VVER-440/213 - The reactor core

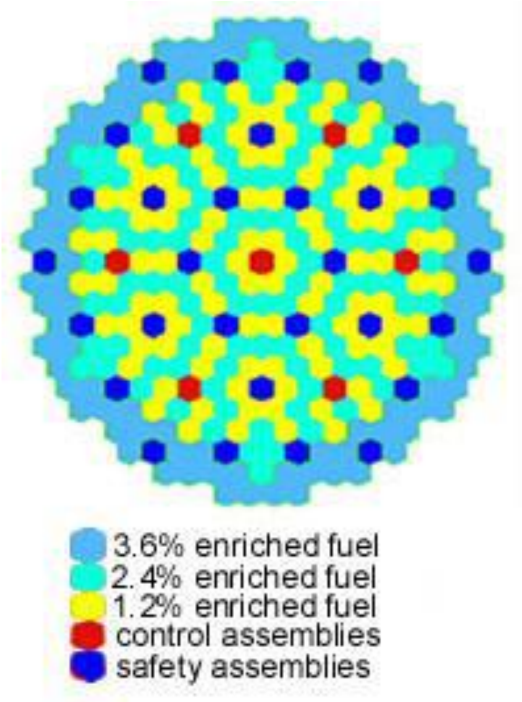
The fuel of the reactor is uranium dioxide (UO2), which is compacted to cylindrical pellets of about 9 mm height and 7.6 mm diameter. In the centreline of the pellets there is an inner cylindrical hole of 1.6 mm. On the one hand, this is useful because the fission product gases emitted from the fuel can fill a sufficiently large volume (and thus the pressure will not be too high in the fuel), and, on the other, the maximum temperature that occurs in the fuel will be lower.

The uranium pellets are inserted into a 2.5 m long and 9 mm diameter tube (cladding) made of a zirconium alloy, which is sealed hermetically. The cladding prevents fission products and other radioactive material from getting into the cooling water.
The fuel pellets along with the cladding constitute the fuel rod. There is a thick gap between the pellets and cladding in order that sufficient space be available for the pellets' heat expansion at the high operational temperatures.

Since it would be practically impossible to change and move about 40 thousand fuel rods, the rods are bundled into assemblies. The cross section of the WWER-440 fuel assemblies is a hexagon and each contains 126 fuel rods. (Most PWRs have rectangular shaped assemblies.) The fuel enrichment can be 1.6 %, 2.4 % or 3.6 %, but normally all the rods in an assembly are of the same enrichment. The distance of the centrelines of the assemblies is 14.4 cm. Altogether 349 assemblies can be inserted into the reactor core and 312 out of these are fuel assemblies.

Model of a fuel assembly in the Visitors Center

In order to control the chain reaction going on in a WWER-440 type reactor, absorber rods made of borated steel are applied, whose sizes are equivalent to that of the fuel assemblies. The control rods are inserted into the reactor from the top. There are altogether 37 such control rods, out of which 30 are always pulled out, i.e. out of core during operation. These are the so-called safety rods, with the aid of which the reactor can be stopped safely at any time. The remaining seven absorbers are used to control power during operation. To the bottom of each control rod a fuel assembly is joined and so fuel can be found in place of the pulled out absorbers.



The reactor core is made up of 312 fuel assemblies, 37 control rods and the coolant, which is light water and also serves as moderator. A map of the core prior to commissioning of the reactor is shown in the figure: each hexagon corresponds to a fuel assembly. Operation of the NPP is stopped a year after its start for refuelling: the burnt-out, originally 1.6% enriched assemblies are removed and the originally 2.4% enriched assemblies are put in their places. The originally 3.6% enriched assemblies are put into the place of the 2.4% ones and their places are filled with fresh (3.6% enriched) fuel assemblies. Later on, the power plant is stopped for a period annually (this is called a refuelling outage) and the mostly burnt-out fuel is removed. The other assemblies are moved according to the above description, while fresh fuel is put into the outer places. So with the exception of the initial loading each assembly spends three years in the reactor. The new type load with 3.84 % and 4,2 % enriched fuel can spend even four or five years in the reactor.

