet length , cm (in) (Enriched Uranium)	0.983 (0.387)
Pellet density (nominal), g/cm^3	10.44
Pellet theoretical density, g/cm^3	10.96
Pellet density (nominal) (% theoretical)	95.25
Stack height density (nominal), g/cm^3	10.313
Clad material	ZIRLO
Clad ID, cm (in)	0.836 (0.329)
Clad OD, (nominal), cm (in)	0.950 (0.374)
Clad thickness, (nominal), cm (in)	0.05715 (0.0225)
Diametral gap, (cold, nominal), cm (in)	0.01651 (0.0065)
Active length, cm (in)	381 (150)
Plenum length (nominal), cm (in)	22.568 (8.885)

Reactor Coolant System

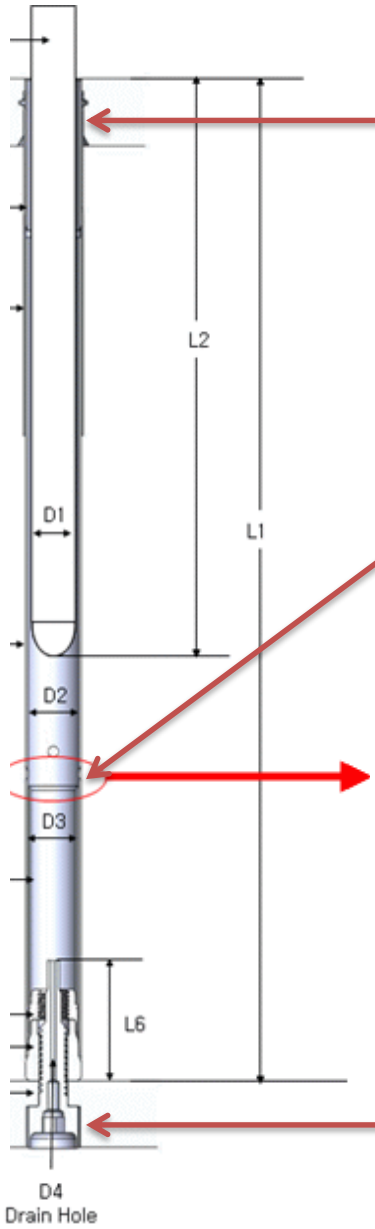
- Nuclear fuel
  - Ceramic pellets
  - The pellets are stacked into 12-foot long, slender metal tubes, generally made of a zirconium alloy.
  - The tube is called the "fuel cladding."
  - When a tube is filled with the uranium pellets, it is pressurized with helium gas, and plugs are installed and welded to seal the tube.
    - ~400 psig ≈ 27 bar (why?)
  - The filled rod is called a "fuel rod."
  - The fuel rods are bundled together into "fuel assemblies" or "fuel elements."
  - The completed assemblies are now ready to be shipped to the plant for installation into the reactor vessel.



*) 핵연료피복재, 핵연료봉, 핵연료집합체

Guide Tube

- Design parameters
  - Control rod drop velocity
  - Bypass minimum
  - Bypass maximum



Upper end fitting

Precipitation !

Dashpot
a damper which resists motion via viscous friction

Lower end fitting

Contents

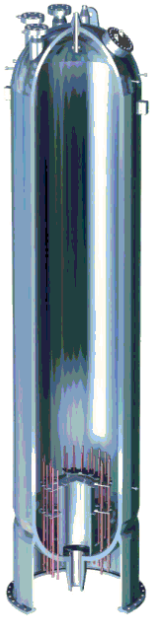
- History of PWR
- Plant Overall
- Reactor Coolant System
- Steam and Power Conversion System
- Auxiliary System
- Plant Protection System
- Other systems

