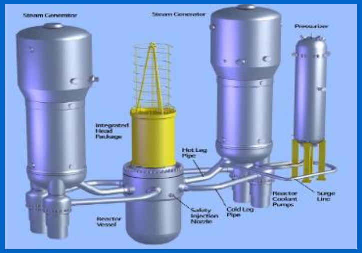
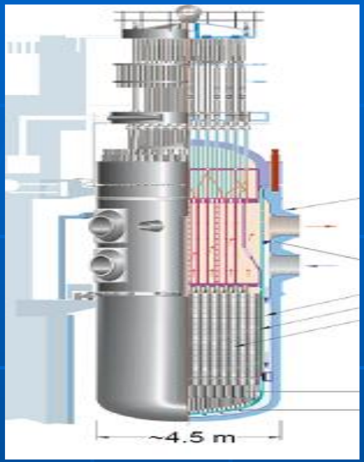
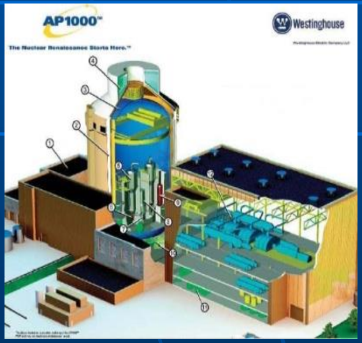
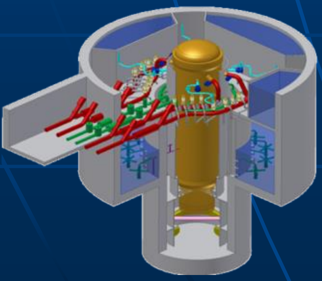
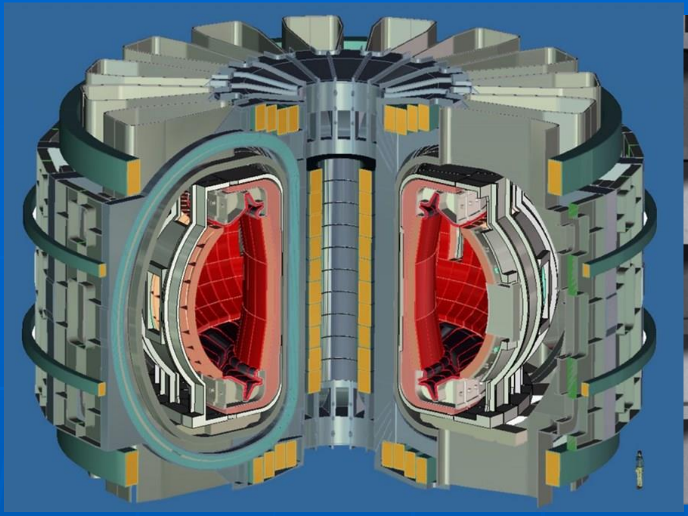
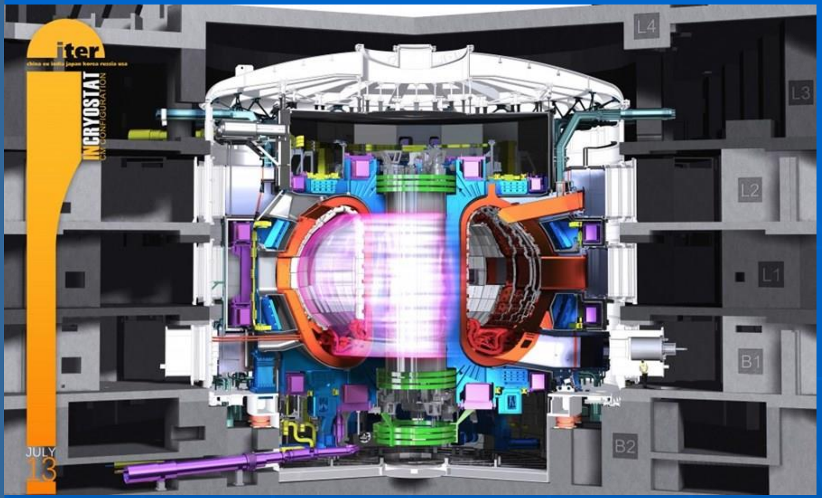












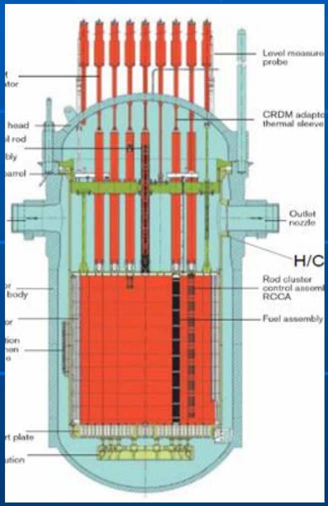
The water cooled performance for fission and fusion reactors

Dr. Tarek Farouk Nagla

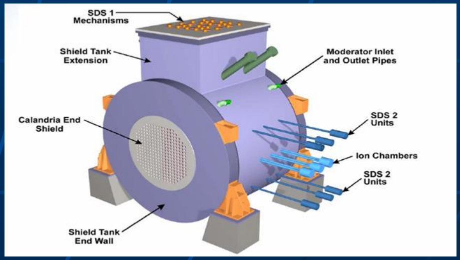
Eng. Mohamed ELMESAWY

Nuclear Power Plants Authority, Cairo ,

Egypt.2023



Tarek_Nagla@yahoo.com



IAEA

IAEA-Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission Reactors Dr-Tarek_Nagla_2023

Tarek Farouk Nagla

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Process Simulation

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NUCLEAR POWER PLANTS AUTHORITY

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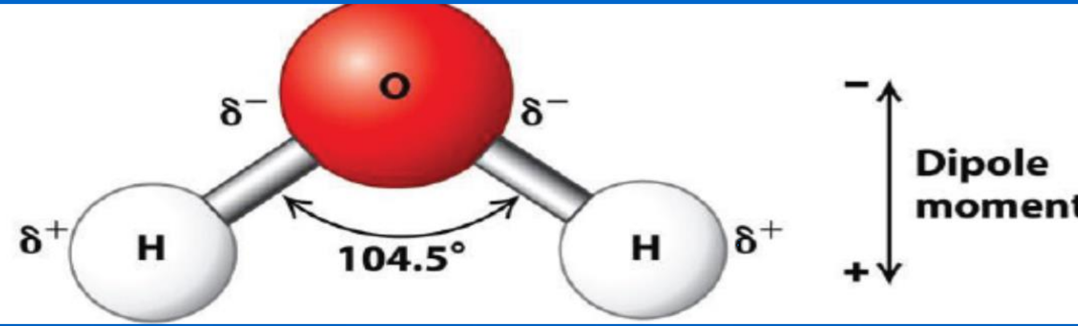
Water (H_2O)

Molecular Structure and Properties



Important unique properties of water are as follows:

1. **Molecular Structure and Properties**
2. **Isotopic Content**
3. **Latent Heat and Specific Heat**
4. **Density Relationships**
5. **Viscosity-Density Relationships**
6. **Surface Tension**
7. **Transparency**
8. **Pressure**
9. **Salinity**
10. **Water Current**
11. **As Universal Solvent**

