TOMSK
POLYTECHNIC
UNIVERSITY

Fundamentals of Nuclear Fuel Cycle

Lecturer
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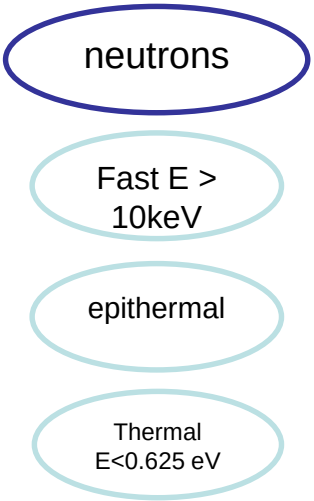
Nuclear Power Plant

is a device used to initiate and control a sustained nuclear chain reaction.

Classification of reactor

1. Type of fission reaction
- thermal,
- epithermal,
- fast



Nuclear Power Plant

Classification of reactor

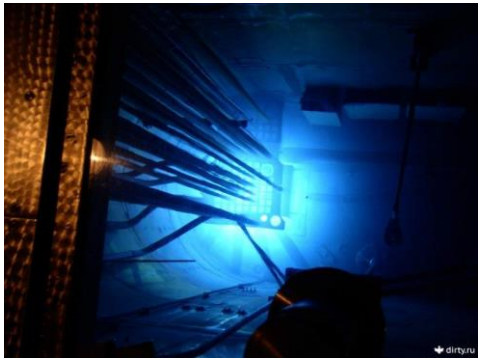
2. Purpose of the reactor

- Power reactor,
- Research reactor,
- Test reactor,
- Transport reactor

3. Type of core construction

- cubical,
- cylindrical,
- octagonal,
- spherical

Classification of reactor



4. Type of the coolant present

- light/heavy water reactors,
- gas-cooled reactors,
- liquid metal-cooled reactors,
- organic-cooled

5. Type of the moderator present

- light/heavy water,
- graphite,
- beryllium,
- etc

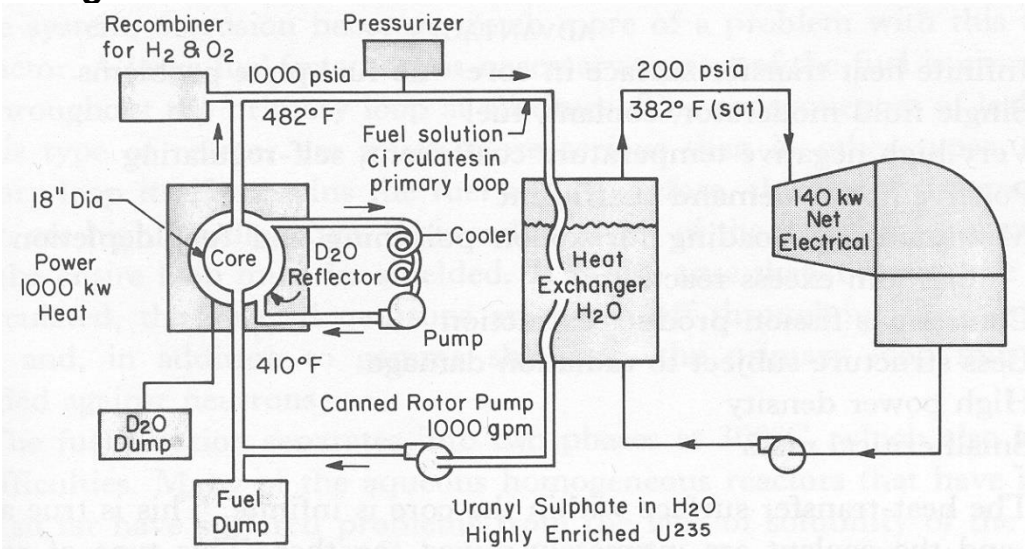
Classification of reactor

Homogeneous reactor
reactor in which the fuel is a mixture with the moderator or coolant

Heterogeneous reactor
Nuclear reactor in which the fuel is separated from the moderator.