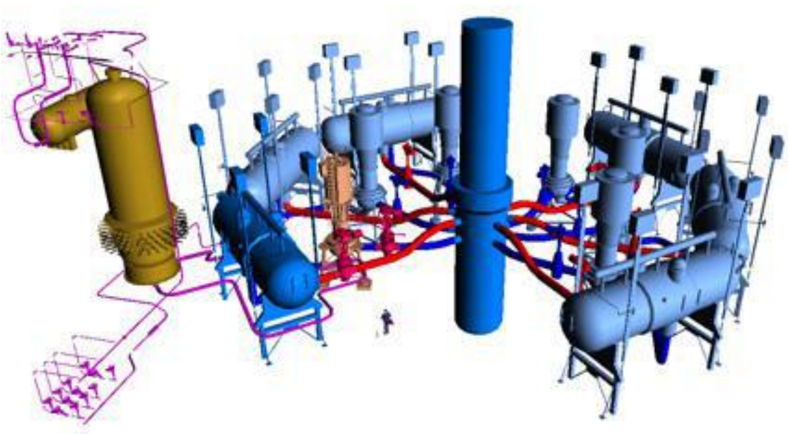
WWER-440/213 - The primary circuit

The reactor core is located in the vertically placed cylindrical reactor pressure vessel, whose total height is 13.75 m and outer diameter is 3.84 m. The vessel is made of steel, its thickness at the height of the reactor core is 14 cm and there is an inner 9 mm thick stainless steel plating (clad lining) as corrosion prevention. The six inlet and six outlet pipe connections are located at different heights on the vessel.

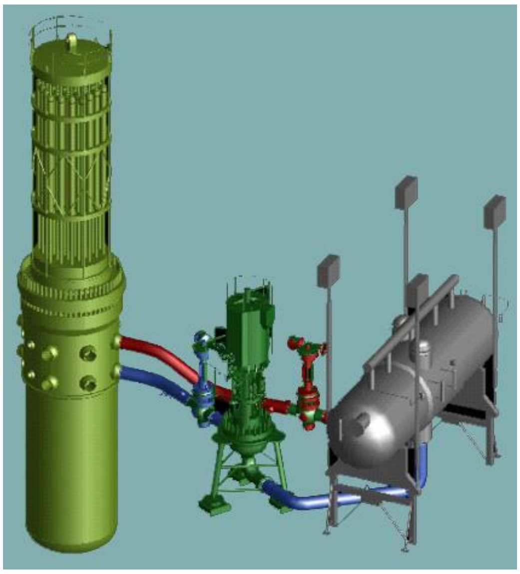
The lifetime of a reactor is determined by the lifetime of the pressure vessel, since this vast component cannot be replaced (actually, it could be replaced, but the cost would be so high that instead of replacing it, the whole reactor is shut down). The crystalline structure of the vessel material is continuously damaged by the constant neutron radiation. Therefore, the maximum designed lifetime of a nuclear power plant can be 30 to 40 years. It can be extended using safety-related and technical measures, and it is an international effort in the nuclear sector.

In order to extend this lifetime, recently the following method has been adopted at the Paks NPP: burnt-out, so-called fourth-year assemblies are inserted to the boundary locations of the core. Since the amount of U-235 is very low in such assemblies, far less neutrons will leave them and thus the vessel is exposed to less intense neutron radiation. Correspondingly, in this so-called low leakage core the fuel assemblies spend four years. It should be noted here that the adverse changes in the structure of the material - the embrittlement - can be reversed if the vessel is heated to a certain high temperature. In this way the dislocations, i.e. errors of the crystalline lattice are "recovered" and the material will be similar to that of a new vessel. Such a method has been applied to several reactors in the world, extending their lifetime.