Thermodynamic Properties of Water and Steam

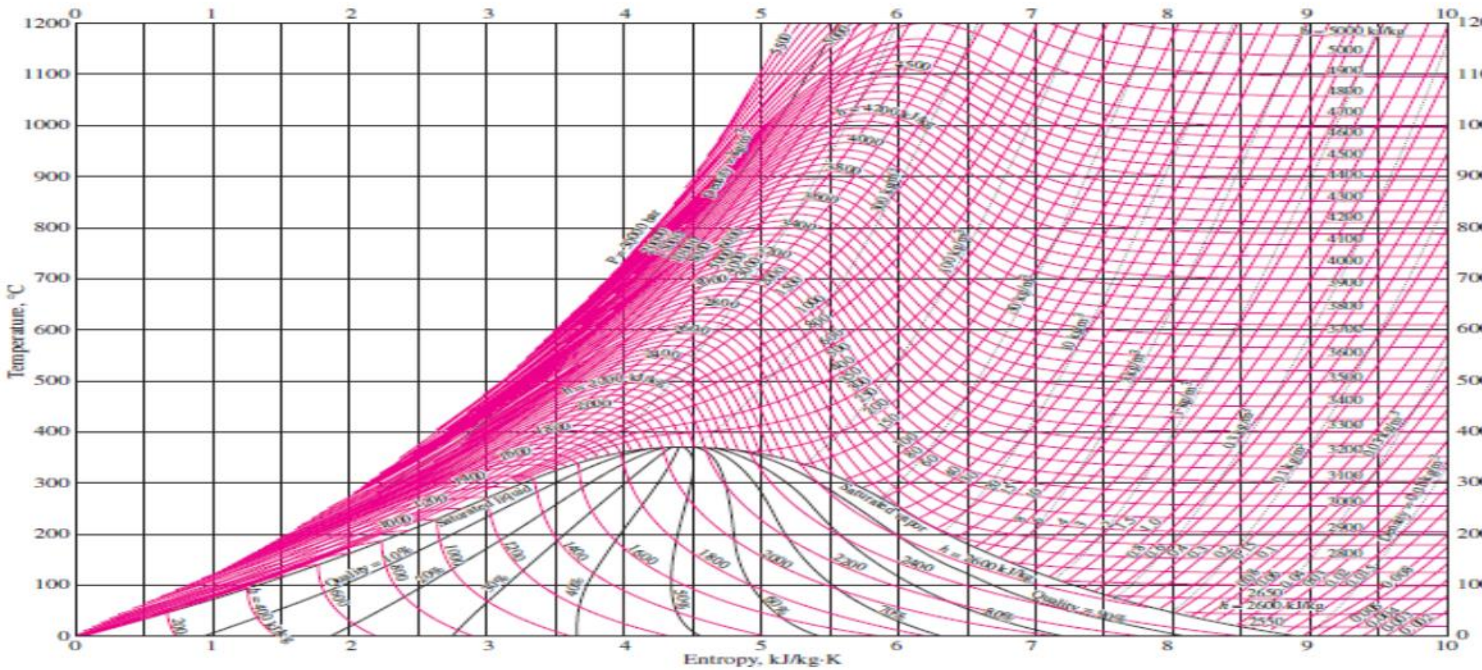
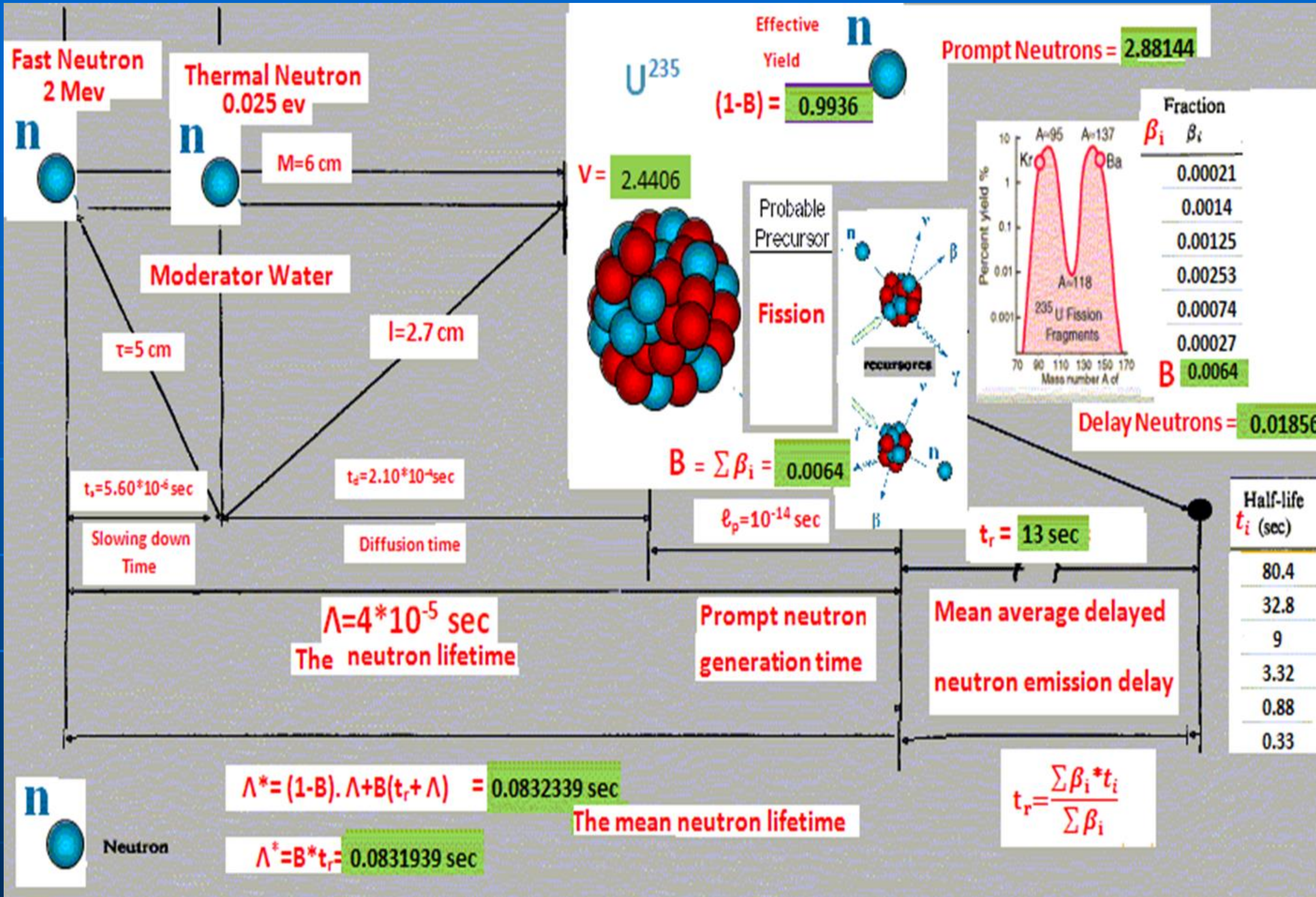


FIGURE A–9

T-s diagram for water.

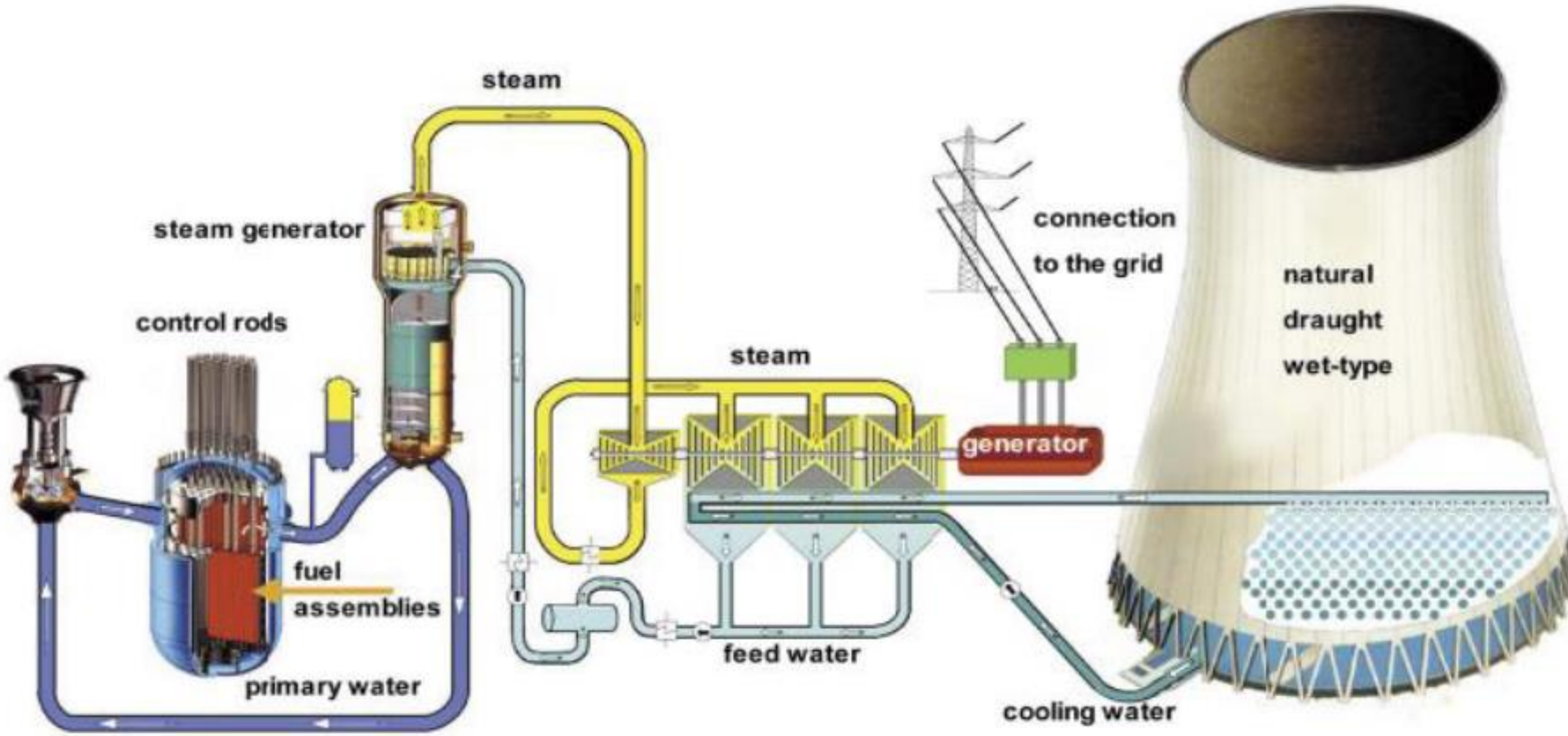
TABLE

Temp. rature °C	Pressure Pa	Density kg/m^3	Enthalpy kJ/kg	Heat capacity kJ/(kg·K)	Specific heat kJ/kg	Thermal conductivity 10^3W/(m·K)	Dynamic viscosity 10^6(Pa·s)	Kinematic viscosity $10^6(m^2/s)$	Thermal diffusivity $10^6(m^2/s)$	Prandtl number



