5. MAIN CIRCULATION CIRCUIT

This Section describes the characteristics of the Main Circulation Circuit (MCC) and the associated thermal-hydraulic systems. This includes the steam pipes delivering steam to the turbine, the feedwater system, the control rod cooling system and the associated water purification systems.

A simplified overview of one of the coolant loops is provided in Fig. 5.1, volumetric data for the various components is listed in Table 5.1. Starting at the inlet to the core (11) the coolant is forced upwards through the reactor core block in a large number of individual fuel channels. Flowing through the core it acquires about 95% of the energy emitted by the fuel elements. The coolant reaches saturation temperatures in the lower part of the channel, starts boiling and exits as a from 23 to 29.1% quality steam-water mixture (mass-fraction).

The MCC consists of two loops, whose components are arranged symmetrically with respect to the vertical axis of the reactor. Each loop has two separator drums (1), which separate the steam from the steam-water mixture exiting from the core block. The separator drums are horizontal cylindrical steel vessels 2.6 m inside diameter and 33.76 m long with elliptical ends. Wall thickness of the shell is 115 mm. The drums are interconnected both at the lower, liquid filled, and the upper, steam filled elevations. In the water-filled zone the drums in the original design were connected by six pipes, each with a 325 mm outside diameter and a wall thickness of 16 mm (325 x 16) mm and in the steam zone the drums are joined by five (325 x 19) mm pipes. In the bottom section of each separator drum, a feedwater header is mounted, which through special mixers provides feedwater to the downcomer pipes. The separated water mixed with the returning feedwater, reaches the suction header (3) through 24 downcomer pipes on each loop (2). From the suction header it flows through four pipes (4) to the four Main Circulation Pump (MCP). During normal reactor operation, only three pumps are operating in each loop, the fourth pump is a reserve. The MCPs are of a vertical, centrifugal, single-stage configuration. The MCP assembly consists of a tank, a removable pump section, and an electric motor. The steel pump tank (5) is covered on the inside with an anti-corrosive mixture. The nominal capacity of the pump is 2.22 m^3/s at a head of 1.962 MPa, speed - 1000 rpm, electric motor power - 5600 kW.

From the MCP, water flows through pressure header pipes (6) to the pressure header (8). The suction and pressure headers are connected by six bypass lines (7), each of which is provided with a gate and a check valve. The bypass (7) ensures that natural circulation of the coolant takes place in case the main circulation pumps are shut-off.

From the pressure header (8), water continues through twenty pipes to twenty group distribution headers (9). The outside diameter of a group distribution header is 325 mm, wall thickness is 15 mm, and the length is ~6 m. Mechanical filters are provided inside the pressure header, while, at the upstream end of the group distribution header, there is a flow limiter, a check valve, and a mixer for water from the reactor emergency core cooling system.

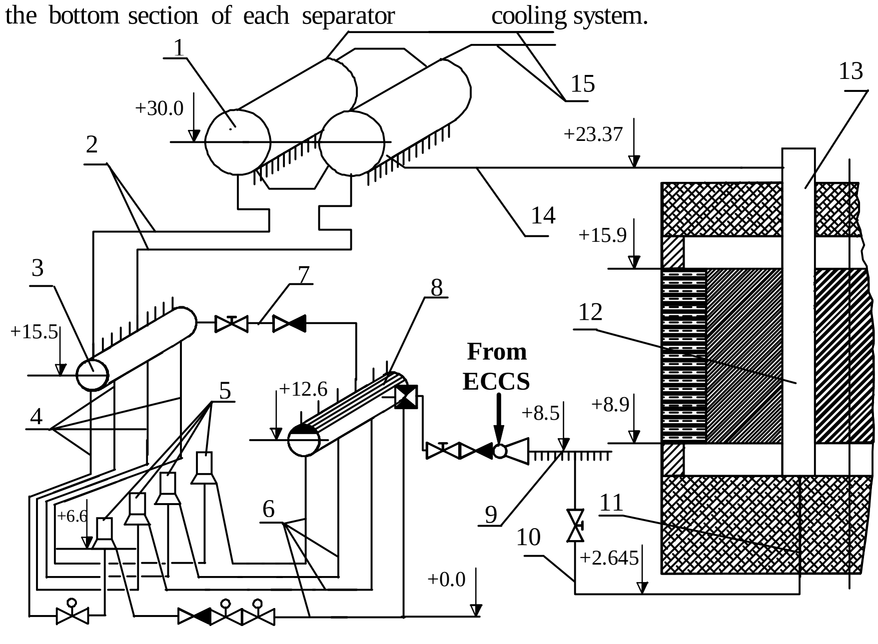


Fig. 5.1 Schematic representation of one loop of the main forced circulation circuit
1 - separator drum, 2 - downcomers, 3 - suction header, 4 - suction piping of the MCP, 5 - MCP, 6 - pressure piping of the MCP, 7 - bypass between headers, 8 - pressure header, 9 - group distribution header with flow limiter, check valve and mixer, 10 - bottom water piping, 11 - fuel channel before the core, 12 - fuel channel within the core, 13 - fuel channel above the core, 14 - steam-water pipes, 15 - steam pipelines

Each group distribution header is connected to 40-43 bottom water pipes (10) leading to fuel channels. The flow in each pipe, and therefore in each fuel channel (12), is set by isolation and control valves and is measured by a ball flow-meter. The steam-water mixture generated in the fuel channel flows through the steam-water pipes (14) to the separator drums (1).

The elevations for the most important components of the MCC are presented schematically in Fig. 5.2. The Figure shows that the total, top-to-bottom elevation of the primary system is over 30 m. The elevation driving the natural circulation loop, that is from the bottom of the core to the bottom of the separator drums is ~21m. These large elevation heads determine the flow parameters of the system under natural circulation conditions.

From the separator drums the generated steam is directed to the turbines. Discharge steam from the turbines is accumulated in condensers, from there the condensate flows down through filters, heaters and deaerators to the main feed water pump and is finally returned to the separator drums. This condensate retrieval system is known as the water feedback system.

The purification and cooling of the water is performed by the Purification and Cooling System (PCS) which is an equivalent of Chemical and Volume Control System (CVCS) in Western LWRs. Part of the water is taken from the MCC, cooled down and filtered by a mechanical filter and an ion-exchanger in the purification bypass. The treated water then joins the feedwater flow.

The reactor also contains a number of channels for control rods and metering devices. These are cooled by a separate circulation system, which is called the Control Rod Cooling Circuit (CRCC). More detailed information regarding the various components and systems which make up the MCC is provided in the subsequent sections of this chapter.

Table 5.1 Water and steam volumes of one loop of the MCC [39]

Component*	Outside diameter x wall thickness, mm	Number per loop	Volume, m^3		Total volume, m^3
			Water	Steam	
(1) Separator drum	2830 x 115	2	162.0	173.6	335.6
(2) Downcomers	325 x 16	24	61.5	-	61.5
(3) Suction header	1020 x 60	1	13.4	-	13.4
(4) MCP suction pipes	828 x 38	4	61.5	-	61.5
(5) MCP tanks	-	4	-	8.0	8.0
(6) MCP pressure pipes	828 x 38	4	72.9	-	72.9
(7) Bypass between headers	325 x 15	6	4.2	-	4.2
(8) Pressure header	1040 x 70	1	11.8	-	11.8
(9) Group distribution headers and inlet pipes	325 x 15	20	32.6	-	32.6
(10) Bottom water pipes -each fuel channel	57 x 3.5	1	0.0412	-	0.0412
-total for 830 channels	57 x 3.5	830	34.2	-	34.2
(11) Fuel channel, before the core -each fuel channel	-	1	0.0189	-	0.0189
-total for 830 channels	-	830	15.7	-	15.7
12) Fuel channel within the core -each fuel channel	-	1	0.0089	0.0070	0.0159
-total for 830 channels	-	830	7.5	5.8	13.3
(13) Fuel channel above the core -each fuel channel	-	1	0.0067	0.0371	0.0438
-total for 830 channels	-	830	5.6	30.7	36.3
(14) Steam-water pipes -each fuel channel	76 x 4	1	0.0152	0.0844	0.0996
-total for 830 channels	76 x 4	830	12.7	70.0	82.7
(15) Pipes from separator drums to turbine	-	-	-	404.7	404.7
Total volume of one circulation loop (830 channels)	-	-	503.6	684.8	1188.4
Total volume of primary circuit (1661 channels)	-	-	1007.3	985.4	1992.7

* Component numbers below correspond to the component numbers in Figs. 5.1 and 5.2

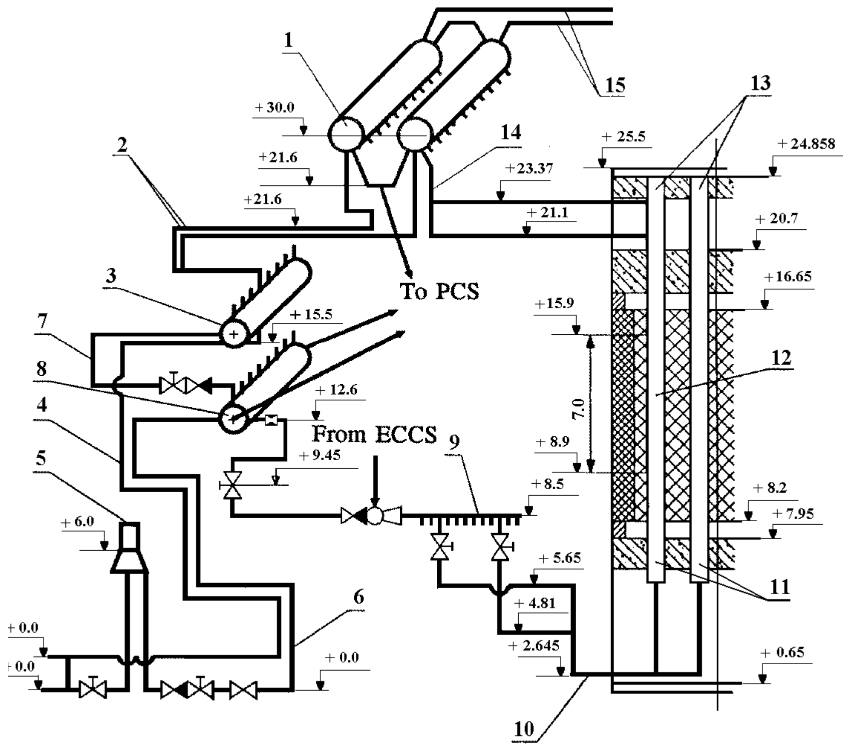


Fig. 5.2 Elevations of the MCC
1 - separator drum, 2 - downcomers, 3 - suction header, 4 - suction piping of the MCP, 5 - MCP, 6 - pressure piping of the MCP, 7 - bypass between headers, 8 - pressure header, 9 - group distribution header with flow limiter, check valve and mixer, 10 - bottom water piping, 11 - fuel channel before the core, 12 - fuel channel within the core, 13 - fuel channel above the core, 14 - steam-water pipes, 15 - steam pipelines (all dimensions in meters)

5.1 THE MCC THROUGH THE CORE

The MCC provides the following types of coolant flow for the proper operation of the core:

- forced-flow cooling under normal operating conditions as specified in Table 5.2 [2,35],
- cooling during transient operation and natural circulation in the event the MCP are shut off,
- emergency cooling in combination with the emergency core cooling system.

Table 5.2 Coolant operating conditions at 4200MW(th) power operation [2,35]

Discharge steam flow rate of the separator drum * , kg/s (t/h)	2055-2125 (7400-7650)
Feedwater flow rate *, kg/s (t/h)	2055-2125 (7400-7650)
Flow rate in the core *, m^3/s (m^3/h)	10.83-13.33 (39000-48000)
Saturated steam pressure in separator drums (absolute pressure), MPa (kgf/cm^2)	6.47-6.96 (66-71)
Fluid temperature entrance of the core, °C	260 - 266
Steam content in the steam-water mixture at core exit (mass fraction), %	(23.0 - 29.0)
Water content in the separated steam (mass fraction), %	about 0.1

* Data applies to a reactor

The coolant is supplied to the 1661 fuel channels from 40 group distribution headers. It exits the core as a steam-water mixture and is directed to four drums separators by means of individual steam-water pipes.

5.1.1 Group Distribution Header, Water Piping, Isolation and Control Valve

The coolant is supplied to the individual fuel channels via group distribution headers (Fig. 5.3), which are horizontal cylinders with 325 mm outside diameter and 15 mm thick walls. The Group Distribution Header (GDH) are securely fastened to support structures to prevent any sliding in case of failure. Each header distributes coolant to 40-43 bottom water pipes (57 x 3.5) mm. These pipes are provided with isolation and control valves between the GDH outlet and the entrance to the fuel channel. Isolation and control valves are used to adjust channel flow on the basis of channel power. Flow rates can be controlled by varying the flow-area of the valves. This is achieved by manual operation from a separate room in the vicinity of the reactor block. The operating life of the isolation and control valves is estimated as 50000 hours. Ball type flow rate meters are mounted downstream of the valves, their indications are transmitted to the Main Control Room (MCR). Construction of a isolation and control valve is represented in Fig. 5.4 and its operation parameters are presented in Fig. 5.5.

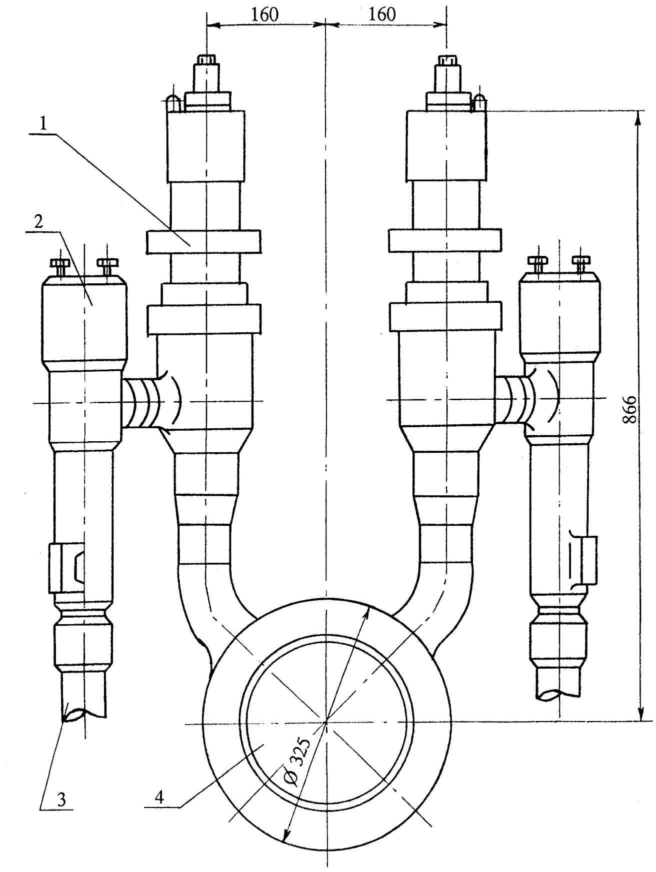


Fig. 5.3 Group distribution header
1 - isolation and control valve, 2 - ball type flow-rate meter, 3 - coolant water pipe leading to the fuel channel, 4 - group distribution header

