ТОМСКИЙ
ПОЛИТЕХНИЧЕСКИЙ
УНИВЕРСИТЕТ

Steam generators and heat exchangers

STEAM GENERATION SCHEMES

Lecture plan

1. Definitions of ‘reactor’, ‘steam generator’, ‘coolant’, and ‘working fluid’
2. Schematic diagrams for steam generation in nuclear power plants
3. Comparative advantages and drawbacks

Basic abbreviated terms

1. Nuclear Power Plant - NPP
2. NPP Steam Generator - SG
3. Nuclear Reactor - NR
4. Working fluid - WF

Nuclear reactor definition

Nuclear reactor is a device used to initiate a controlled and self-maintained nuclear chain reaction that is always accompanied by energy production

Steam generator definition

NPP Steam Generator is a heat exchange device that generates nonradioactive steam in the second (third) loop using the heat of the source coolant.

Coolant and working fluid definitions

Coolant is a medium (agent) that passes through the reactor core and draws off heat from the fuel elements (It is a medium transferring heat to a SG).

Working fluid is a medium that converts heat (thermal energy) into mechanical energy (It is a medium that receives heat in a SG and changes its aggregate state).

Cycle diagrams of steam generation in NPP

- single-circuit NPP (a coolant is also a working fluid);
- multicircuit NPP (two- and three-circuit NPP)

Types of nuclear reactors

		Moderator			
		water H_2O	graphite	heavy water D_2O	no (нет)
Coolant	water H_2O	LWR (PWR, BWR)	LWCGR		
	heavy water D_2O			CANDU	
	liquid metal natrium Na; plumbum Pb)				LMFBR
	gas cooled (carbon dioxide CO_2; helium He)		GCR		

Types of nuclear reactors

1. LWR - light water reactor
   - *PWR - pressurized water reactor. In Russia - WWER*
   - *BWR - boiling water reactor*

2. LWCGR - light water cooled graphite moderated reactor

   No foreign analog; in Russia - RBMK (pressurized tube reactor)

3. GCR -gas cooled graphite moderated reactor
   - *AGR - advanced gas-cooled reactor*
   - *HTGR - high-temperature gas-cooled reactor*

4. LMFBR - liquid metal fast breeder reactor

5. PHWR - pressurized heavy water reactor

   CANDU (Canada deuterium uranium) - pressurized heavy water cooled heavy water moderated reactor

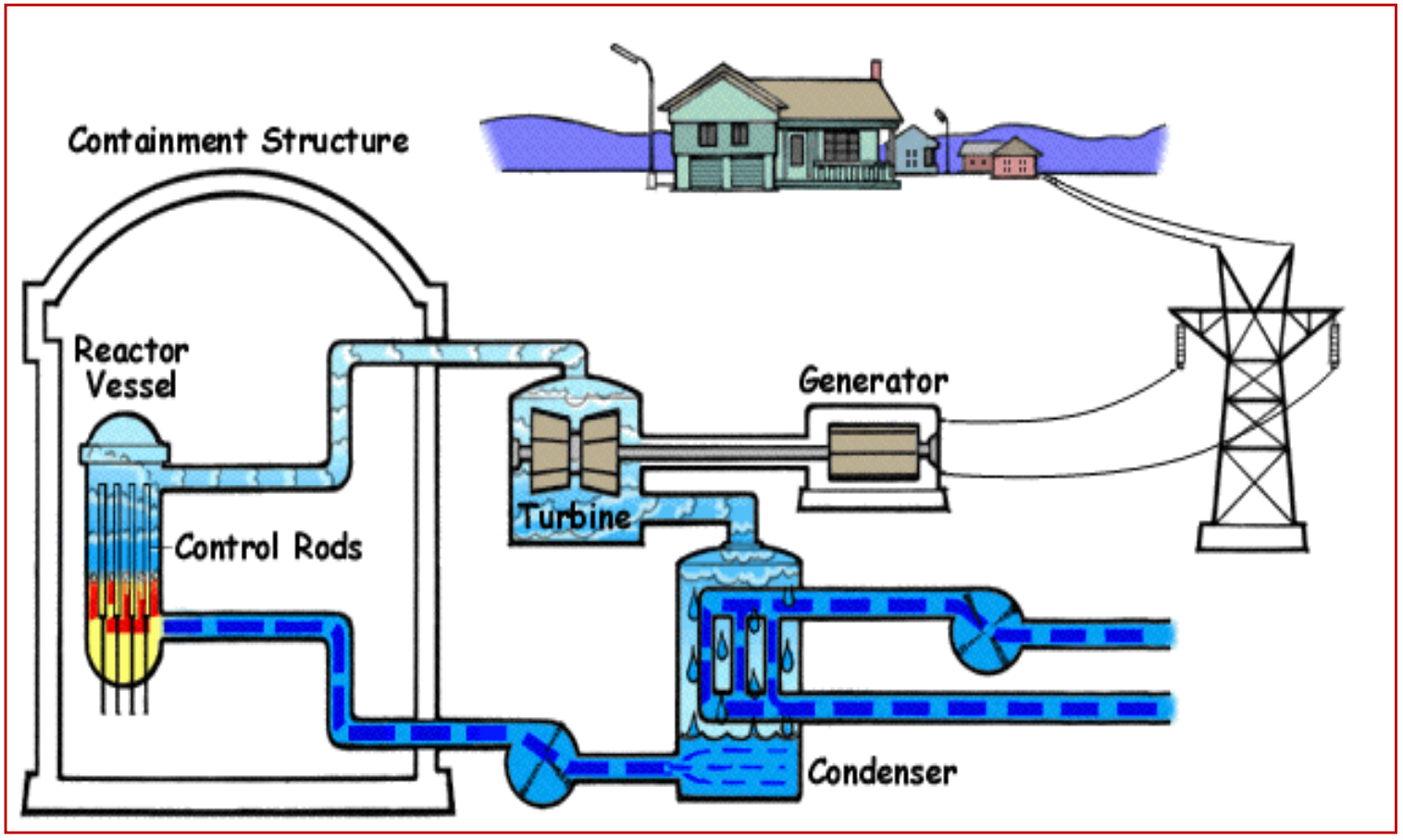
Types of single-circuit NPP units

1. NPP unit with a boiling water reactor (BWR);
2. NPP unit with a light water graphite reactor (LWGR)

for example…

NPP unit with reactor RBMK (channel water graphite reactor)

Boiling water reactor diagram (BWR)



