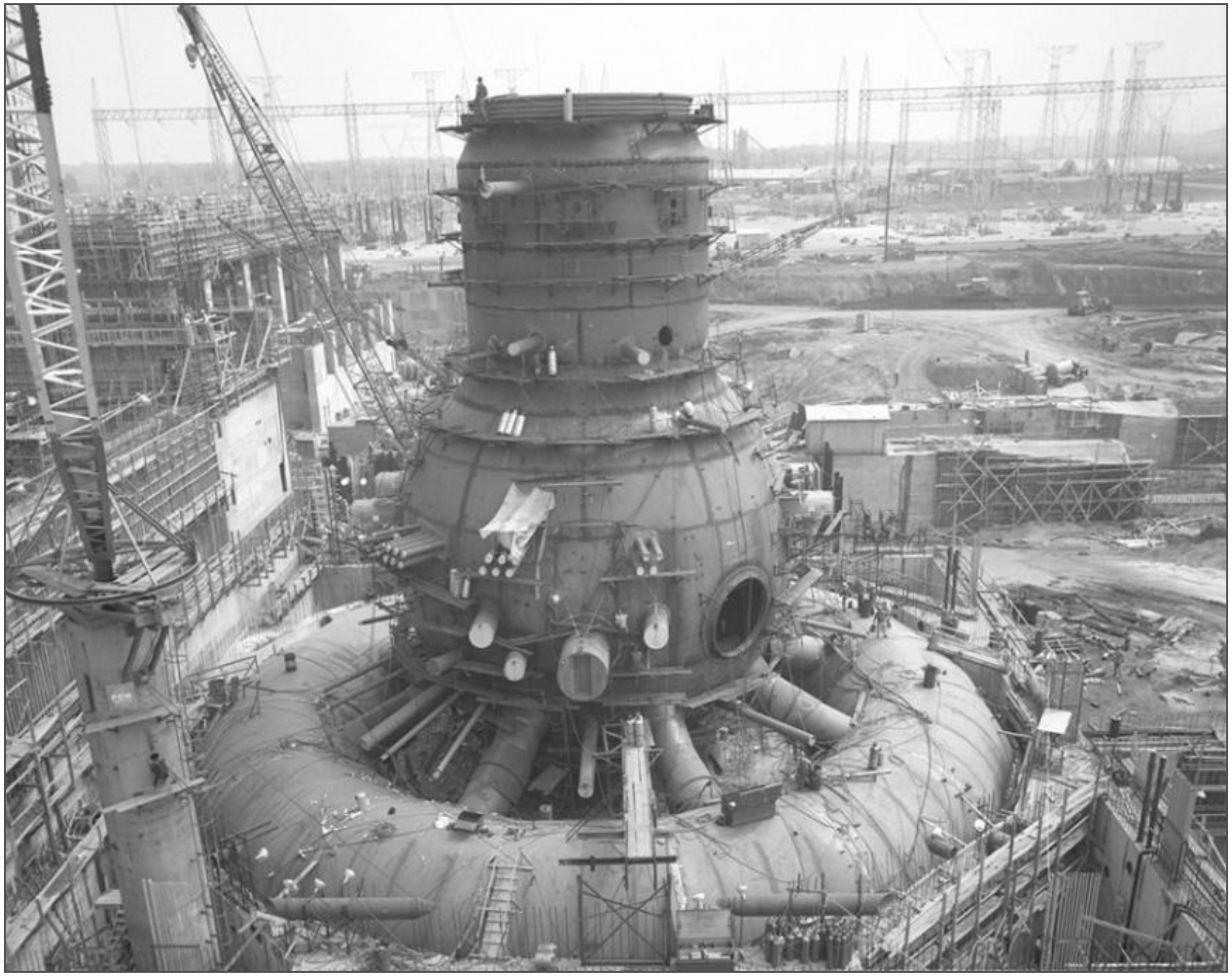
Pressurized Components of Nuclear Power Plants



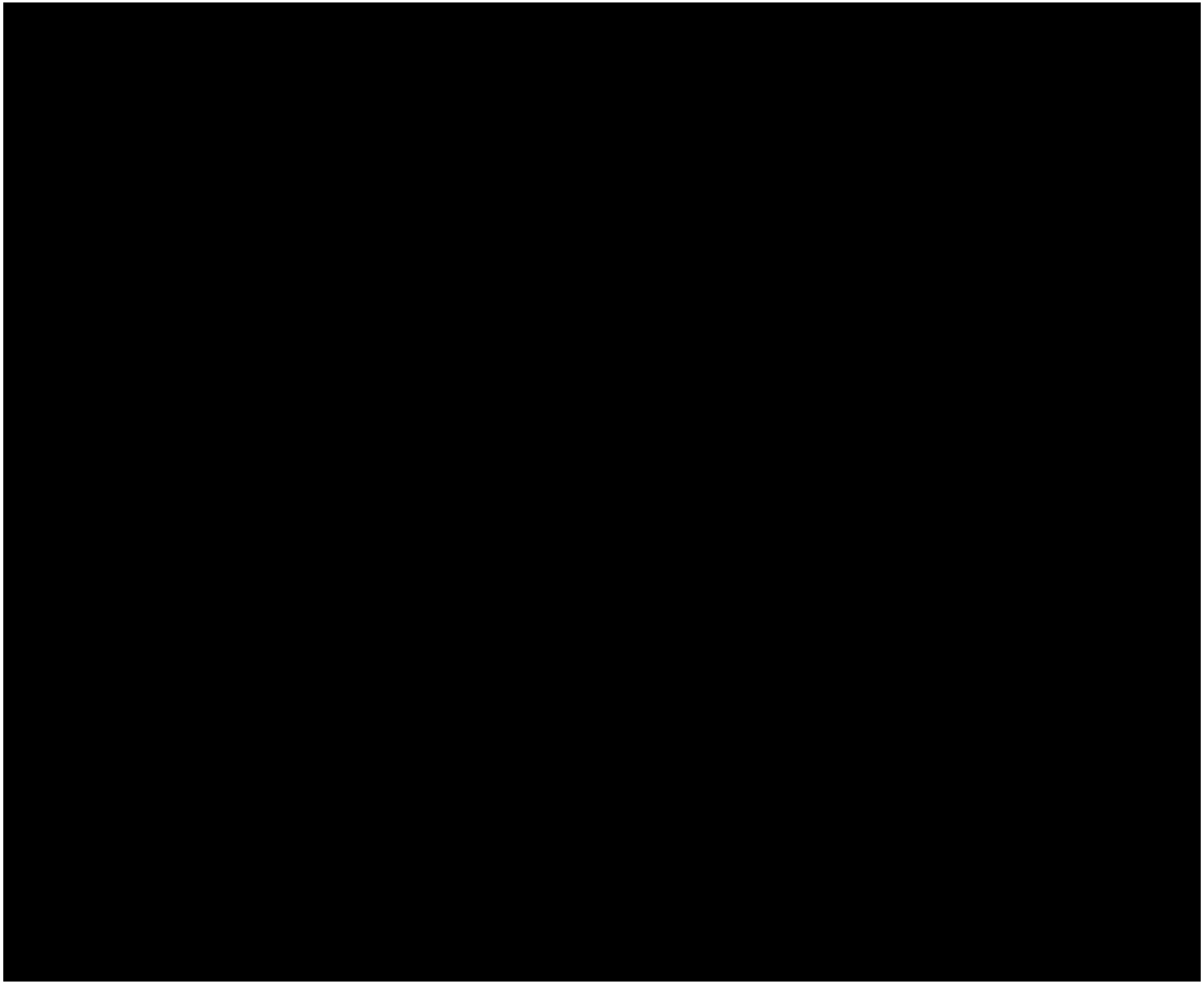
MARK I Containment

Pressurized Components of Nuclear Power Plants

1.	Introduction to Structural Reliability in Nuclear Engineering

1.1.	Risk based reliability engineering
1.2.	Mitigation Strategies
1.3.	Basics on Nuclear Power
1.4.	**Pressurized components of NPP**
1.5.	BWR-Fukushima Accident
1.6.	RBMK Reactor – Chernobyl accident
1.7.	Specifics of nuclear power engineering
1.8.	Production of medical isotopes