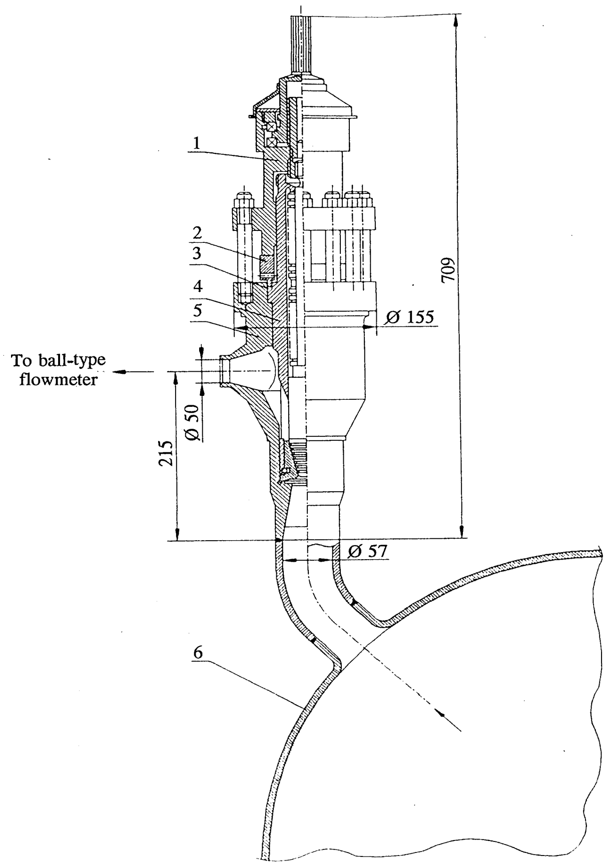
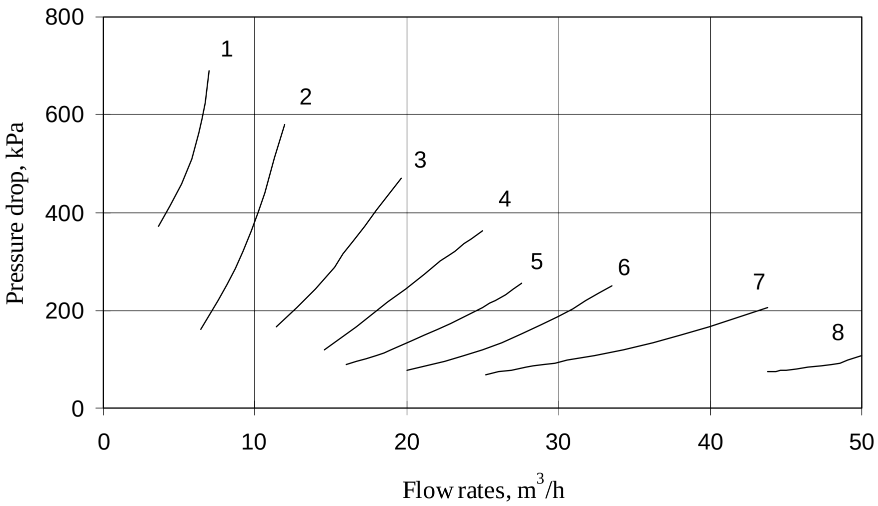


Fig. 5.4 Isolation and control valve
1 - upper housing, 2 - pressurized ring, 3 - copper seal, 4 - bushing, 5 - lower housing, 6 - group distribution header



Curve number	Valve steam position, mm	Flow cross-section area, mm^2
1	2	54
2	4	102
3	6	153
4	8	206
5	10	263
6	12	319
7	16	437
8	24	691

Fig. 5.5 Operation parameters of the isolation and control valve [94,95]

5.1.2 Fuel Channels: Operation Parameters

A detailed description of the mechanical characteristics of an individual fuel channel is provided in Subsection 4.2.4.2. The design thermal-hydraulic parameters of a channel are given in Table 5.3. The Table provides two sets of values, the first column represents the original design parameters [35], the second, best estimate values determined for the current (1997) operating conditions [89].

The axial distribution of thermal-hydraulic parameters along a fuel channel at the maximum power 4.5 MW [35] are shown in Fig. 5.6. Flow rates in the individual fuel channels are based on predictions of fluid and thermal dynamics of the core, and include the variations in local power generation rates. The gradual reduction of power because of nuclear fuel burn-up requires periodic re-adjustment of the flow rate in each channel. Standard adjustments are performed at 30% and 60% burn-up.

Table 5.3 Parameters of the fuel channels

Parameter	Design parameter [35]	Best estimate values [89]
Channel power, MW	4.5	2.53
Coolant flow rate, kg/s (t/h)	6.67 (24)	5.51 (19.8)
Maximum quality at channel exit, %	36.1	23
Coolant inlet temperature in the channel, ^{o}C	260	263
Steam-water temperature at channel exit, ^{o}C	288	283
Pressure drop in the channel, MPa	1.18	0.5

5.1.3 Steam-Water Piping

The steam-water flow from the top of the fuel channels is conducted by way of individual steam - water pipes (76x4) mm to the separator drums. The bottom water pipes leading into the reactor block and the exiting steam-water pipes include several bends, this aids in reducing gamma radiation streaming.

5.2 SEPARATION OF STEAM

Fuel channels heat the coolant water to boiling temperature and discharge a steam-water mixture. The steam quality (steam content in mass fraction) of the steam-water mixture at core exit varies from 23 to 29%. The mixture arrives via the steam-water mixture flow pipes at the separator drums, where the steam and water are separated. The steam (included a water content of up to 0.1% by mass) is directed to the turbines, and the liquid fraction flows by means of the downcomer pipes to the MCP suction headers.

5.2.1 Separator Drums

Separation of steam in the RBMK plant occurs in large horizontal separator drums which contain submerged perforated sheets and upper liquid de-entrainment structures. Industrial-scale tests performed on the RBMK-1000 design drum separator suggested that an increase in efficiency by a factor of 1.5 is possible with relatively minor modifications. These modifications were implemented at Ignalina NPP. The modifications resulted in an almost 3 m longer drum with hardly any change in the diameter. The effect was a cheaper construction, a saving of transportation and material cost and the extension of equipment life.

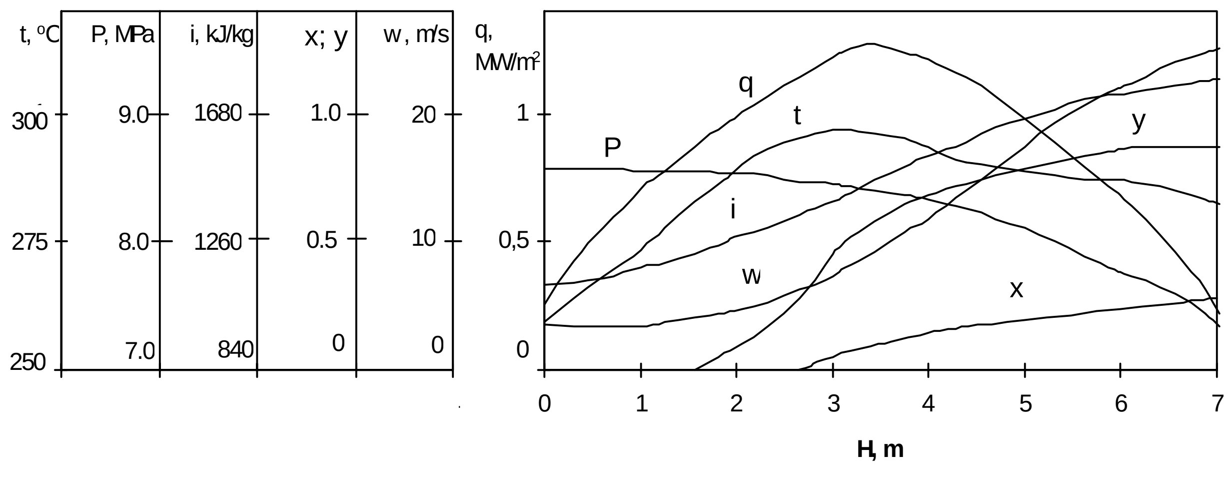


Fig. 5.6 Vertical variation of coolant parameters along the maximum designed power 4.5 MW fuel channel [35]
p - pressure, i - enthalpy, w - velocity, q - heat flux density, y - steam content in the steam-water mixture (volume fraction), t - temperature, x - steam quality

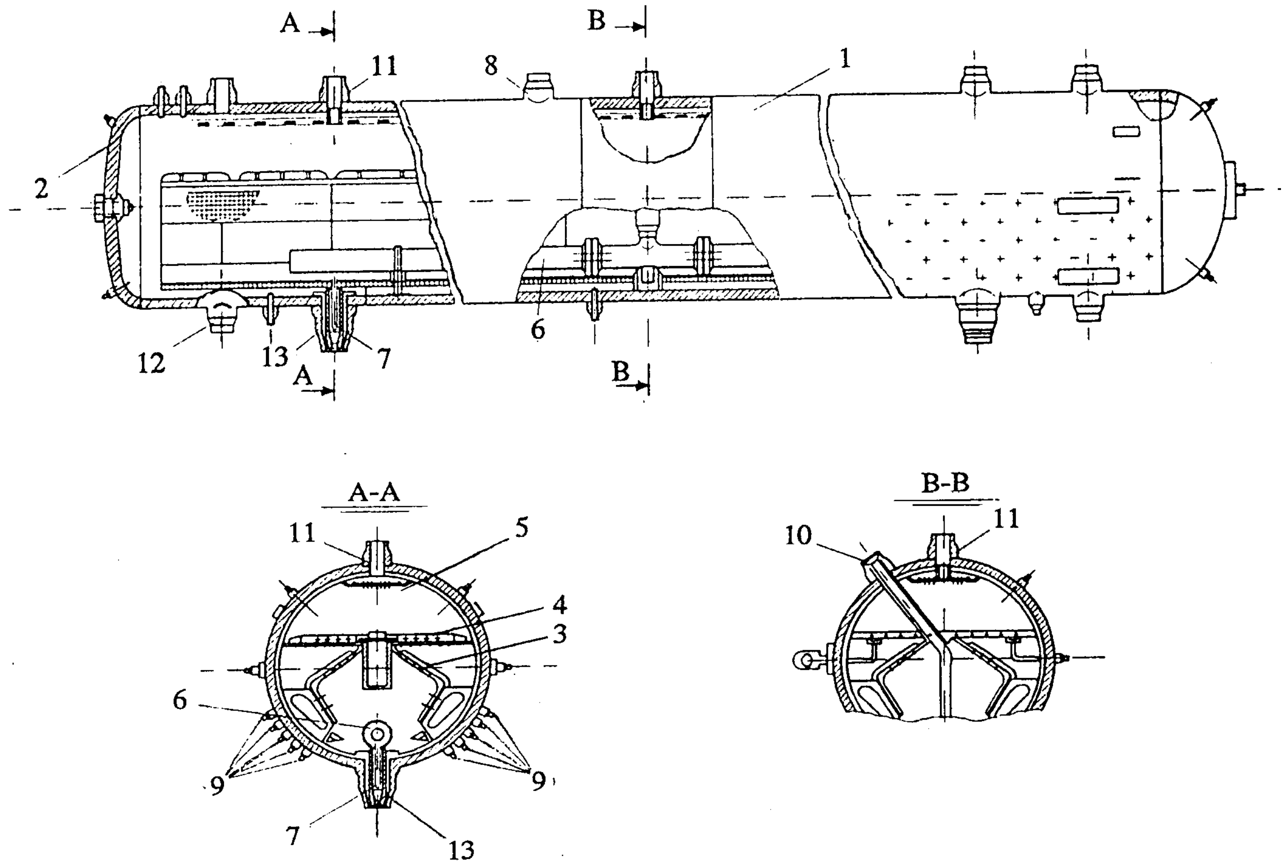


Fig. 5.7 Separator drum
1 - vessel, 2 - cover, 3 - impact plates for steam-water flow, 4 - submerged perforated sheet, 5 - top perforated shield, 6 - feed water distribution header, 7 - jet spray nozzle, 8 - nozzle of steam-pipe, 9 - nozzle of steam-water piping, 10 - nozzle of feed water, 11 - nozzle of connection in the steam zone, 12 - nozzle of connection in the water zone, 13 - nozzle of the downcomers

Each of the reactors at the Ignalina NPP is provided with four separator drums. They perform the following functions:

- separation of steam from the steam-water mixture flowing from the fuel channels,
- mixing of the separated water with feedwater,
- storing of coolant for the MCC.

Construction parameters of the separator drum are represented in Fig. 5.7. This is a horizontal 33.76 m long cylindrical vessel with a 2.6 m inside diameter. It rests on two supports which are located close to the ends, and a mid-level support which prevents longitudinal displacement.

The steam-water mixture arrives at the separator drum, through inlet pipes (9), and a part of the steam becomes separated in the distribution compartments because the flow looses its kinetic energy on impact of the special plates (3). This steam then penetrates the submerged perforated sheet (4) and the barbotage layer above it. Final separation occurs because of gravity force. The separated steam goes through the perforations of the upper shields (5) into the steam-flow piping, the separated liquid flows downward from pipes at the bottom (13). The feed water line has a nominal diameter of 500 mm (10). It enters the separator drum at a 45 degree angle, and extends to a distribution header in the lower part of the drum. The feed water pipe includes a peronite insulation chamber. From the header (6) the feed water is injected at (7) into the downcomer flow (13) to facilitate cooling of the water to be supplied to the MCP. As has been noted, both the steam and liquid containing regions of the two separator drum are connected by a number of pipes.

Thermocouples are installed in both the upper and the lower part of the separator drums. Additional thermocouples are placed in the feed water pipe. Samples of materials used in the piping are stored in a special receptables, so that the degree of corrosion can be checked. The design specifications of the separator drums are listed in Table 5.4 [39,40].

The non-uniform generation of power in fuel channels can lead to an in homogeneous steam-water distribution in the steam drum. This requires design features which serve to reduce both transverse and longitudinal variations of the steam content. This is accomplished by a submerged perforated sheet (4) with a 150 mm thick downward frame. A downflow passages is provided between the frame and the drum wall for that part of water, which penetrates the perforations together with steam. The downflow passages functions as a hydraulic lock against any penetration of steam at the sides of the perforated sheet. The sink is covered by safety plates spaced at 75 mm from the frame.

Table 5.4 Specifications* of the separator drum [39,40] (type - SP-2100)

Number per reactor	4
Steam generation, kg/s	513.9-531.2
Steam-water flow rate, m^3/s	2.71-3.33
Average steam content in the steam-water mixture (mass fraction), %	23-29
Operational pressure, MPa	6.47-6.96
Design pressure, MPa	7.5
Outlet water content in the steam flow (mass fraction), %	>0.1
Feedwater temperature, ^oC	177-190
Feedwater flowrate, kg/s	513.9-531.2
Operational level above the perforated sheet, mm	200 ± 50
Stored operational water volume for nominal steam generation and water level, m^3	63
Reduced steam flow velocity per evaporation cross-section, m/s	0.23
Velocity of steam in perforations of submerged sheet, m/s	3.1
Velocity of steam in perforations of upper shield, m/s	20.5
Outlet steam velocity, m/s	18.62
Size of separator drum: - total length, m	33.76
- inside diameter, m	2.6
- distance between submerged sheet and upper shield, m	0.95
Dry mass of separator drum, kg	292000
Number of outlets: - steam-water piping (nominal diameter d_n=90mm)	424
- steam piping (d_n = 300 mm)	16
- water downcomer (d_n = 300 mm)	12
- connecting pipes at the water level (d_n=300mm)	6
- connecting pipes at the steam level (d_n=300mm)	5
- pressure metering outlets (d_n = 10 mm)	4
- level meterings (d_n = 50 mm)	32
Submerged perforated sheet: - thickness, mm	6
- diameter of perforations, mm	10
- number of perforations	70280
Upper perforated shield: - thickness, mm	5
- diameter of perforations, mm	10
- number of perforations	10620

* Thermal parameters at 4200 MW(th) power

Traverse and circumferential variations of pressure at the entrance of the steam pipes are reduced by a similar perforated shield in the upper part of the drum (5) and by 190 mm inside diameter bushing installed in the steam outlet pipes. The liquid accumulates in the lower part of the drum to be mixed with feed water and directed to the downcomers.

In 1988 an extensive performance-study was carried out in cooperation with RDIPE on unit 1 of the Ignalina NPP [40]. Fluid-dynamic and steam separation parameters of the separator drums were measured for a range of operational modes of the unit. Electric power was varied from 1050 to 1500 MW, this corresponds to an average steam flow rate from 423.6 to 583.3 kg/s, the level of water above the submerged perforated sheet as recorded by the level meters, varied from -50 to +300 mm. The study determined that optimum operating conditions at a 1500 MW(e) nominal power require that the water content in steam flow (mass fraction) is kept well below the 0.1% limit. In the range of power generation covered, the lowest water content in the exiting steam was observed to occur when the water level is maintained 150 to 250 mm above the perforated sheet.

There is an incentive to keep the water level in the steam drums as high as practical, because this water provides a coolant reserve in the event of a Loss Of Coolant Accident (LOCA). On the other hand, excessive liquid levels reduce the degree of de-entrainment. The tests have shown that a liquid layer 200 ±50 mm above the perforated sheet represents a workable compromise.