Classification of reactor

Homogeneous reactor



Schematic Layout
for the Homogeneous Reactor Experiment — I

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Fuels

- **Natural Elements**
  - ^{90}Th, 14.05·10^{9} yr
  - ^{90}U, 4.5·10^{9} yr
    - $^{238}_{92}\mathrm{U} \rightarrow {}^{239}_{94}\mathrm{Pu}$, 99.5%
    - $^{235}_{92}\mathrm{U}$, 0.7%
- **Artificial Nuclides**
  - ^{233}U, 7·10^{8} yr
  - ^{239}Pu, 24·10^{3} yr

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow {}^{239}_{92}\mathrm{U} \xrightarrow{23.5\,\mathrm{min}} {}^{239}_{93}\mathrm{Np} \xrightarrow{2.3\,\mathrm{day}} {}^{239}_{94}\mathrm{Pu}$$

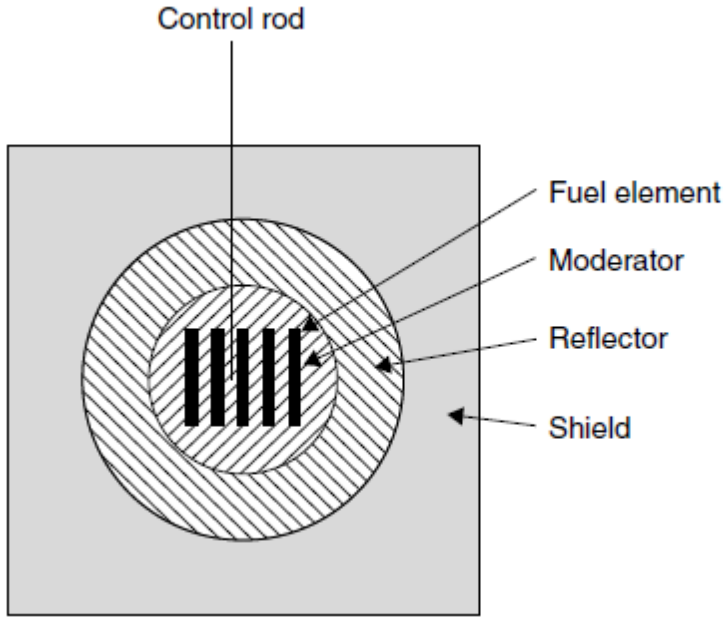
$$^{232}_{90}\mathrm{Th} + {}^{1}_{0}n \rightarrow {}^{233}_{90}\mathrm{Th} \xrightarrow{23.3\,\mathrm{min}} {}^{233}_{91}\mathrm{Pa} \xrightarrow{27.4\,\mathrm{day}} {}^{233}_{92}\mathrm{U}$$

$$\beta^{235} = 0.0064$$

$$\beta^{233} = 0.0026$$

$$\beta^{239} = 0.0020$$

Reactor core



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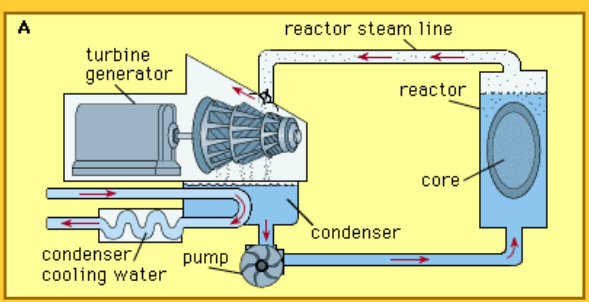
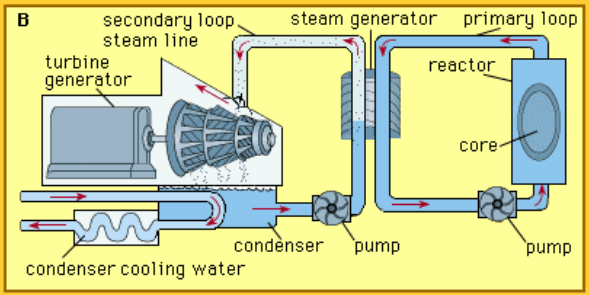
Loops