Fast Neutron
2 Mev
n
Thermal Neutron
0.025 ev
n
M=6 cm
Moderator Water
τ=5 cm
l=2.7 cm
t_s=5.60*10^-6 sec
t_d=2.10*10^-4 sec
Slowing down Time
Diffusion time
U^235
Effective Yield
n
(1-B) = 0.9936
V = 2.4406
Prompt Neutrons = 2.88144
Probable Precursor
Fission
recursores
B = Σβi = 0.0064
ℓp=10^-14 sec
Percent yield %
A=95
A=137
Kr
Ba
A=118
235U Fission Fragments
Mass number A of
Fraction
βi
0.00021
0.0014
0.00125
0.00253
0.00074
0.00027
B 0.0064
Delay Neutrons = 0.01856
tr = 13 sec
Half-life ti (sec)
80.4
32.8
9
3.32
0.88
0.33
Λ=4*10^-5 sec
The neutron lifetime
Prompt neutron generation time
Mean average delayed neutron emission delay
Λ*= (1-B). Λ+B(tr+ Λ) = 0.0832339 sec
The mean neutron lifetime
Λ*=B*tr= 0.0831939 sec
tr= Σβi*ti / Σβi
Neutron

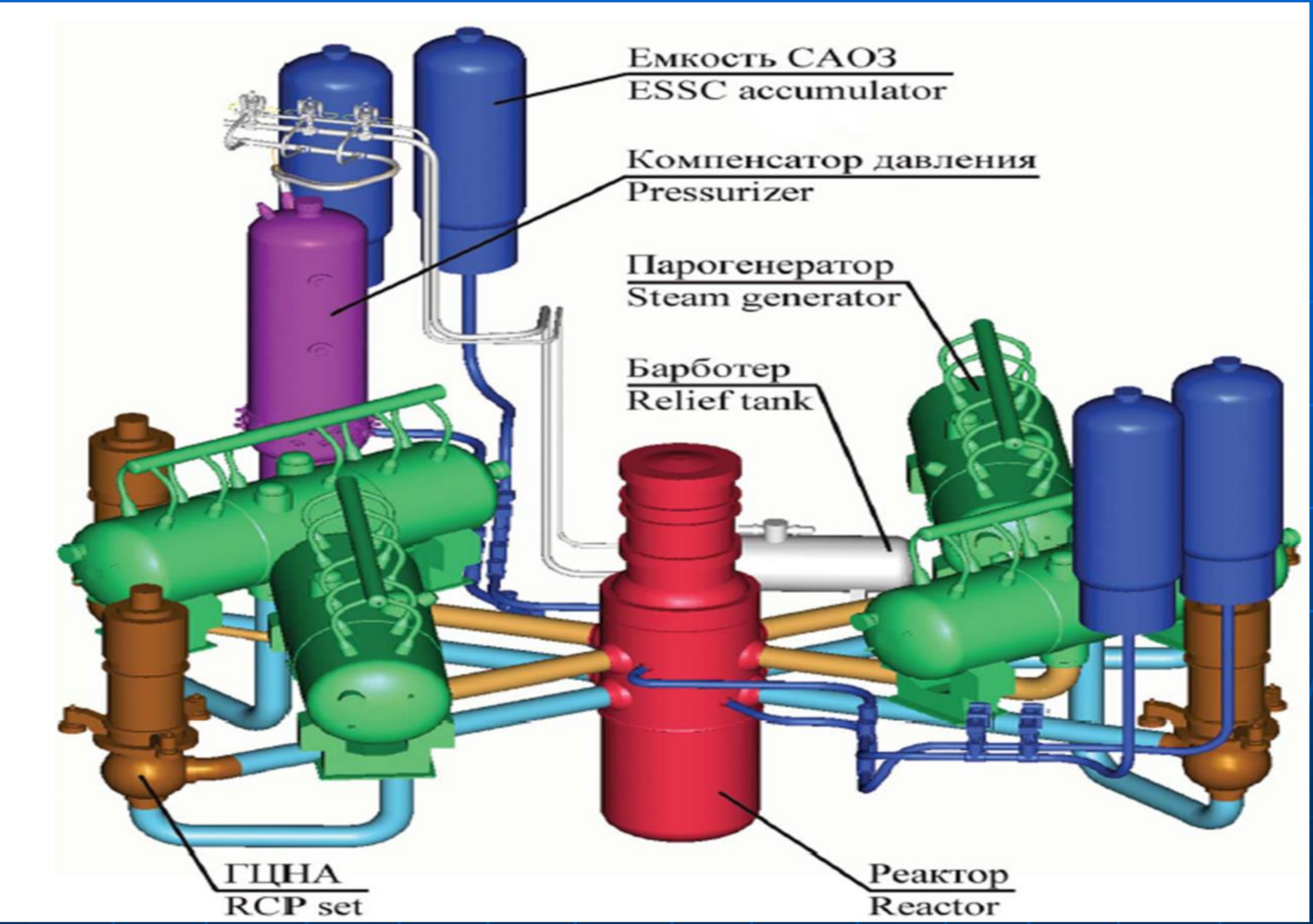
PWR



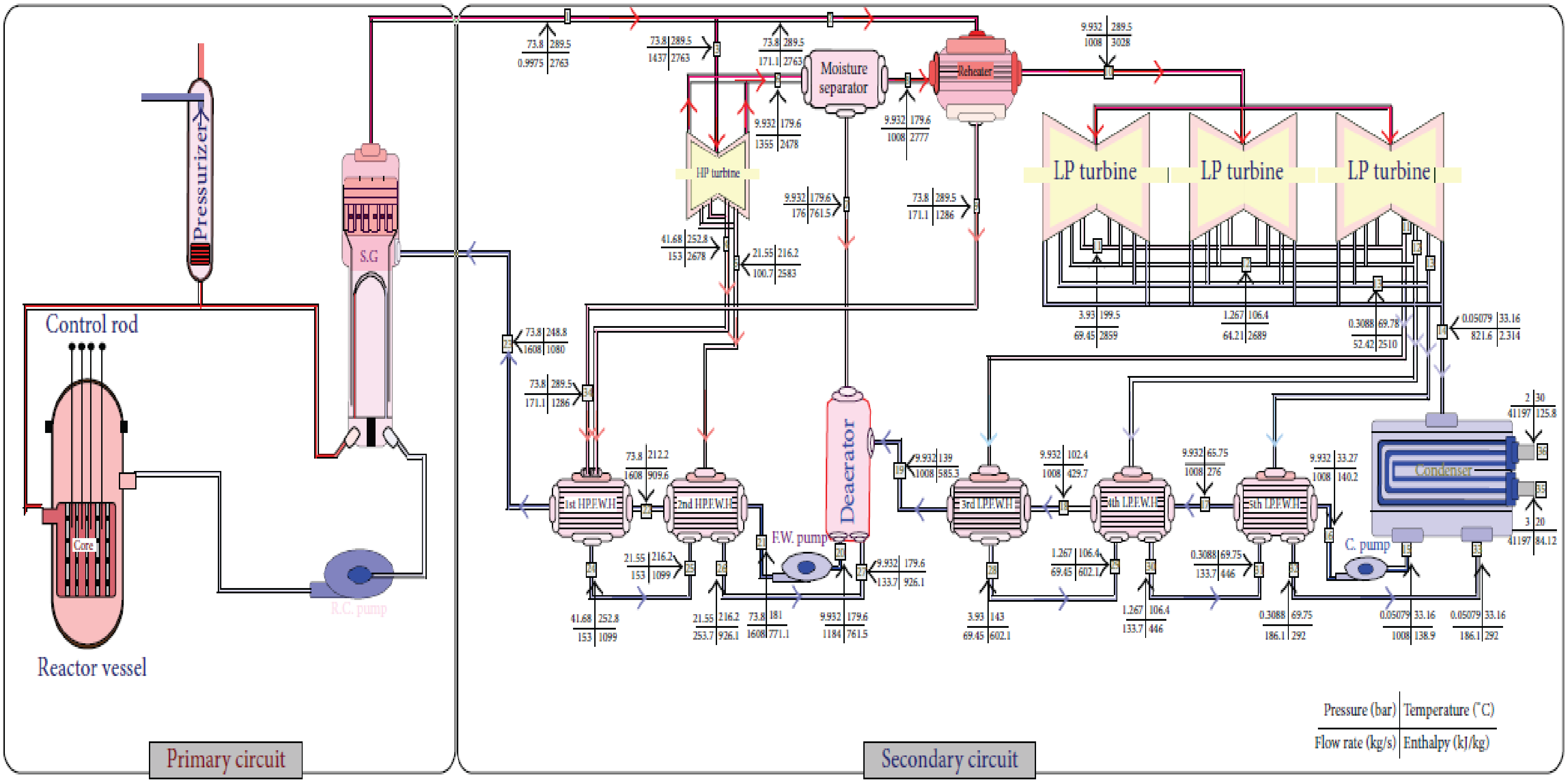
Basic Design of a PWR – Overview OF THE Three Main Circuits