5.2.2 Connections at the Liquid and Steam Level between Separator Drums

The two separator drums within each loop are inter-connected both in the liquid and steam region. There are five connecting (325 x 16) mm pipes in the steam zone, and in the original design there were six pipes (325 x 19) mm in the water zone. The length of pipes is 19.8 m in the water zone and 16.2 m in the steam zone. Presently this number has been reduced to two water region pipes. The connections ensure that equal water levels and steam pressures are maintained in both drums. One of the connection pipes has a branch pipe (325 x 15) mm to supply water to the PCS.

A schematic of steam and water inter-connections between the separator drums is presented in Fig. 5.8.

The number of the inter-connecting pipes at the water level has been reduced because operational experience demonstrated that these pipes present maintenance problems. There are two main causes for this:

- The pipes are subjected to substantial thermal loads and resulting thermal stresses. This is especially true during the shut-down and start-up periods of the plants.

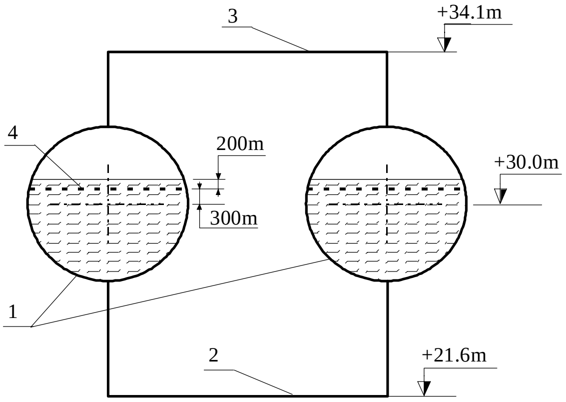


Fig. 5.8 Connections at the liquid and steam level between separator drums
1 - separator drums, 2 - connecting pipes at the water level, 3 - connecting pipes at the steam level, 4 - submerged perforated sheet

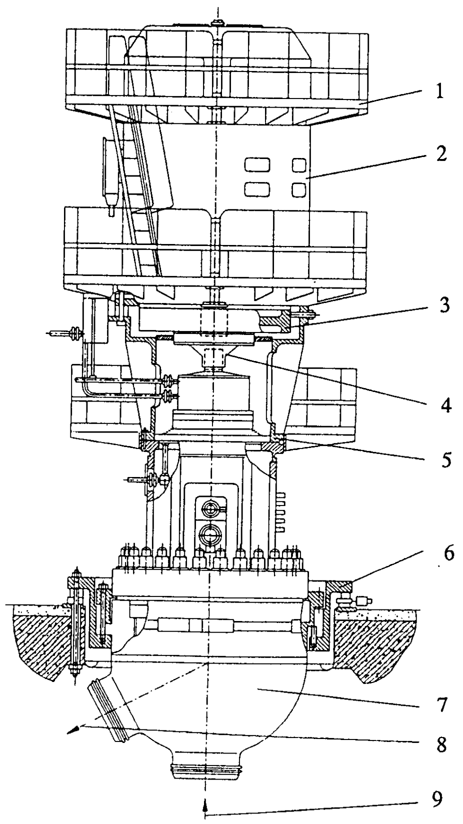


Fig. 5.9 The pump equipment of the RBMK type reactor
1 - service platform, 2 - electric motor, 3 - flywheel, 4 -junction coupling, 5 - support of electric motor, 6 - foundation frame, 7 - tank of the pump, 8 - water outlet, 9 - water inlet

Table 5.5 Specifications of the suction header of the MCP [39] (manufacturer - Izhora Plant, Russia)

Number per reactor	2
Length, m	21.074
Outside diameter, mm	1020
Wall thickness, mm	60

- For most of the operating time fluid velocities in these pipes is very low. As a result particulates settle in these pipes and corrosion processes are accelerated.

A study was conducted [90] which led to the conclusion that liquid level equilibrium could be maintained adequately with two pipes. As a result four of the pipes were removed during the 1996 maintenance outage.

5.2.3 Downcomers

The downcomer pipes direct the water from the separator drums to the suction header of the MCP. Each of the separator drums is connected to the suction header by 12 downcomer pipes (325 x 16) mm. Thus each of the two circulation loops contains 24 downcomers.

5.2.4 MCP Suction Headers

The function of the suction headers is to:

- mix the water coming via 24 downcomers from the separator drums,
- distribute water among the four main pumps.

The suction header is a cylinder with specifications shown in Table 5.5 [39]. The inlet pipes from the downcomers enter the cylinder from above. Its elliptic end covers have circular nozzles of 400 mm diameters. The header rests on two side rails and a fixed mid-level support.

5.3 FORCED CIRCULATION

The suction header supplies coolant to four suction pipes and to four pumps. In the normal power-operation mode, three pumps are used and one is kept in reserve in each loop. Two pumps per loop are employed for operation below 2400 MW(th) power. The exiting water is pumped through the pressure pipes to the pressure header.

5.3.1 Main Circulation Pumps

For the forced circulation of cooling water through the RBMK-1500 reactor at the Ignalina NPP type CVN-8 MCP are employed. These pumps belong to the “wet” stator pump group. The CVN-8 type is a centrifugal, vertical, single-stage pump with a sealed shaft. A schematic of the pump is shown in Fig. 5.9, its characteristics are listed in Table 5.6 [42]. The pump is powered by a vertical type VDA-173/99-6-2 AUChL4 electric motor, which is a three-phase asynchronous motor with a close - connected rotor (2). Motor characteristics are given in the Table 5.7. Rotary moment of inertia from the electric motor to the pump is transferred by means of an elastic coupling mechanism (4) which is provided with rubber packing (coupling type 65 GSP).

Table 5.6 Pump characteristics [42] (type- CVN-8, manufacturer- OKBM (Special Designer Bureau of Engineering), Niznij Novgorod, Russia)

Capacity, kg/s (m^3/h)	2.22± 0.05 (8000±200)
Head, MPa (m of water column)	1.962 ± 0.20 (200±20)
Temperature, °C	270
Absolute suction pressure , MPa (kgf/cm^2)	7.06 (72)
Minimum pressure margin before cooler boiling in the suction branch pipe of the pump, MPa (m of water column)	0.226 (23)
Shaft power, kW	4300 ± 300
Rotational speed, rpm	1000
Water seal pressure range, MPa (kgf/cm^2)	7.85 - 9.81 (80-100)
Water seal flow rate, kg/s (dm^3/h)	0.0138 (50)
Seal leakage (from shaft-sealing device to the atmosphere), kg/s (dm^3/h)	< 0.0069 (25)
Sealing water temperature, °C	
- at inlet	< 50
- at outlet	< 65
Cooling water flow rate though the cooler of sealing system, kg/s (m^3/h)	2.22 ± 0.28 (8±1)
Cooling water excess pressure, MPa (kgf/cm^2)	≤ 0.981 (10)
Cooling water pressure drop at cooler, when flow rate is 2.22 kg/s, MPa (kgf/cm^2)	≤ 0.1962 (2)
Cooling water temperature, °C	
- at inlet of cooler	< 40
- at outlet of cooler	< 60
Lubricant flow rate through radial-axial bearing, m^3/s	8 ± 0.3
Lubricant pressure drop at the inlet of bearing, MPa (kgf/cm^2)	0.147 -0.343 (1.5-3.5)
Lubricant temperature at the inlet of bearing, °C	40 - 50
Lubricant pressure at radial bearing, MPa (kgf/cm^2)	8.83 (90)
Top (radial-axial) bearing temperature,°C	70
Water flow rate through the hydrostatic bearing, kg/s (m^3/h)	11.1 - 16.7 (40-60)
Maximum peak - to-peak amplitude of vibration in bearings, m	< 0.0001
Maximum admissible heating/cooling velocity, °C/min	2
Time to full rotor acceleration, s	16
Time to full rotor deceleration, s	120 - 300
Total moment of inertia (pump&motor&flywheel), kg·m^2	3741
Overall dimensions	
- height, m	9.85
- length, m	3.07
- width, m	2.75
Mass of pump equipment, kg	106000

Table 5.7 Electric motor characteristics

Power, kW	5600
Voltage, V	6000
Current of stator, A	620
cos ϕ	0.9
Rotating speed, rpm	1000
Frequency of mains, Hz	50
Efficiency, %	96

A flywheel (3) is mounted on the motor shaft, which increases the rotary inertia in order to prolong the rotation of the shaft in the event the electric motor fails. The flywheel is of type 64 GSP, which has a massive 0.2 m outside diameter and 0.195 m thick steel (type ST 25) disk. An annular groove is provided in this disk for inserting balancing weights.

The MCPs are joined in groups of four pumps each (three for normal operation and one on standby). Because the MCPs are enclosed in the confinement structure, they are readily accessible for maintenance of the mechanical parts. The pumps are mounted in such a manner, that the elevation of the intake suction and pressure is lower than the branch pipe overlap. The MCP rests on the foundation frame (6) and is attached to it by locking rings. The pump is centered on the foundation frame by a locating pin, and the foundation is centered on the overlap. Verticality of the pump is obtained by concentric discs and jacks. For ease of maintenance the main zone of the pump and its supports is protected from overheating by thermal isolation. The annular gap between the overlap and the outer cylindrical surface of the pump is enclosed within a special steel plate, which is calculated to support a pressure difference of 0.4 MPa. This prevents coolant entry into the service compartments of the pump, in the event that the MCC pipelines were to rupture.

The pump shown in Fig. 5.10, consists of a shell (1) part of which can be removed. The removable part is packed with a cooper seal of trapezoidal cross-section (4), which is needed to assure leak-tightness. The shell is a welded tank fitted with intake (suction) and pressure branch pipes connected to the MCC. The inner cavity of the shell is lined with a corrosion-resistant stainless steel sheet. The tank rests on supporting legs, which are attached to the foundation frame. The removable part consists of a cover with jaws (5), an axial - radial upper bearing and shaft (14), pump rotor (3), pump stator (2), pole (6) and a lower radial hydrostatic bearing.

The upper combined axial - radial sliding bearing consists of a radial bearing and a heel (13) (axial part of bearing) with top and bottom footstep bearings. The shaft (14) is forged steel. The pump rotor (3) (having a specific speed coefficient of 102) is enclosed by double-curved blades. It is welded of two parts: one disc with blades and a covered disc. The wheel and the pump stator are manufactured from stainless steel. The inner surface of the cover (5) is also lined with stainless steel. The upper bearing and the support of the electric motor are attached to the outlet housing (6), which is manufactured from steel casting. These construction features make the maintenance of the removable part easier.

A double - acting mechanical (contact) shaft bearing (10) is used to prevent the coolant flow from entering the service compartment of the pumps. Clean sealing water is fed to the bearing the pressure of which is higher than the pressure of the MCC coolant. The distinguishing feature of this bearing is a very small (on the order of about 10^{-6} m) gap between the two bearing surfaces. It reduces the leakage of water to not more than 25 liters/hour.

The rotor of the pump moves clock-wise (from intake or suction side). To avoid the rotation of the shaft in the opposite direction (which is possible when a check valve is stuck in the open position), a special anti -rotational device is used. It consists of a ratchet, which is mounted in a recess of the flywheel. The reasons for installing the ratchet are:

- radial-axial oil bearing of electric motor is not adapted to work in case when the rotor turns in the opposite direction,
- because the electric motor would be overloaded, it does not permit the pump to be switched on, when the rotor rotates in the opposite direction.

The following auxiliary systems are necessary for assuring proper MCP operation :

- Lubrication system with an oil filter and cooler which is part of the main circulation system. It is specifically designed for each pump.
- A system, which supplies water to the shaft-sealing device. This is common for all eight MCPs. A valve at the sealing-water supply in the branch pipe is used to prevent the MCC coolant flow from entering this system. In the event that the system fails, and the pressure of the sealing-water decreases, the shaft is sealed by MCC water.
- A system, which supplies water to the hydrostatic bearing and is specifically adapted for each pump. The water to this system is supplied from the pressure branch pipe of the pump. Water is filtered by a multi hydrocyclone filter before being supplied to the bearings. When the system fails, water is supplied to the bearings from the sealing-system.
- A system for countering the axial forces of the pump rotor, which is also designed specifically for each pump.

The tank of the pump is designed to last 25 years. The time of operation of the pump to the first inspection (at which time it is necessary to examine the removable part) is about 20000 hours.

5.3.2 Suction and Pressure Piping of the MCPs

These pipes direct the coolant from the suction header to the pump and down-stream from the pump to the pressure header. They have 282 mm outside diameters and 38 mm thick walls. Each individual pipe includes a gate valve and a branch between the gate valve and the pump for the following pipes:

- piping system for countering the axial forces of the pump rotor, (89 x 5) mm,
- inlet-outlet cooling heating pipes, (89 x 5) mm,
- outlet pipe for the pressure water of the hydrostatic bearing, (57 x 4) mm,
- draining pipe for the suction side of the main pump, external (57 x 4) mm,
- supply pipe for the hydraulic system of the pump and to the forced circulation system, (25 x 3) mm.

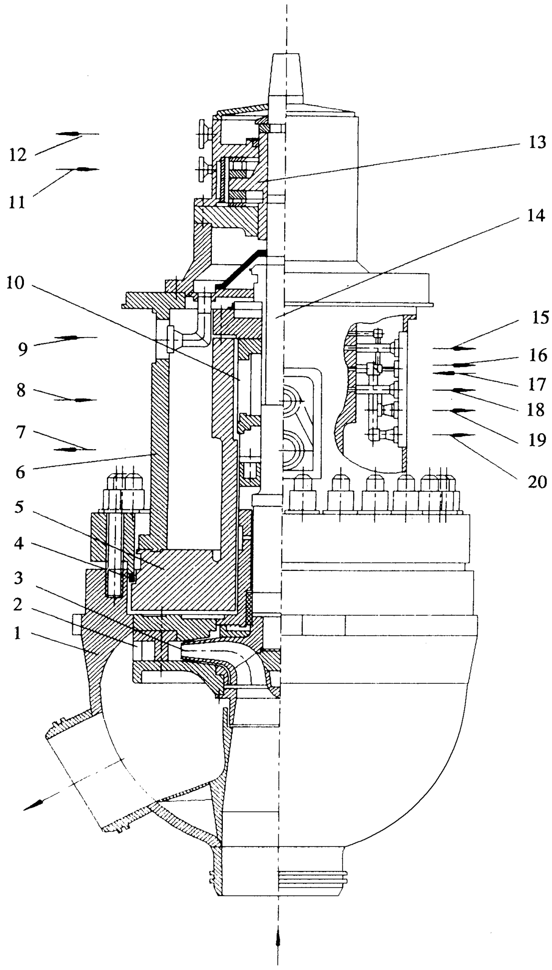


Fig. 5.10 Schematic of the RBMK-1500 pump
1 - outlet case, 2 - pump stator, 3 - pump rotor, 4 - seal, 5 - cover of bearing seat, 6 - outlet housing, 7 - water overflow from behind the pump rotor (from system for countering the axial forces), 8 - water to hydrostatic bearing, 9 - lubricant from block and radial bearing, 10 - shaft sealing device, 11 - lubricant supply to radial bearing and block, 12 - lubricant from block, 13 - pillow block, 14 - shaft, 15 - water from cooler, 16 - outlet of water, which is penetrates through the seal, 17 - water

supply to shaft sealing, 18 - venting, 19 - removal of water - lubricant emulsion, 20 - water to cooler

Each individual pipe on the pressure side of the pump contains a check valve, a throttling-regulating valve, a gate valve and a throttle disc flow rate meter. A branch pipe is connected between the check valve and the pump to supply water to the hydrostatic bearing, (108 x 7) mm. The gate valves are used to disconnect the pump during maintenance from its pressure pipes and pressure headers. The gate valve is open in the stand-by position of the pump, and its proper temperature is maintained by a small amount of water arriving to the suction header through four openings of the 10 mm diameter in the check valve. The type MA11112-800-05 gate valves, used here, are commonly used in other industrial applications. The check valves used are of type PT4409-800-01.

The power of each individual pump is governed by its throttling-regulating valve, Fig. 5.11. The throttling-regulating valve is partially closed at the start, and is gradually opened as the reactor power rises and of the flow rate increases. Table 5.8 [39] provides the characteristics of the throttling-regulating valve.

The throttling-regulating valve is controlled from a MCR.