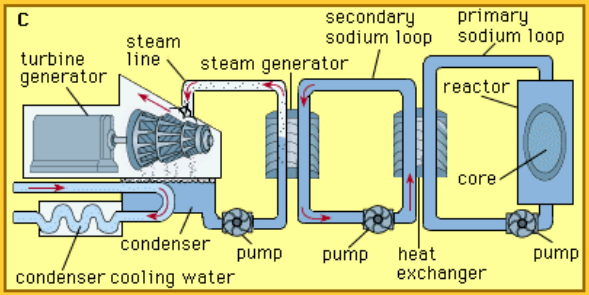
1-loop BWR



2-loop PWR

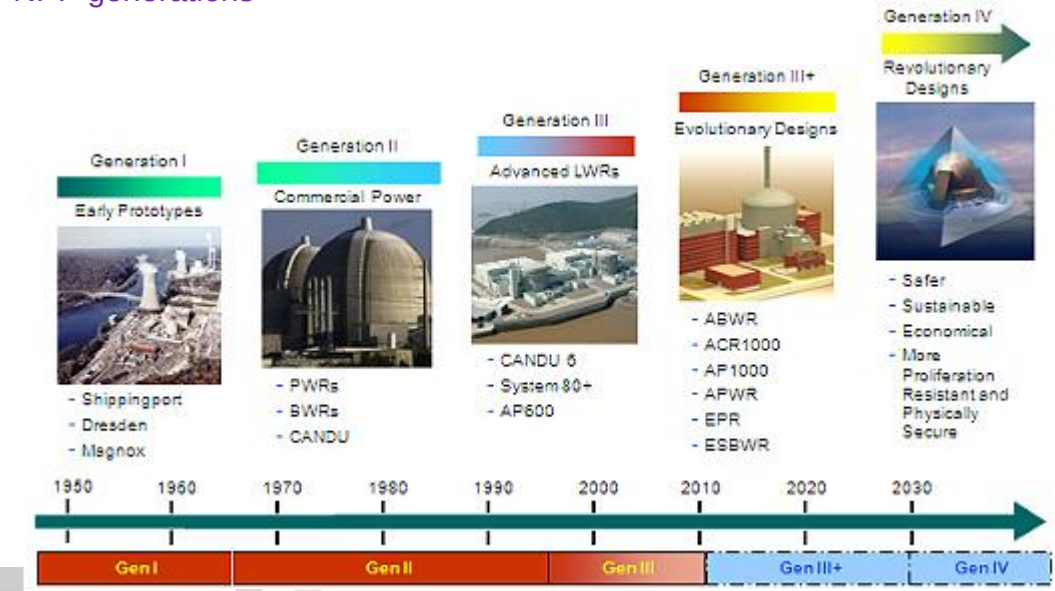


3-loop LMR



Nuclear Power Plant

NPP generations



Operating reactors

Types	Numbers of units	Total MW(e)
BWR	84	77621
FBR	2	580
GCR	17	8732
LWGR	15	10219
PHWR	47	23140
PWR	270	368259

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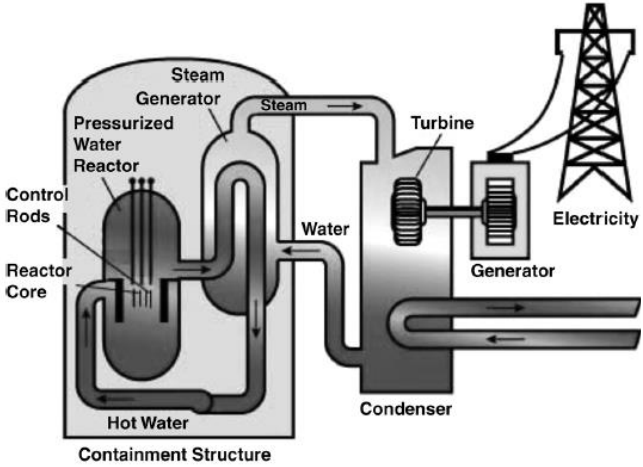
Nuclear Power Plant

PWR

Moderator - light water
Coolant - light water
Fuel – 2.5-4% UO_2
Zircaloy–4 fuel claddings



