3. Thermodynamic cycles of the Steam Turbine NPP

Thermodynamic cycles of the Steam Turbine NPP largely depend on the **Steam Supply System** with a **Nuclear Reactor** being the core of the system.

The value of the initial steam parameters are primarily determined by the features of the **Nuclear Reactor** operation and structure.

Without going into a detailed classification of **Nuclear Reactors**, we will focus on the principles of classification that are important for our NPP unit.

With respect to the neutron spectrum, **Nuclear Reactors** are classified as:

- **thermal neutron reactors** (the energy of neutrons in the fission reaction is ~ 0. 025 *eV*. The velocity of the neutrons corresponding to this energy is 2200 *m/s*).
- **fast neutron reactors** (the neutron spectrum is mainly from 0.5 to 1 *MeV*)
- intermediate spectrum reactors (with the neutron spectrum between the thermal and fast spectra).

Apart from very few exceptions, the Nuclear Power Plants employ thermal neutron reactors. [Currently, there are 4 nuclear units with fast neutron reactors]

Neutron moderation

The energy of the neutrons produced during fission is relatively high, the average energy equals ~ 2 *MeV*

Fast neutrons are converted into **thermal** neutrons as a result of successive collisions with surrounding atoms.

this process is called **moderation**.

the material where moderation occurs is called **moderator.**

The best **moderators** are:

heavy water – D_2O ($_1D^2$ - *deuterium*, $_8O^{16}$ - *oxygen*),

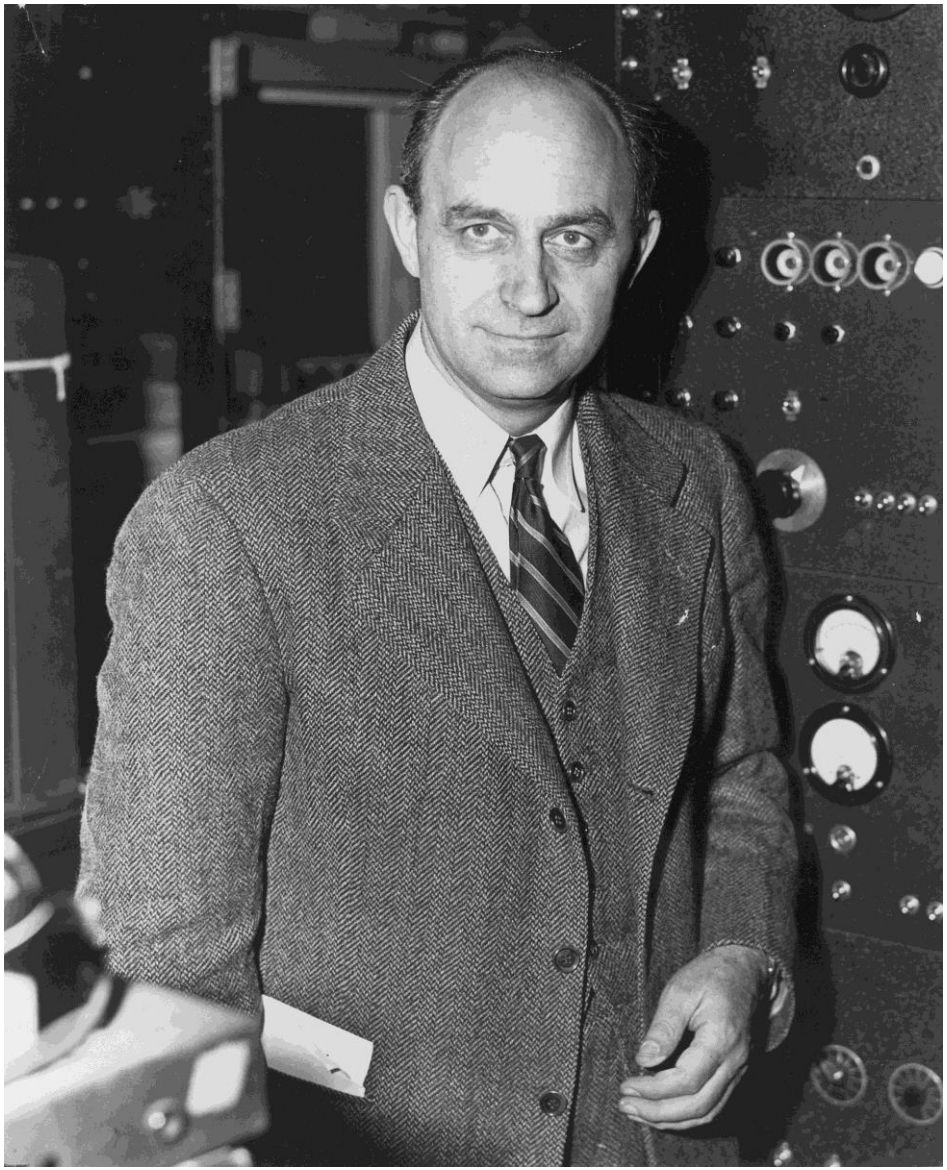
graphite – C ($_6C^{12}$ - *carboneum*),