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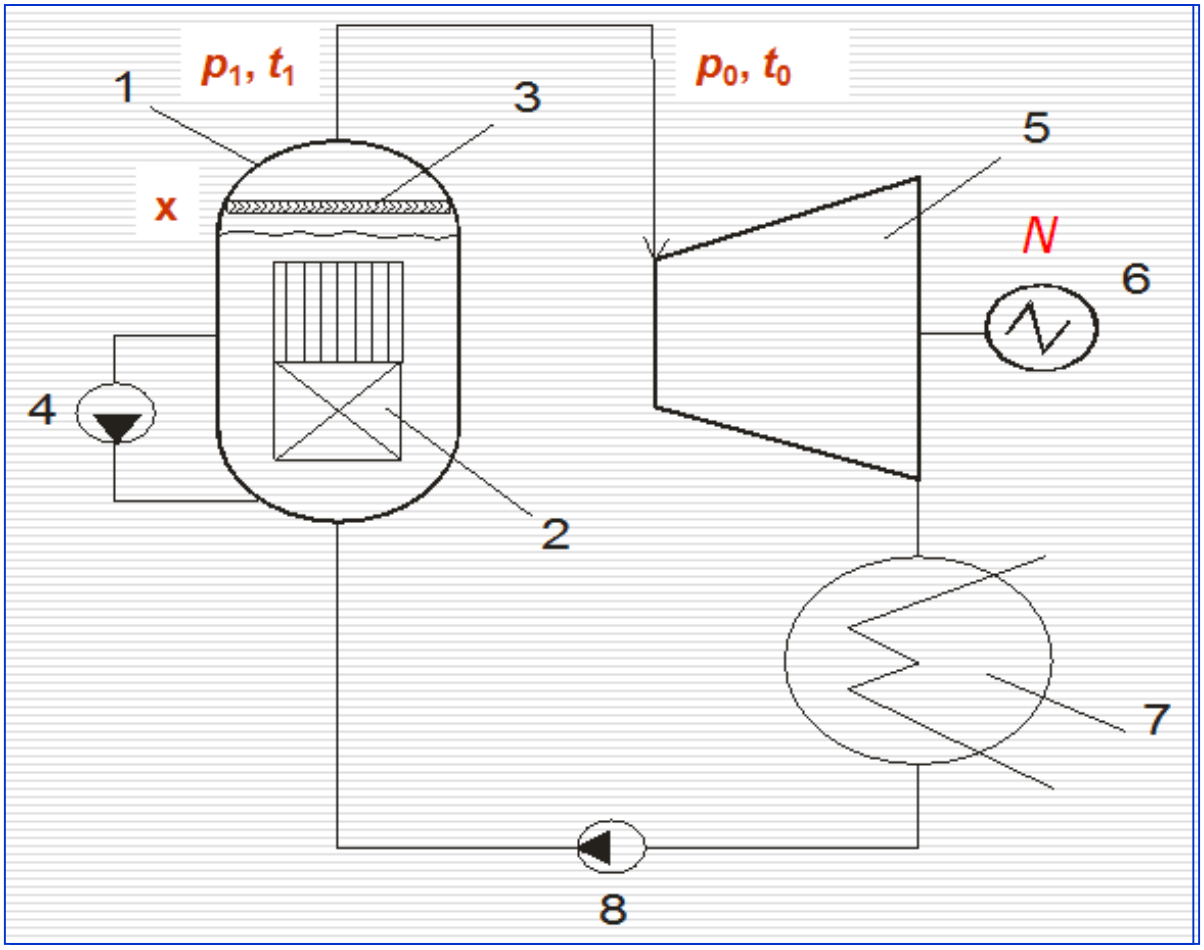
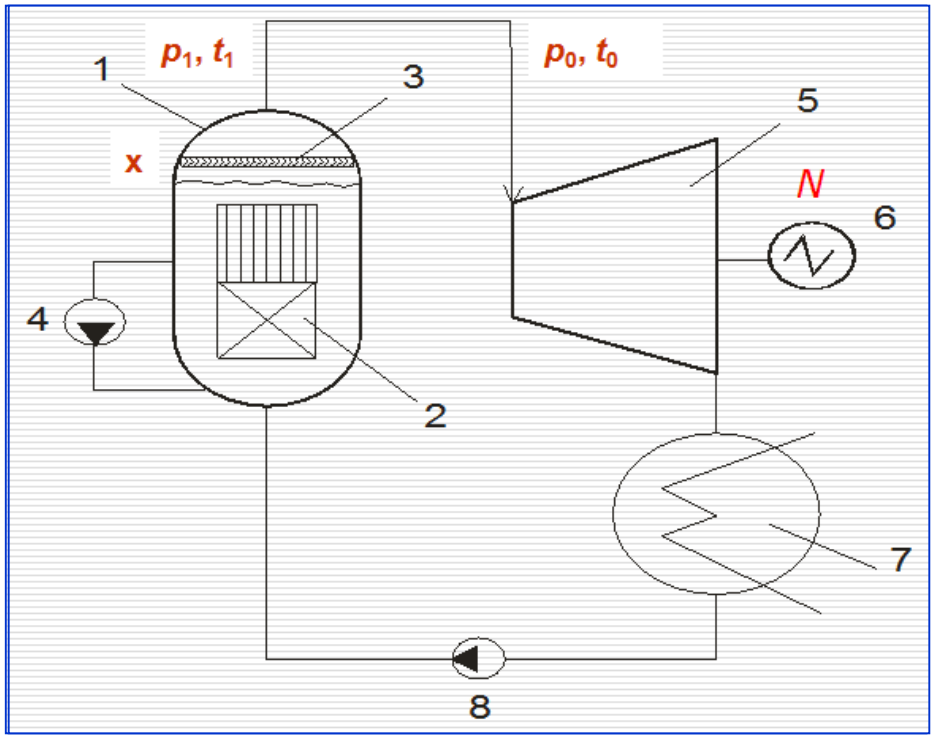
Boiling water reactor (BWR)



Legend to the diagram of power unit with BWR



1 – reactor vessel;

2 – core;

3 – separator;

4 – recirculation pump;

5 – turbine;

6 – electric generator;

7 – condenser;

8 – feed pump;

x – mass steam content (steam quality)

Characteristics of typical BWR power unit

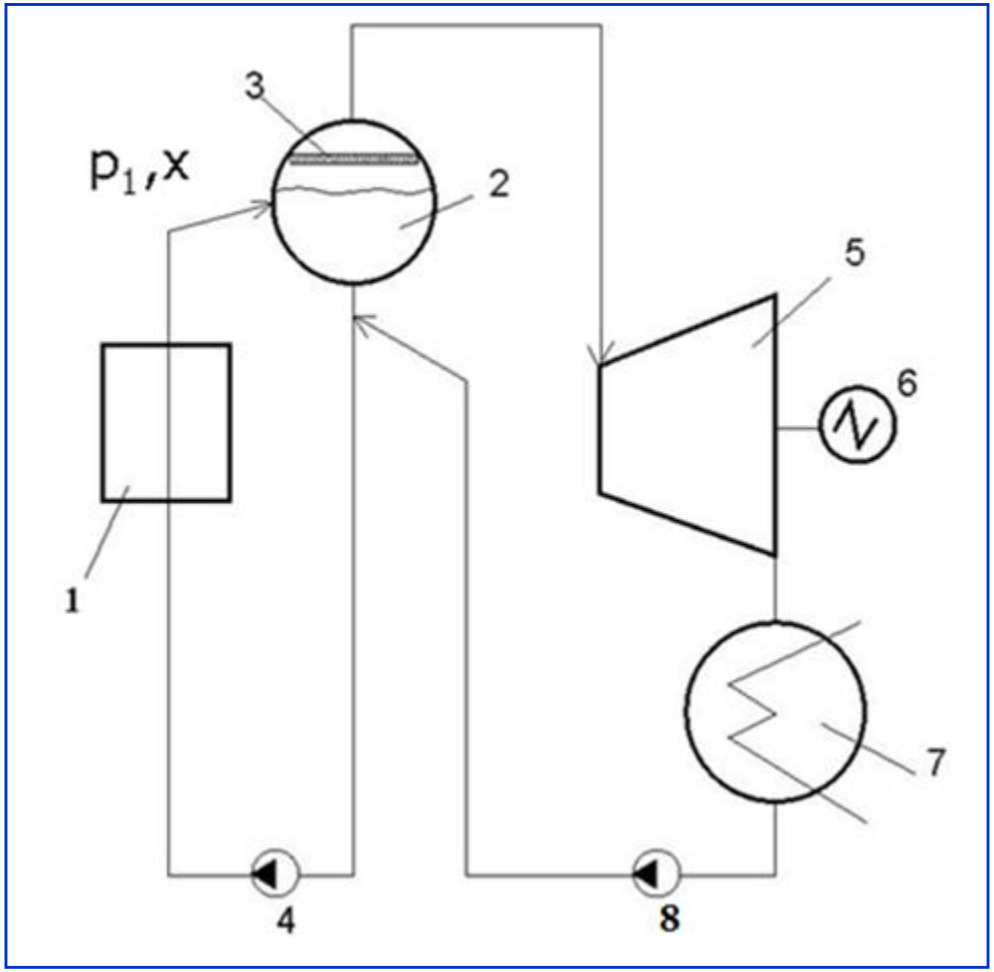
Thermal power Q = 3579 MW;