NPP Video (AREVA)



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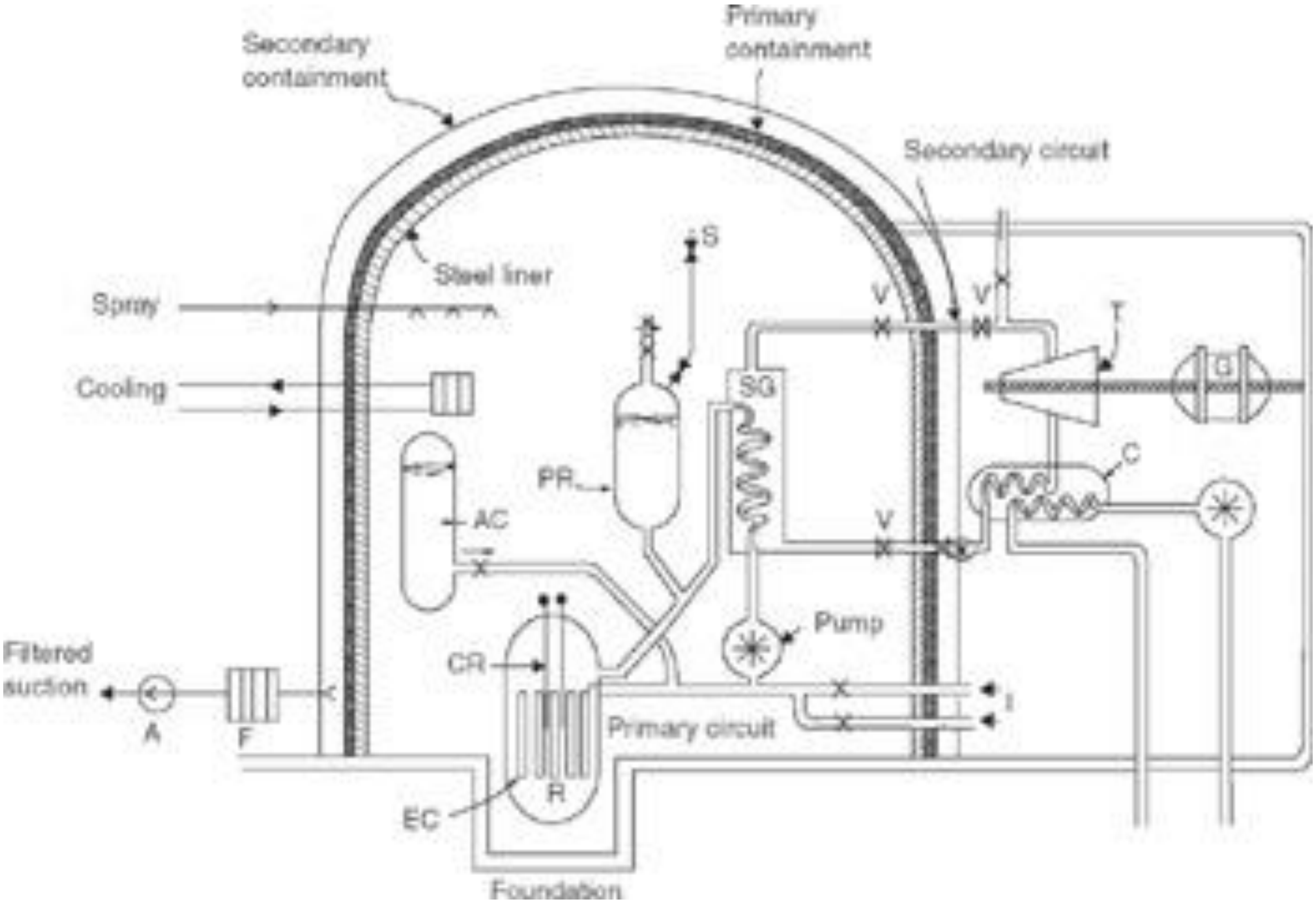