light water – H_2O ($_1H^1$ - *hydrogenium*, $_8O^{16}$).

Material composition of the **thermal** reactor (**thermal** neutron reactor):

- fuel (uranium metal, uranium oxide and uranium carbide…)
- moderator (H_2O, D_2O, C)
- coolant (H_2O, C_2O, *He, liquid metal coolant, etc.*)
- reflector (typically moderator material)
- material of the control and protection system (CPS)

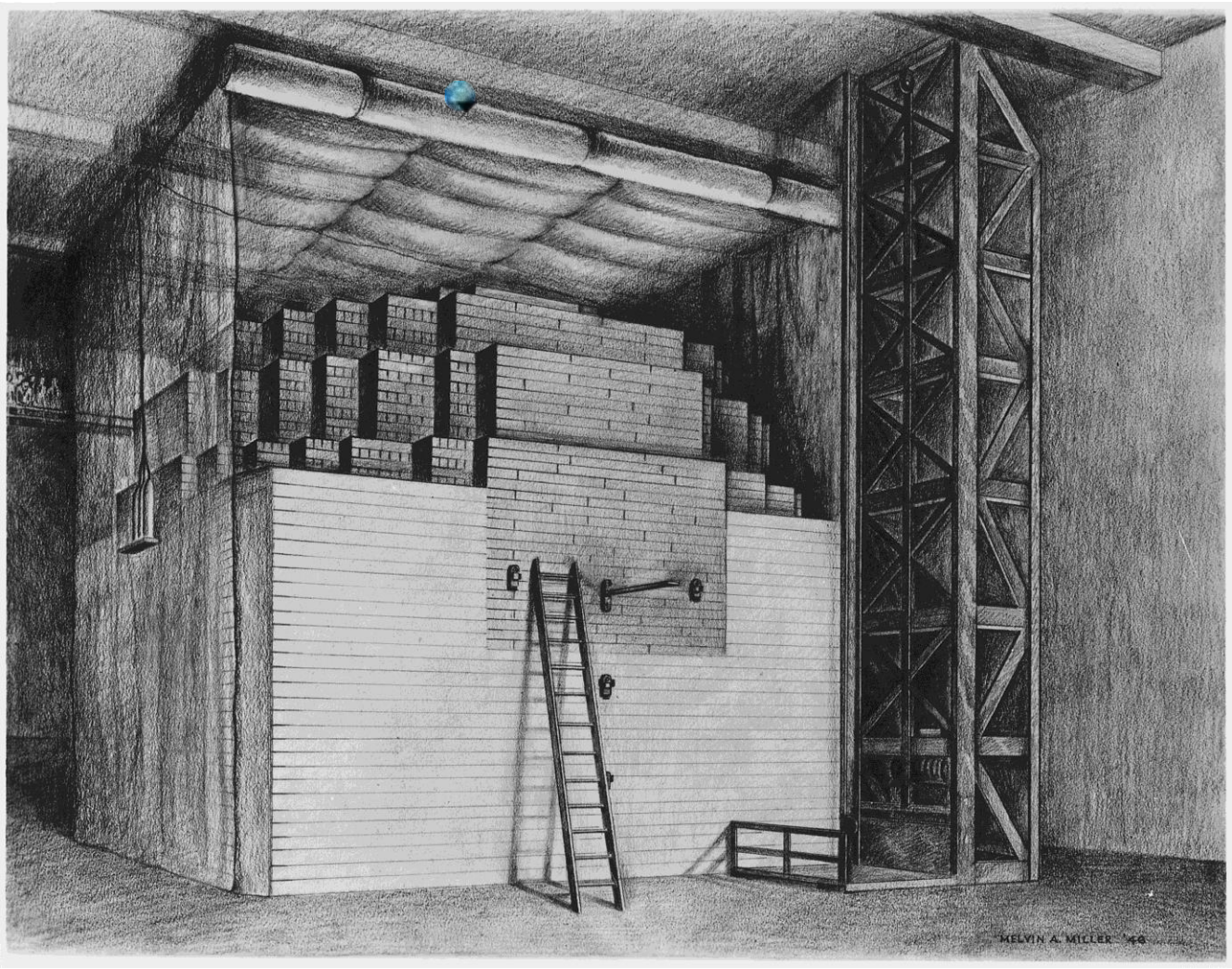
The world's first nuclear reactor



Enrico Fermi

(ital. *Enrico Fermi*; 29 September, 1901, Rome — 28 November, 1954, Chicago)

Chicago Pile-1, CP-1



Type of the reactor	graphite -air
Purpose of the reactor	experimental
Technical Specifications	
Fuel	natural uranium
Thermal power	200 W
Development	
Design	1942