Electric output N = 1250 MW;

Coolant parameters at the reactor outlet:

- pressure $P_l \approx P_0 = 7$ MPa;
- temperature $T_l \approx T_0 = T_{sat}$;
- steam content (steam quality) $0.1 < x < 0.4$

LWCGR power unit



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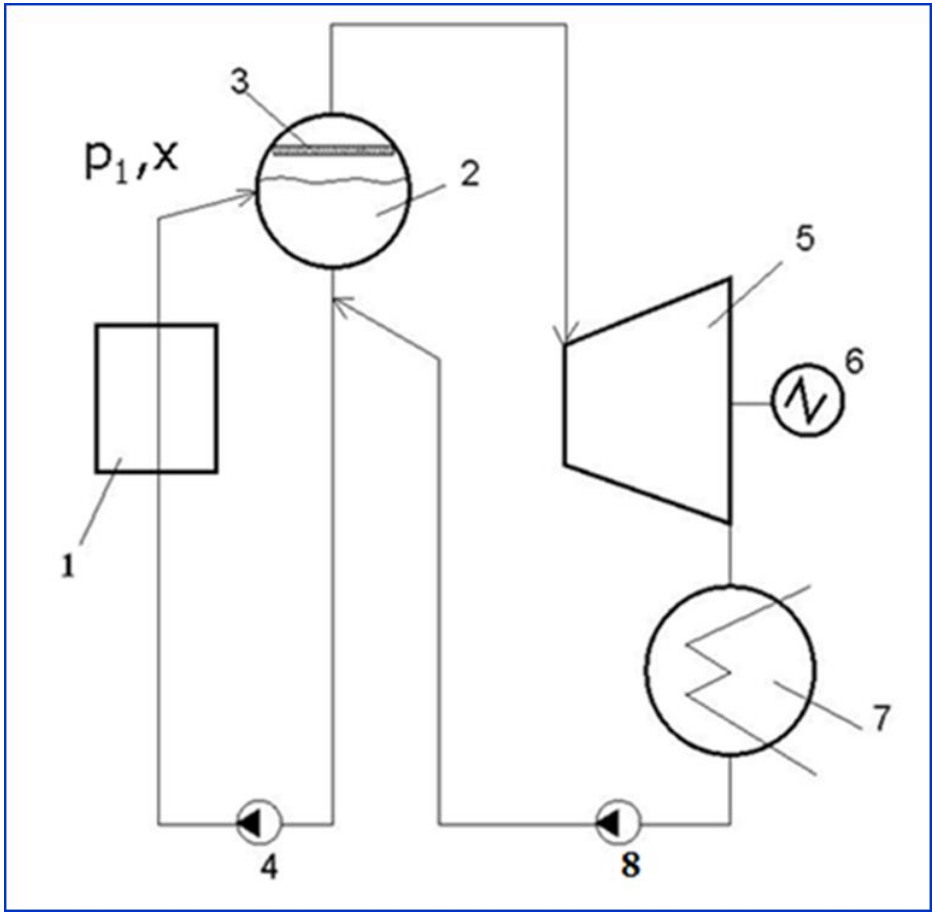
Legend to the diagram of power unit with LWCGR



1 – reactor;

2 – drum separator;

2 – separator;

4 – main circulation pump;

5 – turbine;

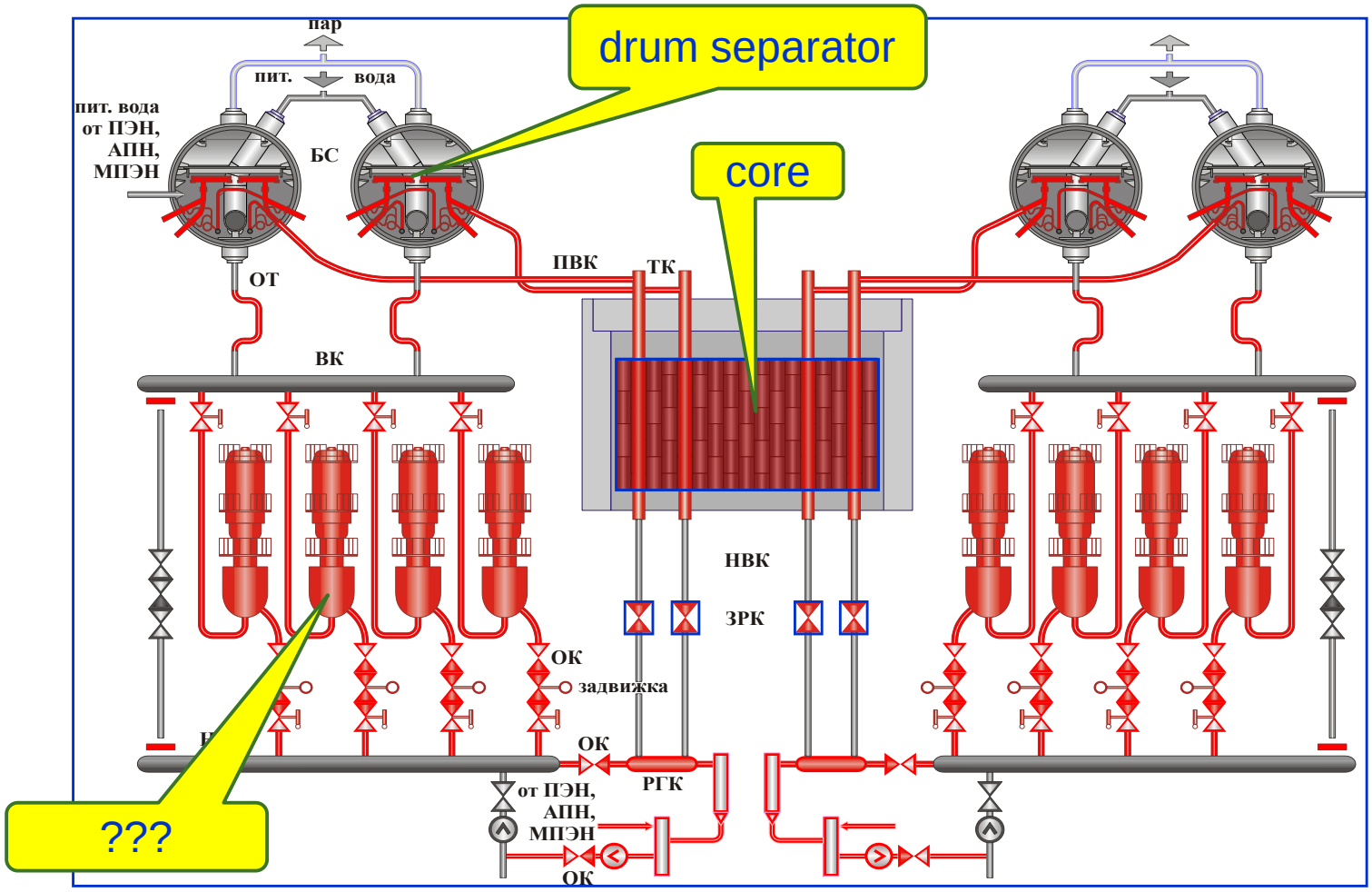
6 – electric generator;

7 – condenser;

8 – feed pump;

x – mass steam content (steam quality).