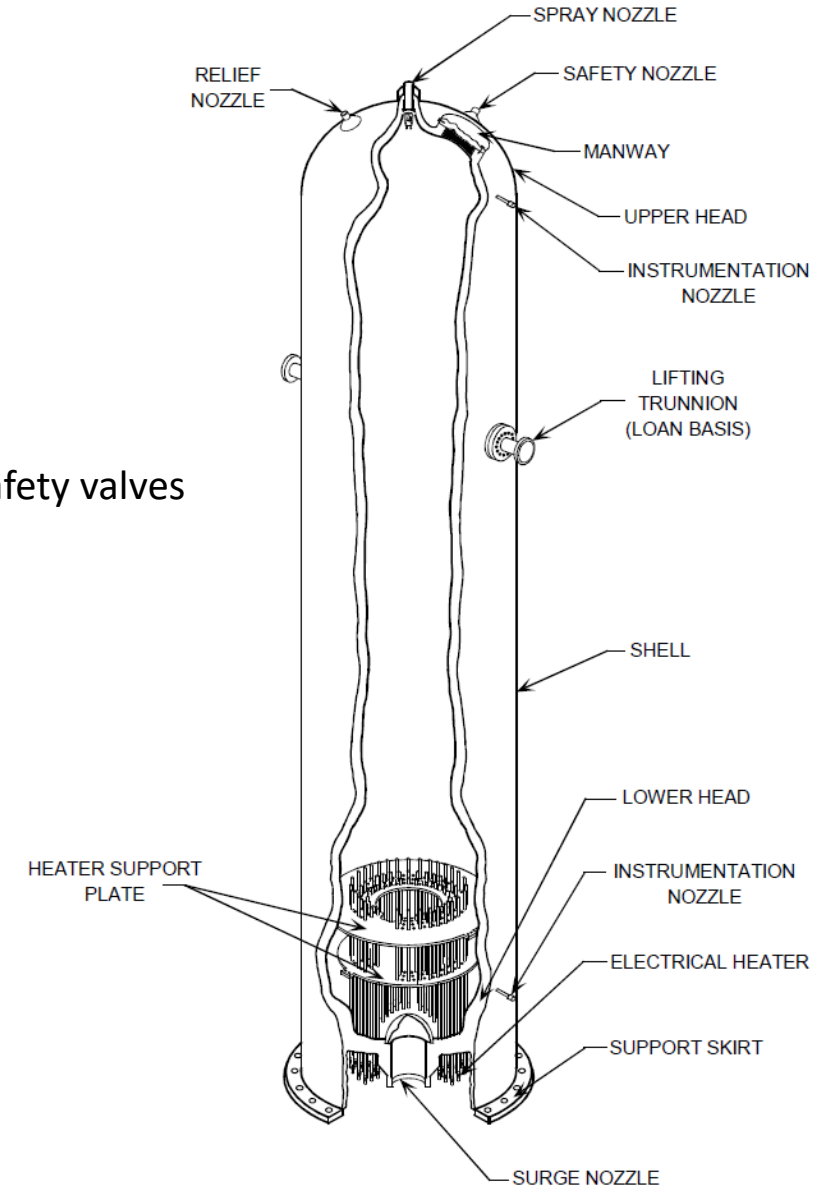
Reactor Vessel
Pressurizer
Reactor Coolant Pump
Steam Generator

Reactor Coolant System

Pressurizer

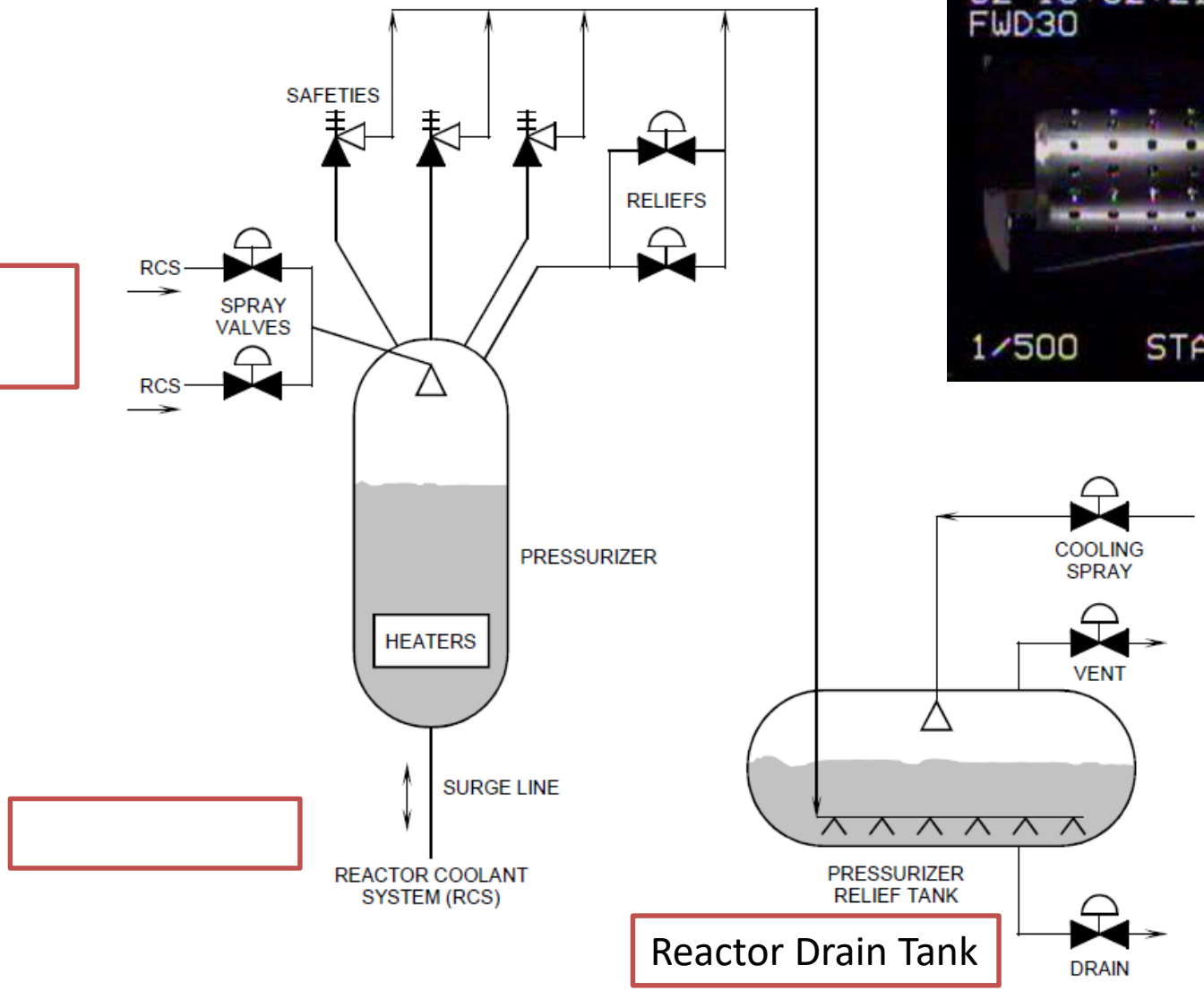
- Provides a means of controlling the system pressure
- Pressure is controlled by
  - Electrical heaters
  - Pressurizer spray
  - Power operated relief valves/ safety valves.
- Operation
  - High pressure: spray (ρ_l=588.5, ρ_g=105.2) $\Rightarrow$ PORV $\Rightarrow$ safety valves
  - Low pressure: heaters $\Rightarrow$ trip
- Dimensions
  - Height: ~ 13 m
  - Inner diameter: ~ 2.4 m
  - Outer diameter: ~ 2.7 m
  - Surge nozzle: ~ 0.3 m
- Installed heater
  - Total 1800 kW (50 kW $\times$ 36 ea)