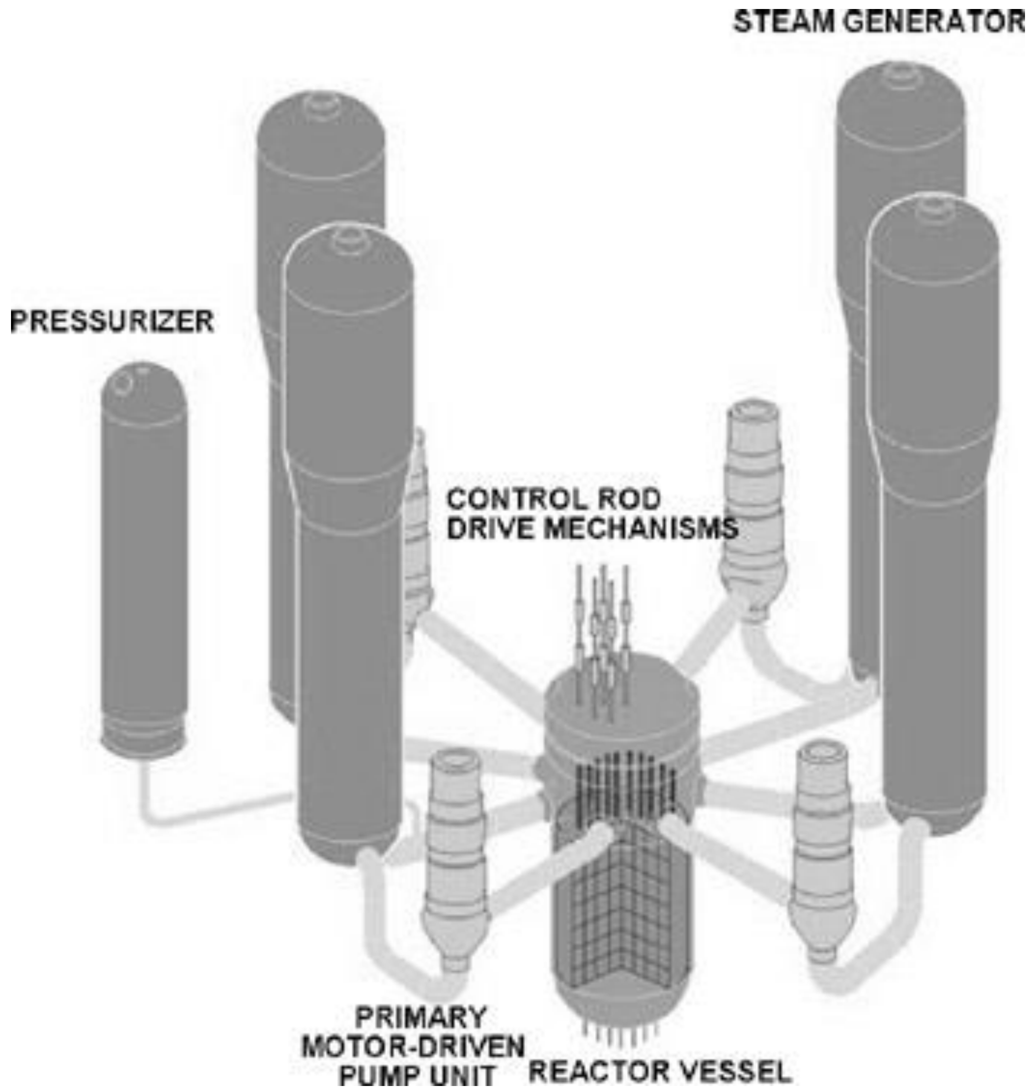
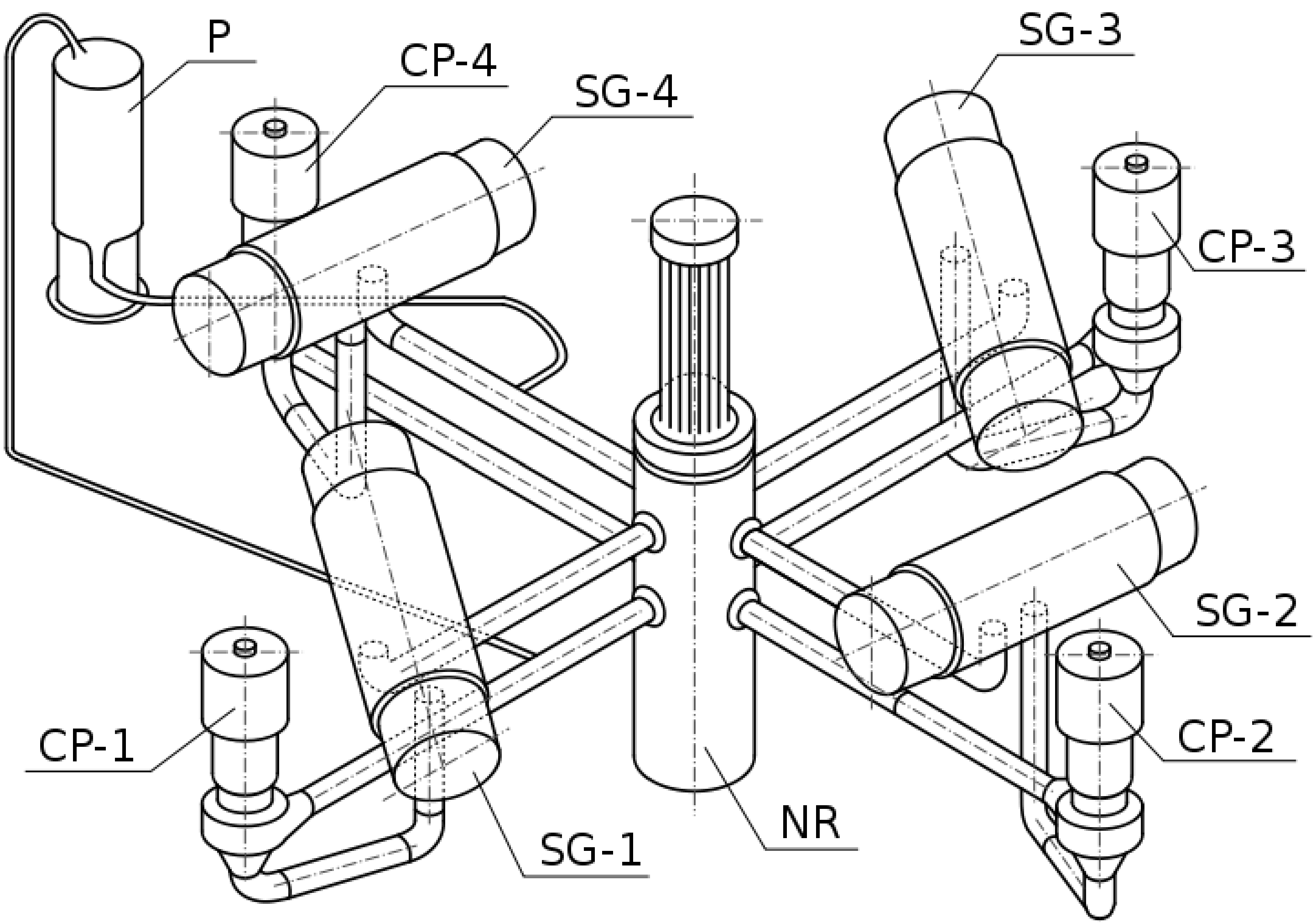