Scientific aspect	Chicago University
Designer	Metallurgical Laboratory, Chicago University
Designer	Enrico Fermi
Project novelty	The first nuclear reactor
Construction and operation	
Construction of the first sample	1942
Location	Chicago University
Start	2 December, 1942
Operation	1942

The first nuclear reactor in Russia

In the *USSR*, the first Soviet reactor F-1 was built in Laboratory No. 2, AS USSR (Moscow).

This reactor reached the critical state on 25 December 1946.

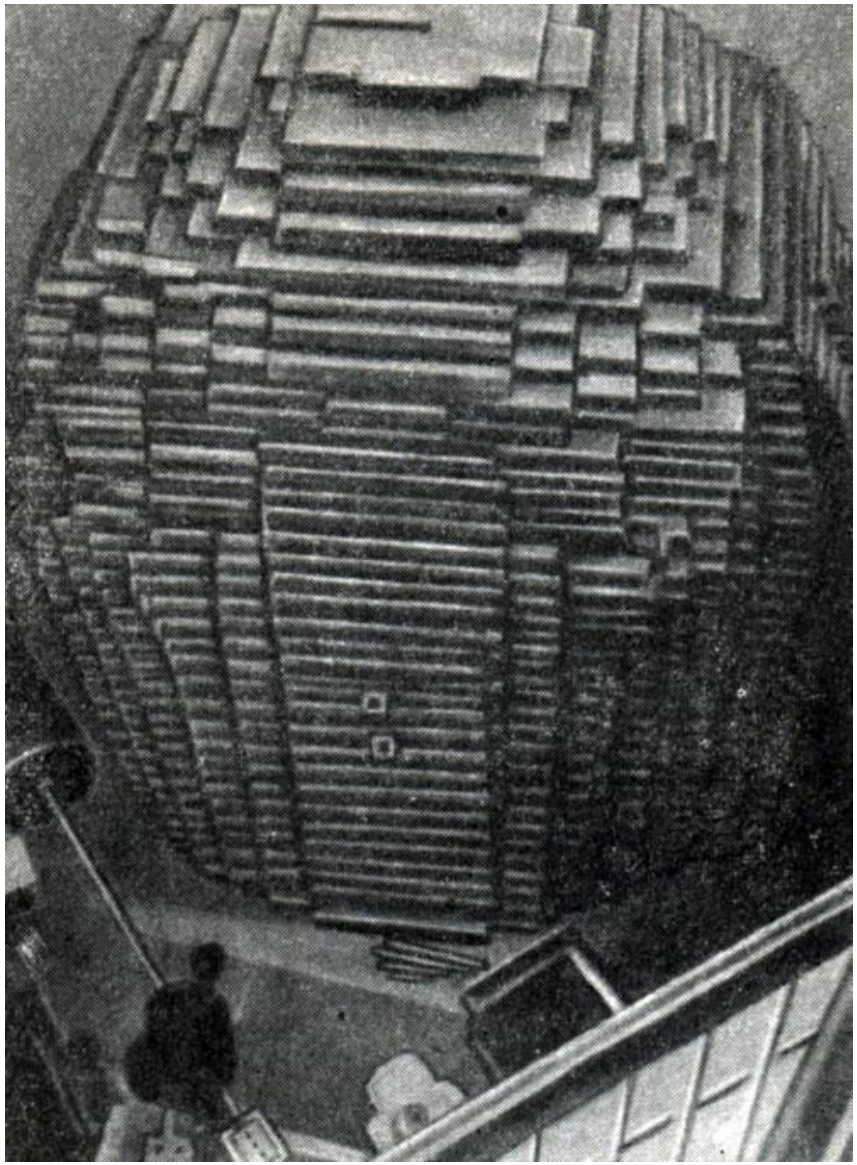
Reactor F-1 was assembled from graphite blocks. It was of spherical shape with a diameter of about 7.5 m. Fuel rods are placed in the holes of the graphite blocks in the central part of the ball 6 m in diameter.