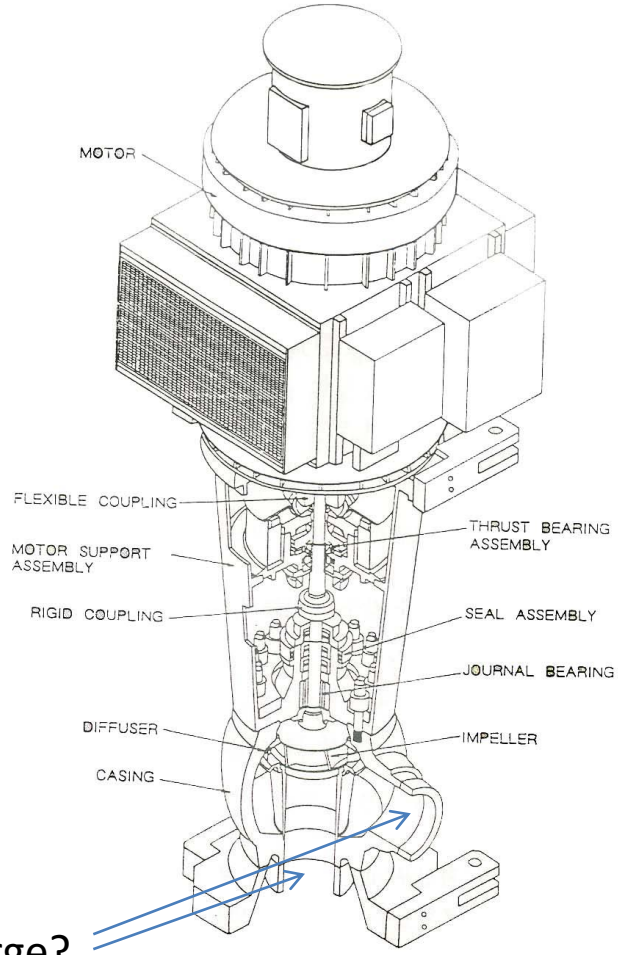
Reactor Coolant System

❖ Pressurizer



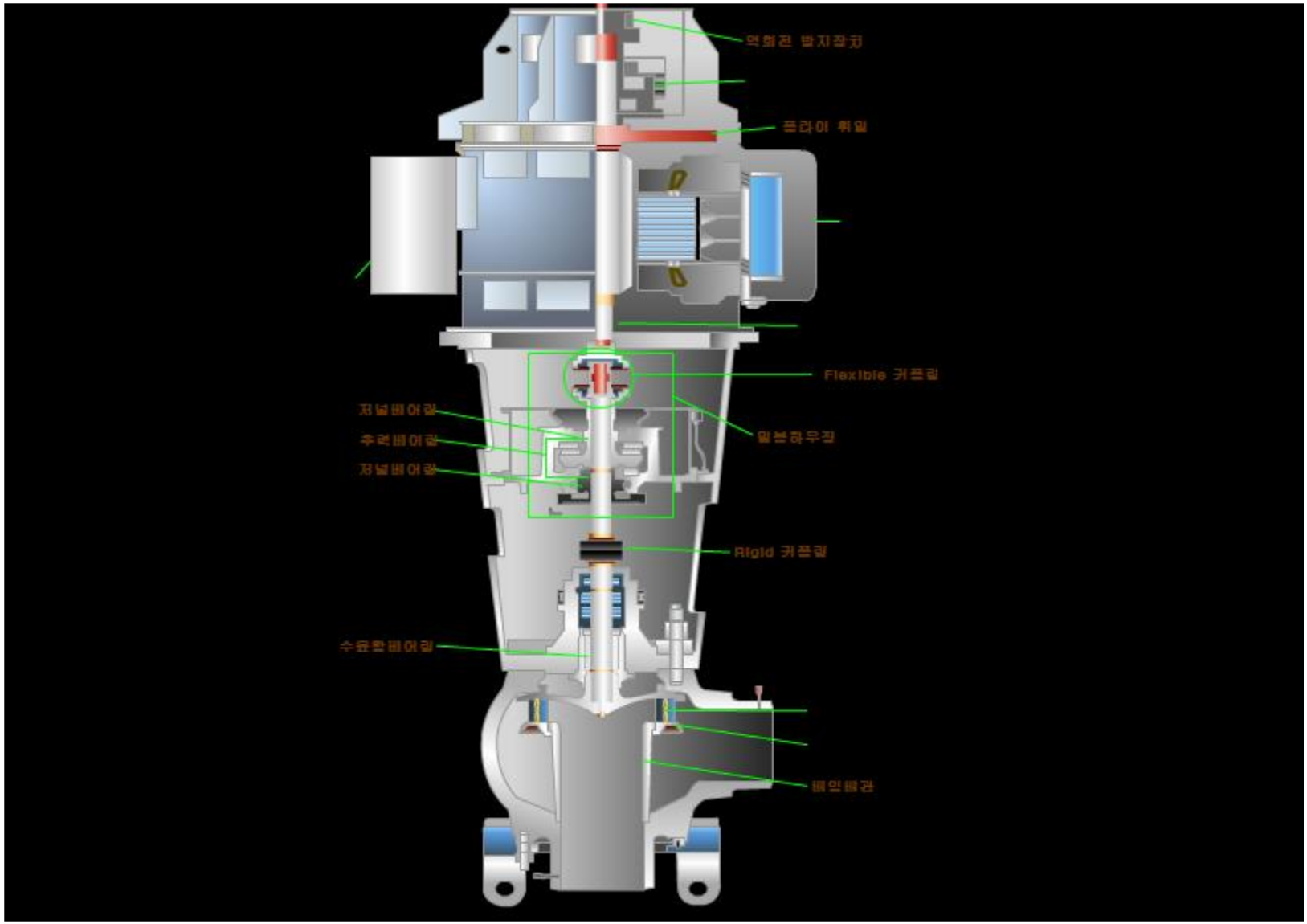
RCP (Reactor Coolant Pump)

- Provide forced primary coolant flow to remove the heat generated by the fission process
  - Natural circulation: sufficient for heat removal when the plant is shutdown
- Increase pressure: 90 psi ≈ 6.2 bar
- Components
  - Motor, hydraulic section, seal package
  - Motor
    - Air cooled, 1190 RPM, 4.5~6 MW (10~20 MWt)
    - Flywheel for coastdown
  - Hydraulic section
    - Impeller, shaft, suction and discharge nozzles etc.
- Height: ~ 11 m, ~$ 20~30 M



Suction?
or Discharge?

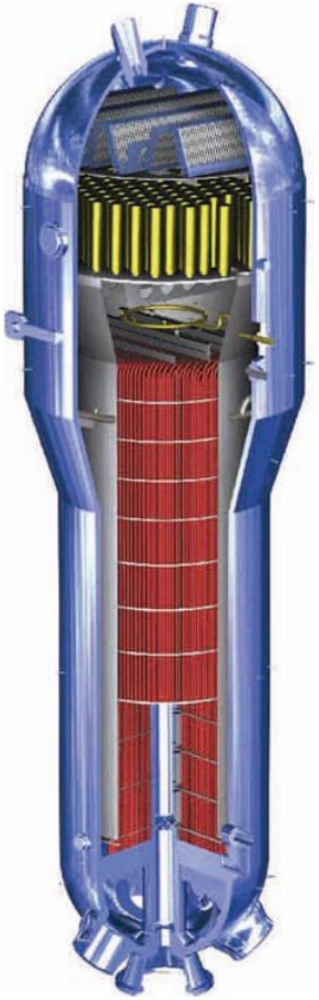
❖ RCP (Reactor Coolant Pump)