4 Loop PWR (EPR)

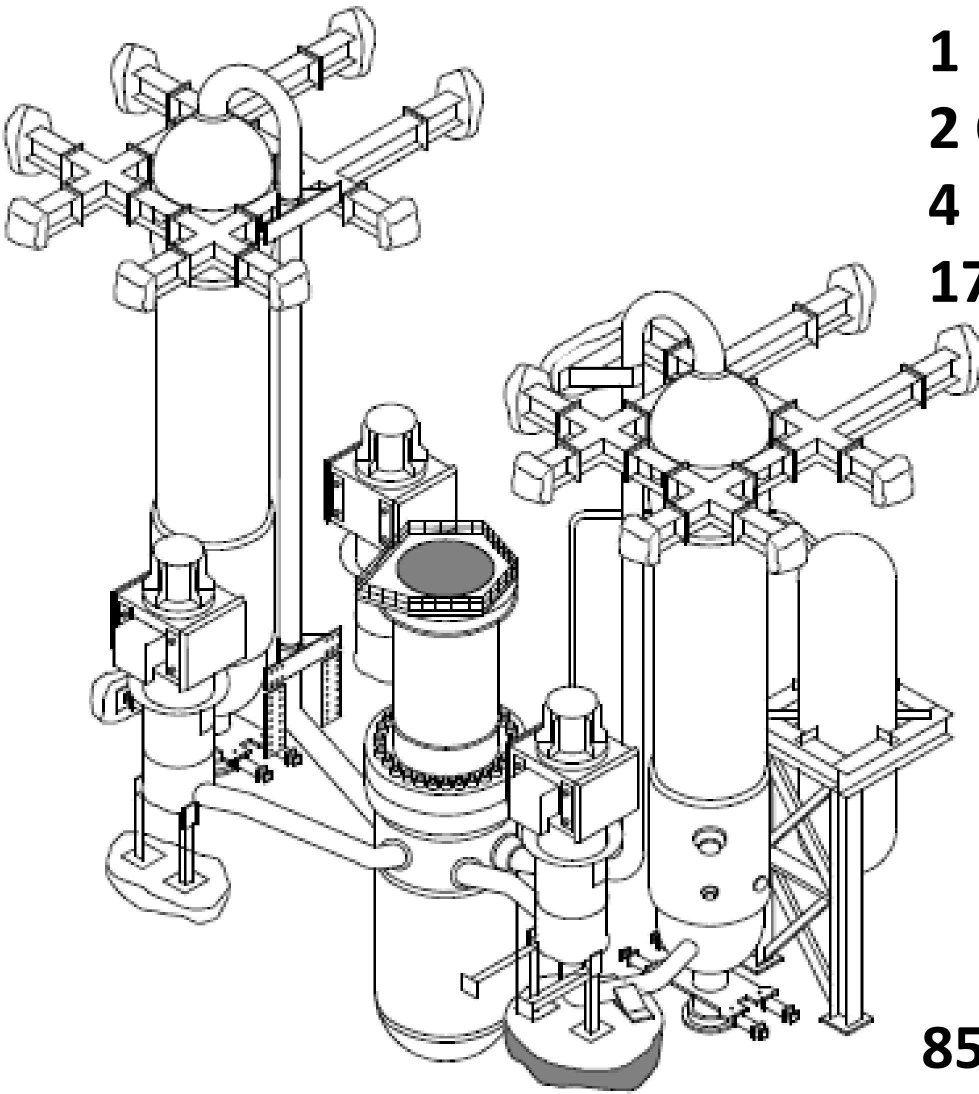


4 Loop Pressurized Water Reactor (VVER 1000)



VVER-1000-Stereometric.svg

Babcock & Wilcox Primary Circuit



1 Pressurizer
2 Once Through SG
4 Reactor Coolant Pumps
177 Fuel Asemblies

850 MW electrical power

PWR Coolant Circuits

- INDIRECT CYCLE: Primary and Secondary Coolant Loops
- Single Phase (Liquid) Reactor Coolant

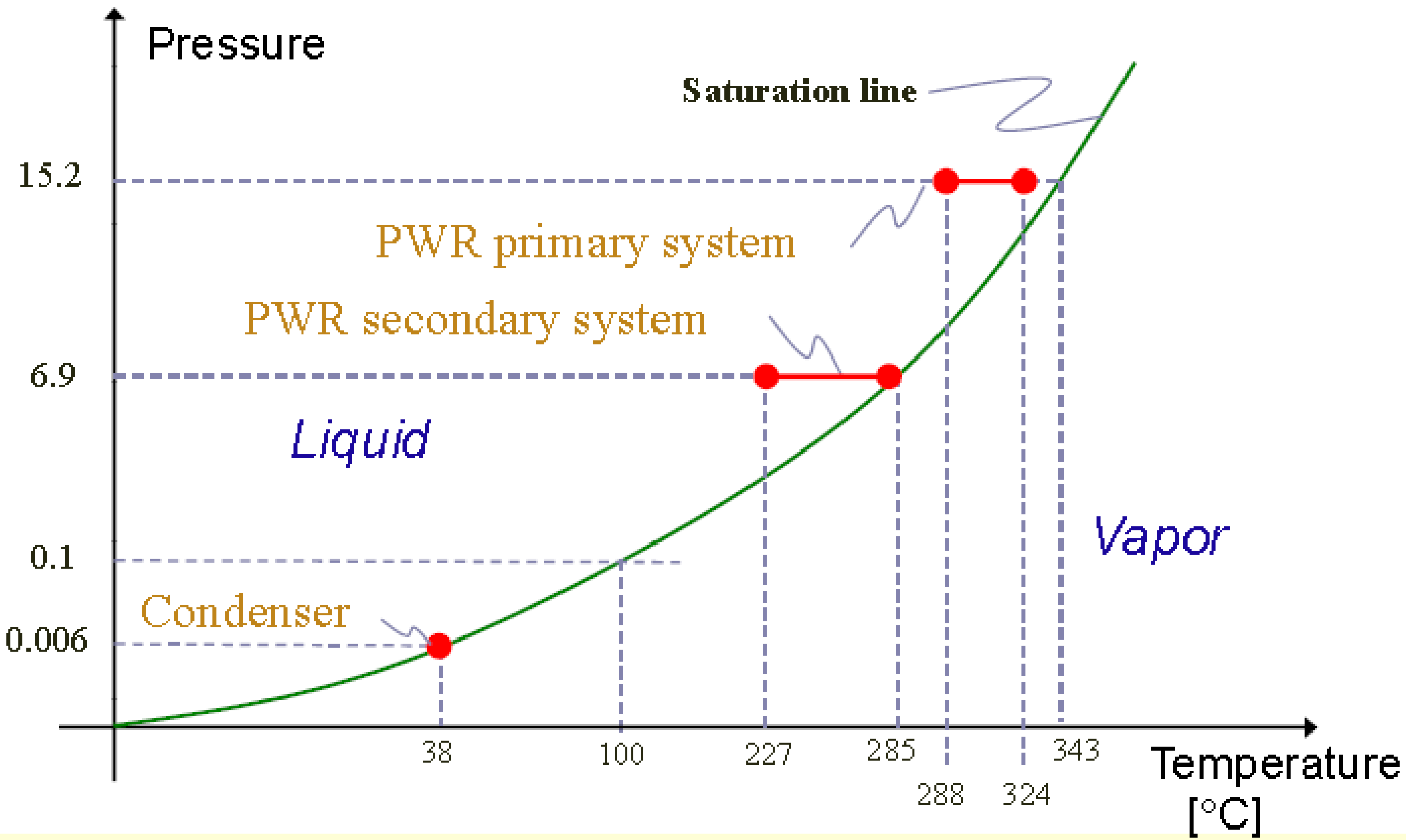
[T_{in}=287.7°C, T_{out}=324°C, P=15.2 MPa, T_{sat}= 343.3°C]

- Two-Phase (Steam-Water) Power Conversion Cycle Loop

[$T_{SG,in}$=227°C, $T_{SG,out}$=285°C, P=6.9 MPa, T_{sat}=285°C]

[$T_{Condenser}$= 37.8°C, P=6.6 kPa]

Phase Diagram of Water



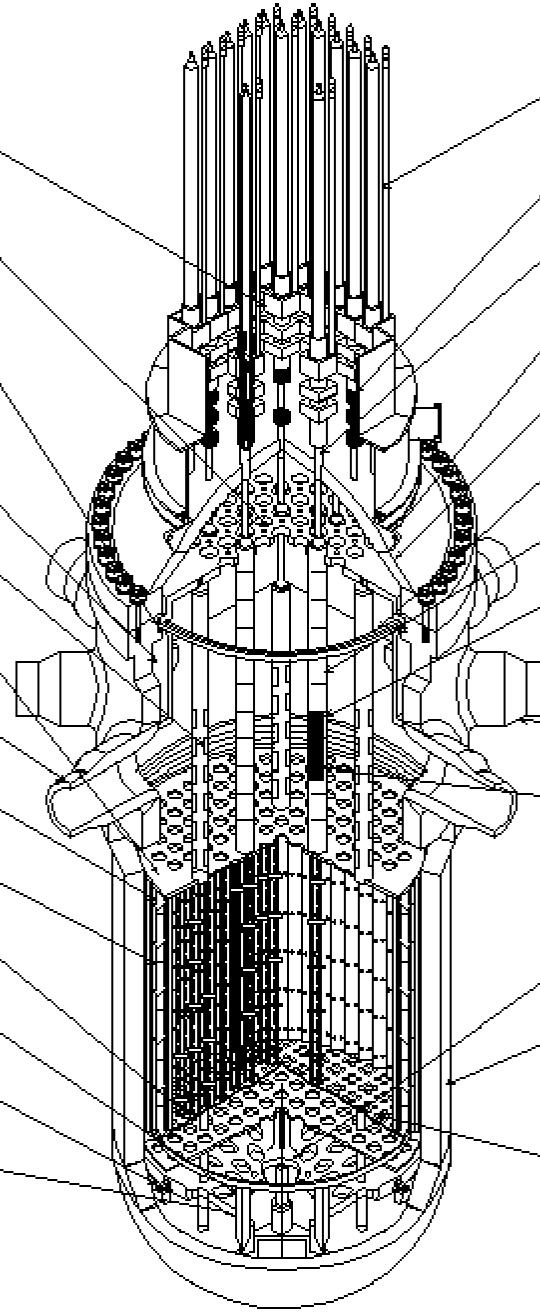
Typical 4 Loop Parameters

Total heat output	~3250-3411 MWt
Heat generated in fuel	97.4%
Nominal system pressure	15.6 MPa
Total coolant flow rate	~1.74 x 10^4 kg/s
Coolant temperature	
Nominal inlet	291.9°C
Average rise in vessel	33.9°C
Outlet from vessel	325.8°C
Equivalent core diameter	3.37 m
Core length, between fuel ends	3.66 m
Fuel weight, uranium (first core)	86,270 kg
Number of fuel assemblies	193