Reactor F-1 as well as the reactor CP-1 did not have a cooling system, therefore it worked at very low power levels (watt fractions, rarely units of watt).

The first nuclear reactor in Russia (USSR)

In Russia, the first reactor was created under the leadership of **Igor Vasilevich Kurchatov**

Igor Kurchatov(30 December 1902 / 12 January1903, Simsk Plant, Ufa province — 7 February 1960, Moscow) — Russian Soviet physicist, the "father" of the Soviet atomic bomb. The founder and first director of the Institute of Atomic Energy from 1943 to 1960, chief supervisor of the nuclear problem in the USSR, one of the founders of the “peaceful atom”. Academician of the AS USSR (1943).



The core of the first Soviet reactor

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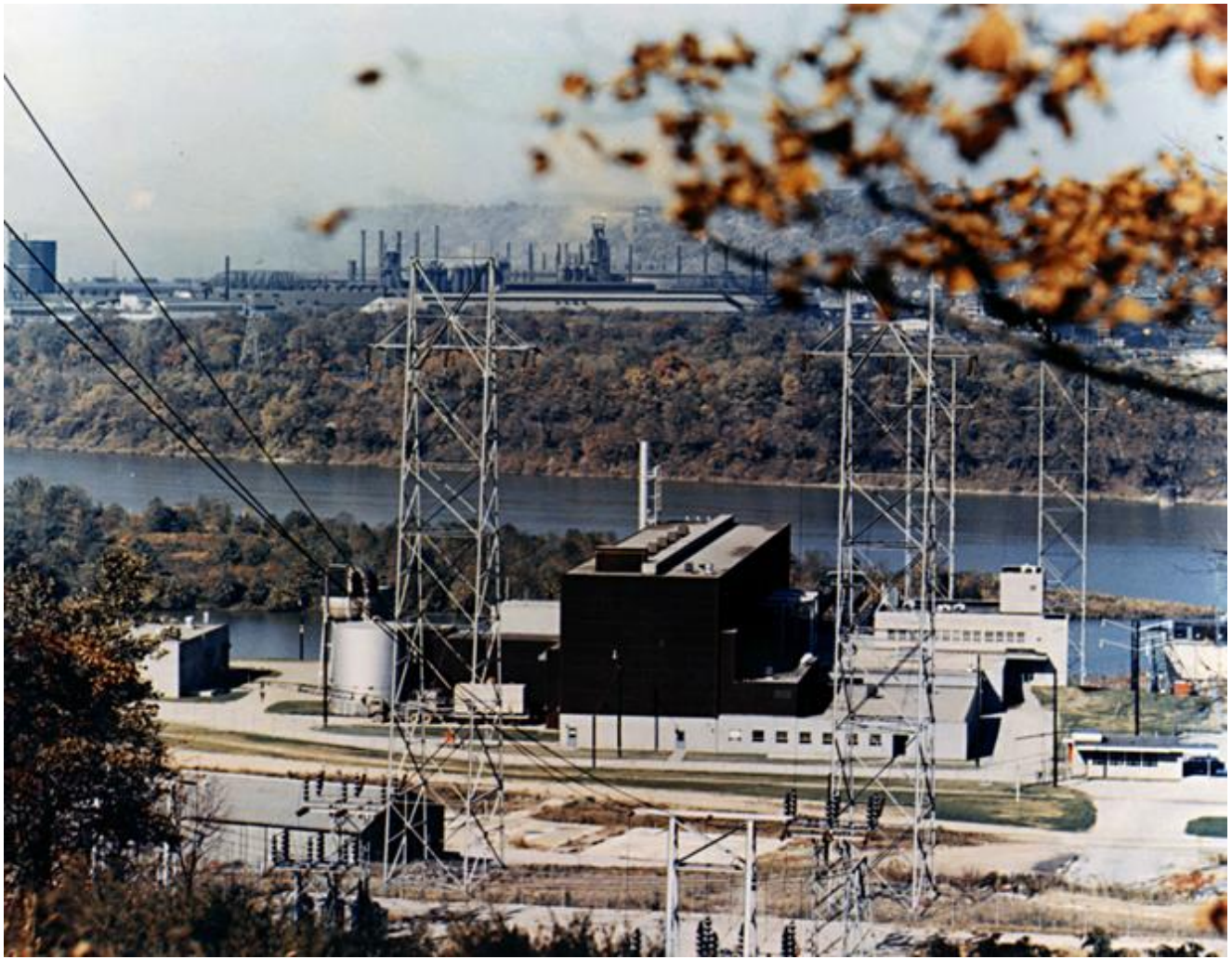
The first world's NPP