5.3.3 MCP Pressure Header

The functions of an individual pressure header are to:

- collect the water from all main pumps of one MCC loop. This water arrives through the pressure pipes,

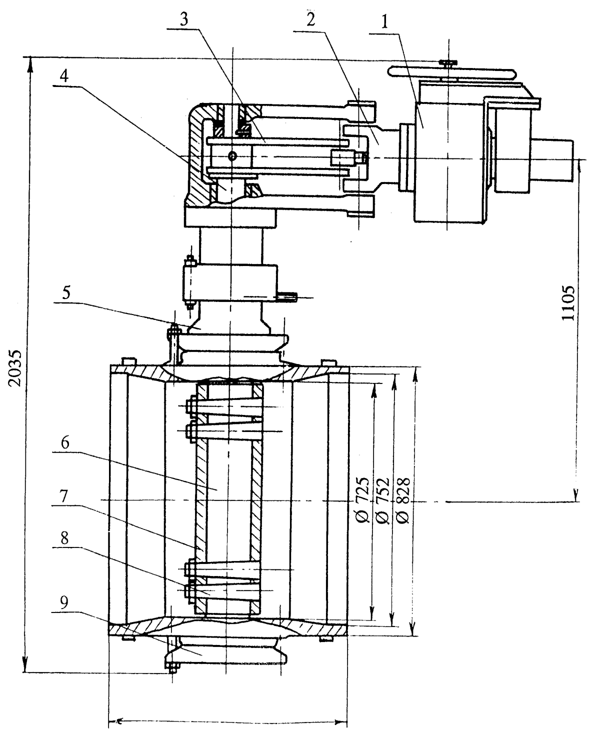


Fig. 5.11 A schematic representation of the throttling-regulating valve

1 - electric drive, 2 - speed reducer, 3 - pivot arm, 4 -pivot axis, 5 - top cover, 6 - beam, 7 - disc, 8 - pin, 9 - bottom

- supply the coolant to the twenty pipes and the twenty group distribution headers (325 x 15) mm,
- supply the water to the PCS along two pipes connected to the stagnation region of the header (159 x 9) mm.

The construction of a pressure header is similar to that of a suction header, except for its wall thickness, as shown in Table 5.9 [39]. The outlets to the group distribution header contain filters for solid particles and flow rate controls which are 120 mm long Laval diffusers of cylindrical diameter of 151.1mm.

5.3.4 Pipe Connections between Suction Headers and Pressure Headers

Each suction header in a separate circulation loop is connected by six pipes (325 x 15) mm with the respective pressure header, to ensure that natural circulation can take place when the pumps are disconnected. Each of the pipes include a gate valve type C23202K-0160-300 and a check valve C20 401-160. The type C20 401-160 check valve is made in the former Czechoslovakia.

The exploitation of these by-pass pipes has been modified as a result of the Barselina study [91]. The study directed attention to the circumstance that in the event of a Design Basis LOCA (That is, the break of the pressure header), if one of the check valves would fail to close, this would lead to an increased rate of coolant loss. Studies were conducted which determined that adequate natural circulation can be maintained through the stalled rotor blades of the MCP's [92]. It was then suggested to remove these pipes altogether. In fact, this modification has been adopted in the Leningrad plants [93]. However, these pipes are useful during maintenance shutdown. Therefore in the Ignalina NPP the procedure was adopted to close the manually operated gate valves within these pipes (see Fig. 5.1) during operating mode of the reactor and to open during maintenance.

Table 5.8 Specifications of throttling-regulating valve [39] (type - RT 96510-800)

Number per reactor	8
Capacity, kg/s (m^3/h)	< 2.22 (8000)
Pressure drop, MPa	1.766
Pressure, MPa	9.81
Nominal diameter, mm	800

Table 5.9 Specifications of the pressure header of the MCP [39] (manufacturer - Izhora Plant, Russia)

Number per reactor	2
Length, m	18.204
Outside diameter, mm	1040
Wall thickness, mm	70

5.3.5 Pipe Connections between the Pressure Header and the Group Distribution Header

Water is distributed to individual group distribution header by means of 20 pipes (325 x 15) mm. Each pipe has a manual-control gate-valve, a check valve and a mixer to mix the cold water from the Emergency Core Cooling System (ECCS) and the hot water from the MCC. The type C23201-0160-300 gate valves are closed for servicing the pressure header or the isolation and control valves. The check valve prevents back-flow from the fuel channels in case of failure of the pressure header. Fig. 5.12 shows a schematic of a type C20 401-0160 check valves employed for this purpose. All check valves have are provided with guard devices (2) which prevent a disconnected valve disc (1) from closing the flow path to the respective group distribution header. The valve is partially open when the pressure on both sides is equal.

Mixers protect the MCC from thermal or hydraulic shocks. Flanges designed to prevent pipe whip in the event of a pressure surge are fixed to the structural beams of the plant and to a special framework.

5.4 STEAM PIPING

These pipes supply the steam from the separator drums to the turbine and to plant internal plant needs. This includes steam for the pressure safety system of the MCC, and through a reducer to the plant steam system. Table 5.10 lists the design steam parameters.

The piping is schematically presented in Fig. 5.13. From the separator drum (1) the steam is carried along 16 pipes (325 x 19) mm, to two steam headers (2) (630 x 25) mm. From there the steam of one MCC loop is collected by four steam pipes (3) (630 x 25) mm, and fed to the turbine (5). Each separator drum is connected by the pipe line (3) to two turbogenerators.

To ensure a uniform longitudinal sink from the separator drum, steam pipes (3) are connected mid-way to the steam headers (2). Each of the steam pipes (3) has a parallel Steam Discharge Valve (SDV-C) (7) to direct the steam to the condensers of the turbines. The pressure of

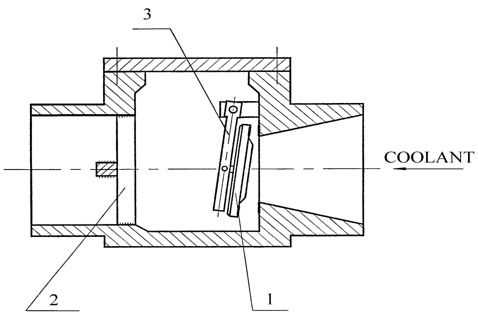


Fig. 5.12 A schematic representation of the GDH check valve

1 - disk, 2 - protective cross, 3 - suspender

the steam is also controlled, and peaks of pressure are eliminated by the high pressure steam loop (8) The two high pressure steam loops, one for each MCC loop, consists of pipes and discharge valves, and is connected by four pipes to the steam zones of the two separator drums. The Steam Discharge Valve (SDV-A) (10) and six Main Safety Valves (MSVs) (9) discharge the steam to the pressure suppression pool of ACS tower. When the pressure decreases bellow 5.89 MPa (60 kgf/cm^2), two valves (which control steam flow rate to one turbine) close and two similar valves of the other turbine are closed when the pressure falls below 5.39 MPa (55 kgf/cm^2) (this is absolute pressure).

5.4.1 Protection of the MCC from Pressure Surges

The MCC is protected from over-pressures by a steam discharge system employing pressure relief valves. One loop of this system consists of:

- four fast-acting SDV-C which, as shown in Fig. 5.13, direct the excess steam to the turbine condenser (7) (two for each steam header),
- one fast-acting SDV-A (10),
- six MSVs (9).

The SDV-A and MSVs are located in the high pressure steam loop (8) joining the four steam headers of the separator drums of one loop. The steam discharged through these valves goes into the ACS tower. The parameters of the steam discharge system are shown in Table 5.11 [43].

Table 5.10 Operation parameters of the steam

Absolute pressure in the separator drums, MPa	6.47-6.96
Absolute pressure of the turbine supply inlet, MPa	6.18- 6.67
Inlet temperature of the turbine, ^{o}C	279.5
Water content in the steam flow (mass fraction) at the turbine inlet, %	< 0.5
Maximum flow rates for two turbines at 4200 MW (th), kg/s	2055-2125

Table 5.11 Parameters of the protective steam discharge valves [43]

Trademark	Number per reactor	Activation pressure (off/on), MPa (kgf/cm^2)*	Capacity per valve, kg/s (t/h)
SDV-C	8	6.96/6.77 (71/69)	152.8 (550)
SDV-A	2	7.06/6.77 (72/69)	97.2 (350)
MSV group I	2	7.36/7.06 (75/72)	97.2 (350)
MSV group II	4	7.45/7.16 (76/73)	97.2 (350)
MSV group III	6	7.55/7.26 (77/74)	97.2 (350)

* Excess pressure

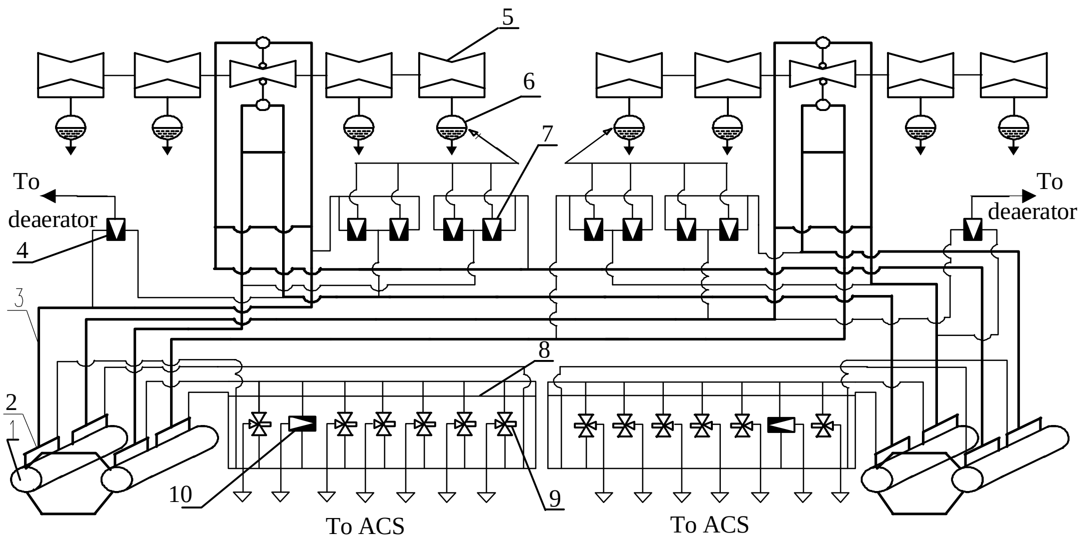


Fig. 5.13 Steam piping
1 - separator drum, 2 - header, 3 - main steam pipes, 4 - SDV-D, 5 - turbogenerators, 6 - condensers, 7 - SDV-C, 8 - high pressure steam loop, 9 - MSV, 10 - SDV-A

5.4.1.1 Fast-Acting Steam Discharge Valve SDV-C

Steam pipes leading to the condensers of all turbines are provided with fast-acting steam discharge valves. To ensure a uniform drain from the separator drum, two steam pipes are connected to each SDV-C valve. This keeps the piping hot even when the reactor is shut down. If condensation occurs in the lines, the inclined inlet-outlet pipes facilitate free flow of the condensate. Each SDV-C contains a throttle to decrease the energy of the steam flow.

The SDV-C valves admit a portion of the steam from the steam piping, control it in the throttle valves and supply it to the condensers of the turbines. These valves are activated under the following conditions :

- reactor startup,
- reactor cool down,
- generation of excess steam,
- stoppage of both turbines,
- stoppage of the single operating turbine,
- stoppage of one of two operating turbines,
- reduction of power of the single operating turbine.

An individual SDV-C is limited to a 152.8 kg/s flow rate. This adds up to 1222 kg/s for all eight SDV-C in the steam pipelines or 50% of the maximum 2444 kg/s steam generated by the reactor at 4800 MW (th). The valve is activated in about 10 s after the limiting 7.06 MPa pressure is reached. The fast-acting steam discharge valve is an (on/off) isolating throttle described in Table5.12 [39].

Electric drives of the SDV-C are operated in the following three modes by:

- controller signals,
- logical electronic control,
- manually.

Table 5.12 Fast-acting steam discharge valve to turbine condenser [39] (type - 1034-300/300-7, manufacturer - Tchechovskoy Plant of Energy Engineering, Russia)

Number per reactor	8
Capacity, kg/s	152.8
Overpressure protection (excess), MPa	6.96
Opening/closure time, s	< 10
Operating temperature, ^{o}C	280
Pressure at outlet, MPa *	1.0
Temperature at outlet, ^{o}C *	183
Nominal diameter at inlet and outlet, mm	300/300
- average lifetime, years	30
- average lifetime between major servicing, years	5
- average lifetime between major servicing, cycles	750
- probability of safe operation, %	92

* Design values

Each valve is connected to an automatic controller and a position indicator on the MCR. In the first operating mode, the SDV-C is activated by a high pressure signal from the separator drum. In the second mode, the computer returns either a "close" or a "keep closed" command under a combined action of the following conditions: increased pressure in the turbine condenser (pressure in condenser is more than 0.023 MPa), an excessive level of the condensate, temperature downstream of steam discharge valve is more than 100 ^{o}C, or failure of the electric currant. Finally, remote manual control (third case) is used in transient operation during start-up or cool-down of the reactor, or in the case of failure of the other two operating modes.

5.4.1.2 High Pressure Steam Loop

The steam piping consists of two identical high pressure steam loops. Each of these loops is connected by four pipes (630 x 25) mm to the steam zones of the separator drums of the respective closed loop of the MCC, as shown in Fig. 5.10. A high pressure steam loop contains six MSVs and one SDV-A. The SDV-A valve is connected to the high pressure loop by two pipes (325 x 16) mm. The MSV of the loop and the SDV-A discharge the steam through their individual pipes (630 x 12) mm to the fifth pool of the ACS tower. Part of the steam also escapes through closed MSV and SDV-A valves. This steam is collected and directed through a (630 x 8) mm pipe to the condenser in the machine hall. The inclined supply and discharge pipes facilitate free flow of condensate.

The SDV-A obtains steam from the steam piping, reduces its energy by throttling and directs it to the fifth condensation pool of the ACS tower. It is activated when turbine load decreases substantially doe to:

- loss of electrical AC power,
- one turbogenerator is disconnected and the condenser vacuum of the other turbogenerator decreases.

SDV-A is also available to cool the reactor in case of an accident. It will be activated in those conditions when the opening of the SDV-C valve is insufficient to control the rise in pressure or when the SDV-C valve fails to function.

The activation pressure of SDV-A is set at 7.06 MPa, nominal steam flow rate after activation is 97.2 kg/s. The fast-acting steam discharge valve is an (on/off) isolating throttle, as shown in Table 5.13 [39].

Table 5.13 Fast-acting steam discharge valve to fifth pool of the ACS tower SDV-A [39] (type - 1034-300/300-7, manufacturer - Tchechovskoy Plant of Energy Engineering, Russia)

Number per reactor	2
Capacity, kg/s	97.2
Overpressure protection (excess), MPa	7.06
Opening/closure time, s	< 10
Pressure at outlet, MPa*	1.0
Operating temperature, ^{o}C*	280
Temperature at outlet, ^{o}C*	183
Nominal diameter at inlet and outlet, mm	300/300
- average lifetime , years	30
- average lifetime between major servicing, years	5
- average lifetime between major servicing, cycles	750
- probability of safe operation, %	92

* Design values

Two types of fast-acting steam discharge valves are operated by electric drives. They differ only in their activation pressure, which is 7.06 MPa for the SDV-A and 6.96 MPa (excess pressure) for the SDV-C valve. The computer control issues either "close" or "do not open" directions at 6.77 MPa operation pressure. Remote manual operation from the MCR is available.

The MSV are intended for emergency protection of the piping and other primary system components from pressure rises for which the activation of the SDV-A, and SDV-C safety valves become insufficient.

The activation pressure for separate groups of MSVs are given in Table 5.11. The opening/closing time for MSVs is less that 0.5 s, the time delay for opening is less that 4 s and for closing about 10 s. All of the original 24 Main safety valves (12 valves per unit) were replaced by new more reliable French-design valves in 1996. Safety significant characteristics of these valves, such as actuation pressure (on/off) and capacity of these new MSVs remain the same as for old ones.