Light water graphite reactor diagram (RBMK-1000)



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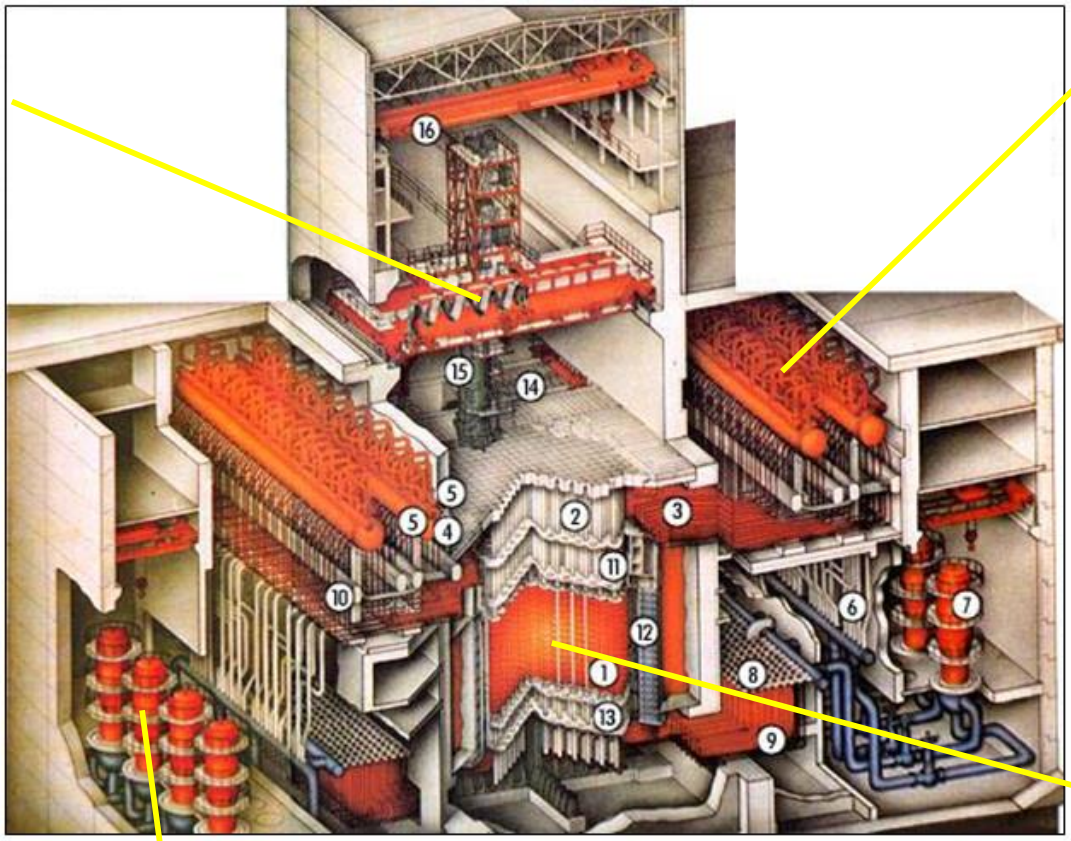
RBMK-1000 plant layout

Refuelling machine



Drum separator

Reactor

Main circulation pump

Characteristics of RBMK-1000-type unit

Thermal power Q = 3200 MW;

Electric output N = 1000 MW;

Coolant parameters at the reactor outlet:

- pressure P_1 = 7.4 MPa;
- temperature $T_1 = T_{sat}$;
- steam content x = 0.15

Advantages and drawbacks of power units with boiling water reactors

- simpler cycle arrangement;
- no complicated and metal-intensive steam generator and pressurizer;
- less coolant pressure in comparison with pressurized water reactors (PWR)

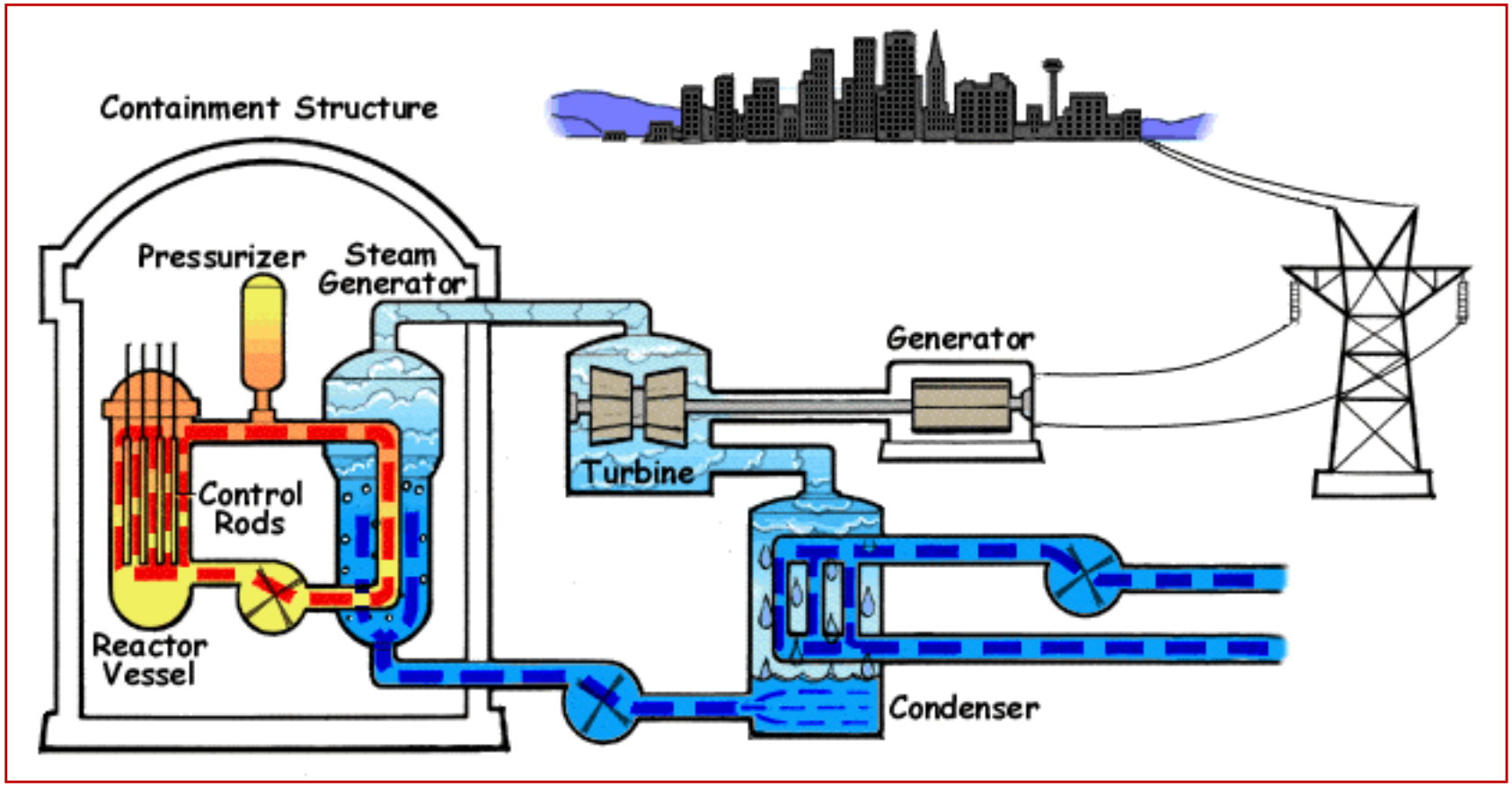
- possibility of radioactivity carryover into a turbine;
- complicated construction of a reactor (large size);
- stricter requirements for coolant purity;
- bad dynamic characteristics