PWR

WWER-1000



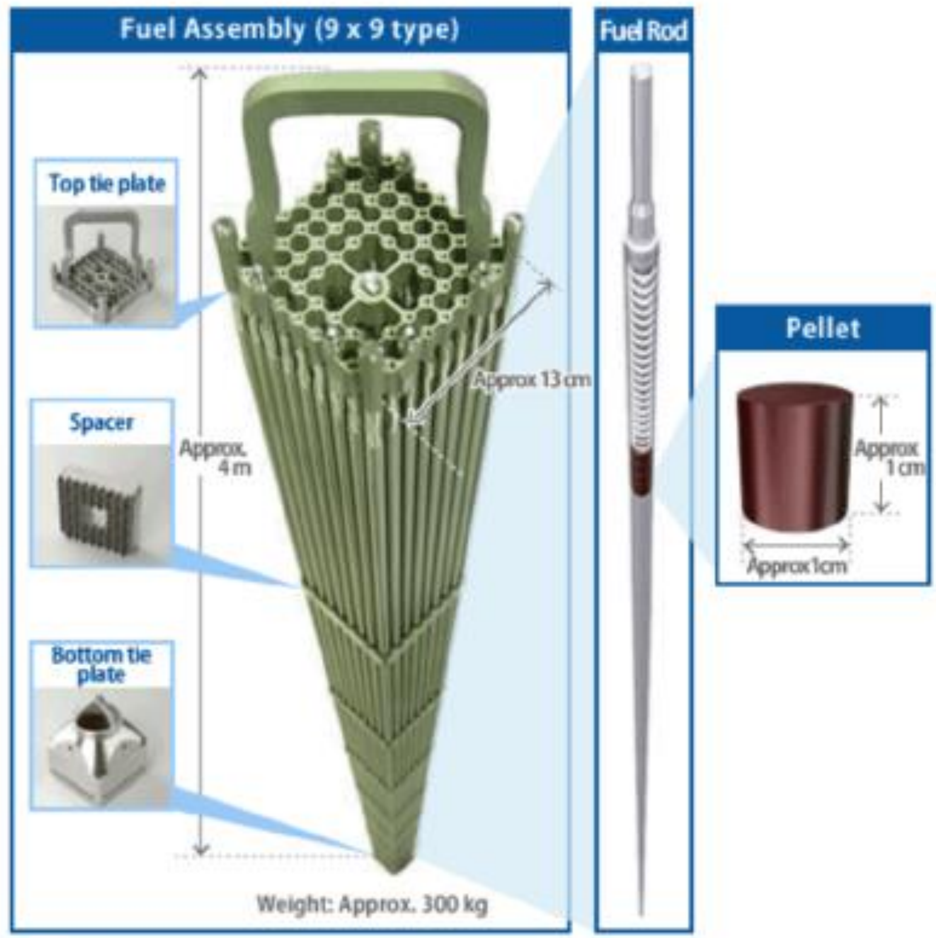
PWR



PWR NPP thermodynamic and heat balance analysis.

PWR ZR ALLOY CLADDING WATER SIDE CORROSION

Typical Fuel Assembly in LWR Reactors

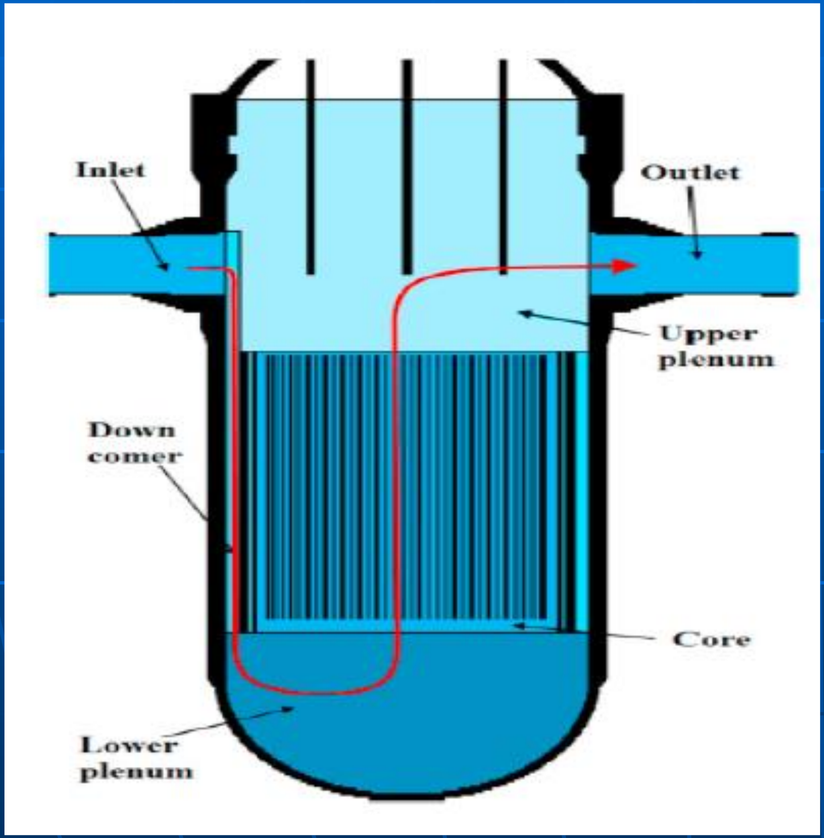


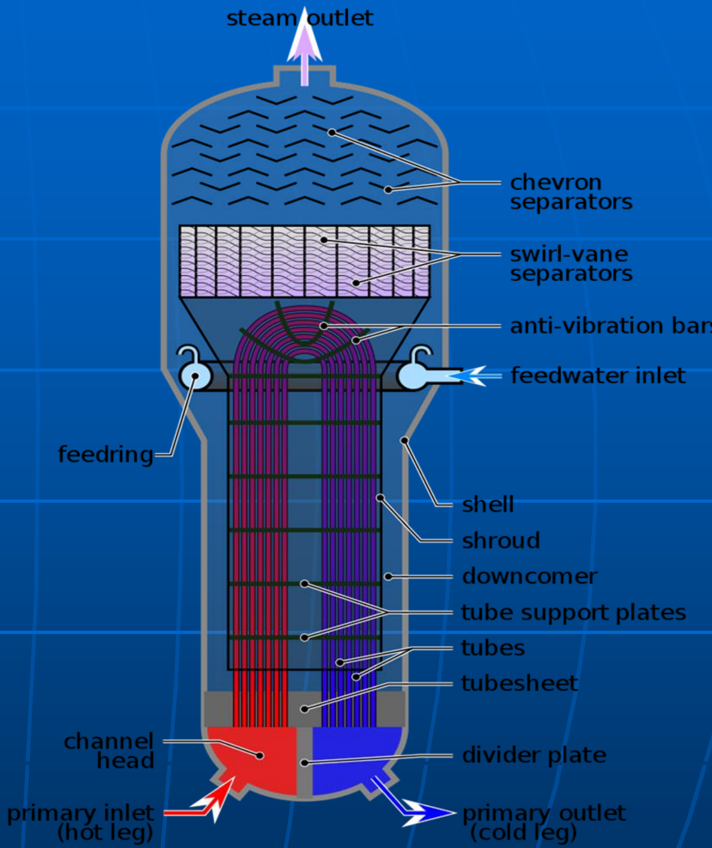
Fuel assemblies vary with manufacturer and over time

PWR

Boric Acid Corrosion of Carbon Steel Reactor Pressure Boundary Components in PWR Plants