Steam - in steam generator
No bulk boiling in RPV
Top entry control rod cluster

Two circuit systems of pipelines

PWR

Cladding tubes - 10mm (outer) , thickness 0.7 mm
Fuel pins – 200 (per f.e.)
Fuel elements – 180
Control rod – Ag-In-Cd Alloy or B_4C

Liquide Phase Tin=287.7 C, Tout= 324 C, P=15.2 MPa, Tsat= 343.3 C
Steam phase $T_{SG,in}$ = 227 C, $T_{SG,out}$ = 285 C, P=6.9 MPa, Tsat = 285 C

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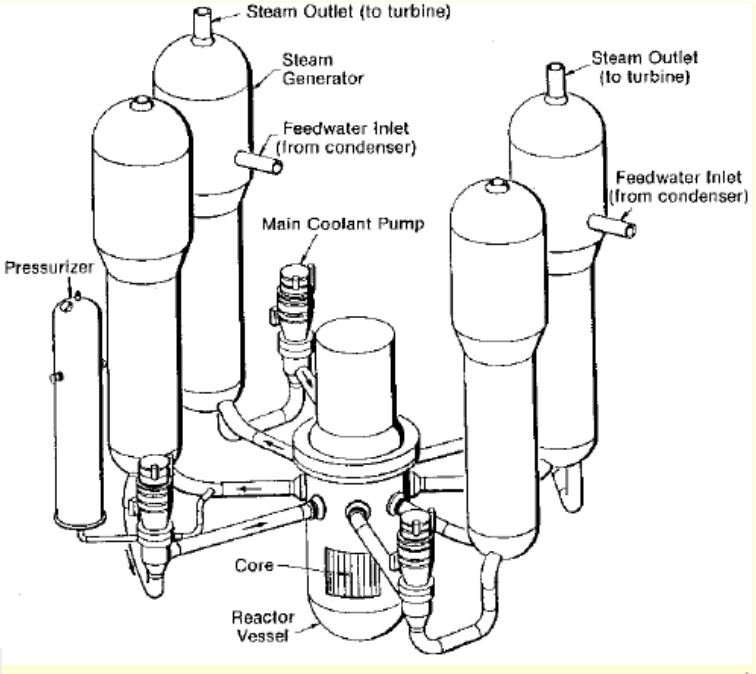
PWR



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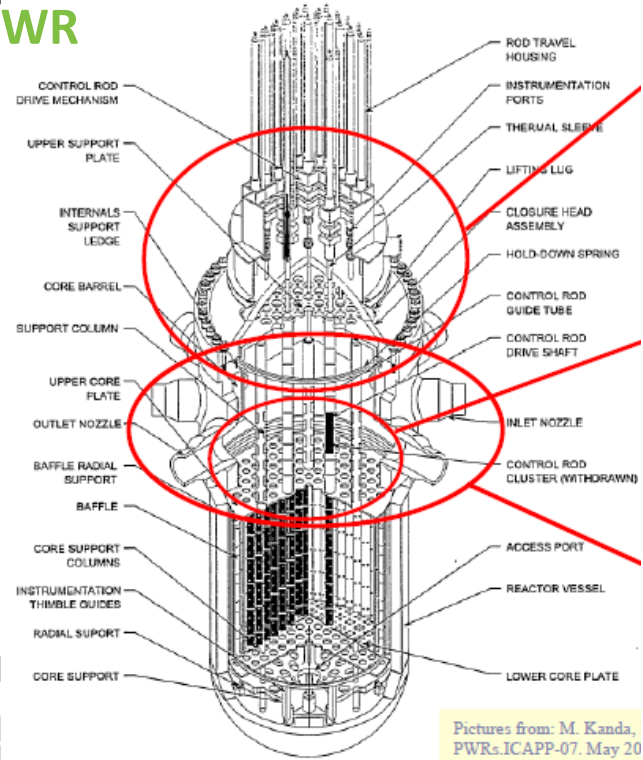
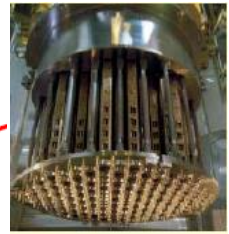
Nuclear Power Plant