5.5 THE WATER FEEDBACK SYSTEM

The water feedback system shown in Fig. 5.14 carries fresh water to the separator drums in either normal, transient or emergency operation of the reactor. From the condenser of the turbine the coolant arrives at the first stage condensate pump (1), then it is pre-heated in the ejector (2) and filtered (3). From the second stage condensate pump (4) it is heated in a series of five heaters (6) up to 190 ^{o}C, and then mixed with the condensate from the other turbogenerator and arrives at the deaerator (8) to be sent into the main feed water pump (5) and to the main feeder (13). Auxiliary feed water pumps (7) supply the coolant to the auxiliary feeder. The liquid stored in the deaerators can be used in emergency both through the main feeder and through the auxiliary feeder (12). The deaerator is heated by steam from the inter-turbine sink and from the fast-acting Steam Discharge Valve to the Deaerator (SDV-D) (9).

5.5.1 Operation

In normal or transient operation of the reactor, for pressure variations from 10% to nominal value, feedwater is supplied to the separator drums by the Main Feed Water Pumps (MFWP). The six parallel pumps ensure a reliable nominal-load operation of the separator drums with a 10 % reserve even when one of the pumps fails, and one, as is the case under normal operating conditions, is on standby.

Auxiliary Feed Water Pumps (AFWP) are activated:

- to fill the MCC before starting the reactor,
- for start-up, shut-down or for low-pressure operation, up to 10 % of nominal power,
- if MFWPs are switched off.

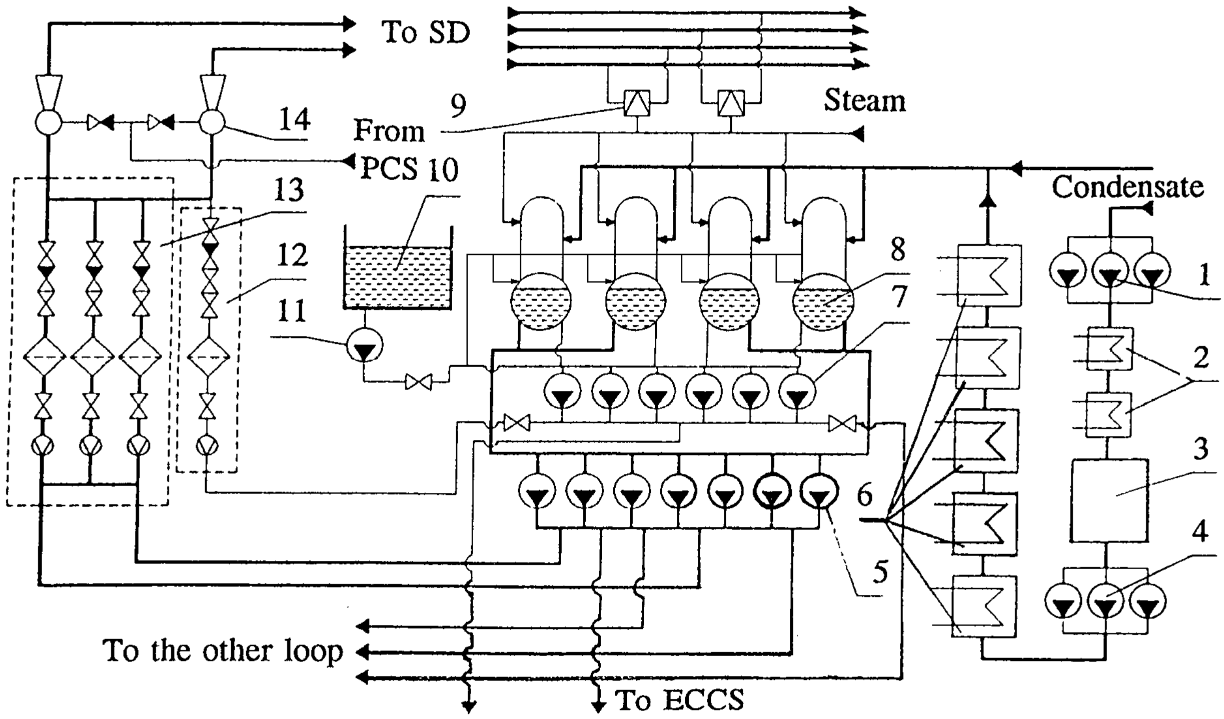


Fig. 5.14 Water feedback system
1 - condensate pump of the first stage, 2 - main ejector and seal ejector cooler, 3 - condensate filter, 4 - condensate pump of the second stage, 5 - MFWPs, 6 - low pressure reheaters, 7 - AFWPs, 8 - deaerators, 9 - SDV-D, 10 - deminiralized water storage tank, 11 - auxiliary deaerator makeup pumps, 12 - auxiliary feeder, 13 - main feeder, 14 - mixer

In addition to this, the MFWPs and the AFWPs are utilized to cool the reactor during an emergency (for example, in case of a LOCA event). Note that the pumps are not tripped in the event of an accident, but continue to operate until they are able to do so. In accident scenarios which have been analyzed MFWPs can be stopped due to cavitation or loss of off-site-power.

The suction and pressure pipes of the MFWPs are connected to the suction and pressure headers. Each header consists of gate-valve separated chambers to ensure normal operation of at least three MFWPs with one maintained on standby for servicing. The pressure piping can feed the two MCC loops if one of the MFWPs fails. Control valves are installed in the piping of both main and auxiliary feed lines to ensure the safe operation even with very low pressures in the separator drums, e.g., during a transient involving loss of coolant from the MCC.

Feedwater arrives at the separator drums from the main feeder lines, one per the MCC loop, along four pipes (530 x 28) mm, one for each separator drum. The feeder system consists of three parallel lines, one standing by, interconnected at their two ends.

Two auxiliary feeder systems, one per each MCC loop, supply the coolant to the separator drums from AFWPs along two pipes (219 x 13) mm. They are connected to the separator drums downstream of the main feeders. Feedwater is supplied to the pressure headers by both the main and the AFWPs along two pipes, one (426x24) mm, the other (219 x 13) mm to be fed to the emergency headers.

To avoid cavitation in the AFWPs when they are activated due to a pressure loss in the deaerators, four deaerator auxiliary makeup system pumps are connected to the suction headers of the AFWPs. They take water from the auxiliary deminiralized water storage tanks. The volume of the water, stored in this tank, should never be less than 1000 m^3.

A recirculation piping system is included to eliminate overheating and pressure fluctuations of the feedwater in the low-power operation mode. These pipes connect main and emergency feed pumps pressure headers to the deaerator.

5.5.2 Operation Parameters of the Water Feedback System

When the two turbogenerators of a reactor function at their nominal power, the groups of deaerators pairs and the six MFWPs operate on their normal loads. Total flowrate of the feedwater is then 2444 kg/s. When a single turbogenerator is running, only one pair of deaerators is in operation, the others are disconnected. Total flow rate of the feedwater is then 1222 kg/s, all other parameters are at their nominal magnitude.

In transient operation modes, such as start-up, cool-down or low-power operation, feedwater arrives from the AFWPs, provided the flow rate needed is below 10 % of the nominal value. The level of liquid in the separator drums is then maintained within ± 50 mm of the nominal level. For feedwater parameters in nominal and in transient operation, see Table 5.14.

5.5.3 Components of the System

Components of the feedwater piping system are described at the beginning of this Section. Here some details of their construction are presented.

5.5.3.1 Condensate Pumps

Two-stage lines supply the condensate to the deaerators. The lower-stage pipes carry the condensate from the condenser of the turbine via the purification system into the suction side of the upper line where it is carried via the low-pressure reheaters into the deaerators.

The upright four-stage pumps of the lower pumping line, specified in Table 5.15 are vertical. The vertical construction of the pumps allows to maintain the pumps without disconnecting the piping. Their shafts are mechanically sealed to prevent leakage. The pumps are installed in a closed container, are connected by shafts extending across the concrete wall and are fixed by joints to the pumps at one end and to the electric motors at the other.

The pumps of the second stage are horizontal. The centrifugal, one - stage, with double - sided rotor, it possesses sufficient pressure not only to withstand the high resistance of the four reheaters, but also to lift the condensate into the deaerators, see Table 5.16 [41].

5.5.3.2 Filtration of the Condensate

The combined desalination filters with integral regenerators filter-out all electrolytes and all silica acids coming from the suction side of the coolant in the condensers. The condensate is compressed to 3.2 MPa and filtered in a downward flow across a bed of H-kationite and OH-anionite. Kations in the coolant are exchanged to H ions on the kationides, and any ions to OH on the anionite. Filtration cycle takes 95 days, then the ionite bed is transferred to the regenerator to restore its activity. The filter is an upright single-shell cylinder with the upper, medium and lower distributors. The parameters of filters are present in the Table 5.17.

Water quality behind condensate filters must meet the following criteria [36]:

- Relative electric conduction at 25 ^{o}C, μS/cm ≤ 0.1
- Bulk chloride ion concentration, μg/kg ≤ 3
- Bulk silicium acid concentration, μg /kg ≤ 30
- Bulk oxygen concentration, μg /kg ≤ 400
- Bulk natrium concentration, μg /kg ≤ 3
- Bulk copper concentration, μg /kg ≤ 2

5.5.3.3 Pre-Heating the Condensate

The condensate is pre-heated in five regenerating reheaters. Reheater 1 is a double-shell unit, pre-heaters 2, 3, 4, 5, are single - shell vertical units with tube bundles. The higher - pressure liquid - fraction internal flow occurs in the stainless steel tubes in a shell - side flow of steam of a lower pressure. This arrangement reduces the shell - side pressure and prevents liquid from boiling. The steam goes to the top, but the steam-water mixture is discharged at the bottom. The reheaters are specified in Tables 5.18 - 5.22 [44].

Table 5.14 Operation parameter of feedwater

Parameters *	Nominal operation**	Starting transient	Cooling transient	Low load
Pressure in separator drums, MPa	6.47-6.96	0.2-6.96	6.96-0.2	6.96
Pressure in deaerators, MPa	1.28	0.2-1.28	1.28-0.2	1.28
Feedwater flow - rate, kg/s	2055-2125	0-278	278-0	278
Pressure in the pressure header of MFWP, MPa	8.9	-	-	-
Pressure in the pressure header of AFWP, MPa	-	0.2-9.1	9.1-0.2	9.1
Pressure in the main feeder, MPa	8.55	-	-	-
Pressure in the emergency feeder, MPa	-	0.2-8.4	8.4-0.2	8.4
Feedwater temperature, ^{o}C	177-190	30-190	190-50	190

* Absolute pressures
** At 4200 MW (th) power

Table 5.15 Specification of the condensate pump of first stage [41] (type - 1500-120, manufacturer - Scientific and Industry Union "Nasosenergomash" Sumy, Ukraine)

Number per reactor	6
Capacity, m^3/s	0.417
Head, MPa	1.117
Pumping power, kW	559
Efficiency, %	80
Cavitation margin, m	2.3
Absolute suction pressure, MPa	0.296
Temperature of pumping water, ^oC	70
Overall dimensions, m:	
- height	3.440
- length	1.900
- width	1.860
Mass of pump equipment (with electric motor), kg	24170
Electric motor (type - VAN (AV) 15-36-8AMU4, manufacturer - "Uralelektrotyazmash", Russia)	
Rotational speed, rpm	740
Electric motor power, kW	1000
Voltage, V	6000
Mass of the electric motor, kg	10710

Table 5.16 Specifications of the condensate pump of second stage [41] (type - 1500-180-2, manufacturer - Scientific and Industry Union "Nasosenergomash" Sumy, Ukraine)

Number per reactor	6
Capacity, m^3/s	0.417
Head, MPa	1.766
Pump power, kW	1141
Efficiency, %	84
Cavitation margin, m	22
Temperature of pumping water, ^oC	70
Overall dimensions, m:	
- height	1.740
- length	2.020
- width	1.513
Mass of pump equipment (with electric motor), kg	8715
Electric motor (type - 2AZM-1600/6000UCh14)	
Rotational speed, rpm	2975
Electric motor power, kW	1600
Voltage, V	6000
Mass of the electric motor, kg	5280

Table 5.17 Specifications of condensate filters [19] (type - AFISDNr-3.0-1.6)

Nominal diameter, m	3.0
Nominal pressure, MPa	1.6
Capacity, kg/s	150
Overall height, m	4.1
Entire mass, kg	6600
Height of the filter bed, m	1.0
Composition of the filter bed	ions KU-2 and AV-17

Table 5.18 Low pressure reheater PND-1 [44] (type - PN-1200-42-4-IA, manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	4 (2/turbine)
Condensate mass flow rate, kg/s	422.5*
Pressure, MPa:	
- of steam	< 1.0*
- of heating condensate	< 4.2*
Maximum temperature of steam, ^oC	150*
Hydraulic drag resistance of condensate, MPa	0.0216*
Heat transfer surface area, m^2	1200
Heat transfer rate (power), MW	37.9*
Heater dimensions, m:	
- height	10.450
- diameter	2.632
Dry mass, kg	46500
Mass with water, kg	70000

Table 5.19 Low pressure reheater PND-2 [44] (type - PN-1900-42-4-IA, Manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	2 (1/turbine)
Nominal condensate flow rate, kg/s	733.9*
Pressure, MPa:	
- of steam	< 1.0*
- of heating condensate	< 4.2*
Maximum temperature of steam, ^oC	145*
Hydraulic drag resistance of condensate, MPa	0.0210*
Heat transfer surface area, m^2	1900
Heat transfer rate (power), MW	118.3*
Heater dimensions, m:	
- height	10.280
- diameter	3.364
Length of shell, m	8.345
Internal shell diameter, m	2.200
Outside tube diameter, mm	16
Thickness of tube wall, mm	1
Dry mass, kg	68900
Mass with water, kg	95000

Table 5.20 Low pressure reheater PND-3 [44] (type - PN-1900-42-4-IIA, manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	2 (1/turbine)
Nominal condensate mass flow rate, kg/s	818.6*
Pressure, MPa:	
- of steam	< 1.0*
- of heating condensate	< 4.2*
Maximum steam temperature, ^oC	145*
Hydraulic drag resistance of condensate , MPa	0.0260*
Heat transfer surface area, m^2	1900
Heat transfer rate (power), MW	79.2*

Dimensions, m:	
- height	10.280
Continue Table 5.20	
- diameter	3.264
Length of shell, m	8.345
Internal shell diameter, m	2.200
Outside tube diameter, mm	15
Thickness of tube walls, mm	1
Dry mass, kg	68200
Full mass with water, kg	95000

Table 5.21 Low pressure reheater PND-4 [44] (type - PN-1900-42-4-IIIA, manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	2 (1/turbine)
Nominal condensate mass flow rate, kg/s	818.6*
Pressure, MPa:	
- steam	< 1.0*
- condensate	< 4.2*
Maximum steam temperature, ^{o}C	190*
Hydraulic drag resistance of condensate, MPa	0.0250*
Heat transfer surface area, m^2	1900
Heat transfer rate (power), MW	89.8*
Dimensions, m:	
- height	10.280
- diameter	3.280
Length of shell, m	8.345
Internal shell diameter, m	2.200
Outside tube diameter, mm	16
Thickness of tube walls, mm	1
Dry mass, kg	69400
Full mass with water, kg	95000

Table 5.22 Low pressure reheater PND-5 [44] (type - PN-1900-42-4-IVA, manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	2 (1/turbine)
Nominal condensate mass flow rate, kg/s	1051.4*
Pressure, MPa:	
- steam	< 1.0*
- condensate	< 4.2*
Maximum temperature of steam, ^{o}C	190*
Hydraulic drag resistance of condensate, MPa	0.0390*
Heat transfer surface area, m^2	1900
Heat transfer rate (power), MW	70.8*
Dimensions, m:	
- height	10.280
- diameter	3.280
Length of shell, m	8.345
Internal shell diameter, m	2.200
Outside tube diameter, mm	16
Thickness of tube wall, mm	1
Dry mass, kg	70000
Full mass with water, kg	95000

* Design values

5.5.3.4 Deaerators

The condensate from each turbogenerator is subject to deaeration in two parallel thermal-jet deaerators. Oxidant gases, particularly oxygen, are thus eliminated, the condensate is pre-heated and its supply in the main and auxiliary feed water system is renewed. Aside from this primary purpose, the deaerators also heat up the feedwater and store water for the separator-drums and the ECCS. Primary deaeration occurs even earlier, in the condenser storage of each turbogenerator.