Types of two-circuit NPP units

1. NPP unit with a water-water reactor of a non-boiling type (PWR, WWER, CANDU, etc);
2. NPP unit with a gas-cooled reactor (AGR, HTGR)

Note:
PWR – Pressurized water reactor
CANDU – Canada Deuterium-Uranium (reactor)
AGR – Advanced gas-cooled reactor
HTGR - High temperature gas-cooled reactor

NPP with pressurized water reactor (PWR)



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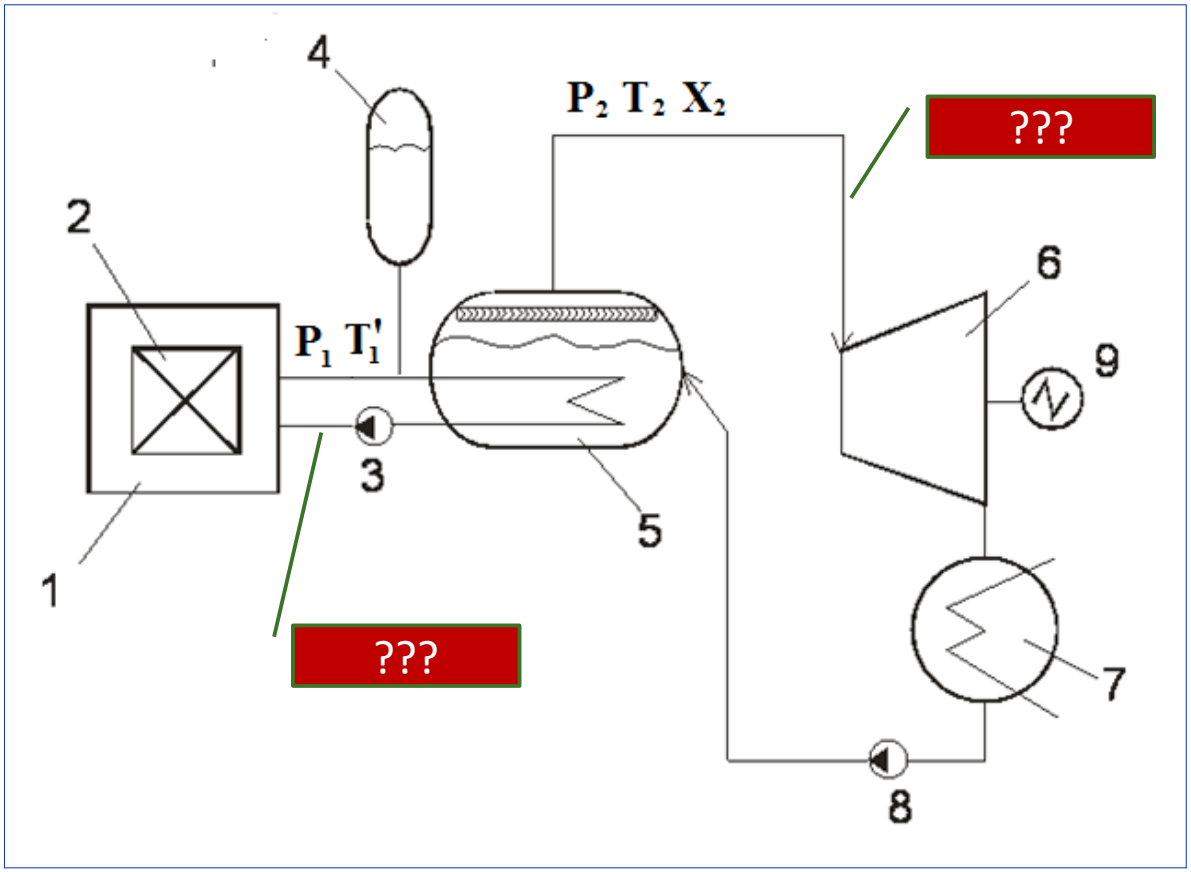
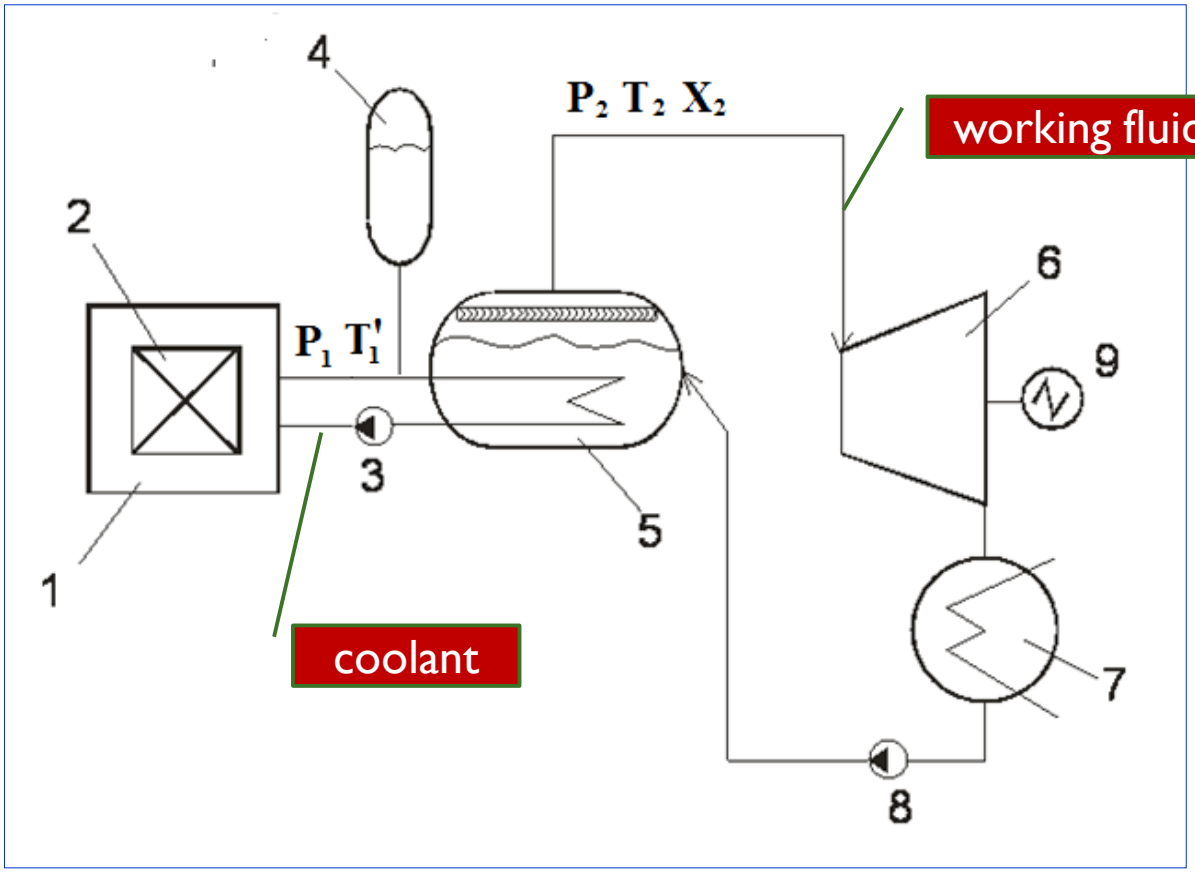
Power unit with pressurized water reactor