On June 27, 1954, in Obninsk near Moscow, the energy was generated by the first world's nuclear power plant .

Nuclear power plant with AM-1 reactor (peaceful atom) with **power of 5 MW** generated industrial electricity and paved the way for the use of nuclear energy for peaceful purposes. It successfully worked for almost 48 years. On April 29, 2002, the first nuclear power reactor was **shut down**.

The first US NPP

Shippingport NPP – the first nuclear power plant in the US and America – is located in Pennsylvania. Construction of the first **US NPP** was started on September 6, 1954 a few months after the start of the first world's nuclear power plant, **Obninsk NPP, USSR**. On May 26, 1958, Shippingport NPP was put into operation.



68 *MW* power

After 25 years it was decommissioned.
In 1985, it **was dismantled**.

The first UK NPP

Sellafield Nuclear Power Plant (Calder Hall) is located on the coast of the Irish Sea, near the town of Seafield in Cumbria, UK. Sellafield NPP operated from 1956 to 2003.

Calder Hall NPP is famous for the fact that the first nuclear power plant in a capitalist country (the world's first nuclear power plant was built in **Obninsk**), although the construction of the station was started in 1947. However, the official opening of the plant took place only on **October 17, 1956** (**the power of the first unit was 46 *MW***).

Calder Hall NPP included four reactors with a total **power of 240 *MW***.
Calder Hall NPP produced weapon-grade plutonium until 1995.

On September 30, 2007, NPP **dismantling** was started.

Types of thermal neutron nuclear reactors

Different combinations of fuel, moderator and coolant made the basis for different types of reactors:

1. Moderator is heavy water, fuel is natural uranium…….**CANDU** (CANada Deuterium Uranium) reactors. Channel-type reactor.

2. Moderator is graphite, fuel is natural uranium…….**Magnox (**Magnox reactor is a gas-cooled graphite-moderated reactor, in which carbon dioxide is the coolant, and natural uranium is fuel. Fuel cladding is magnesium alloy**)** reactors. Channel-type reactor.

3. Moderator is light water, fuel is uranium enriched …….**WWER**/**PWR** and **BWR** reactors. Reactors with a large amount of heat supply to the coolant.

4. Moderator is graphite, fuel is enriched uranium…….**RBMK** reactors. Channel-type reactor.

Schematic diagrams of NPP cycle arrangement

a) Direct steam NPP cycle

In Russia (USSR), the reactors based on ***RBMK, High-Power Channel-Type Reactor (boiling)***.