Corrosion and deposition on the secondary circuit of steam generators

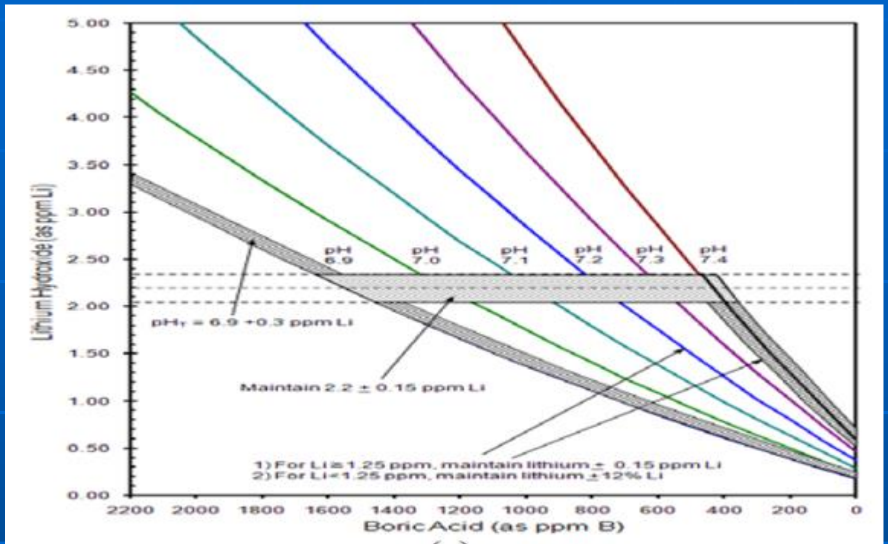




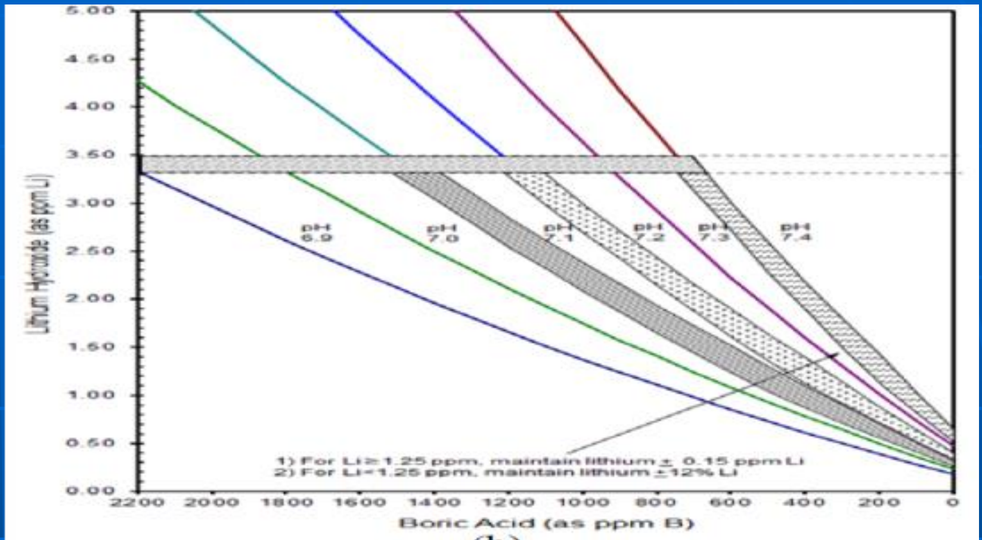
general corrosion , stress corrosion cracking , pitting corrosion, stainless steels ,nickel base alloys safety, security , reliability,

PWR

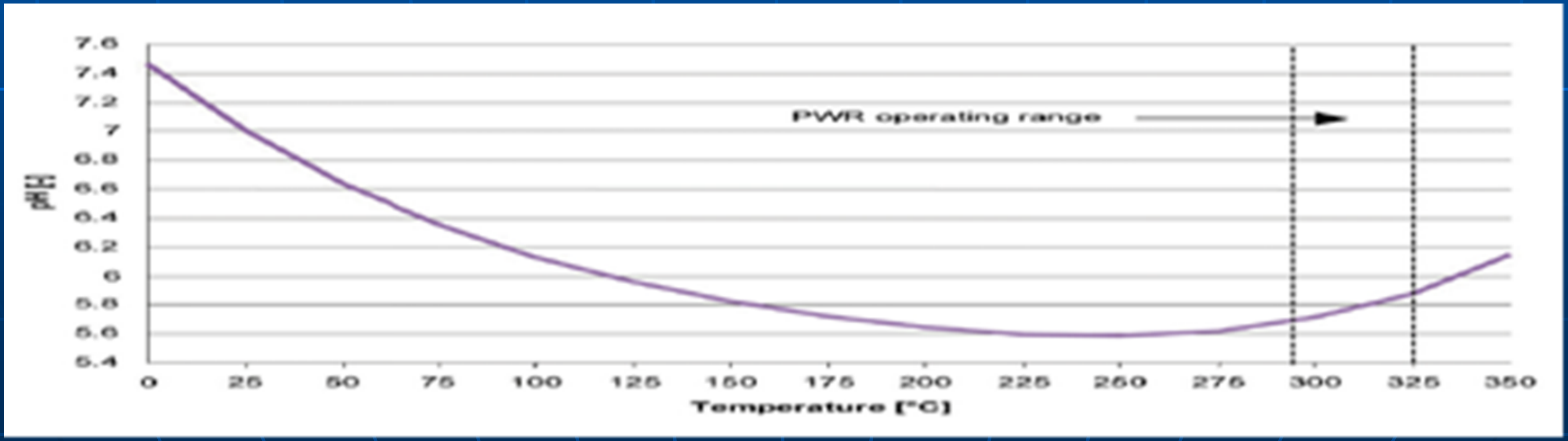
pH control curves: (a) modified chemistry regime and (b) elevated pHT regime at 307 ℃ [5].



(a)



(b)



Zinc Water Chemistry

PWR

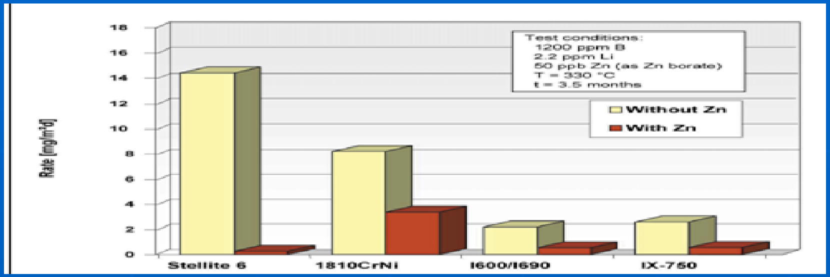


Table pH control PWR plant is recommended for boron-free operation

Ammonia-Based Water C

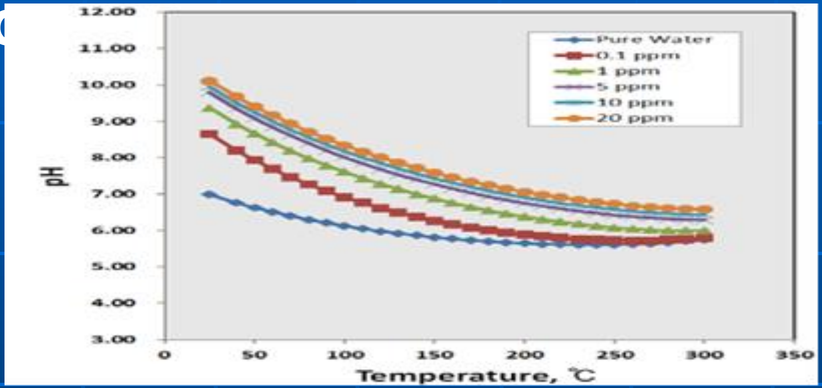
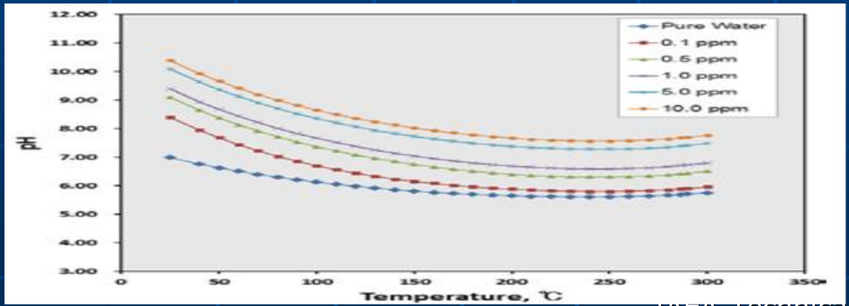