Transport of the heat generated in the reactor core is performed by the six cooling loops, which surround the reactor. The spatial configuration can be seen in the figure. (To illustrate the sizes, a scaled drawing of a man is shown in the centre.) The difference between the cooling loops is only that the so-called pressurizer, which helps ensure constant pressure, is connected to one of them (the pressurizer is described later).



Let us examine the structure of a cooling loop in detail!



Water warmed up to 297 oC (nominal value) discharges from the reactor on the so-called hot leg (red pipe) and gets to the steam generator. The steam generator is an enormous (3.2 m diameter, 12 m length) lying cylinder-shaped heat exchanger, in which part of the heat of primary circuit water is transferred to the secondary water, while the primary water cools down to 267 oC. In the steam generator the radioactive primary circuit water flows through 5,536 heating pipes, each of 16 mm diameter, thus boiling the secondary side inactive water.

The cooled down coolant returns to the reactor on the cold leg (blue pipe). Water in the primary side is circulated by the main circulating (coolant) pump (dark green). Each coolant loop can be separately shut using the so-called main isolating valve. There are two isolating valves in each loop (red, blue).

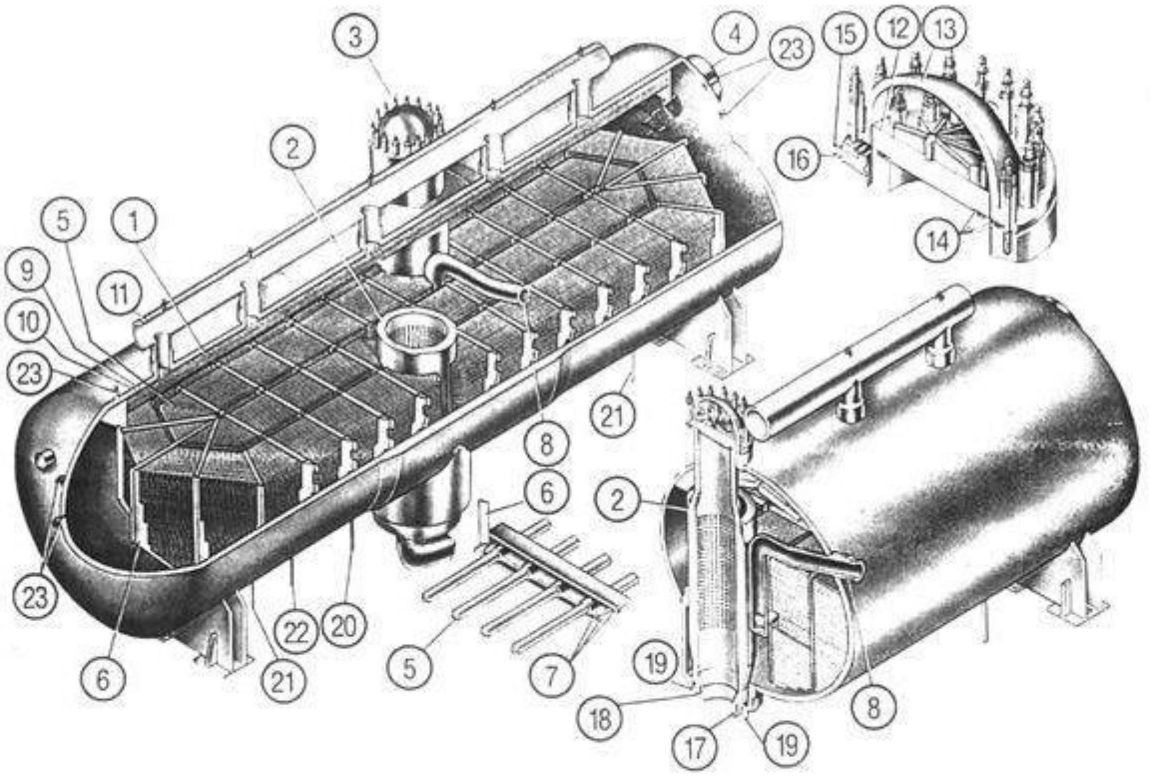
The WWER is a pressurized water reactor, which means that in the primary circuit high pressure ensures that the coolant does not boil. (The boiling point of water is 100 oC at atmospheric pressure, i.e. 1 bar, while at the nominal primary pressure, 123 bars, the boiling point is about 325 oC.) It is the pressurizer's (or expansion tank's) task to keep the pressure at a constant value. Each unit has one pressurizer, which is connected to the hot leg of a loop. The pressurizer is a vertical tank, the bottom of which is connected to the hot leg and the top - through valves - to the cold leg. Inside the tank there is boiling water at a temperature of 325 oC and steam above.