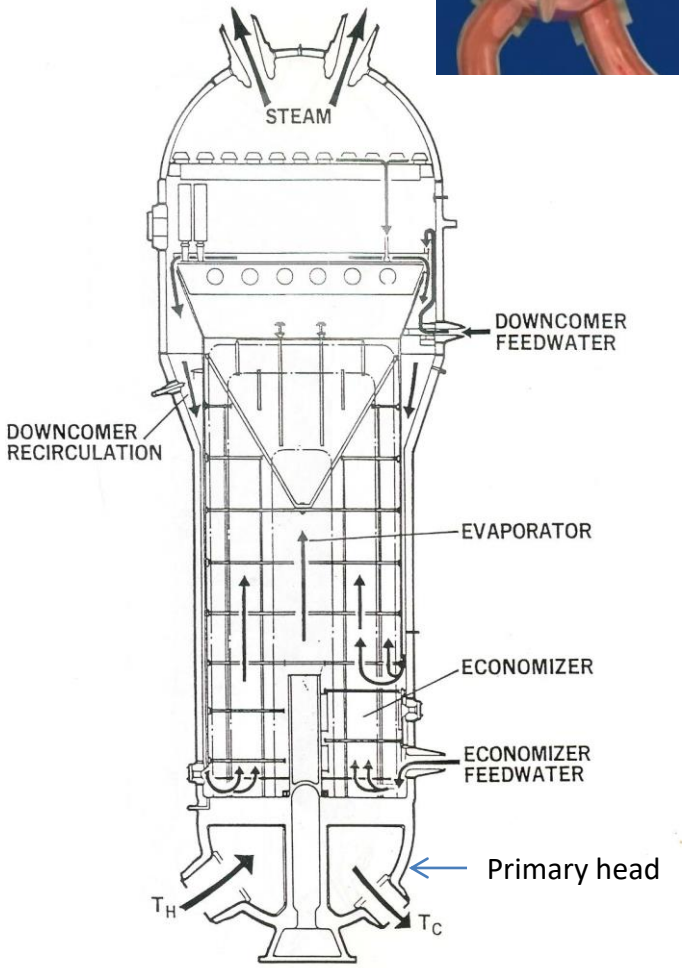


Reactor Coolant System

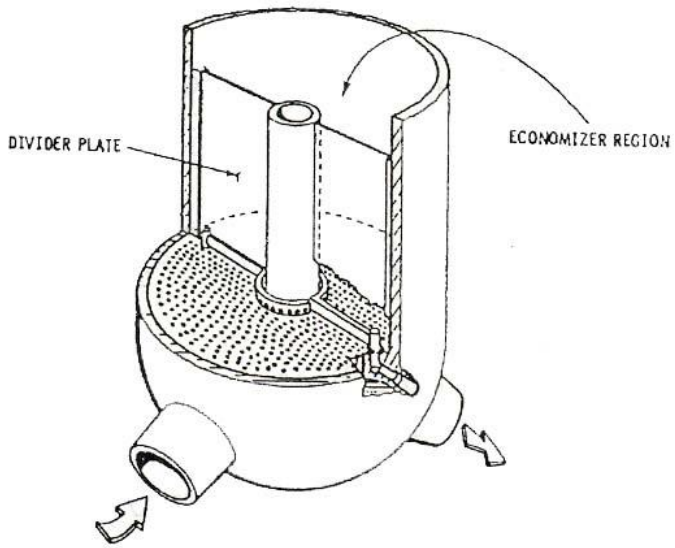
Steam Generator

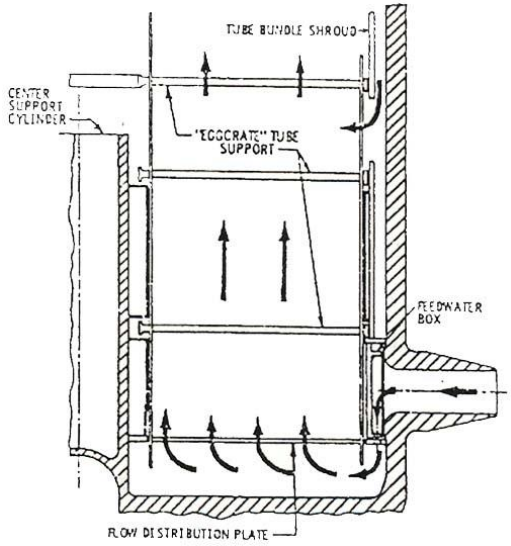
- Primary side (tube)
  - U-tubes: 19.05 mm I.D., 1.07 mm thickness
  - Length: ~ 19.4 m
  - OPR1000: ~ 8,214 tubes/SG
  - APR1400: ~ 13,102 tubes/SG
  - 1 Inlet: 323 °C, 2 outlets: 290 °C
  - Inconel-600
- Secondary side (shell)
  - Height: 20~23 m, diameter: 4.5~6 m
  - Pressure: 70~75 Bars
  - 3 Inlets: ~232 °C, 2 outlets: ~285 °C
- Operation
  - Steam-water mixture ⇒ separator⇒ drier
  - Separator: mixture spin (exit water < 2 %)
    - Centrifugal separator
  - Drier: rapid direction change
  - Exit water content < 0.25 wt %
    - To prevent damage to the turbine blading