The deaerators are equipped with reducers and safety valves. They are heated by steam from the primary discharge of the turbines and from the SDV-D during the turbine start-up, as long as the primary discharge pressure is lower than in the deaerator. To prevent overflow of the deaerators in the starting operation modes of the reactor, excess water from the deaerator can be returned to the deminiralized water storage tank. The feedback unit of two expansion vessels and two overflow coolers is capable of returning water at the rate of 27.8 kg/s.

An individual deaerator consists of a DP-2600 deaeration column and a BDP-120-1-11 deaeration vessel, the functions of which are:

- stable deaeration and pre-heating during nominal feedwater flow-rates from 722 kg/s to 216.7 kg/s and pre-cooling from 10^{o}C to 40^{o}C,
- reduction of the mass content of oxygen below 15 µg/kg for its pre-treatment concentration below 3000 µg/kg,
- pre-heating from 30^{o}C to 178^{o}C at start-ups, transient and emergency operation for 30.5 kg/s flow rate and 0.94 MPa deaeration pressure, for oxygen concentration outside the 15 µg/kg level.

Other specifications of the deaerator are presented in Table 5.23 [44].

5.5.3.5 Main Feed Water Pumps

The main feed water pumps are horizontal centrifugal four-stage pumps with internal casings and a balancing drum, two radial bearings, one sliding high-pressure bearing and high-pressure end seals. These operate on compressed condensate from the suction headers of the top pumping line. Before starting up the reactor the pumps are pre-heated. A pressure-lubricated gear-sleeve connects the pump to the electric motor. The pumps are equipped with pressure lubrication units. The lubricant seals and other heat exchangers are cooled by lake water.

Inlets of the pumps are flange-sealed, their upward outlets are welded together. The pumps are driven by asynchronous three-phase closed-loop cooled electric motors. Specifications of the MFWP are presented in Table 5.24 [41].

Table 5.23 Specifications of the deaerator [44] (type - DP-2600, manufacturer - Industry Union "Sibirenergomash", Barnaul)

Number per turbine	2
Maximum capacity, kg/s	722.2
Minimum capacity, kg/s	216.7
Working absolute pressure, MPa	0.93-1.28
Permissible absolute pressure with relief valves in operation, MPa	1.475
Hydraulic test pressure, MPa	1.6
Working temperature, ^oC	187
Admissible wall temperature, ^oC	200
Diameter of column, m	3.451
Height of column, m	7.536
Mass of column, kg	26000
Mass of column with water, kg	88000
Internal volume, m^3	193
Volume of column, m^3	62
Effective volume of storage (accumulator) tank, m^3	120
Reliability:	
- average lifetime , years	30
- average lifetime between major servicing, h	50000

Table 5.24 Specifications of the main feed water pump [41] (type - PEA-1650-80, manufacturer - Frunze Scientific and Industrial Union, Sumy, Ukraine)

Number per reactor	6 operational + 1 in reserve
Operation parameters:	
- capacity, m^3/s (t/h)	0.458 (1650)
- head, MPa (m of water column)	8.9 (910)
- permissible cavitation margin, MPa (m)	0.147 (15)
- inlet temperature, ^oC	190
- maximum inlet absolute pressure, MPa	1.57
- maximum outlet absolute pressure, MPa	11.87
- leakage in the end seals, kg/s	0.0055
- power, kW	4451
- mass, kg	12700
Electric motor:	
- type	2AZM1-800/6000 U4
- rotational speed, rpm	2982
- voltage, V	6000
- power, kW	5000
Overall mass, kg	24700
Electric motor mass, kg	12700
Overall dimensions:	
- height, m	1.980
- length, m	2.995
- width, m	1.830
Operation parameters:	
- efficiency , %	83
- overall efficiency , %	81
- average lifetime between major servicing, h	8000
- average lifetime, years	30

Table 5.25 Specifications of the emergency feed water pump [41] (type - PEA 250-80, manufacturer - Frunze Scientific and Industrial Union, Sumy, Ukraine)

Number per reactor	5 operational + 1 in reserve
Operation parameters:	
- capacity, m^3/s (m^3/h)	0.069 (250)
- head, MPa (m)	8.6 (880)
- permissible cavitation margin, MPa (m)	0.088 (9)
- inlet temperature, ^oC	190
- inlet pressure, MPa	1.25
- maximum inlet absolute pressure, MPa	1.57
- maximum outlet absolute pressure, MPa	11.87
- leakage in end-seals, kg/s	0.0055
- admissible concentration of solid particles, g/kg	5×10^{-3}
- power, kW	725
Mass of assembly, kg	8330
Overall dimensions:	
- height, m	1.340
- length, m	2.320
- width, m	1.290
Electric motor:	
- type	2AZM1-800/6000 U4
- rotational speed	2970
- voltage , V	6000
- power, kW	800
- mass of electric motor, kg	3680
Operation parameters:	
- efficiency, %	75
- cavitation margin, m	9
- average time between major servicing, h	8000
- average lifetime, years	30

5.5.3.6 Auxiliary Feed Pumps

The auxiliary feed water pumps are horizontal six-stage split pumps with divided internal sections and an axial discharge. They carry axial forced-lubricated bearings and high-pressure end-seals fed by the condensate from the suction headers of the second pumping line. All heat exchangers are cooled by lake water. The outlets are welded in the upward direction, the inlets are flange-sealed. Each pump is connected to an electric motor by a gear sleeve of a thick lubricant to a three-phase synchronous closed-loop cooled electric motor, see Table 5.25 [41].

5.5.3.7 Main Feeder

The main feeder consists of three parallel lines (one in reserve), their inlets and outlets interconnected. Each of the lines contains:

- mechanical filter,
- control valve,
- check valve,
- two isolating gate valves.

Solid particles are filtered out by an upright hermetic-vessel filter with a spherical cover, which can be removed to replace the bed. Water flows in 500 mm diameter pipes welded to the main pipelines. Three more end-pieces of 10 mm diameter expel the air and maintain a proper pressure drop in the filtering bed. The upper part of filter is equipped with a removable grid and exchangeable filter bed, and one more removable pipe which feeds the water to the upper part to be filtered in downward flow. All these units must be replaced whenever the pressure drop across the filter reaches to 0.3 MPa, as seen in Table 5.26.

The control valves maintain proper levels of water in the separator drums. The option for manual operation of these valves is available from the MCR. Some details of the control valve are given in Table 5.27.

Check valves exclude inverse flow from the separator drums in a failure of the feed-water piping somewhere between the suction pump and the valve. The gate valves disconnect any pipe on the failure of:

- control valve,
- check valve,
- filter.

The gate valves are operated from the MCR.

5.5.3.8 Auxiliary Feeder

The AFWPs feeds water into the separator drum via two pipes (219 x 13) mm and are connected into the feedwater piping downstream of the main feeder. The auxiliary pumps supplies the water to the emergency feeder which contains:

- two isolating gate valves,
- one mechanical filter,
- two control valves,
- one check valve.

The equipment operates in the same manner, as the respective equipment in the main feeder, but for their operation parameters. The characteristic of filter and control valve are present in Tables 5.28, 5.29.

5.5.3.9 Mixers

Feedwater piping includes mixers for the feedwater and the return by-pass water from PCS to prevent thermal shocks when purified cooled water is supplied into the hot feedwater piping. Some details of the mixer are given in Table 5.30.

5.5.3.10 Valves in the Feedwater Piping

All valves are manufactured in the Tchechovskoj plant of energy engineering and some valves come from the former Czechoslovakia. Most important among them are control valves in the pressure piping of both the main and the emergency pumps. They ensure reliable operation of the pumps in their parameter ranges even with underpressure in the suction header. Details are given in Table 5.31. Similar type 1046-250E control valves are installed in the pressure piping of the auxiliary feed water pumps, they are specified in Table 5.29.

Table 5.26 Specifications of the filter (type-2200.T6.76TU)

Number per reactor	6
Capacity at 4200 MW (th) power, kg/s	514-531
Nominal volume, m^3	2
Filtration surface area, m^2	9.11
Actual filtration surface area, m^2	0.723
Pressure drop in a clear filter, MPa	0.057
Admissible pressure drop, MPa	0.3
Minimum size of removed particles, mm	0.1
Operation absolute pressure, MPa	11.8
Operation temperature, ^oC	190
Mass of the filter bed, kg	15
Heating and cooling rate, $^oC/h$	120
Admissible wall temperature, ^oC	200
Nominal pipe diameter, mm	500
Overall dimensions, mm:	
- length	2190
- width	1610
- height	3550
Mass, kg	12800
Reliability:	
- average time between major servicing, h	80000
- lifetime, years	30
- admissible overload cycles in lifetime	< 600

Table 5.27 Specifications of the control valve (type - 1046-500-E1, manufacturer - Tchechovskoj Plant of Energy Engineering, Russia) for main feeder

Number per reactor	6
Nominal flow diameter, mm	500
Operation pressure, MPa	11.8
Operation temperature, ^oC	190
Pressure drop, MPa	1.0
Maximum shaft torque, N.m	900
Control unit:	
- type	876-E-0-05
- power, kW	4.3
Complete closing and opening time, s	80
Mass, kg	2550

Table 5.28 Specification of the filter (type - 550.T6.77TU)

Number per reactor	2
Capacity, kg/s	153
Nominal diameter of end pieces, mm	250

Table 5.29 Specification of the control valve (type - 1046-250-E, manufacturer - Tchechovskoj Plant of Energy Engineering, Russia) for auxiliary feeder

Nominal flow diameter, mm	250
Operational absolute pressure, MPa	11.8
Operational temperature, ^oC	250
Pressure drop, MPa	0.98
Maximum shaft rotational moment, N·m	470
Control unit:	
- type	793-ER-02-02
- power, kW	1.7
Complete closing and opening time, s	53
Mass of equipment, kg	737

Table 5.30 Specification of the mixer

Number per reactor	4
Outlet (feedwater) flow rate, kg/s	514-531
Temperature of feedwater, ^oC	177-190
Flow rate of purified water, kg/s	≤ 27.8*
Temperature of purified water, ^oC	30-245
Nominal pressure, MPa	7.4

* At 4200 MW (th) power

5.6 PURIFICATION AND COOLING SYSTEM

There are two systems which maintain the necessary quality parameters of the MCC coolant:

- Water Cooling System,
- Water Purification System.

The water purification system (bypass filters) is intended to fulfill the following tasks:

- maintain coolant quality at levels which provide reliable operation of fuel elements and equipment,
- purify the MCC water eliminating corrosion products and soluble salts,
- control the level of coolant radioactivity,
- provide water for flushing the MCC for maintenance operations.

The water cooling system performs the following functions:

- pre-cools the coolant of the MCC to 50 ^oC, directs it to the bypass filters of the water purification system and returns it back to the MCC, during either normal or transient operation of the reactor,
- supplies the coolant to the reactor during a normal shut-down and in an emergency,
- maintains forced circulation cooling of the reactor core during servicing,
- cools excess water to 50 ^oC and discharges it into the deminiralized water-storage tank during start-up of the reactor,
- supplies cold water to the auxiliary units.

Table 5.31 Specification of the control valve (type - 1046-400-E, manufacturer - Tchechovskoj Plant of Energy Engineering, Russia)

Nominal flow diameter, mm	400
Operation absolute pressure, MPa	11.8
Operation temperature, ^oC	250
Pressure drop, MPa	0.98
Maximum admissible pressure drop ,MPa	6.50
Maximum shaft rotational moment, N·m	1840
Control unit:	
- type	B.099.102-05M
- power, kW	8.5
Complete closing and opening time, s	47
Mass of valve, kg	2531

In normal operation, the PCS extracts cooling water at flow rates up to 111 kg/s. Operating parameters of the coolers are adjusted to match those of the filters, for which the inlet temperature should not exceed 50 ^oC.

A simplified overview of the PCS is shown in Fig. 5.15. Two type CNR-500-115 electric pumps (7) circulate the water in the PCS during start-up or shut-down of the reactor. These pumps are not utilized in normal operation of the reactor. Two regenerators, each consisting of six sections (8) are used to heat the water returning from the bypass filters of the water purification system. Two additional coolers (9) cool the bypass flow upstream of the filters using the coolant of the intermediate loop.

During normal operation of the reactor, the water is taken from pressure headers (5) at a rate of about 111 kg/s and a temperature of 255^oC - 265^oC. It is cooled down in the regenerator (8) to 68^oC by the returning purified flow, and post-cooled in (8) to 50^oC, before being directed to the filter. The purified water is passed through the regenerator (8) to be heated up to 240^oC and through the mixer to be mixed with the feedwater, and finally arrives at the separator drum (1). A control valve and a flowrate meter control both the flowrate and the temperature of the purified coolant. The bypass filters are disconnected as soon as the temperature exceeds 60^oC.

The PCS pump is a centrifugal horizontal single-step pump with the two-gear wheel mechanically sealed at the ends. The particulars are given in Table 5.32 [41].

An individual regenerator is a surface type, horizontal shell-and-tube heat exchanger, made up of two parts, each of which consists of three sections. The specifics of which are shown in Table 5.33 [46].

Another cooler is a surface type, horizontal shell-and-tube heat exchanger. Details of the cooler are listed in Table 5.34 [46]. The bypass filters of the water purification system ensure that the properties of the coolant listed in Table 5.35 [35,36] are maintained.

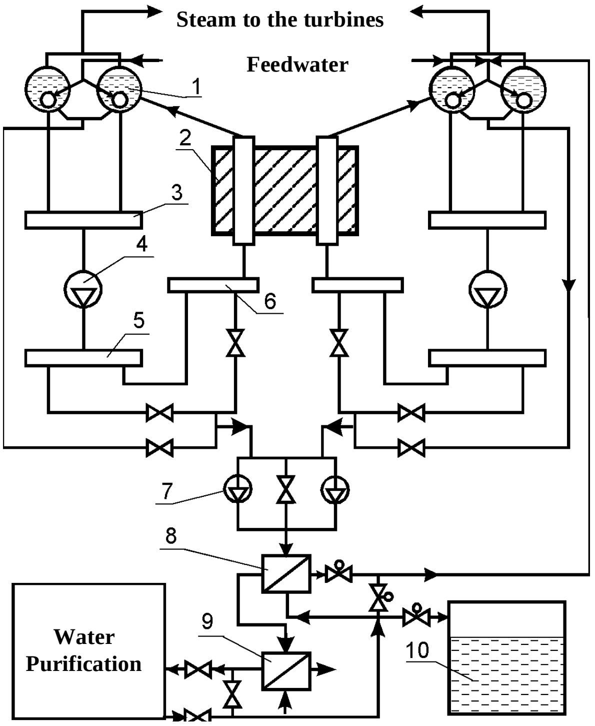


Fig. 5.15 A schematic representation of purification and cooling system
1 - separator drum, 2 - reactor, 3 - suction header, 4 - main circulation pump, 5 - pressure header, 6 - group distribution header, 7 - PCS pump, 8 - regenerator, 9 - additional cooler, 10 - deminiralized water storage tank

Two types of bypass filters are used to purify water below 60°C, namely:

- Mechanical perlite filter beds remove corrosion particles and lubricants. During normal operation the perlite bed is regenerated every ten days. During transient operation modes, when the fouling rate of the coolant increases it is regenerated daily.
- Combined ion exchangers remove dissolved salts and fission product contamination. The kationide KU-2-8ChS and ionide AB-17-8ChS beds 1:1 is designed for the nuclear industry. The filtering material is not regenerated.

One of the four mechanical filters is always is in operation, while of the two ion exchangers one is active. The operating ion exchanger is succeeded by one more filter to protect the MCC from solid particles in case of disintegration of the drain grid of the ion exchanger. They are similar to the mechanical filters, but do not have an accumulating layer. Operation with mechanical filters only is possible while replacing the ion exchangers or while the inlet temperature exceeds 90 °C. Since they are low-pressure units, the filters are protected from the pressure of the MCC by either gate valves with control drainage or by safety valves.