Table pH control PWR plant is recommended for boron-free operation

Chemistry parameter	Normal range
pH at 286.5 °C	6.9 - 7.4
pH at 25 °C	9.6 – 10.1
Potassium, ppm	1.7 – 5.0
Ammonia, ppm	≤2.0
Dissolved Hydrogen, cc/kg H2O	25 – 50
Dissolved Oxygen, ppm	≤0.005

Potassium-Based Water Chemistry



Lithium Water Chemistry

PWR as change of primary coolant chemistry for long-term fuel cycle

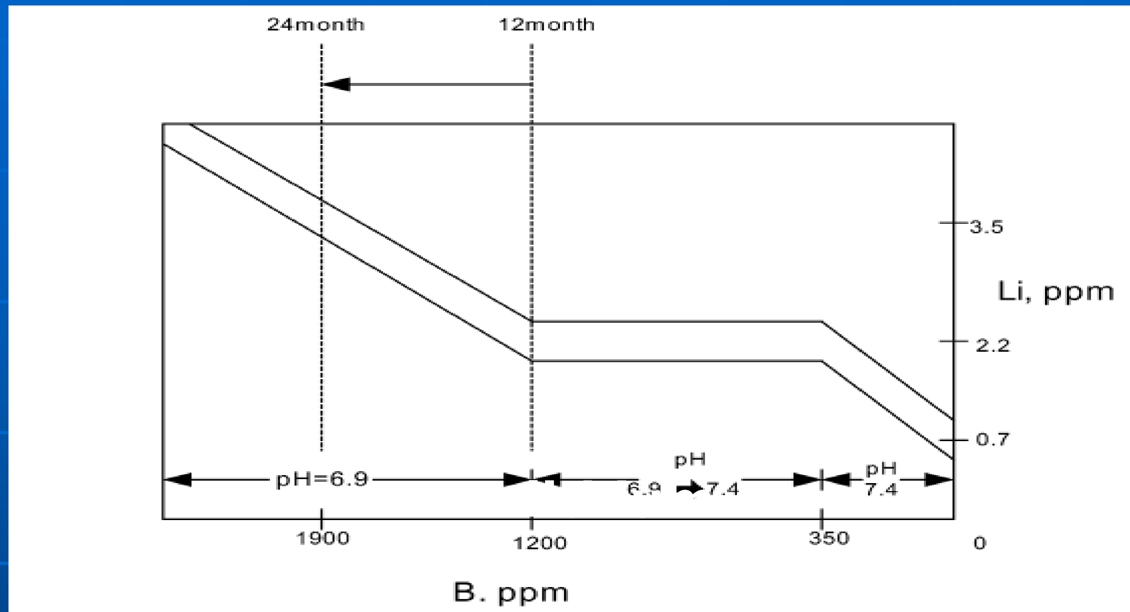


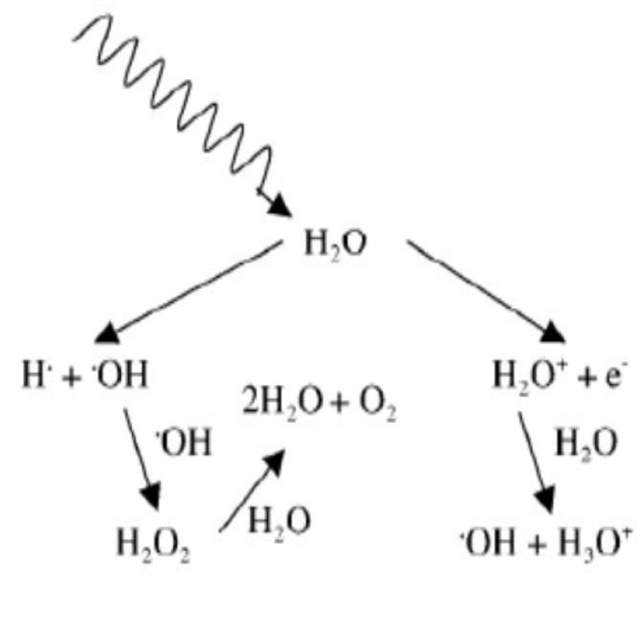
Fig. Chemical change at modified regime.

Typically, 12-month fuel cycles begin with no more than 1200 ppm boron at a start of a cycle, so the maximum of 2.2 ppm lithium is required to satisfy the requirement of pH 6.9 (Fig.). Long-term fuel cyclesof 18 or 24 months have forced chemistry personnel to select an operating pH regimethat minimizes ‘‘negative effects’’ rather than maximizes ‘‘the benefits’’

PWR Neutron Activation of Coolant Water

Radiolysis is the dissociation of molecules by ionizing radiation. It is the cleavage of one or several chemical bonds resulting from exposure to high-energy flux.

Isotope	Natural Abundance[%]	Reaction	Activation product	$t_{1/2}$ [s]	Decay products
^{16}O	99.76	(n , p)	^{16}N	7.13	2.742 MeV gamma (1%)
					6.129 MeV gamma (67%)
					7.115 MeV gamma (5%)
^{17}O	0.04	(n , p)	^{17}N	4.14	0.383 MeV neutron (35%)
					0.884 MeV neutron (1%)
					1.171 MeV neutron (53%)
					1.700MevV neutron (7%)
					0.110 MeV neutron (3%)
^{18}O	0.04	(n , γ)	^{19}O	26.9	0.197 MeV gamma (63%)
					1.357 MeV gamma (33%)
					1.444 MeV gamma (3%)

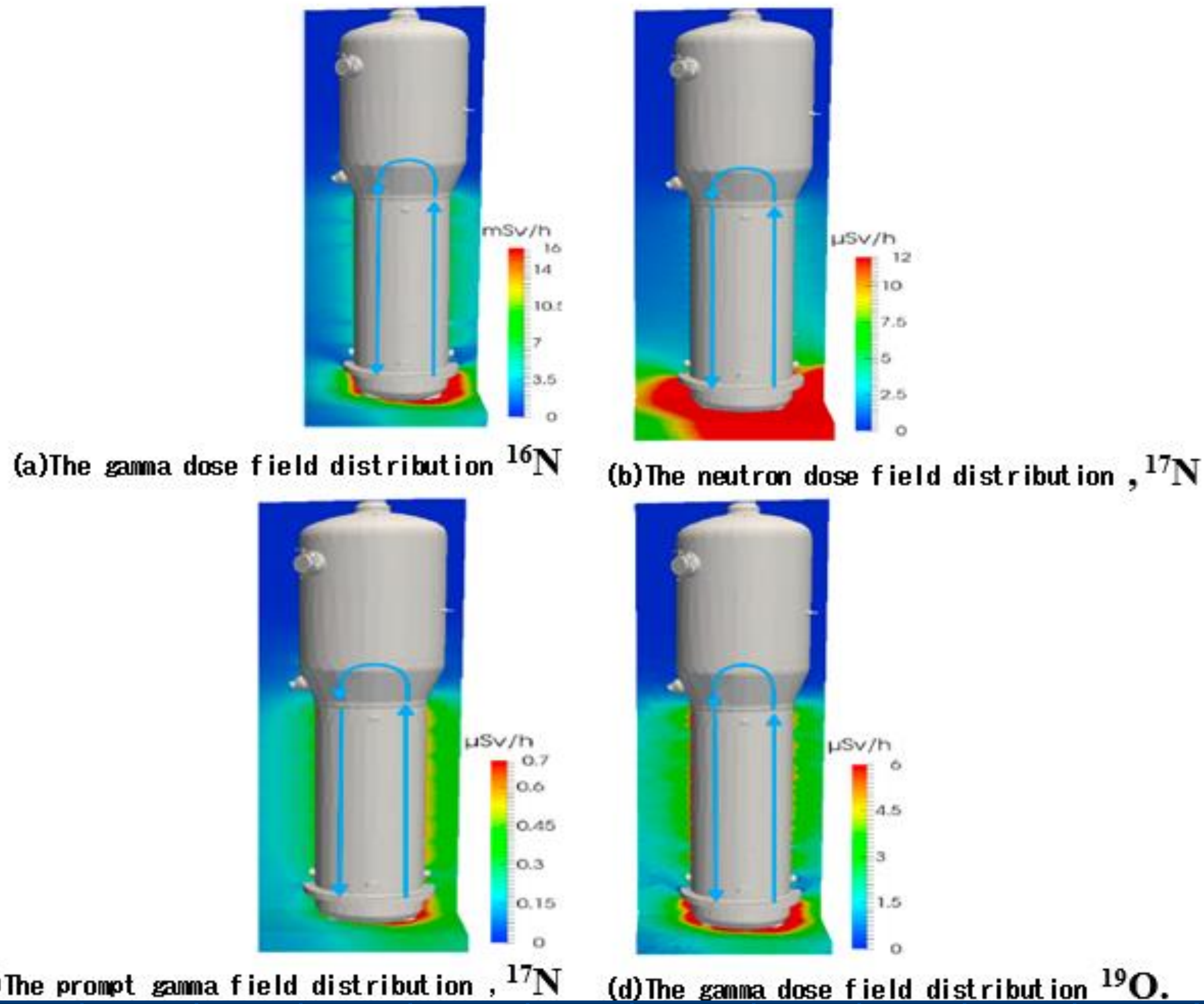


Radiolytical decomposition of water

Table - Summarized data of activated isotopes of cooling water obtained from ENDF/B-VII.1 data library