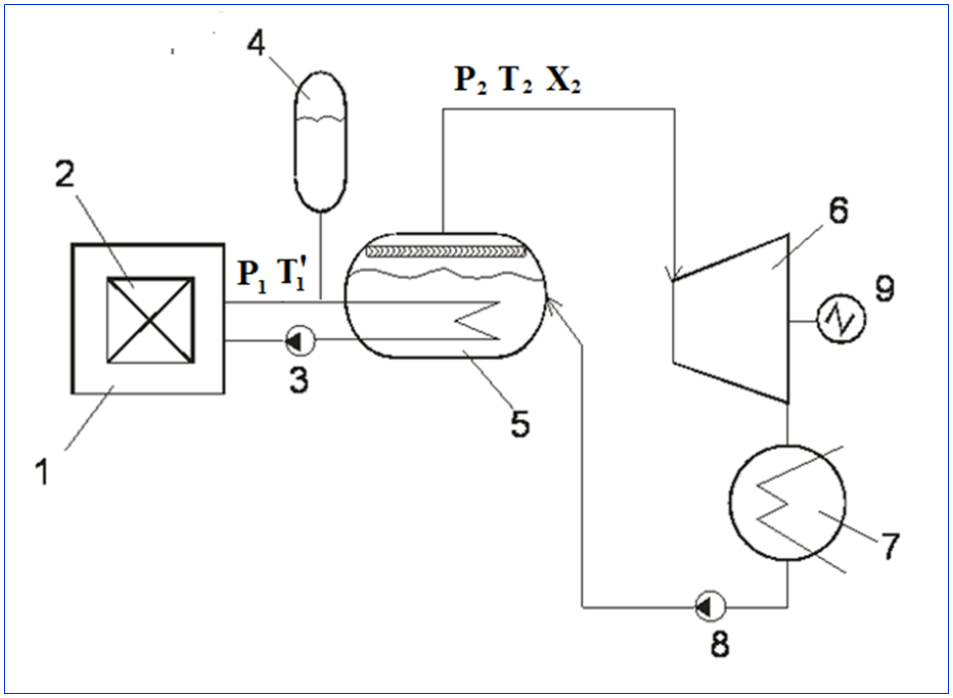
Note. *First PWR NPP: 68 MW, 1958, Shippingport Atomic Power Station, USA*

Power unit with pressurized water reactor



Note. *First PWR NPP: 68 MW, 1958, Shippingport Atomic Power Station, USA*

Legend to the diagram of power unit with PWR



1 – reactor;

2 – core;

3 – reactor coolant pump;

4 – pressurizer;

5 – steam generator;

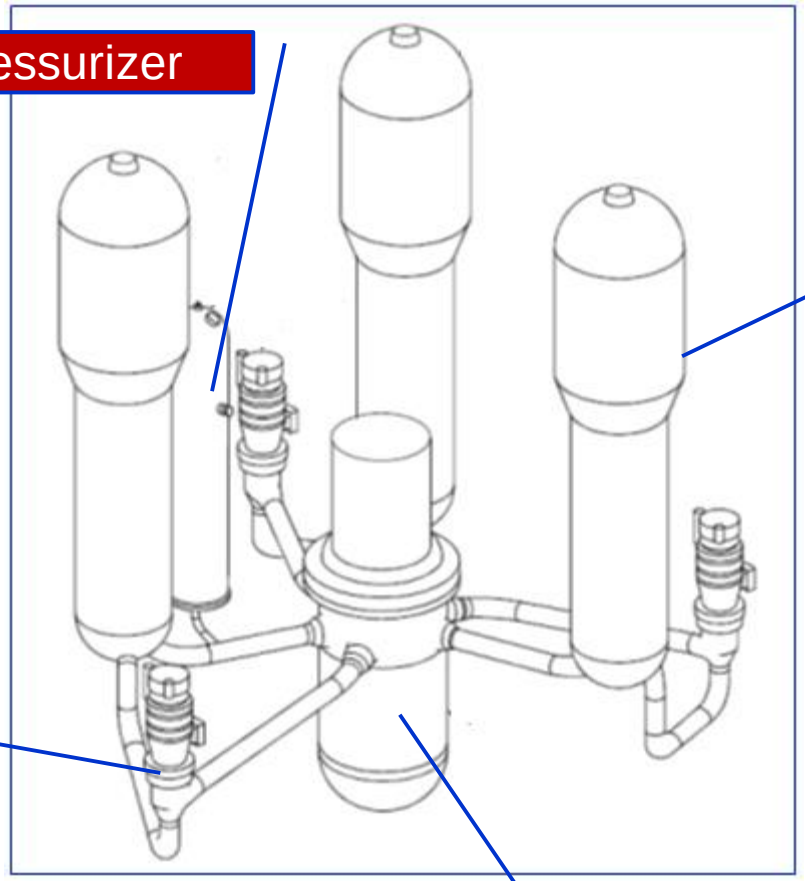
6 – turbine;

7 – condenser;

8 – feed pump;

9 – electric generator.

Primary circuit equipment of PWR unit



PWR-1240 power unit characteristics

Thermal power Q = 3600 MW;

Electric output N = 1244 MW;

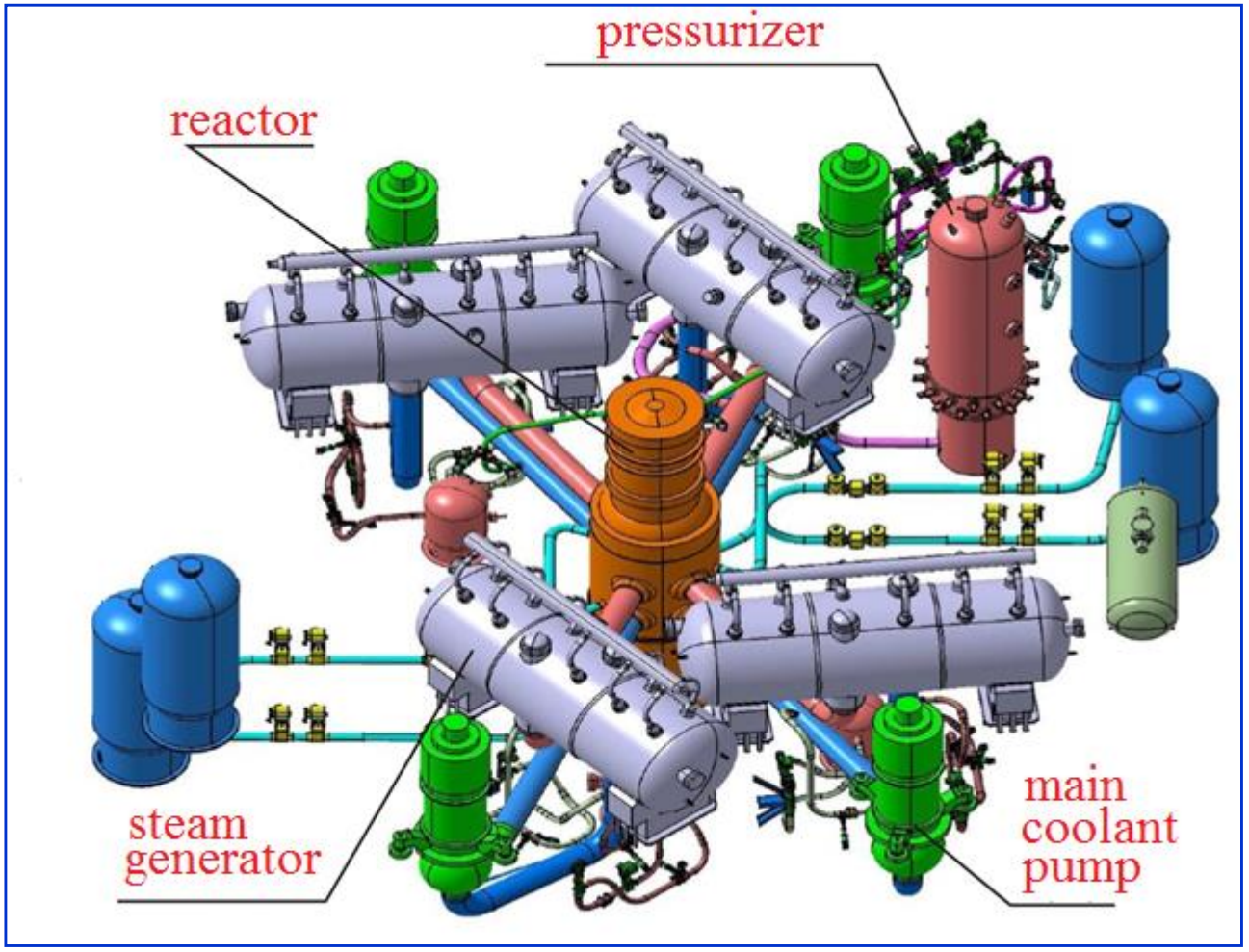
Coolant parameters at the reactor outlet::