PWR





Pictures from: M. Kanda, PWRs.ICAPP-07. May 20

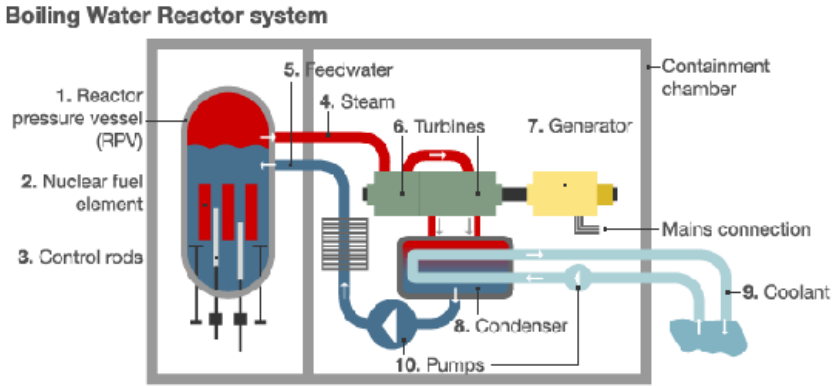
PWR

Reactor pressured vessel

Overall length of assembled vessel, closure head and nozzles	13.36 m
Diameter	4.56 m
Material	Carbon steel
Volume of Coolant	134 m3

BWR

Pressure	7.1 MPa		
Power (t/e), MW	3323/1130	Tin, C	278.3
Vessel (d/th/l),m	6.4/0.16/22	Tout,C	287.2



BWR

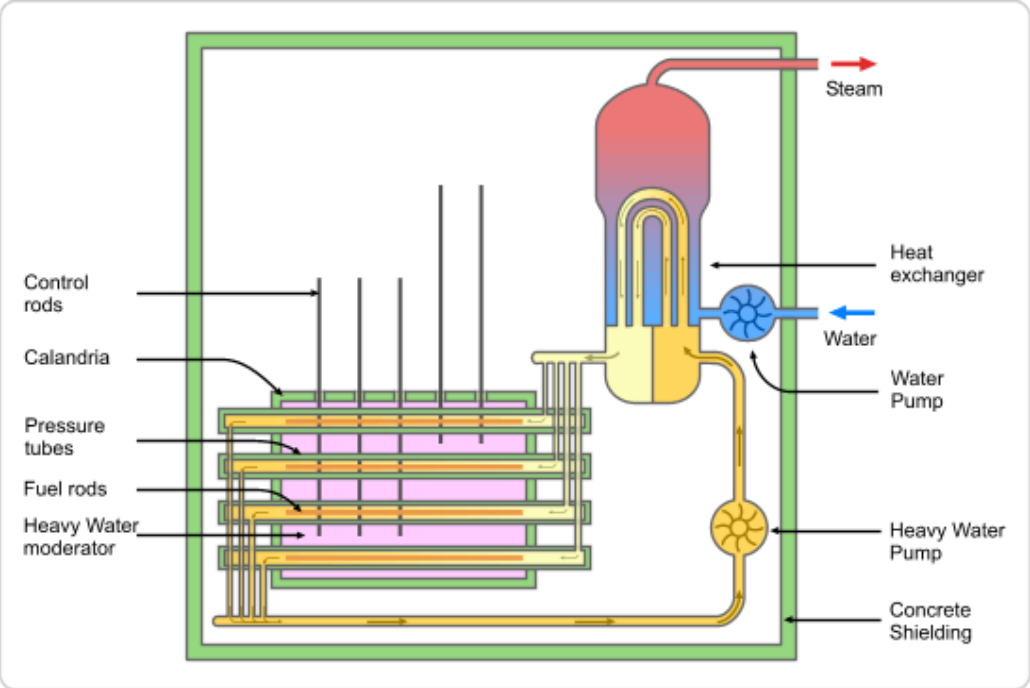
Steam generated in RPV
RPV with separator and dryer
No steam generator
No pressurizer
Bottom control rod drives
Zircaloy 2 fuel claddings tubes