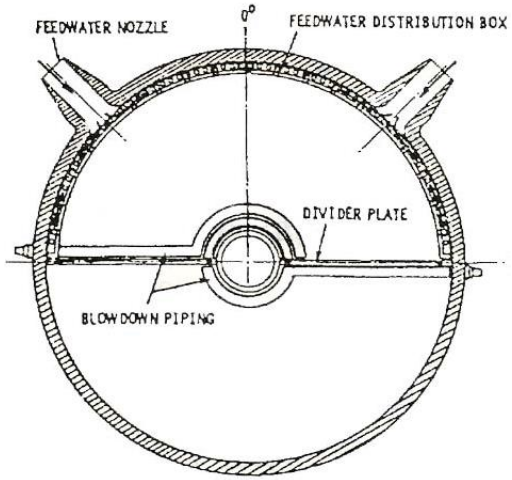


❖ Steam Generator



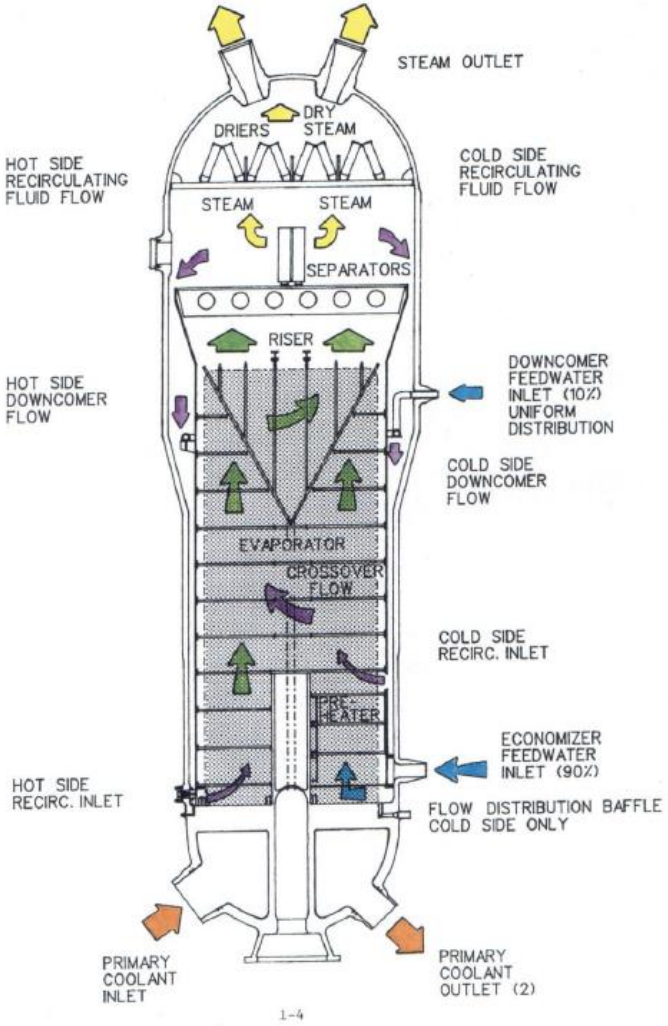


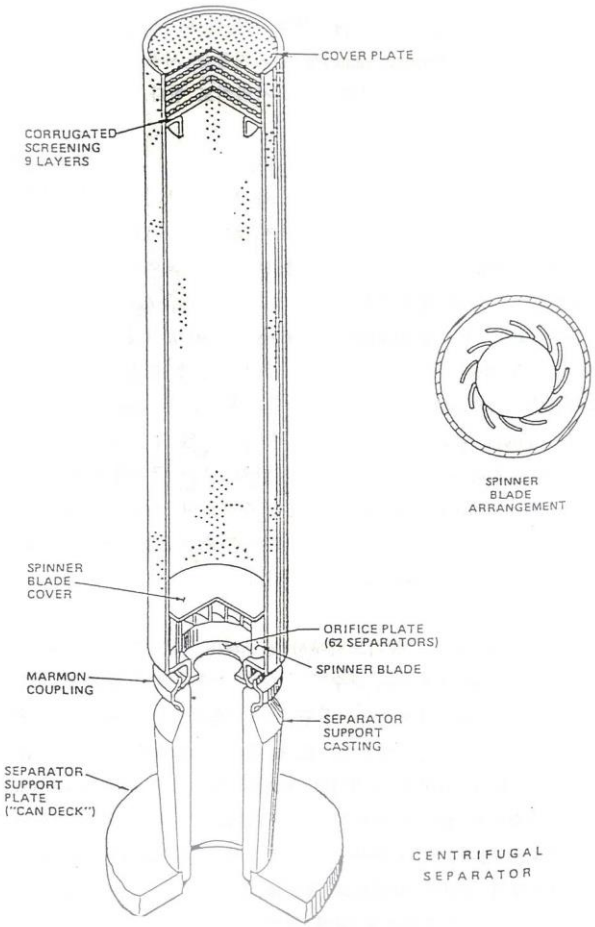
350 mm

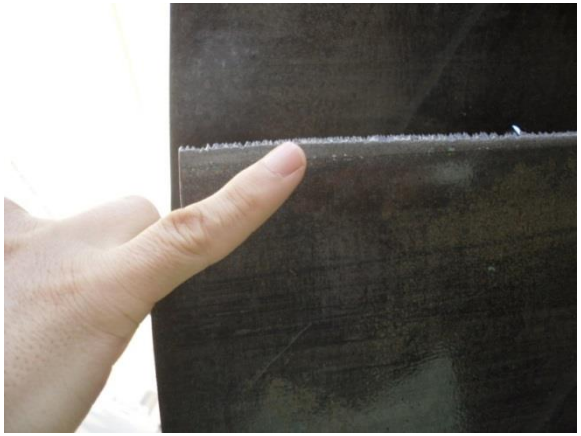


❖ Steam Generator

Recirculation ratio : 3.9
(100 (Steam) + 290 (Saturated water)) / 100 (Feedwater)