Table 5.32 Purification pump [41] (type - CNR-500-115, manufacturer - Frunze Scientific and Industrial Union, Sumy, Ukraine)

Number per reactor	2
Capacity, m^3/s (m^3/h)	0.0555-0.1389 (200-500)
Head, MPa (kgf/cm^2)	
- for 0.0555 m^3/s	12.36 (126)
- for 0.1389 m^3/s	9.81 (100)
Absolute inlet pressure, MPa	0.2-7.8
Water temperature range, °C	15-284
Actual power:	
- for 0.055 m^3/s, kW	144
- for 0.1389 m^3/s, kW	224
Efficiency for 0.1389 m^3/s, %	73
Cavitation margin, MPa (m)	0.167 (17)
Sealing flow rate, kg/s	1.53
Flow rate of leak water, kg/s	0.83
Flow rate in the intermediate sealing loop, kg/s	0.055
Electric motor:	
- type	AZM1-500/6000UChL4
- power, kW	500
- voltage, V	6000
- rotational speed, rpm	2985
- cooling water flow rate, kg/s	1.81
- mass, kg	3000
Overall dimensions:	
- length, mm	1515
- width, mm	1080
- height, mm	850
- total mass, kg	4950
Average time between major servicing, h	10000

Table 5.33 Specification of the regenerator [46]

Number per reactor	2	
Heat transfer surface area, m^2	1284	
Heat transfer rate (power), MW	53.7	
Hydro - testing pressure, MPa	13.8	
Tube outside diameter, mm	12	
Wall thickness, mm	1.2	
	starting operation	nominal power operation
- flow to the filter (tube internals)		
flow rate, kg/s (t/h)	55.5 (200)	55.5 (200)
inlet temperature, °C	70-284	260
outlet temperature, °C	70-124	68
absolute inlet pressure, MPa	1.08-9.1	9.1
pressure drop (tube internals), kPa	202	202
- flow from the filter (tube externals) flow rate, kg/s (t/h)	30-55.5 (100-200)	55.5 (200)
inlet temperature , °C	50	50
outlet temperature , °C	70-269	245
absolute inlet pressure , MPa	0.3-7.9	7.9
pressure drop (tube externals), kPa	18.5-57	57

Table 5.34 Specifications of the additional cooler [46]

Number per reactor	2		
Heat transfer surface area, m^2	292		
Heat transfer rate (power), MW	4.16		
Hydro - testing pressure, MPa	13.8		
	starting operations	nominal power operations	cooldown operations
- flow to the filter (tube externals) flow rate, kg/s (t/h)	55.5 (200)	55.5 (200)	125 (450)
Inlet temperature, ^oC	124	68	180
outlet temperature, ^oC	50	50	-
absolute inlet pressure, MPa *	< 2.8	< 9.1	< 2.5
pressure drop (tube externals), kPa	4.0	4.0	79.0
cooling water flow (tube internals) flow rate, kg/s (t/h)	375 (1350)	65 (234)	576 (2075)
maximum inlet temperature, ^oC	35	35	35
maximum outlet temperature, ^oC	46.1	50.4	-
maximum pressure, MPa *	0.4-0.7	0.4-0.7	0.4-0.7
pressure drop (tube internals), kPa	24.0	1.0	108.0

* Absolute pressure

The mechanical filter has the form of an upright cylinder with a removable flange sealing on the top and with welded elliptic ends. The top cover is removed for replacing and servicing. The filtration element has the form of a cylinder and is filled with perlite. Table 5.36 [19, 44, 45] shows some of the technical specifications of the mechanical filters.

The ion exchanger is a single upright vessel consisting of a housing plus upper and lower distributors. The housing is a welded cylinder with welded elliptic ends. The specifications of the filters are given in Table 5.37 [19,44,45].

The filtering material in the ion exchanger filters is not regenerated. The spent material is removed and stored. The covers and the valves are manufactured in the Tchechovskoj plant of energy engineering, some valves were manufactured in the former Czechoslovakia.

Table 5.35 Specifications of water quality [35,36]

	pre-filter	post-filter
Water pH at 25 ^oC	6.5-8.0	-
Relative electric conduction, µS/cm	≤ 1.0	≤ 0.1
Calcium hardness, µg(equiv.)/kg	≤ 5.0	
Bulk chloride ion concentration, µg/kg	≤ 70	≤ 3
Bulk mineral oil concentration, µg/kg	≤ 100	≤ 100
Bulk iron concentration, µg/kg	≤ 50	≤ 10
Bulk silica acid concentration, µg/kg	≤ 700	-
Bulk copper concentration, µg/kg	≤ 20	≤ 2
Bulk oxygen concentration, µg/kg	-	≤ 15

Table 5.36 Specifications of the filter [19,44,45] (type - AFNP-1.2-9.0, manufacturer - Industrial Union "Krasnij Kotelshik", Taganrog, Russia)

Number per reactor	4 operational + 1 in reserve
Capacity, kg/s:	
- normal operation	27.8
- maximum	69.4
Absolute pressure, MPa :	
- operational	9.35
- hydraulic testing	12.0
Dimensions, m:	
- diameter	1.30
- height	3.00
Filtration surface area, m^2	25
Filtering bed:	
- number	150
- dimensions, mm:	
diameter	55
length	1055
Mass, kg	8300
Pressure drop, MPa	< 0.4
Filtration factor for corrosion products:	
- normal operation	3-5
- transient operation	20-100
Pre-regeneration lifetime, hours:	
- normal operation	240
- transient operation	12
Filtration rate, m/h	4
Erosion rate of perlite bed, m/h	2.4
Annual consumption of perlite, t/year	2.4
Reliability:	
- average time between major servicing, h	24000
- average regeneration time, h	200
- lifetime, years	30
- overall number of refills	< 600

5.7 CONTROL ROD COOLING CIRCUIT

The piping of Control Rod Cooling Circuit (CRCC) cools the channels of the CPS rods, fission chambers, Power Density Distribution Monitoring System (PDDMS) sensor and Radial Reflector Cooling Channels (RRCC). The coolant must be distributed in the circuit to ensure that proper temperature fields prevail in the channels of the control meters and of the graphite moderator. This cooling circuit includes:

- 121 CPS channels containing control rods and safety instrumentation,
- 4 fission chamber channels, into which fission chamber cassettes are inserted during reactor start-up, (these chambers are removed during operation),
- 20 channels containing the in-core Power Density Sensors of the Axial Monitoring (PDMS-A),
- 156 channels of RRCC.

Other parameters of the cooling loop are presented in Table 5.38 [2,35,37,36].

Table 5.37 Specification of the ion exchanger [19,44,45] (type-AFI-2.4-9.0, manufacturer-Industrial Union "Krasnij kotelshik", Taganrog, Russia)

Number per reactor	1 operational + 1 in reserve
Capacity, kg/s	55.5
Absolute pressure, MPa :	
- operation	9.35
- hydraulic testing	11.7
Diameter, m	2.40
Filtration surface area, m^2	4.5
Height of filtration bed, m	1.00
Volume of filtration bed, m^3	5.3
Filtration bed:	
- kationite	KU-2-8ChS
- anionite	AV-17-8ChS
Mass, kg	26900
Overall hydraulic drag, MPa	< 0.4
Filtration factor:	
- dissolved resins	10-100
- non-volatile isotopes	10-100
Volume ratio of filtration material (purified water /filtration material)	80000
Filtration rate, m/h	45
Annual consumption of filtering materials, t/years:	
- HNO_3, 60%	1.0
- NaCH, 42%	1.3
Reliability:	
- safe operation time in the starting period, h	2000
- accrued operation time, h	20000
- average operation pre-repair resource, h	24000
- lifetime, years	30
- number of refills	< 600

The cooling in this circuit, Fig.5.16, is gravity driven. Water flowing from the top tank (1) penetrates the strainer (2) and arrives at the pressurized distribution header (3). From the distribution header the coolant is distributed along pipes which contain control valves and flow-rate meters to the channels. Outlet water from the channels of the control rods, of the PDDMS sensor and of the fission chambers is collected by the discharge piping and directed to a compartment underneath the reactor.

The RRCC are the peripheral channels within the radial graphite moderator.

Table 5.38 Specification of the CRCC [2,35,36,37]

Overall flow rate , kg/s	333
Flow rate , kg/s:	
- CPS channels, fission chamber channels, PDDMS sensor channels	1.05-12.4
- RRC channels	0.41-0.69
Emergency flow rate reduction in arbitrary channel, kg/s	0.97
Emergency flow rate augmentation in arbitrary channel, kg/s	1.39
Water temperature of the circuit, ^oC:	
- inlet	40
- outlet pre-cooling	70
- maximum admissible outlet temperature	85
- average reactor outlet temperature from the RRCC	65
- maximum allowable outlet temperature from the RRCC	90
Maximum temperature inside servomotors of the CPS, ^oC	<85
Absolute pressure in the distribution header, MPa	0.4
Channels of Fast-Acting Scram (FAS) rods:	
- flow rate of nitrogen per channel, m^3/h	0.12-0.70
- excess inlet nitrogen pressure , kPa	0.98-4.9
- maximum admissible concentration of hydrogen, %	5
Inlet purification flow-rate, kg/s:	
- operational	0.55-2.78
- starting after a long shutdown	5.55
Water quality:	
- bulk chloride ion concentration, μg/kg	50
- bulk iron concentration, μg/kg	100
- bulk aluminum concentration, μg/kg	100
- bulk mineral oil concentration, μg/kg	100
- water pH at 25 ^oC	4.5-6.2
Recovered water flow rate in coolers, kg/s	794
Temperature of recovered water, ^oC:	
- inlet	< 28
- outlet	40
Emergency cool-down, with main pumps disconnected, s	300-420
Maximum admissible concentration of hydrogen of the top and bottom tanks, %	0.4

These special type channels maintain a counter-current flow. Cold water is carried downward a central pipe and then returns in up-ward flow along the annulus. From there, the water is carried down under the reactor, to the return pipes and ends up in the distribution header (7) of the cooling circuit. The channels which contain fast-acting scram rods, are cooled by flow of falling film. Nitrogen is supplied from the top into these channels to purge hydrogen, which is generated by radiolysis. The outlet steam-water mixture flow is accumulated in a separate header and flows down into the bottom tank, passing the coolers. The distribution header (7) of the cooling circuit distributes the coolant water to four coolers (8), two of which are sufficient for normal operation, the others are on stand by and can be serviced. The coolant accumulated in the bottom tank (10) is cooled by recovered water where it is accessible to suction pumps (11). The bottom tank, 3 m below these pumps is pressurized. Special connection pipes lie between the outlet of the coolers and the inlet of the pump, so that when necessary the bottom tank can be disconnected. From the pressure side pipes of the pump, water arrives via strainer (2) into pressure header (12), and is carried up by the pressure piping (15) to the top tank, which is above the reactor. Pumps operate to assure that excess water is available in the top tank. This excess water flows by means of an overflow pipe (17) to the bottom tank.

When reactor start-up is initiated from a dry circuit, it must be filled by purified deminiralized water via piping (9). Another source to fill the circuit is the condensate from the header of the second pumping stage. In normal operation the water is continuously purified by taking portions from pressure header (12) and piping (13) into the intermediate tank, and by returning via (9). For repairs the circuit water must be removed from both the piping and the bottom tank. This is accomplished by discharge pump (14). Hydrogen from the spaces between the top and the bottom tank is removed by the ventilation system (16). Air flow of 0.5 kg/s is supplied to the air space above the top tank. The air is then purified and vented through the chimney. A suction ventilation of 0.2 kg/s is used in the bottom tank. There are the alarm instrumentation for hydrogen content in control rod cooling circuit tanks (one alarm sensor per tank). These monitors are used to measure hydrogen concentrations and to prevent the buildup of potentially explosive hydrogen levels.

5.7.1 Top Storage Tank

The top storage tank contains up to 180 m^3 of water for emergency cooling. The water inventory of this tank is sufficient that in the event of failure of the CRCC circulation pump, gravity fed water from this tank can provide cooling to the CPS channels for 5 to 7 minutes. The two parts of the tank are in separate compartments and constitute concrete enclosures lined with steel sheets 3mm thick on the sides and 5 mm thick at the bottom, with piping and instrumentation. The two parts operate as one top tank. Design parameters are specified in Table5.39 [37].

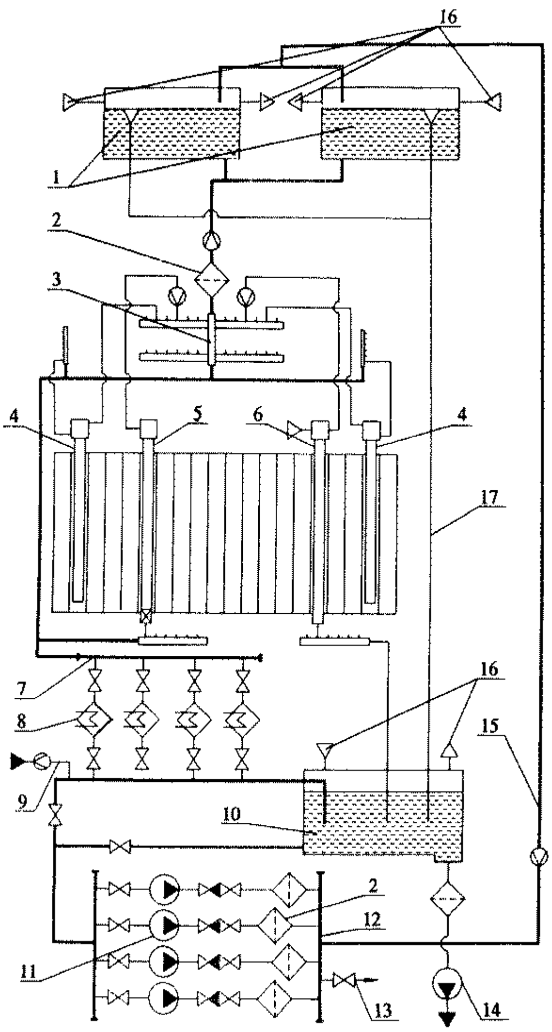


Fig. 5.16 Control rod cooling circuit
1 - top storage tank, 2 - strainer, 3 - distribution header, 4 - radial reflector cooling channels, 5 - channels for CPS control rods, fission chambers, PDDMS sensors, 6 - FAS rod channels, 7 - distribution header, 8 - coolers, 9 - filler piping, 10 - bottom storage tank, 11 - CRCC pumps , 12 - pressure header, 13 - bypass purification inlets, 14 - discharge pump, 15 - pressure pipe, 16 - ventilation of storage tanks, 17 - excess water sink overflow pipe

5.7.2 Distribution Piping

Two pipes, coming from the top tank, carry the water to the distribution header. The pipes are 300 mm nominal diameter and are joined to a single pipe (426 x 8) mm. The header is preceded by a flow-rate meter and a strainer of 400 mm nominal diameter for both coarse and fine filtration. The pressurized distribution header directs flows to individual channels. This is a cylinder (426 x 8) mm with four perpendicularly positioned headers made up of two pipes (219 x 10) mm. Individual pipes carry the water to each channel containing control rods, PDDMS sensor, fission chambers and RRCC.

Table 5.39 Specification of the top tank [37]

Dimensions of one part, m:	
- width	2.00
- length	5.90
- height	9.45
Total amount of water stored, m^3	180
Water level from the of the tank, m	7.6

5.7.3 Connections between the Instrumentation Channels and the Heat Exchangers

The circuit contains three types of headers:

- headers for the outlet water from the channels of control rods, PDDMS sensor and fission chambers. These headers (325 x 12) mm are Y-shaped with identical branches of (325 x 12) mm size,
- headers for the water flows from the channels of fast-acting scram control-rods,
- header for the outlet water from the channels of the radial- reflector cooling channels. These consist of pipes (219 x 10) mm with 13 smaller pipes (76 x 4) mm welded to the first pipe. This header and the distribution header are on the same level. The outlet pipe (159 x 6) mm carries the water to the general header to be mixed with the water from the CPS control rods and other channels.

The general header gives the water to the outlet pipe (426 x 8) mm to the distributor header (428 x 8) mm. The water is distributed to the individual coolers by pipes (325 x 12) mm. Each heat exchanger is preceded by a manual operated gate valve.

5.7.4 Coolers

The circuit includes four coolers which are horizontal shell-and-tube heat exchangers and are cooled by the recovered lake water in the tubes, to cool a shell-side (outside) flow of the coolant. The specifications are shown in Table 5.40 [37].