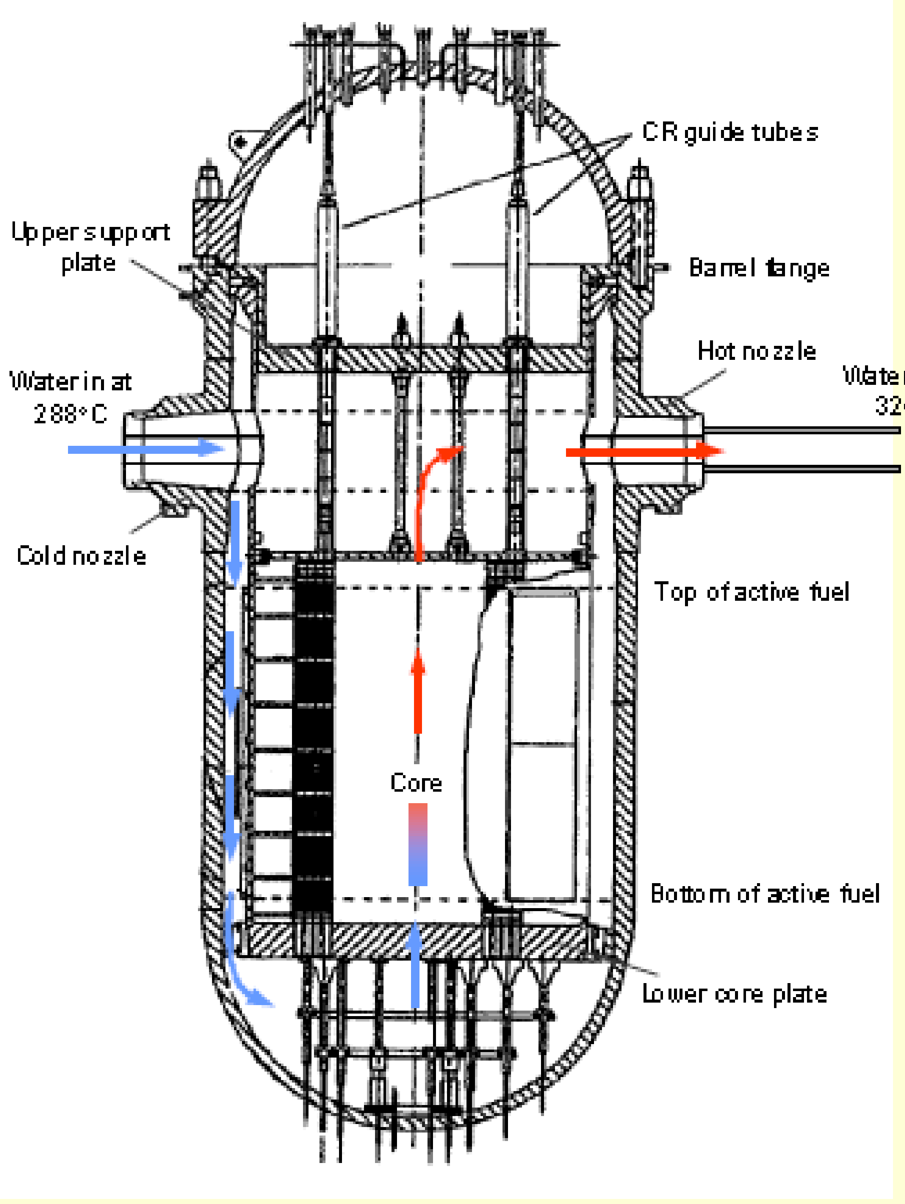
TYPICAL 4-LOOP REACTOR VESSEL PARAMETERS

Overall length of assembled vessel, closure head, and nozzles	13.36 m
Inside diameter of shell	4.39 m
Radius from center of vessel to nozzle face	
Inlet	3.33 m
Outlet	3.12 m
Nominal cladding thickness	5.56 mm
Minimum cladding thickness	3.18 mm
Coolant volume with core and internals in place	134.2 m^3
Operating pressure	15.51 MPa
Design pressure	17.24 MPa
Design temperature	343.3°C
Vessel material	Carbon steel
Cladding material	Stainless steel
Number of vessel material surveillance capsules, total	8

Reactor Vessel and Internals



Flow Path within Reactor Vessel



Michael Kröning

TOLMI

Central Ring with Outlet and Inlet Nozzles

Closure Head with Control Rod and Instrumentation Nozzles

Core Plate

Geometry of the fuel

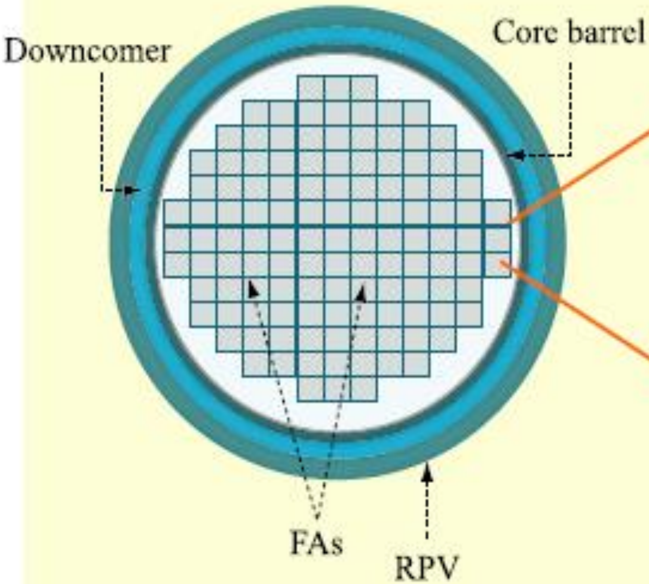


Image by MIT OpenCourseWare.