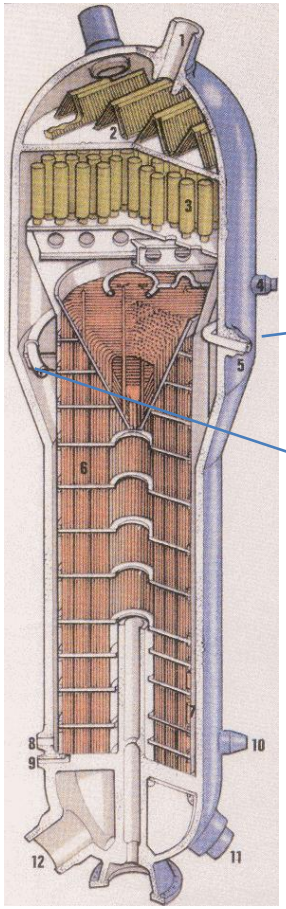


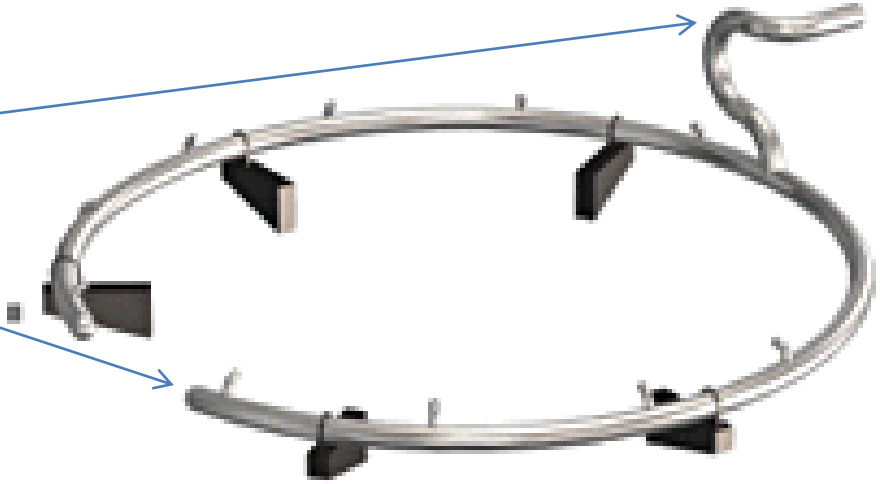




Steam Generator

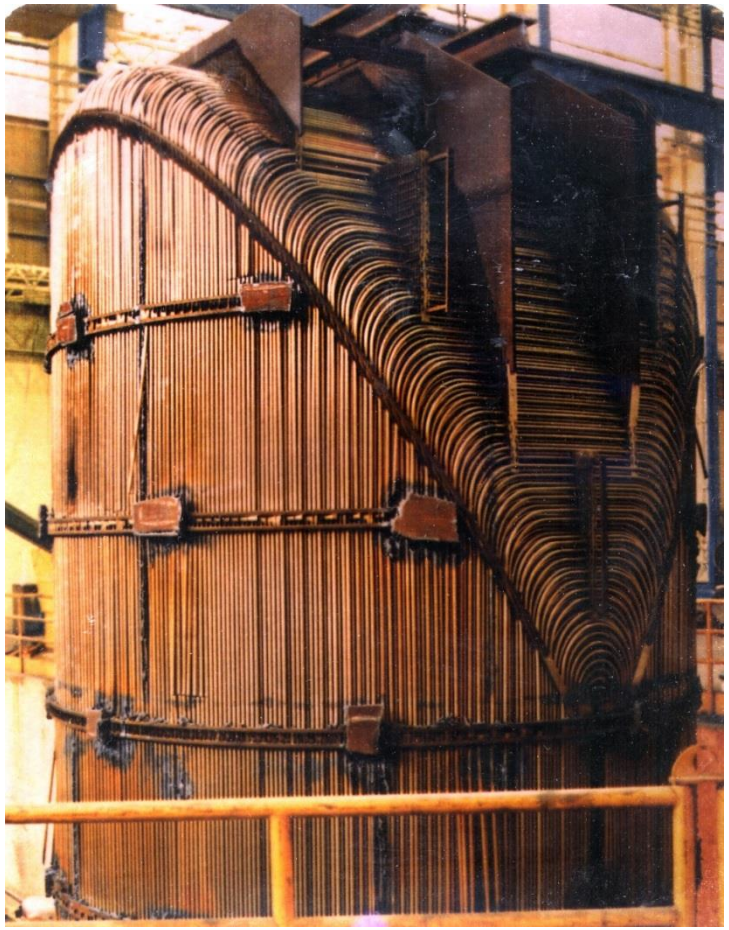
- Inverted J-Nozzle
  - To prevent condensation-induced water hammer