If the primary pressure starts to rise, after reaching a certain value injection valves open that bring water from the cold leg to the pressurizer. Due to the "colder" (267 oC) water, steam will condense and thus the pressure will drop. If the pressure increases further in spite of this, the so-called safety flush-out (or pressure release) valves open, through which part of the steam can get to a tank. (Too high pressure would jeopardize the components.)

If the primary pressure decreases, water might start to boil. In order to prevent this, electric heaters switch on automatically in the pressurizer. Due to the heating there will be intense boiling, more steam will be generated and this leads to a pressure increase.

WWER-440/213 - The secondary circuit

The conversion of the heat released from the reactor to kinetic and then electric energy is done in the secondary circuit. The primary water, which circulates in small tubes at a temperature of 300 oC boils the feed-water that enters the steam generator at 70 bars and 223 oC. The moisture content of the generated steam of 260 oC must be decreased, otherwise the turbine blades would be damaged. This purpose is served by moisture separator shutters put into the way of steam. When steam passes through these plates, water drops deposit and thus the moisture content of the outgoing steam will only be 0.25 %.



Structure of the steam generators in WWER-440 units

1 - steam generator body, 2 - primary cold leg collector, 3 - primary hot leg collector, 4 - manhole, 5 - heat exchanger tubes, 6 - vertical distance grid, 7- horizontal distance grid, 8 – feedwater pipeline, 9 - separator, 10 - perforated sheet, 11 - steam header, 12 - primary circuit header cover, 13 - secondary circuit header cover, 14 cover seals for the primary and secondary circuit, 15 - secondary circuit seal cover monitoring location, 16 secondary circuit air vent, 17 - primary circuit seal cover monitoring location, 18 - primary circui air vent,
19 - header periodic blowdown, 20 - steam generator periodic blowdown, 21 - steam generator permanent blowdown, 22 - nozzle, 23 - pipe unions for steam generator level checking.

The steam leaves the steam generator at a mass flow rate of 490 t/h and heads towards the turbine, where, by bumping into the blades, it rotates the turbine. Out of the six steam generators three feed a turbine in a given unit (there are two turbines for each unit). In the turbogenerator, one shaft connects the high pressure case, the low pressure case and the generator rotor. The high pressure case has six stages, that is the expansion and work of steam is done in six steps. The temperature of the steam leaving the high pressure cylinder will go down to approximately 140 oC and its moisture content will rise to 12 %. Therefore, before it enters the low pressure case, it must go through the so-called moisture separator reheater, which removes the harmful drops and raises the temperature above the saturation value. The two low pressure cases both have five stages.

The steam that has already done its work goes to the condenser, where in almost 11,000 tubes cooling water taken from the Danube flows. The steam condenses at about 25 oC on the cooling tubes. Two condensers belong to each low pressure turbine. The pressure (vacuum) is kept at 0.035 bar in the condensers (steam is driven through the turbine by the pressure difference between the steam generator and condenser).

The condensed coolant is brought back to the steam generator by feedwater pumps after it gets through cleaner and preheater equipment. Preheating is mainly necessary because in this way higher overall plant efficiency can be achieved. Preheating is done using steam from the turbines. The final temperature of the feedwater is 224-225 oC before entering to steam generators.