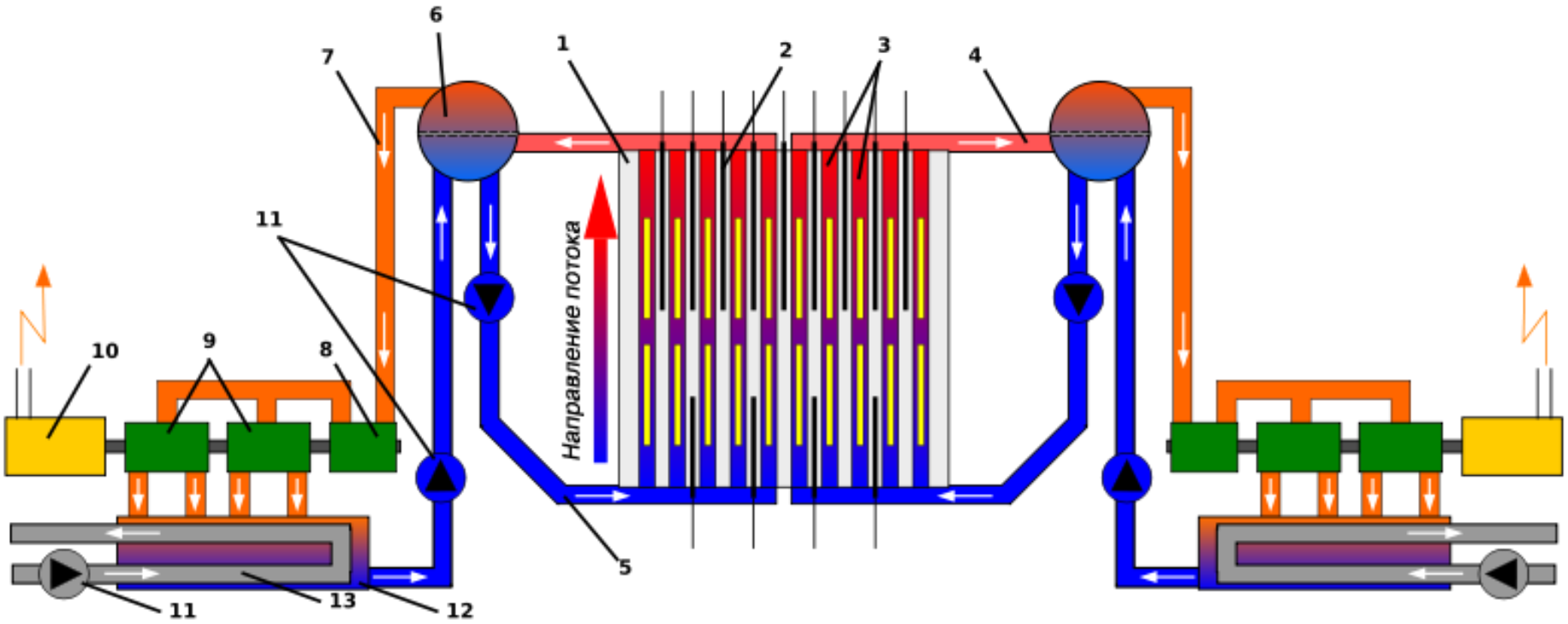
in the USSR, **17** power units were built using RBMK reactors (15 units with RBMK-1000 and 2 power units with RBMK-1500).

11 power units in Russia (Leningrad NPP-1, Kursk NPP, Smolensk NPP)
4 power units in Ukraine ~~(Chernobyl NPP)~~
2 power units in Lithuania ~~(Ignalina NPP)~~

Reactors based on ***BWR, Boiling Water Reactor*** built in other countries:

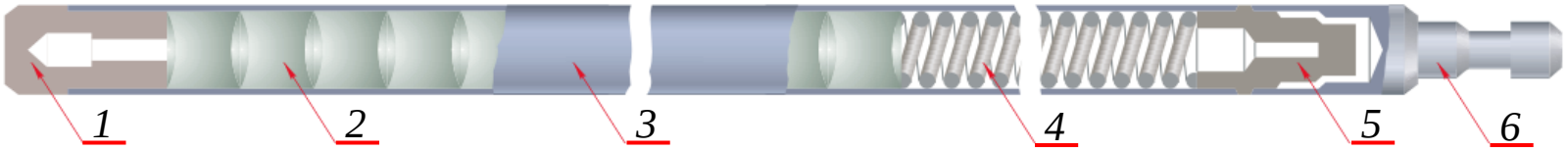
29 power units in the USA
35 power units in other countries (mostly American-made).