PWR

MCNP



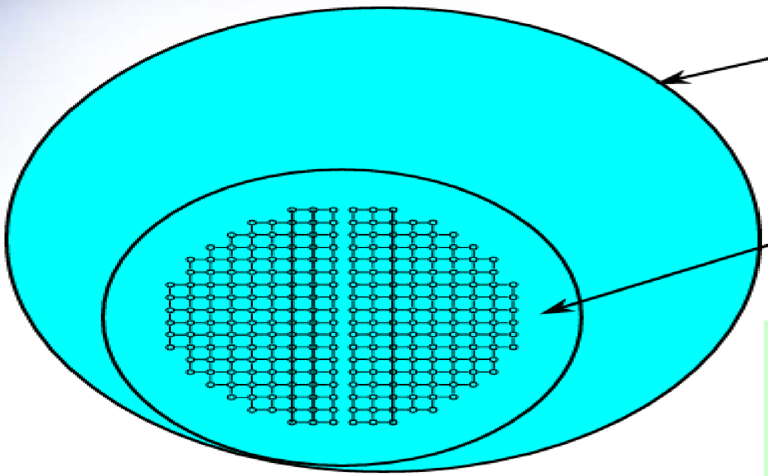
Results of prompt gamma and neutron due to decay of isotope 16N, 17N and gamma dose field due to decay of isotope 19O

Evolution of ACR Physics from CANDU 6

Major Differences between CANDU 6 and ACR

- Coolant
  - CANDU 6 (D_2O)
  - ACR (H_2O)
- Fuel
  - CANDU 6 (NU in 37-element bundle)
  - ACR (2.0 % SEU in 42 pins, Central Pin Dy/NU, CANFLEX bundle)

Core Size Comparison



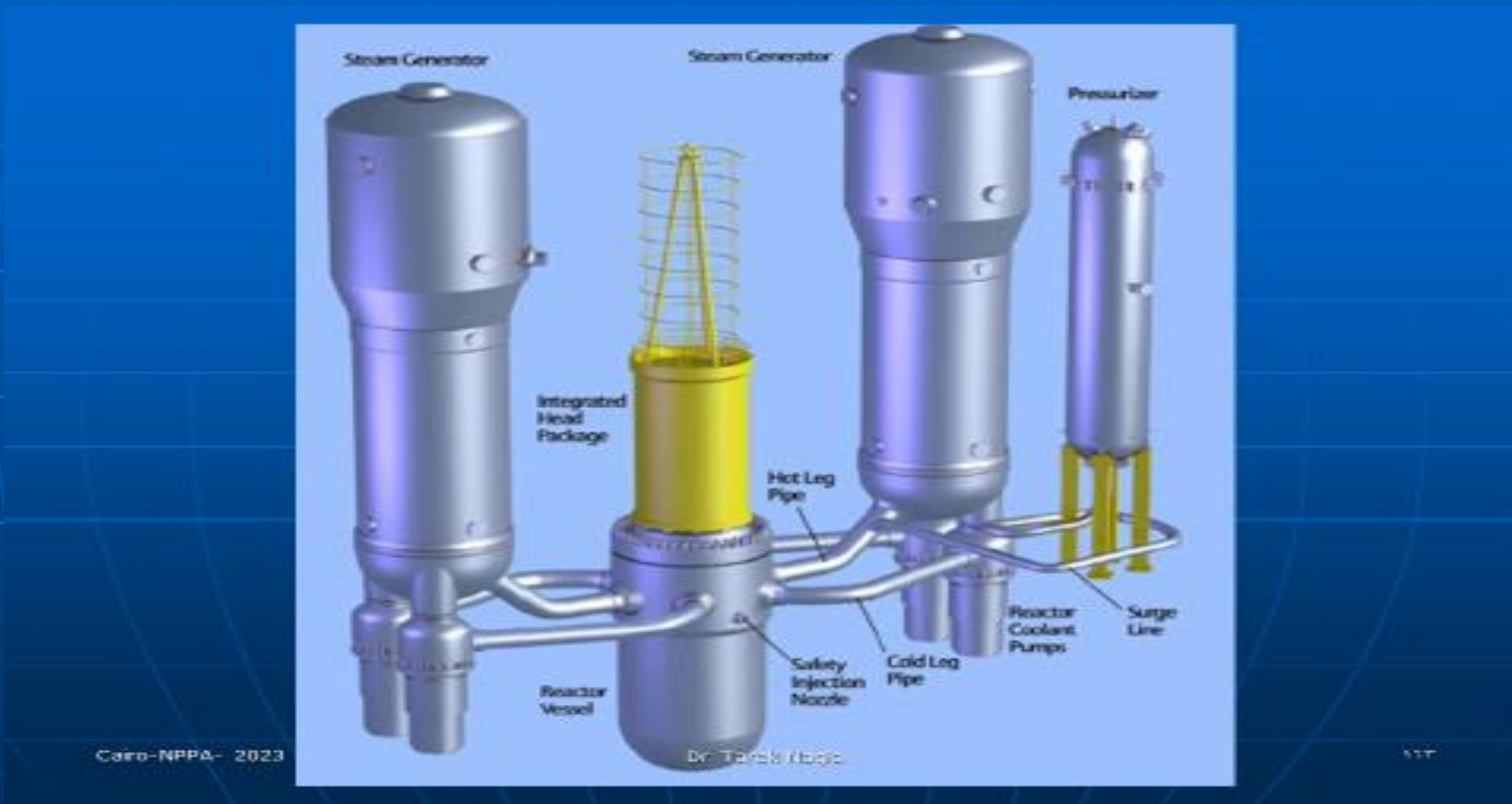
CANDU 6
728 MWe
380 channels
Diameter = 760 cm
(299 inches)

ACR
731 MWe
284 channels
Diameter = 520 cm
(205 inches)

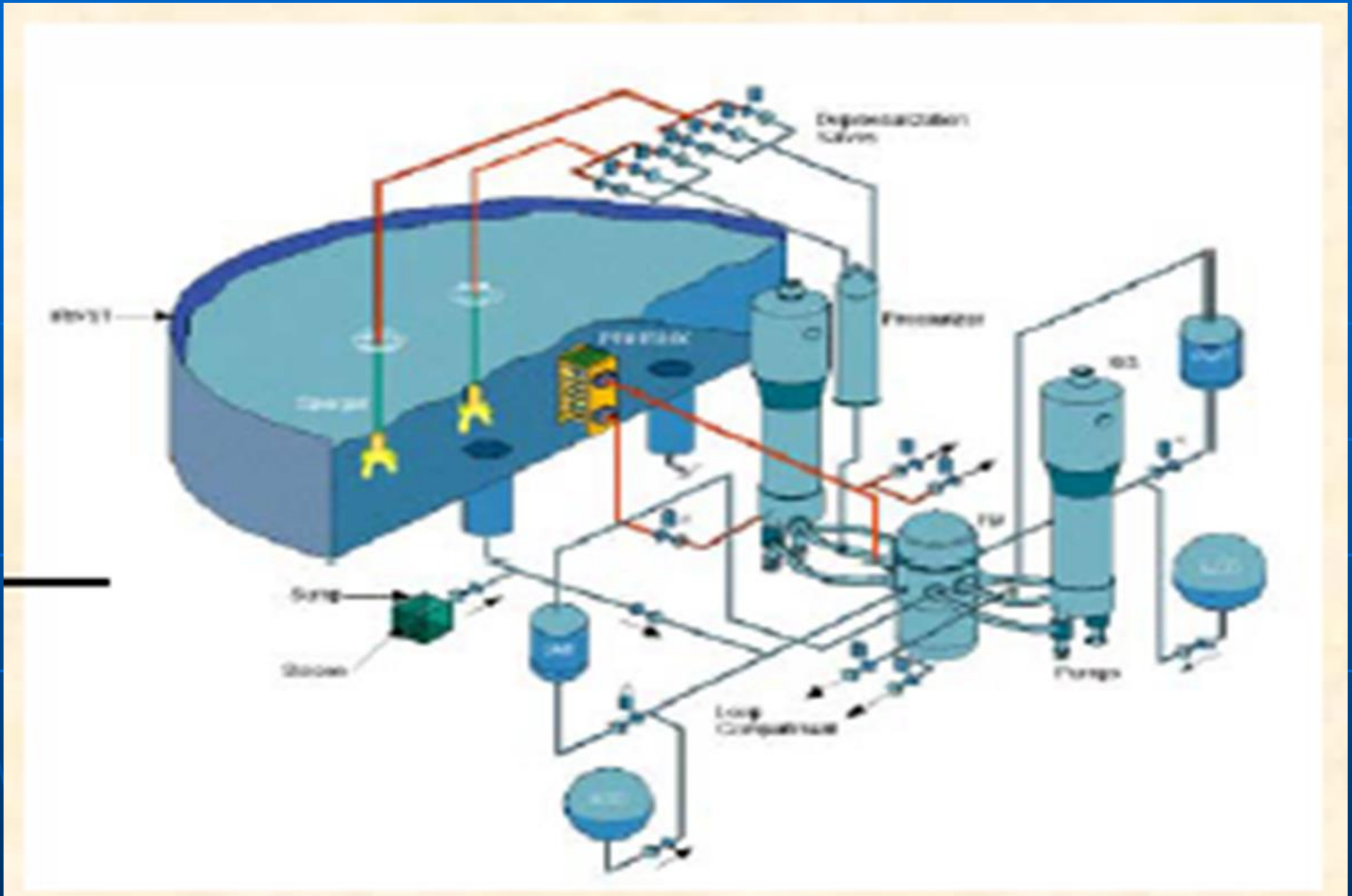
Calandria volume reduced by a factor of 2.5 (smaller lattice pitch).
By using H_2O coolant, less than 25% of D_2O used in C6 is required.