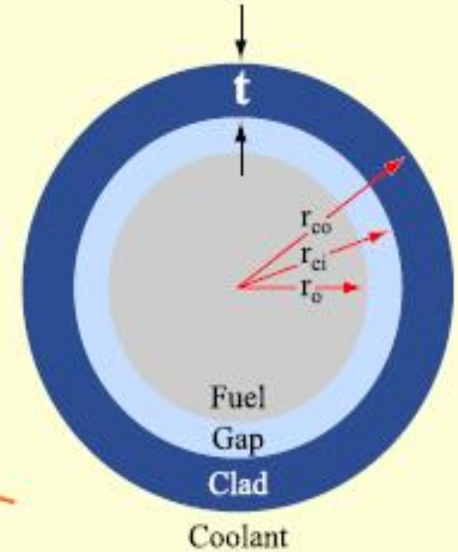


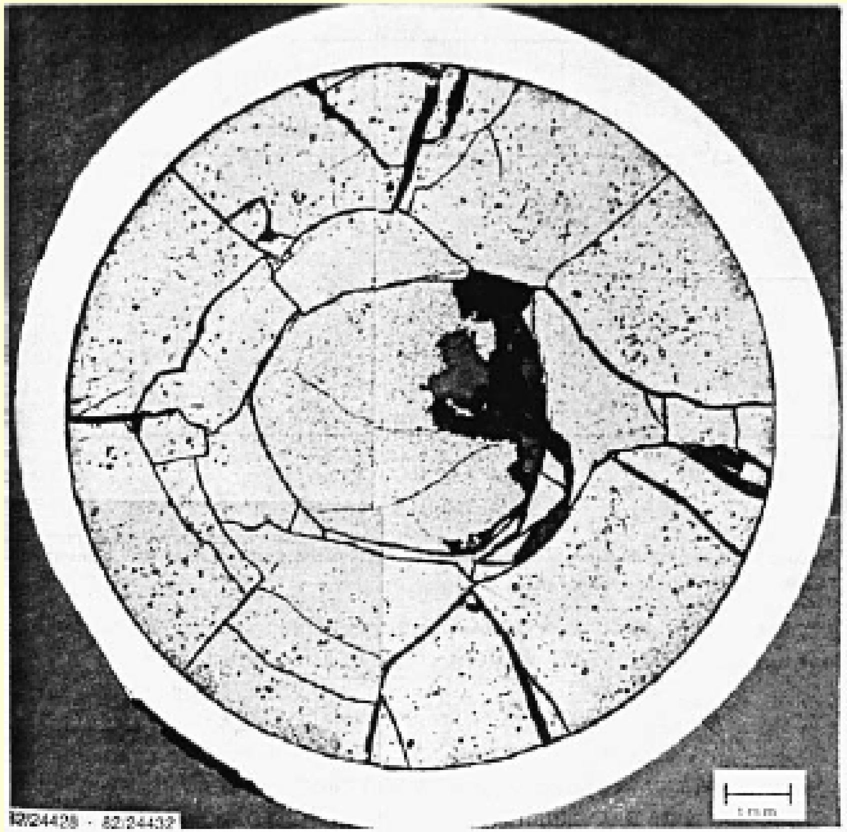
Image by MIT OpenCourseWare.

Cross Section of a Representative Fuel Pin (not drawn to scale)

mm (in.)	BWR	PWR
$2r_o$	10.40 (0.409)	8.20 (0.323)
$2r_{co}$	12.27 (0.483)	9.50 (0.374)
t	0.813 (0.032)	0.57 (0.023)

Why the fuel/clad gap?

- Provides clearance for fuel pellet insertion during fabrication
- Accommodates fuel swelling without breaking the clad →
- Filled with helium gas

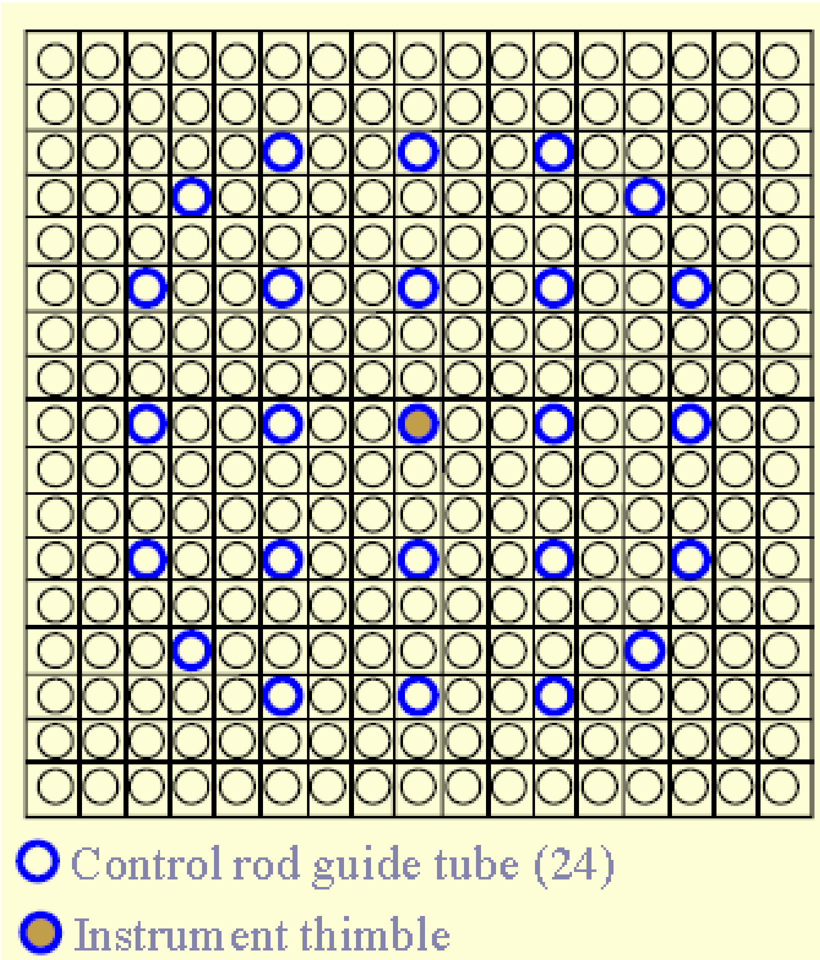


Example of a Cracked Fuel Cross Section

Source: Todreas & Kazimi, Vol. I, p. 333

Reactivity Control

PWR Control Rod



Made of B_4C for scram or
Ag-In-Cd for fine tuning

Dissolved Boron (boric acid, H_3BO_3)

Compensates for loss of reactivity due to fuel burn-up.

High concentration at BOC (beginning of cycle),
decreased to zero at EAC
(end of cycle)

Pros:

uniform absorption throughout core
concentration is easily controlled

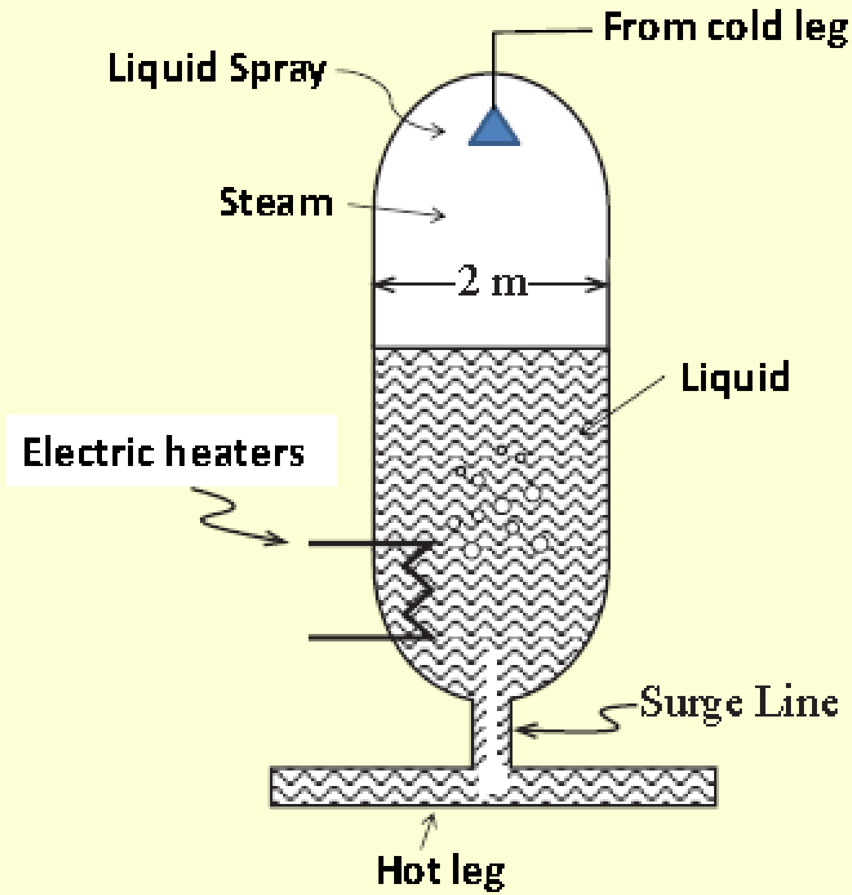
Cons:

coolant slightly acidic
requires addition of other chemicals
can deposit as crud
requires stainless steel

PWR PRESSURIZER

Pressurizer (Saturated Liquid-Steam System: P=15.5 MPa, T=344.7˚C)

Controls pressure in the primary system



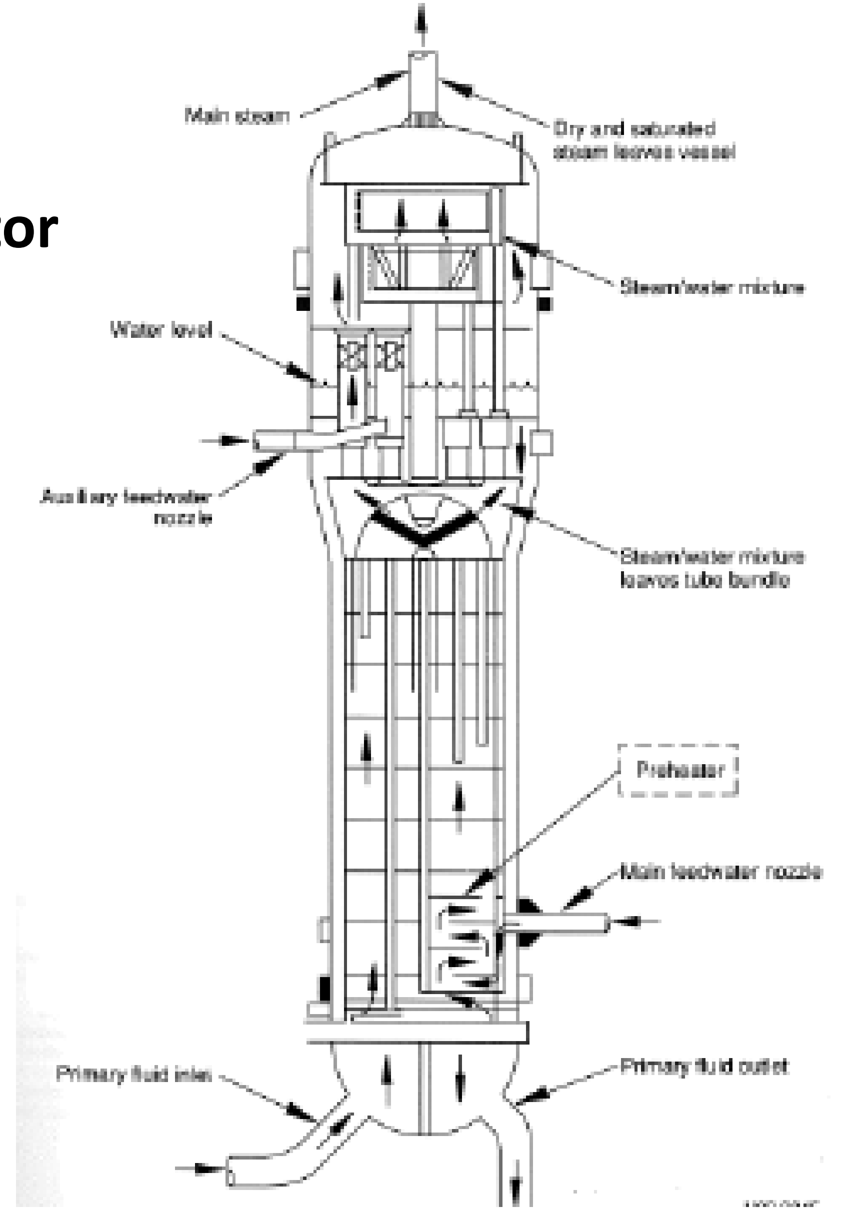
- Pressure can be raised by heating water (electrically)

- Pressure can be lowered by condensing steam (on sprayed droplets)

PRESSURIZER TYPICAL DESIGN DATA

Number and type	1 Two-phase water and steam pressurizer
Overall height	16.08 m
Overall diameter	2.35 m
Water volume	30.58 cu m
Steam volume	20.39 cu m
Design pressure	17.2 MPa
Design temperature	360°C
Type of heaters	Electric immersion
Number of heaters	78
Installed heater power	1800 kW
Number of relief valves	2 Power-operated
Number of safety valves	3 Self-actuating
Spray rate • *Pressure transient* • *Continuous*	 3028 L/m 3.79 L/m
Shell material	Mn-Mo steel, clad internally with stainless steel
Dry weight	106,594 kg
Normal operating weight	125, 191 kg
Flooded weight (21.1°C)	157,542 kg

U-Tube Steam Generator

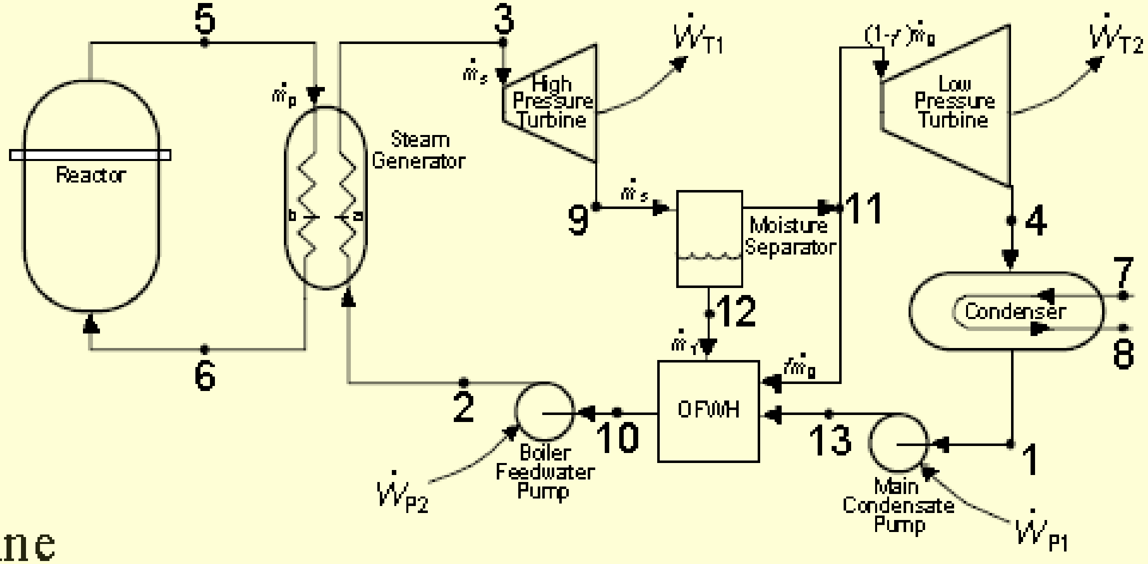


PWR STEAM GENERATORS

Primary side, Hot ($T_{in} = 324^{\circ}C$, $T_{out} = 288^{\circ}C$): High Pressure Liquid
Secondary side, Cold ($T_{sat} = 285^{\circ}C$): Lower Pressure Steam and Liquid