Table 5.40 Specification of the coolers [37]
(type - 1200TNG-1-6-M8 / 20G-6-1)

Number per reactor	4
Heat transfer surface area, m^2	671
Shell-side pressure, MPa	1.0
Tube-side pressure, MPa	1.0
Length of shell, m	5.942
Average diameter of shell, m	1.200
Wall thickness of shell, mm	8
Diameter of tube sheet, m	1.240
Thickness of tube sheet, mm	30
Number of tubes	1801
Length of tubes, m	6.000
Outside diameter of tubes, mm	20
Wall thickness of tubes, mm	2
Volume of tubes, m^3	2.715
Volume of shell, m^3	3.109

5.7.5 Connections between the Coolers and the Circulation Pumps

The piping from the coolers leads to the bottom storage tank. The tank feeds the water via four pipes (426 x 8) mm into the pumps. Each pump is preceded by a manually operated gate valve. To circumvent the bottom tank, a bypass piping (325 x 12) mm facilitates the operation.

5.7.6 Bottom Storage Tank

The bottom tank stores the coolant previously heated in the channels and cooled in the coolers. Also it stores excess water from the top storage tanks. Since this tank is at a higher elevation, it creates a higher static suction head for the pumps. This is a concrete tank covered by steel sheets with a bottom drain. Any leakage is controlled and accumulated. The tank is lined with steel sheets 3 mm thick on the sides and 4 mm thick on the bottom, specifications of the tank are provided Table 5.41 [37].

Excess water can be sent to the deminiralized water storage tank by four parallel pipes, each containing an electrically powered gate valve.

5.7.7 Circulation Pumps

The circulation pumps unit consist of a horizontal centrifugal single-stage pipe with a double sided rotor and a spiral shell, and an electric motor installed on a common foundation, as specified in Table 5.42 [37].

Table 5.41 Specifications of the bottom storage tank [37]

Operation volume, m^3	300
Width, m	4.8
Length, m	10.9
Height, m	6.6
Bottom level, m	-7.2
Water level from the bottom of the tank, m	1.2-2.0

Table 5.42 Specifications of the pump [37] (type 8NDV-Ch-U4 (D630-90K), manufacturer - Industrial Union "Livgidromash", Livny, Orel district, Russia)

Number per reactor	4
Capacity, m^3/s	0.175
Head, MPa	0.883
Cavitation margin, m	5-8
Efficiency, %	75
Diameter of rotor, mm	525
Pumping power, kW	200
Pressure in suction, MPa	0.3
Electric motor type	A03-355-54
Rotational speed, rpm	1450
Electric motor power, kW	250

Voltage, V	380
Mass of electric motor, kg	2535
Mass of pump unit, kg	3410

A reliable electric circuit is connected to the electric motors. The pumps are operated from the MCR. Safe operation of the pumps is facilitated by pressure-cooled bearings and elimination of hydrogen generated by radial dialysis. The bearings are cooled by pure deminiralized water from the feedwater piping.

5.7.8 Connections between the Pumps and the Top Tank

Pump outlet pipes (325 x 12) mm, each pipe contains a strainer, a check valve, an electrically powered gate valve, and a flow-rate meter. The strainer of replaceable nets (of 1.6 x 1.6 mm and 0.63 x 0.63 mm grids) filter out the mechanical fouling. The gate valves are open when the pump is on standby, and are closed when the pump is in maintenance.

The pumps are under the bottom storage tanks, well below the reactor. They pump the water along pressure pipes (426 x 8) mm up to the top storage tank well above the reactor. To prevent inverse flows, the piping is extended above the water level in the top tank and is protected by a check valve.

5.7.9 Other Piping and Auxiliaries

Excess water from the top storage tank is directed via the overflow piping of two separate pipes (325 x 12) mm to the bottom storage tank. After maintenance the dry piping is filled with water and its supply is continuously renewed by deminiralized water through pipes (57 x 3) mm from one of the coolers. The pipes include manually operated gate valves and control valves with electrically operated drives from the MCR.

A separate bypass piping (57 x 3) mm takes the water from the pressure header of the pumps for purification. The bypass pipes contain an electrically operated valve, a manual operated gate valve and a flowrate meter. The purified water is returned to the main piping via a manually operated gate valve.

The gate valves disconnect the bypass from the loop, and the control valve controls the purification supply from the MCR. In the CRCC the following types of gate valves (type: MA11071-300M-07, MA11071-300M-10, MA1175-400-36-2B), check valves (19nz47nz IA-44078.02 and IA44077-400-2B), and control valves (I68055-150-26-2B) are used.

Table 5.43 Specification of the discharge pump [37] (type - Ch45/31-K-2D-U2)

Capacity, m^3/s	0.0125
Head, MPa	0.304
Cavitation margin, MPa	0.05
Maximum inlet pressure, MPa	0.5
Efficiency, %	54
Electric motor type	4A132M2
Electric motor power, kW	11.0
Rotational speed, rpm	2900

To empty the bottom tank for maintenance the discharge pump sends the water to the intermediate tank. The parameters of the centrifugal single-stage pump are described in Table 5.43 [37].

5.8 FUEL CLADDING INTEGRITY MONITORING SYSTEM

The fuel cladding monitoring system is intended to monitor fuel cladding integrity. An indicative parameter of fuel integrity is the radiation level the coolant leaving the reactor core. This is characterized by the level of activity of nuclear fission products in the steam and coolant. The fuel cladding monitoring system serves both safety and operational tasks. As a safety related system it is intended to prevent violation of the design limits or damage of fuel elements and to restrict radiation impact on personnel, population and environment. The purpose of the Fuel cladding monitoring system is to identify fuel assemblies with leaking fuel elements (fuel cladding failure) during power operation, refueling, transients modes and plane preventive maintenance. This system also helps to determine the necessity and scheduling of unplanned reloading of fuel assemblies with leaking fuel elements. In addition, it also provides redundant monitoring of coolant flowrate in fuel channels and a check of the fuel type. A schematic of the system is presented in Fig. 5.17. There are separate group monitoring and individual channel monitoring subsystems, which are structurally independent, but are related.

The group monitoring subsystem diagnoses fuel element failure with a delay no longer than 10 minutes. Upon detection of a leaking fuel element it activates the warning and alarm signaling that a violation of fuel cladding integrity occurred, and also actuates the signal which activates the individual channel monitoring subsystem. This subsystem consists of four identical monitoring trains (A1-A4). Each of these trains includes two sampling lines, a gas removal device (3), a moisture separator (4), a heater (5), and two sensors equipped with electric precipitators (6), which are separated by a delaying tank (7). Sampling lines are used to transport steam from steam lines of each separator drum into the chillier (2), where the steam is cooled and condensed. Radioactive inert gases (isotopes of krypton and xenon) are removed from the condensate by a gas removal device (3). A moisture separator (4) and a heater (5) are used to decrease the absolute and relative humidity of the gas. Condensate from the gas removal device (3) and moisture separator (4) is drained to a special drainage system. Operation of the sensors is based on electronic precipitation of ions of rubidium and cesium on a wire, which is then moved to the scintillation detector to record the beta-activity of the precipitated isotopes. The first sensor is used to monitor the total activity of radioactive inert gases, the second one, the activity of relatively long-lived isotopes. Estimation of the state of fuel cladding is based on the results of measurements of these two sensors. After passing the sensors the samples of gas are removed by a special ventilation system.

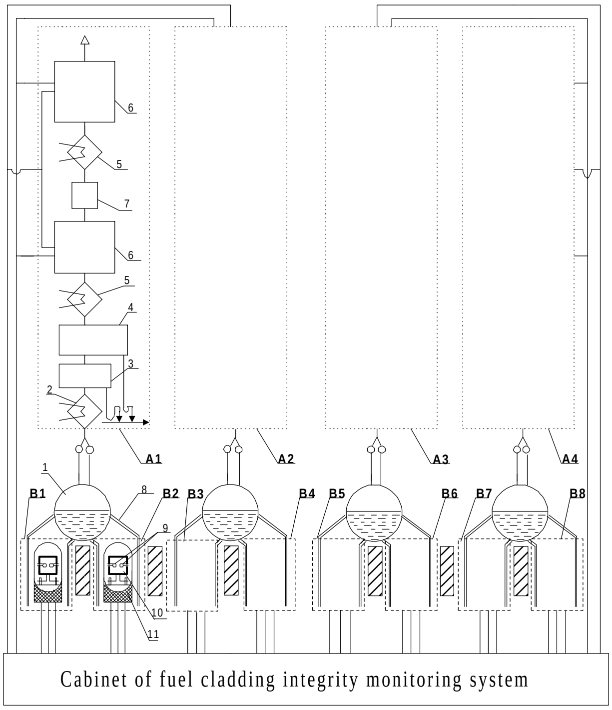


Fig. 5.17 Schematic of fuel cladding integrity monitoring system

A - the train of group monitoring subsystem, B - the train of individual channel monitoring subsystem,
1 - separator drum, 2 - cooler, 3 - gas removal device, 4 - moisture separator, 5 - heater, 5 - heater, 6 - sensor with electric precipitation, 7 - delay tank, 8 - row of steam-water pipelines, 9 - individual channel monitoring sensor, 10 - cart, 11 - box

Monitoring of fuel cladding integrity of individual channels is intended to estimate the state of the fuel cladding by recording the gamma-activity of the coolant in each steam-water pipe exiting the core block. In addition the system provides spectral analysis and is capable of identifying weather the design limits of fuel clad damage are violated. It can diagnose the type of fuel channel loading using relative changes of signal amplitude generated by the residual activity of nitrogen-16 in the steam-water piping. The individual channel monitoring subsystem consists of eight monitoring trains (B1-B8), Fig. 5.17. Each of these provides monitoring for two rows (8) of steam-water pipes going to the drum separators (1). Each monitoring train measuring the gamma-activity of the coolant in the steam-water piping includes two scintillation sensors (9). The sensors are placed in a lead protecting cover with apertures for collimation. The protecting cover is assembled on special carts (10). There are four rows of pipes supplying steam water mixture to the drum separator. Movable enclosures (11) containing the sensor assembly are guided along the rows of steam-water pipes.

The output from the group and individual channel monitoring systems of fuel cladding integrity is provided in an analog mode on paper in recording devices, signal analysis is performed using special algorithms. The design of the fuel cladding monitoring system provides two possibilities for system operation - with and without use of the plant computer system. Measurements from group and individual monitoring subsystems are checked in all ranges of reactor power. If fuel assembly with leaking fuel elements are identified by the fuel cladding integrity system, and if operational limits of fuel element damage are violated (that is activity of I-131 in MCC coolant above 4.0 10^{-6} Cu/kg, then such a fuel assembly is removed from the fuel channel. The reactor must be shut down immediately, if measurements in corresponding drum separator increase two or more times as compared to the initial value. The reactor must be shut down if the following failures of the fuel cladding integrity monitoring system are not repaired in a specific time:

- in 2 hours after a simultaneous failure of both the individual and the group monitoring subsystems,
- in 8 hours after failure of the individual channel monitoring subsystem (this assumes that the group monitoring system is functioning properly) if the following conditions exist: in the row of pipes being monitored there are fuel channels loaded with fuel assemblies for which the “Coolant flow reduction” signal is activated or for which the flow meter has failed.

5.9 MATERIALS

The materials must be weldable, suitable for operation in radioactive environment and in other aggressive media. A list of materials used in MCC construction is given in Table 5.44.

Table 5.44 Materials

Element	steel type, unless otherwise specified
Materials of pressure tubes	
Group distribution headers	08Ch18N10T
Cases of control valves	17247.4
Water piping	08Ch18N10T
Fuel channel:	
- lower	08Ch18N10T
- core	zirconium-niobium alloy (Zr+2.5%Nb)
- upper	08Ch18N10T
Steam-water piping	08Ch18N10T
Materials used for the steam separation parts	
-Separator drum:	
- case- two-layer steel sheet	22K-Sv-08Ch18N10G2B or 22K-08Ch18N10T
- steam piping and steam-zone connection outlets feed-water pipes	22K-VD
- outlets for downcomers water zone connections	22K-VD, 08Ch18N10T
- outlets for steam-water mixture flow pipes	22K, 08Ch18N10T
- internal units	12Ch18N10T
Connections between drums in the steam zone	st. 20
Connections between drums in the water zone	08Ch18N10T
Downcomers	08Ch18N10T
Suction header:	
- case	19MN5 (Japan)
- end pieces	22K-08Ch18N10T
- outlets	22K, 08Ch18N10T
Materials used for the forced circulation	
Main circulation pump tanks	15Ch2MFA
Suction and pressure pipes of the MCP:	
- pipes	19MN5 (Japan)
- gates	22K-VD
- check valves and throttle control valves	st.20
Pressure header:	
- vessel	19MN5 (Japan)
- covers	22K-08Ch18N10T
- outlets	22K, 08Ch18N10T
Pipes between suction and pressure headers:	
- pipes	08Ch18N10T
- gates, reverse, valves	17247.4 (Czechoslovakia)
Materials used in the steam piping	
Main steam pipes	16GS
High pressure steam loop	st.20
Other pipes	st.20
Framework (SDV-C, SDV-A, MSV):	
- casings	st.20
- covers	st.20, 20ShTU108-667-77

Continue Table 5.44

Materials used in the feedback system	
Condensate pumps of first stage:	
- pump rotor	20Ch13L-1
- shaft	40Ch
- shell	20K, VSt3sp5, VSt3sp2
- pump stator	20Ch13L-1
- casing	20Ch14
- pressure cover	09G2S-6
- safety bushing	20Ch13
- bearing shell	20Ch13
- sealing ring	20Ch13
- first stage rotor	20Ch13L-1
Condensate pumps of second stage:	
- pump rotor	20Ch13L-1
- shaft	40Ch
- shell	20L-III and 25L-III
- safety bushing	20Ch13
- sealing ring	20Ch13
- bracing pin	35ChM
Pre-heater:	
- material of shell	08Ch18N10T
- material of tubes	08Ch18N10T
Deaerator:	
- vessel	08Ch18N10T
- perforated sheets	12Ch18N10T
- other	st.20K, VSt3spK, st.20
Main feed water pumps:	
- housing and cover	st22K, st22K-VD, 40ChFA
- shaft	38ChM3FA
- wheel and rails	alloy 20Ch13L-1
- casing and shell	20Ch13
- seal ring	20Ch13
Auxiliary feed water pumps:	
- housing and cover	st22K
- shaft	40ChFA
- wheel and rails	alloy 20Ch13L-1
- casing and shell	20Ch13
- discharge valve	20Ch13
- hydroseal, ring seal	30Ch13
Mechanical filters:	
- housing and cover	15GS
- filtering bed	12Ch18N10T
Mixer:	15GS
Piping:	
- pipes	15GS
- housing: (Russian made)	st.20
(Czekoslovakian made)	11416.1
Materials used in the PCS	
PCS Pumps:	
- housing	12Ch18N10T
- sealed cover	12Ch18N10T
- shaft	14Ch17N2
- wheel	20Ch13L

Continue Table 5.44

Regenerator:	
- housing and covers	08Ch18N10T
- coolers	08Ch18N10T
- strainers, filters cover	08Ch18N10T
- tubes, external diameter 16 mm, wall thickness 1.2 mm	08Ch18N10T
Piping	08Ch18N10T
Intermediate loop	Vst3sp2
Vessel of AFNP-1.2-9.0 filter	08Ch18N10T
Vessel of AFI-2.4-9.0 filter	08Ch18N10T
Control valves:	
- case	12Ch18N10T
- shaft	14Ch17N2
- gate and saddle	12Ch18N10T
- sealing bed	asbesto-graphitic ring AG-50
Gate valve:	
- case	08Ch18N10T
- spindle	14Ch17N2
- sealing bed	asbesto-graphitic ring AG-50
Gate valve made in Czechoslovakia:	
- case	st.1724
- spindle	AK1N1 and st.17247
Piping	08Ch18N10T

Continue Table 5.44

Materials used in the CRCC	
Top storage tank:	
- side sheets	12Ch18N10T
- bottom sheets	12Ch21N5T
Distribution piping	12Ch18N10T
Coolers:	
- shell	two-layer 16GS + 12Ch18N10T
- tube sheet	12Ch18N10T
- tubes	12Ch18N10T
Bottom storage tank:	
- side sheets	12Ch21N5T
- bottom sheets	12Ch21N5T
Pumps:	
- housing	12Ch18N9TL
- rotor	12Ch18N9TL
- shaft	12Ch18N9T
- shell	12Ch18N12M3TL
- cover	12Ch18N12M3TL
- sealing ring	12Ch18N10T
- safety bushing	12Ch18N9T