Advanced Power Reactor 1400 MWe

Korea Electric Power Corporation (KEPCO) and Korea Hydro & Nuclear Power Co., Ltd. (KHNP)



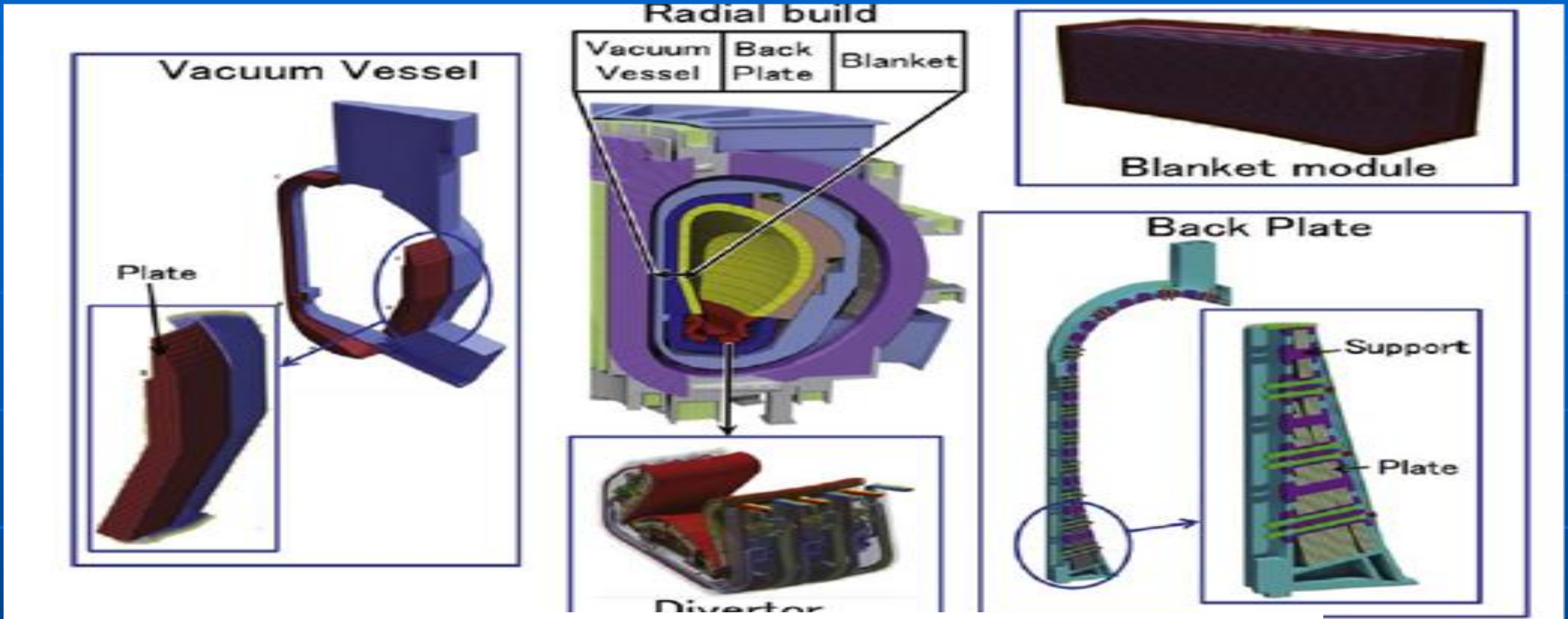
Advanced Passive AP1000 MWe



Passive Safety Systems

Japan's DEMO

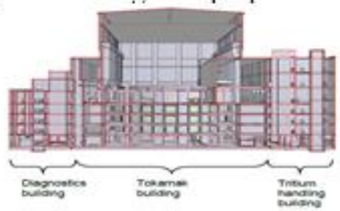
Cooling Water System design for fusion Tokamak Reactor



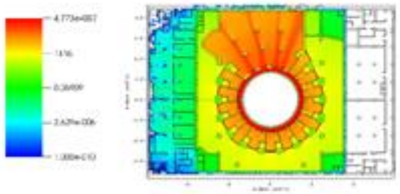
Component	Temperature	Pressure	Thermal energy
Blanket	290–325 °C	15.5 MPa	1574 MW
Divertor (RAFM)	290–325 °C	15.5 MPa	291 MW
Divertor (Cu-alloy)	200–230 °C	5 MPa	172 MW
Back plate	200–210 °C	3 MPa	16 MW
Vacuum vessel	100–105 °C	1.1 MPa	0.043 MW

Fig. In-vessel components image of Japan's DEMO

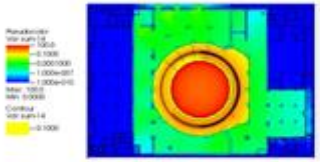
Water Radiolysis in Fusion Neutron Environments for ITER



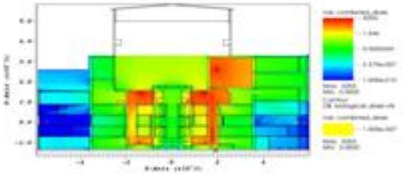
(a)Illustration of the three buildings constituting the ITER complex.



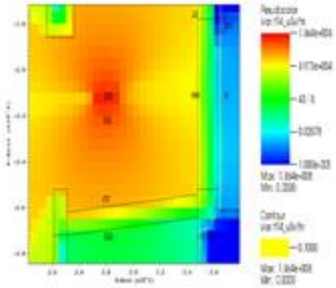
(b)Biological dose rate μSv/hr, neutrons during plasma operation – example results, level L2.



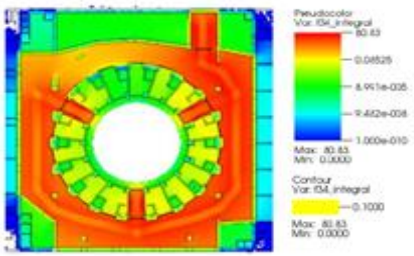
(c)Biological dose rate Activated pipe chases and cryostat μSv/hr, at 106s after shutdown – example results.



(d)Total photon dose rate (Sv/h), during plasma operation.



(e)Total photon dose rate (μSv/h).



(f)Integral dose to silicon from 54 cask transfers (from three port cell locations), in units of Gy.

Fig. MCNP Calculation results for detailed radiation maps of the ITER complex have been produced during plasma operation and after shutdown to the required dose rate cut-off criteria

SUMMARY

Optimization of Water Coolant Chemistry to Ensure Reliable Water Reactor Fuel Performance at High Burnup and in Ageing Plant, it was necessary to control the chemical water by added suitable chemical elements, to avoid corrosion problems and also to properly adjust the normal operation and shutdown the nuclear power plant, and this has already been implemented for decades and it is a proven technology (PWR, VVER, BWR, CANDU, etc.),. But in the case of fusion reactors, Still under research ,for example Japan's DEMO, it is clear in this research that Japan's DEMO use of water as a coolant is used in the same range of temperatures and pressures used In PWR.

THANK YOU FOR YOUR ATTENTION