BWR

Cladding tubes - 12.5 mm (outer) Fuel rods – 62 (per f.b.)
Fuel bundles – 764
Control rod – Hg or B_4C

Nuclear Power Plant

CANDU



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CANDU

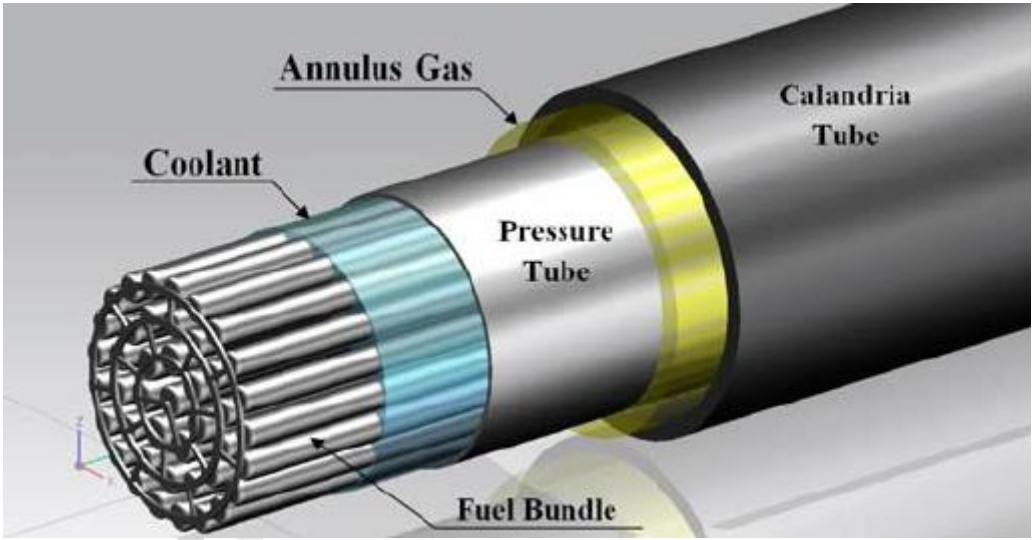
Moderator - heavy water
Coolant – heavy water
Fuel – Natural UO2

Tcoolant = 300 C, Pcoolant = 10 MPa
Modular reactor

Stainless steel tank – COLANDRIA

Fuel channel – 380
Fuel bundles - 4560
12 fuel bundles in 1 fuel channel
37 fuel element in a bundle