Process flow diagram for NPP with RBMK reactor



1 – graphite moderator
2 – control rods
3 – fuel channels
4 – steam
5 – water
6 – steam drum барабан-сепаратор
7 – dry steam
8 – high pressure turbine
9 – low pressure turbine
10 – generator
11 – circulating pumps
12 – condenser
13 – condenser coolant flow circuit

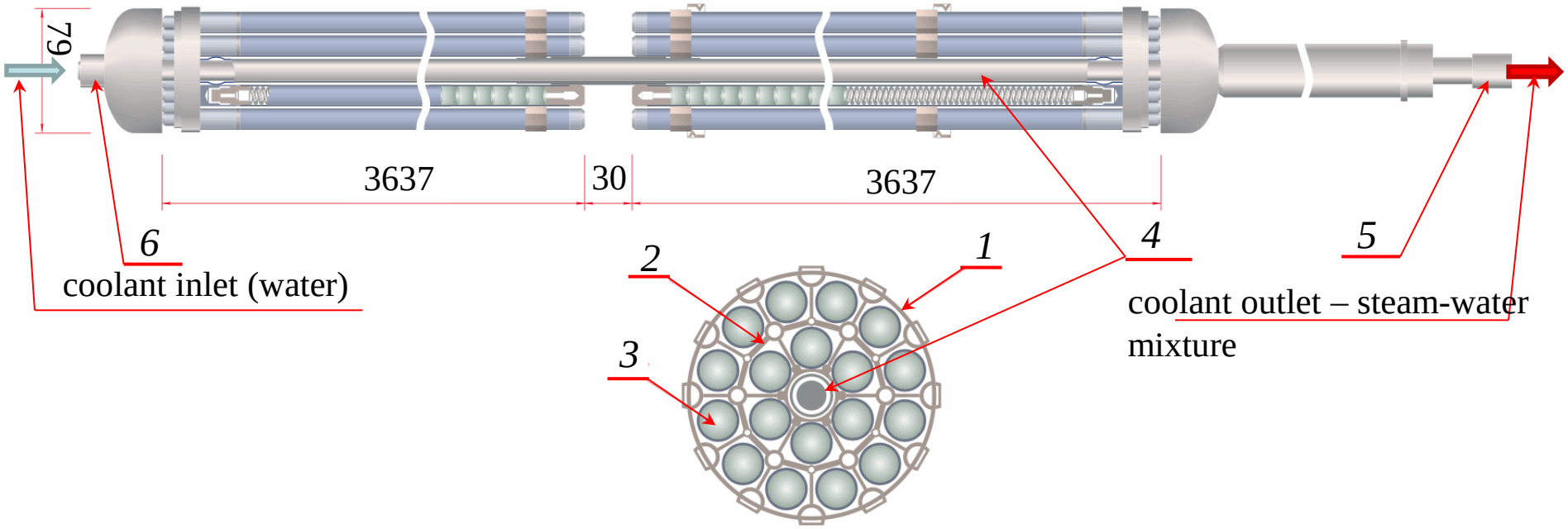
Fuel element (FE) and fuel assembly (FA) of RBMK reactor



FE: 1 is plug, 2 is fuel pellet, 3 is cladding, 4 is spring, 5 is sleeve, 6 is tip