- Water Boils on Shell Side of Heat Exchanger
- Steam Passes through Liquid Separators, Steam Dryers
- Liquid Water Naturally Recirculates via Downcomer
- Level Controlled via Steam and Feedwater Flowrates

PWR Power Cycle (Secondary System)



Turbine

Low Steam Pressure Requires:

Large turbine

Lower rotational speed (1800 RPM)

Condenser

Steam Side at Low Pressure

Cooling water from sea, river or cooling tower

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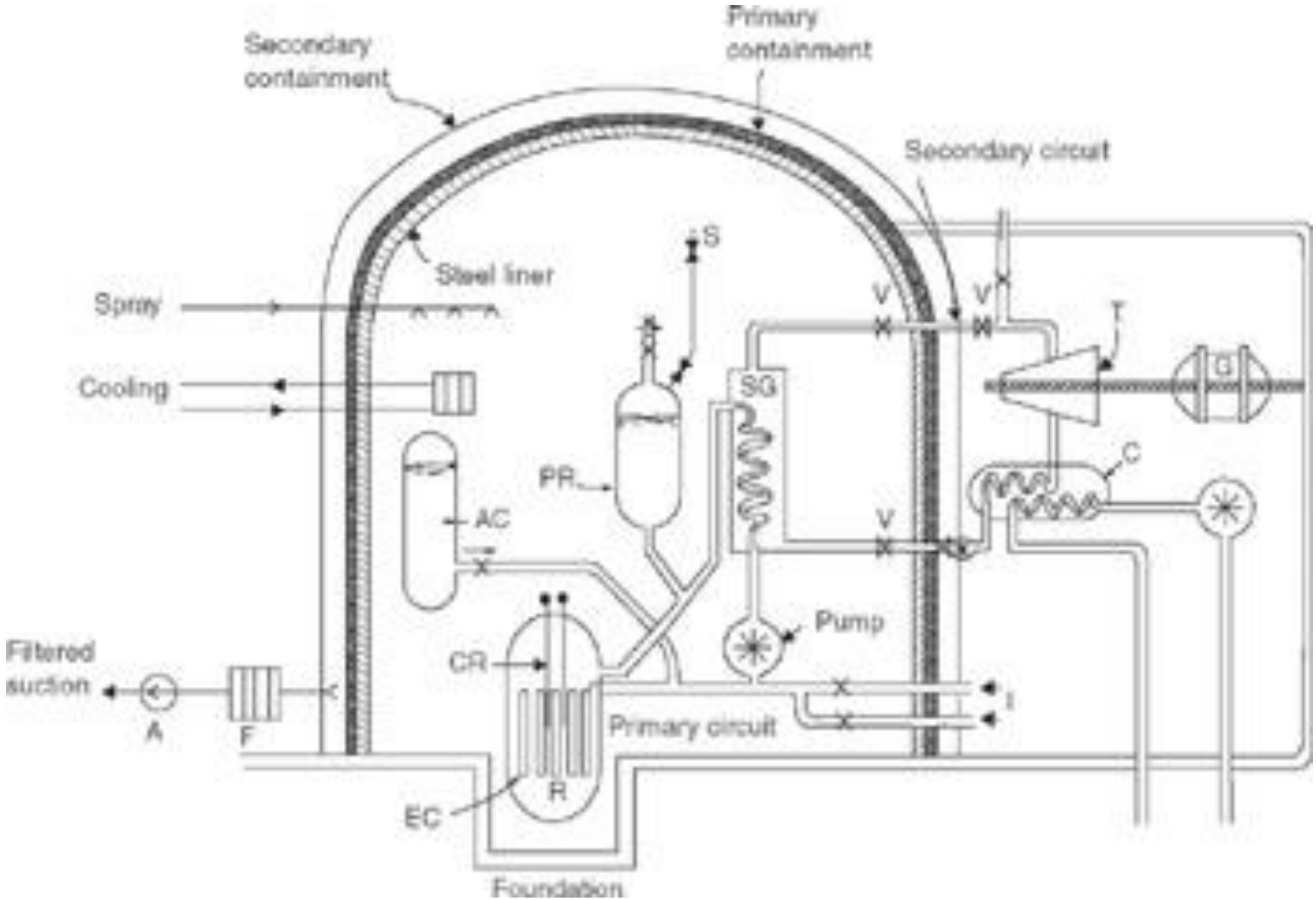

USED MATERIALS

USNRC Technical Training Center: *Pressurized Water Reactor (PWR) Systems*, Reactor Concepts Manual

Jacopo Buongiorno: *PWR Description,* MIT open course ware: 22.06: Engineering of Nuclear Systems, CANES (Center for Advanced Nuclear Energy Systems), MIT

John Lamarsh, Anthony Baratta: *Introduction to Nuclear Engineering*. Prentice Hall, 2001, ISBN 0-201-82498-1

Pressurized Components of Nuclear Power Plants

Aqueous homogeneous reactors (AHR) are a type of nuclear reactor in which soluble nuclear salts (usually uranium sulfate or uranium nitrate) are dissolved in water. The fuel is mixed with the coolant and the moderator, thus the name "homogeneous" ('of the same physical state') The water can be either heavy water or ordinary (light) water, both of which need to be very pure. A heavy water aqueous homogeneous reactor can achieve criticality (turn on) with natural uranium dissolved as uranium sulfate.[*citation needed*] Thus, no enriched uranium is needed for this reactor. The heavy water versions have the lowest specific fuel requirements (least amount of nuclear fuel is required to start them). Even in light water versions less than 1 pound (454 grams) of plutonium-239 or uranium-233 is needed for operation. Neutron economy in the heavy water versions is the highest of all reactor designs.[*citation needed*]

Their self-controlling features and ability to handle very large increases in reactivity make them unique among reactors, and possibly safest. At Santa Susana, California, Atomics International performed a series of tests titled The Kinetic Energy Experiments. In the late 1940s, control rods were loaded on springs and then flung out of the reactor in milliseconds. Reactor power shot up from ~100 watts to over ~1,000,000 watts with no problems observed.

Aqueous homogeneous reactors were sometimes called "water boilers" (not to be confused with boiling water reactors), as the water inside seems to boil, but in fact this bubbling is due to the production of hydrogen and oxygen as radiation and fission particles dissociate the water into its constituent gases. AHRs were widely used as research reactors as they are self-controlling, have very high neutron fluxes, and were easy to manage. As of April 2006, only five AHRs were operating according to the IAEA Research Reactor database.

Corrosion problems associated with sulfate base solutions limited their application as breeders of uranium-233 fuels from thorium. Current designs use nitric acid base solutions (e.g. uranyl nitrate) eliminating most of these problems in stainless steels.

- Reduced O&M costs
  - Low cobalt steel alloys to reduce exposure