- pressure P_1 = 15,5 MPa;
- temperature T'_1 = 330 ^{O}C;

Working fluid parameters at the SG outlet:

- pressure P_2 =7,3 MPa;
- temperature $T_2 = T_{sat}$;
- dryness fraction X_2 = 1

Primary circuit equipment of WWER-1000 unit



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WWER-1000 power unit characteristics

Thermal power Q = 3000 MW;

Electric output N = 1000 MW;

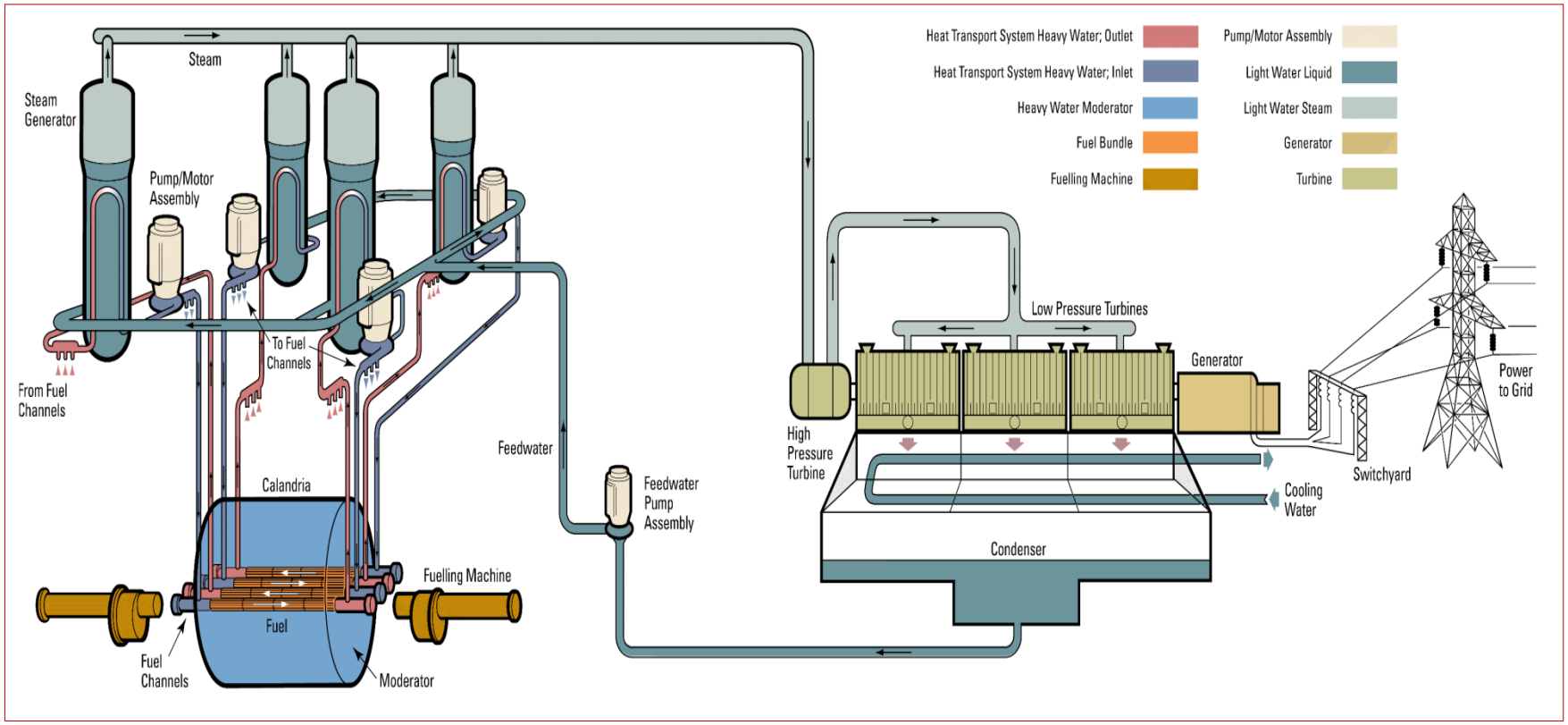
Coolant parameters at the reactor outlet::

- pressure P_1 = 16 MPa;
- temperature T'_1 = 320 ^{O}C;

Working fluid parameters at the SG outlet:

- pressure P_2 = 6.27 MPa;
- temperature $T_2 = T_{sat}$;
- dryness fraction X_2 = 1

Block diagram of CANDU power unit



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Advantages and drawbacks of two-circuit plants with non-boiling reactors