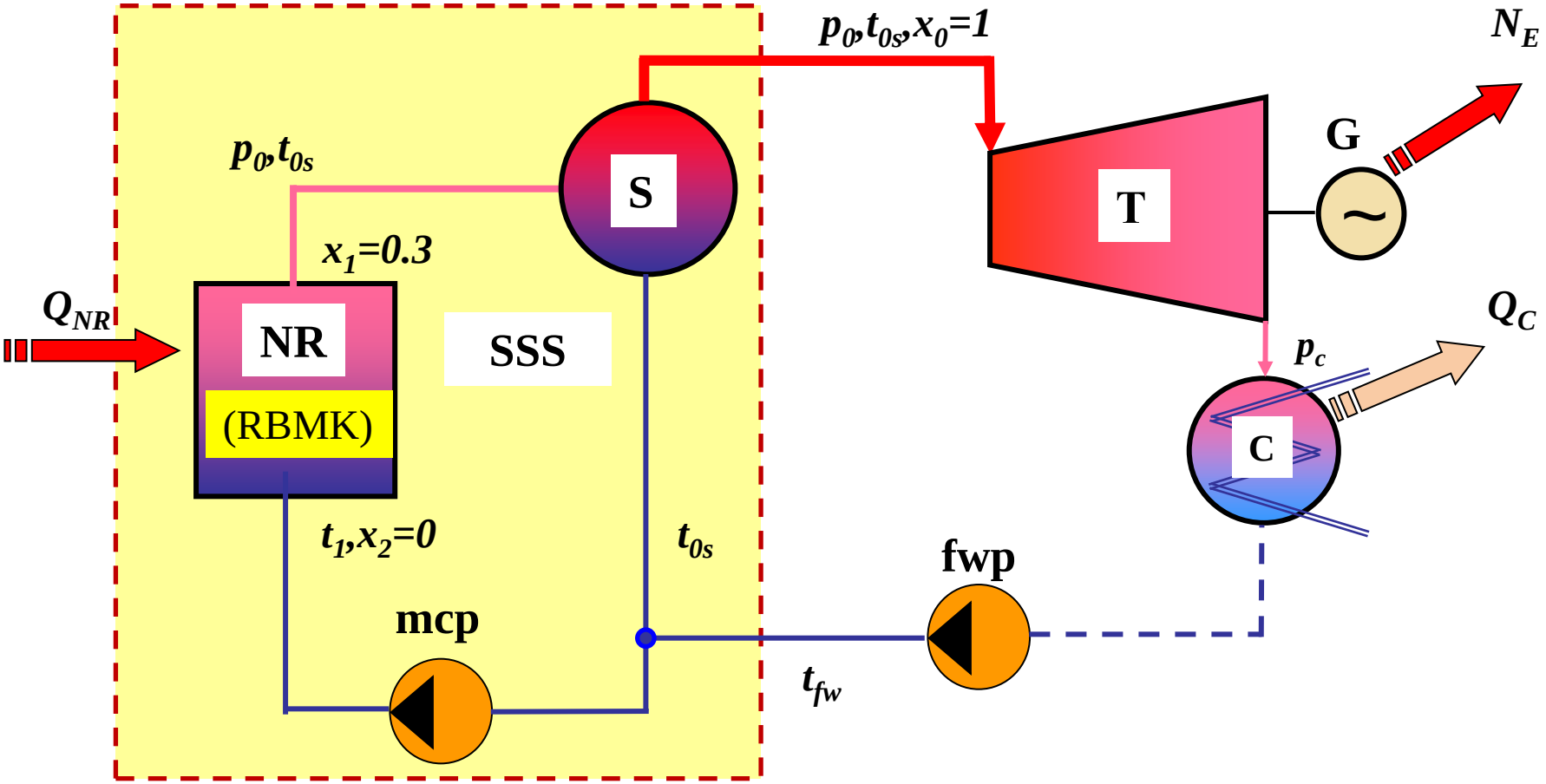
UO_2 fuel with $_{92}U^{235}$ enrichment according to 2.3÷2.6%. Fuel mass is 3.6 *kg*.

Cladding made of zirconium alloy is 13.6 *mm* in diameter, wall thickness is 0.9 *mm*.



FA: 1 is FA cladding; 2 is spacer; 3 is a fuel element; 4 is a hollow bearing rod; 5, 6 are top and bottom tips

Schematic diagram of NPP cycle arrangement with RBMK reactor



$$p_0 \approx 6,5 МПа$$