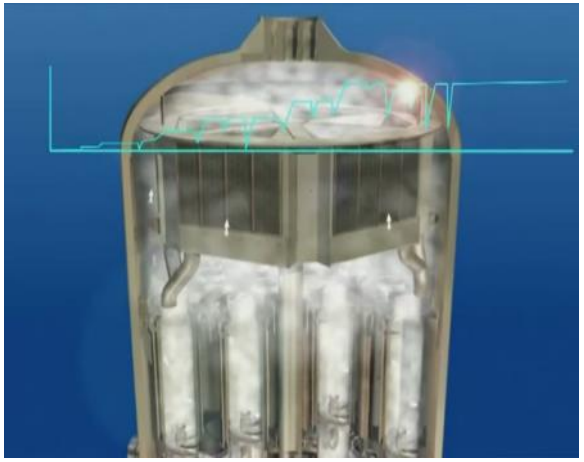


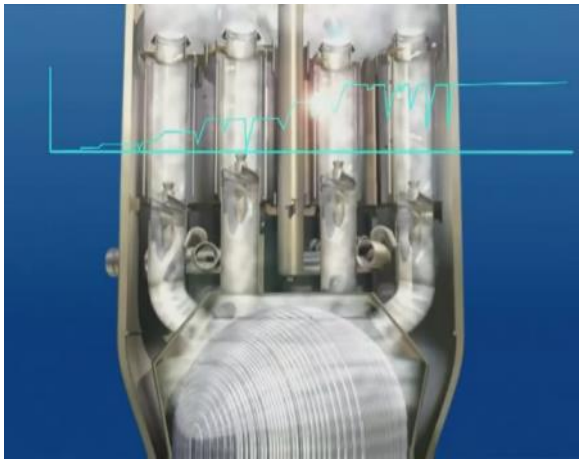


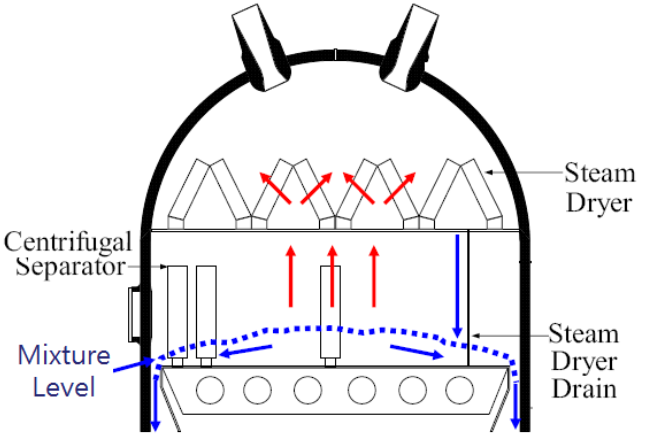
Reactor Coolant System

❖ Steam Generator









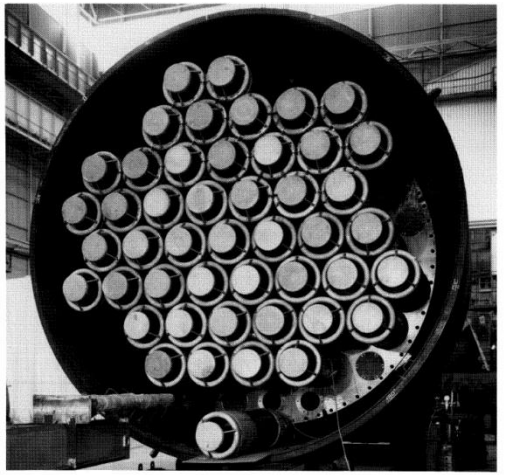
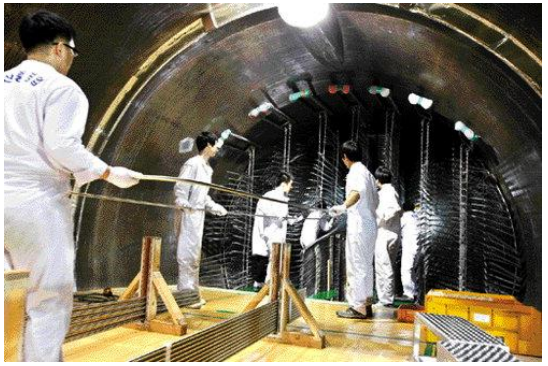
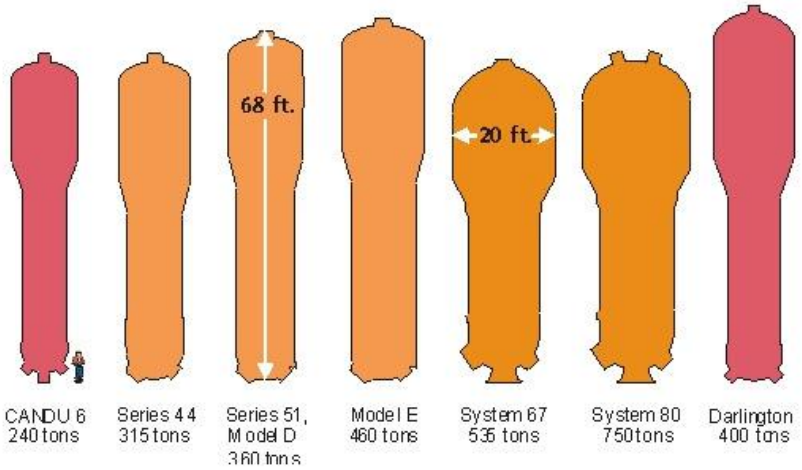


FIGURE 51. Moisture separator arrangement in a KWU SG.

Reactor Coolant System

❖ Steam Generator





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Condensate System
Main Feedwater System