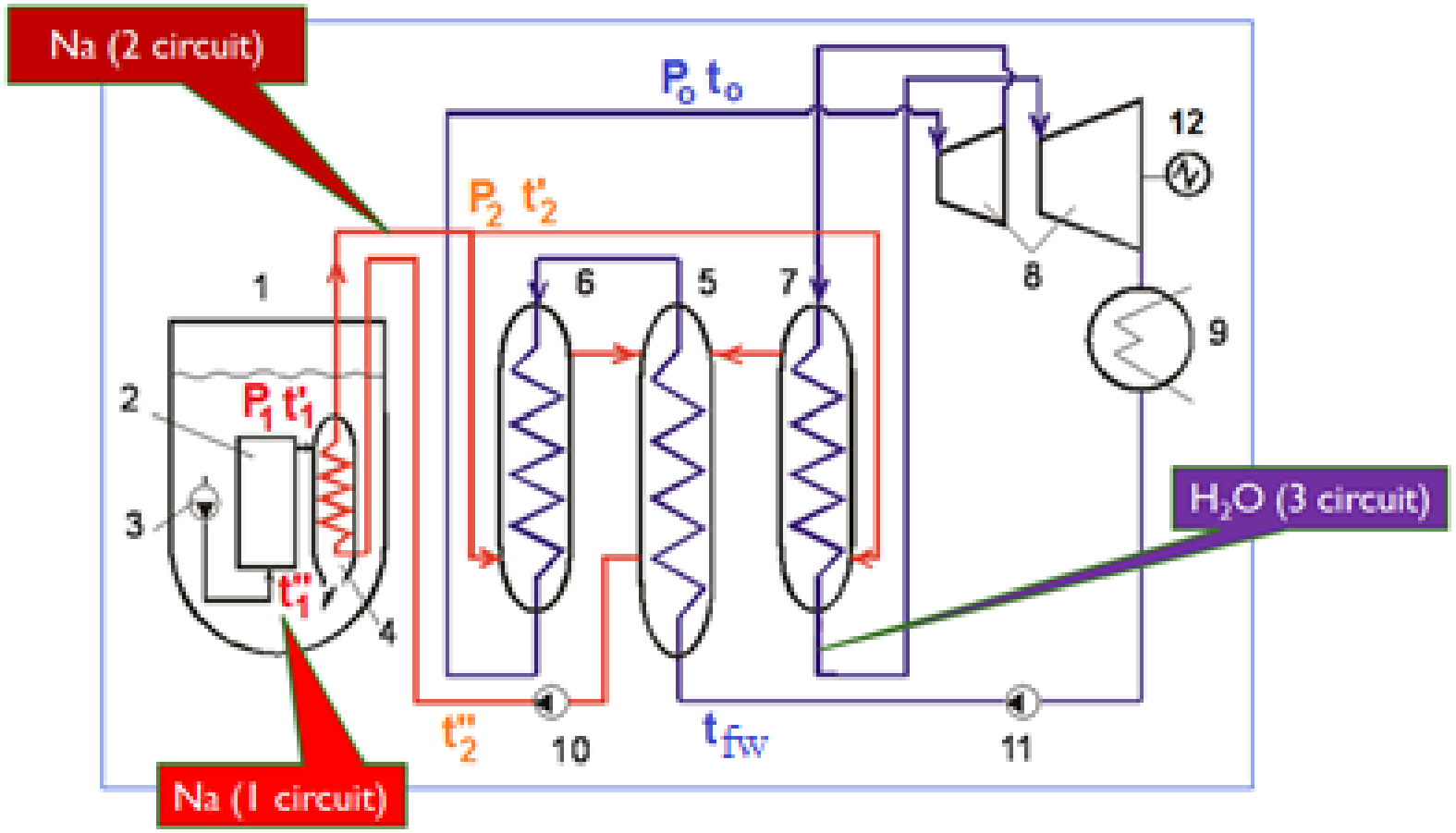
- no radioactivity carryover into a steam turbine;
- good dynamic properties (SG as a buffer storage tank);
- relatively low requirements for chemical water treatment

- sophistication and rise in plant price (SG, pressurizer);
- low thermal efficiency;
- technological constraints in the production of nuclear steam supply system (reactor vessel, SG).

Types of three-circuit NPP units

1. NPP unit with fast breeder reactor cooled by liquid metal (LMFBR)

Power unit with BN-600 reactor



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Legend to the diagram of power unit with BN-600 reactor

1 – reactor;

2 – reactor core;

3 – reactor coolant pump;

4 – Na-Na heat exchanger;

5, 6, 7 – steam generator section;

5 – evaporation module;

6 – primary superheater (PSH) module;

7- secondary superheater (SSH) module;

8 – turbine;

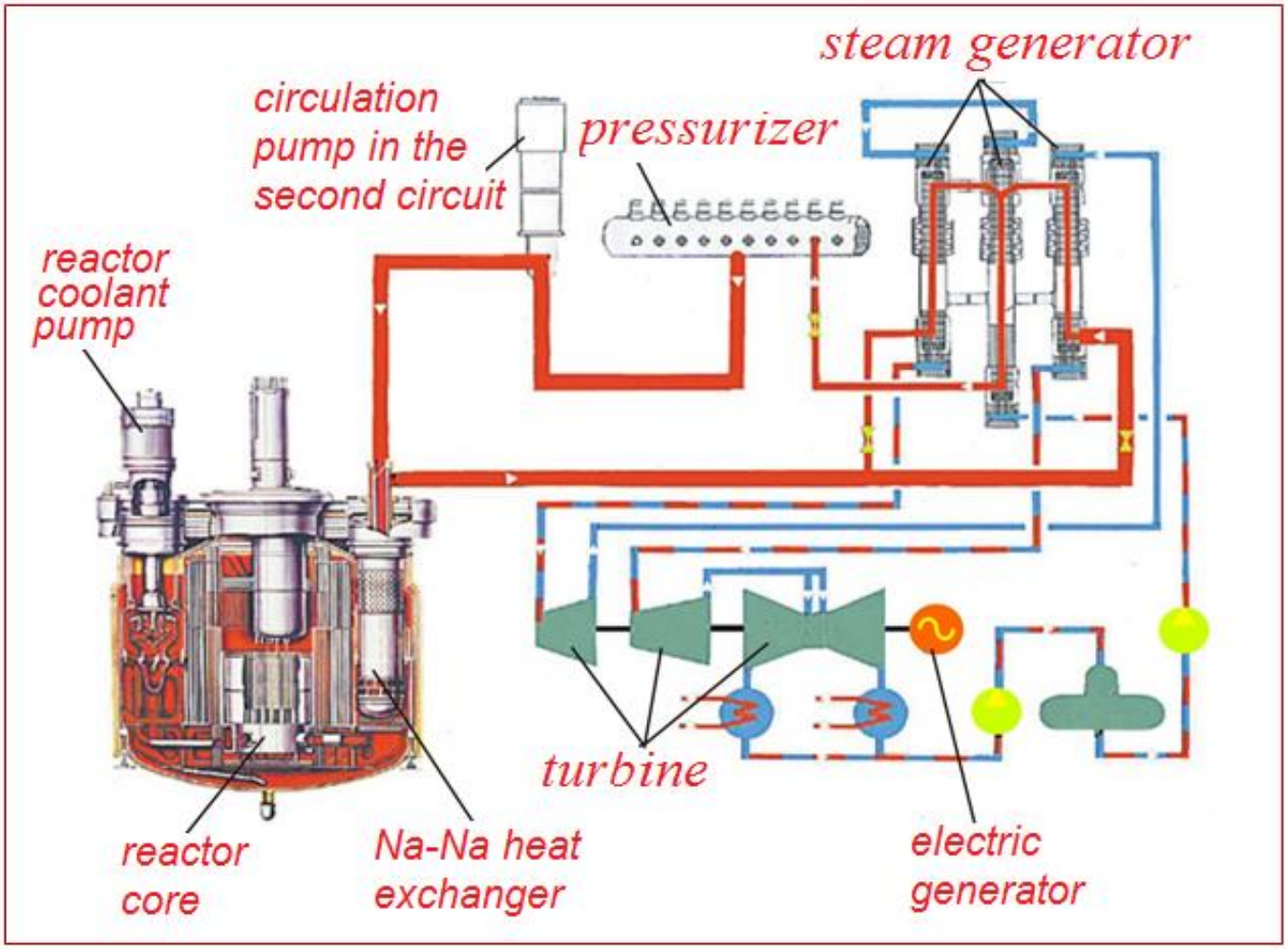
9 – condenser;

10 - circulation pump in the second circuit;

11 – feed pump;

12 – electric generator.

Block diagram of BN-600 power unit



Parameters of NPP unit with BN-600 reactor

- Thermal power Q = 1500 MW.
- Electric output N = 600 MW.
- Coolant parameters at the reactor outlet:

  - pressure P_1 = 0.14… 0.15 MPa;

  - temperature T'_1 = 525…550 ^{0}C.
- Steam (working fluid) parameters at the turbine inlet:

  - pressure P_0 = 13.7 MPa;

  - temperature T_0 = 505 ^{0}C

Advantages and drawbacks of three-circuit plants with BN-type reactors

- high thermal efficiency;
- no radioactivity in the turbine

- complexity and high price of the process design (3 circuits);
- complicated operation of a nuclear steam supply system (liquid metal coolant);
- presence of intermediate heat exchanger and steam generator

Thank you for attention!