CANDU


Annulus Gas
Calandria
Tube
Coolant
Pressure
Tube
Fuel Bundle

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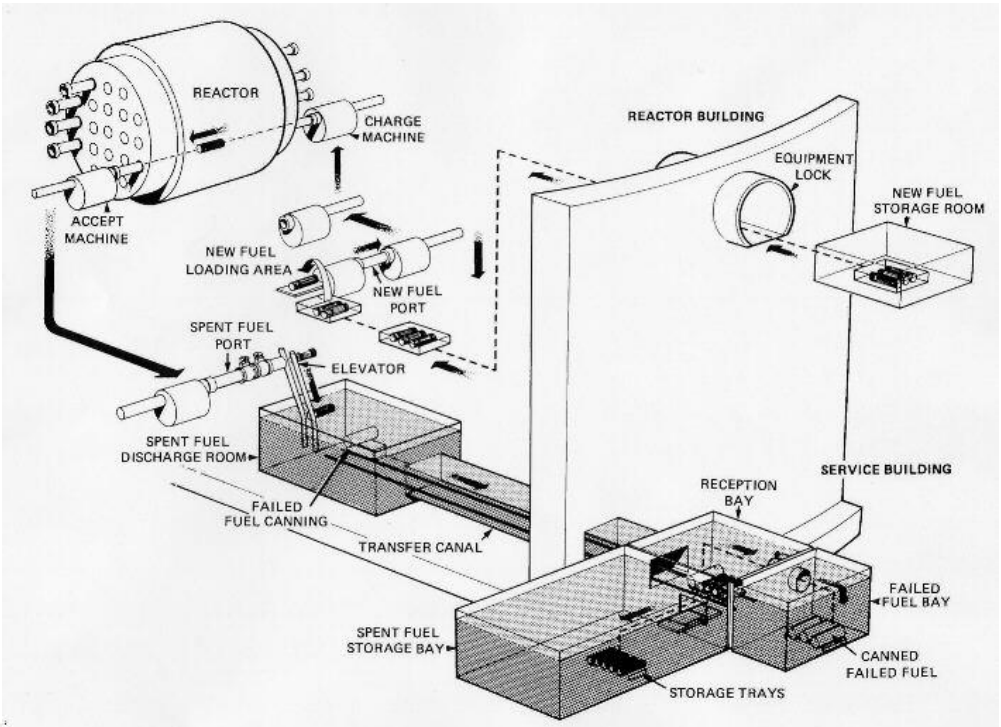
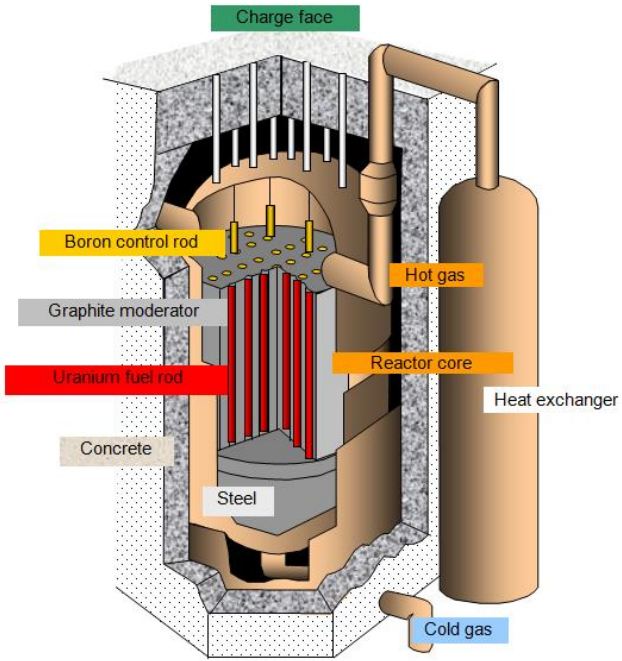
CANDU



Gas-cooled reactors

1. Magnox

Coolant – CO_2
Moderator - graphite
Fuel – natural U metal
Fuel rod – MAGNOX (Mg allo
Vessel diameter – 14 m
lengths – 8 m
Tout – 400 C
Fuel channels - 1696



Gas-cooled reactors

2. Advances gas reactor (AGR)

Coolant – CO_2

Moderator - graphite

Fuel – 2.5% UO_2

Fuel rod – MAGNOX (Mg alloy)

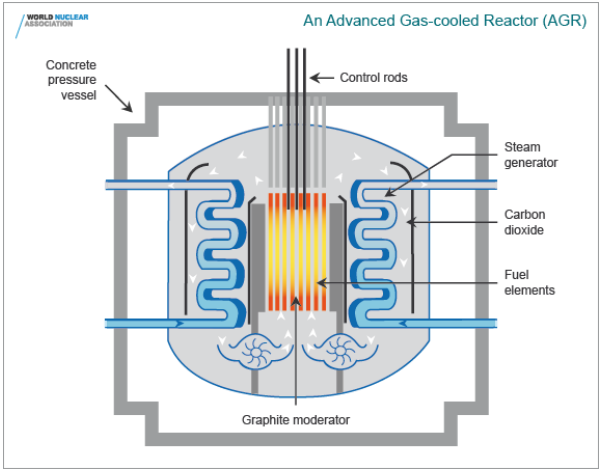
Vessel diameter – 9.5 m

lengths – 8.3 m

Tout – 650 C

Fuel channels – 332

8 fuel rods in a channel



LWGR (RBMK)

Coolant – light water
Moderator - graphite
Fuel – 2 - 2.4% UO_2
Fuel rod – Zircaloy
Vessel diameter – 12 m
lengths – 7 m
Tin – 270 C
Tout – 284 C
Fuel channels – 1693
18 fuel rods in an assembly