TOMSK POLYTECHNIC UNIVERSITY

SYSTEMS AND ELEMENTS OF IRT-T RESEARCH NUCLEAR REACTOR

Workshop

Recommended for publishing as an educational and methodological manual by the Editorial Board of Tomsk Polytechnic University

Tomsk Polytechnic University Publishing House
2025

UDC 621.039.55(076.5)=111
BBC 31.46я7=432.1
S98

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S98 **Systems and Elements of the IRT-T Research Nuclear Reactor. Workshop** : educational and methodological manual / A.G. Naymushin, A.E. Ovsenev, M.K. Kublinskiy et al. ; Tomsk Polytechnic University. – Tomsk : TPU Publishing House, 2025. – 88 p.

The manual contains a description of five chapters devoted to the study of the core and tank design of the IRT-T nuclear reactor, technological systems, devices for measuring technological parameters, control and protection systems, as well as the methodology of control rod calibration. The works are carried out at the research nuclear reactor IRT-T.

It is intended for senior students studying in 14.04.02 "Nuclear science and technology" (Master's degree levels), as well as for senior students of related specialties.

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FOREWORD

The Tomsk Type Research Reactor (IRT-T), commissioned in 1967, was created as a training and research nuclear reactor. Being a powerful source of neutron and gamma radiation, it allows conducting scientific research in such areas as neutron activation analysis, pilot production of neutron-alloyed silicon, production of radiopharmaceuticals. The main advantage of the IRT-T reactor is its flexibility, both in terms of core and reflector layout and in terms of operating modes.

This laboratory workshop contains 5 chapters covering material from a range of academic disciplines within the Division for Nuclear-Fuel Cycle (DNFC) of the TPU School of Nuclear Science and Engineering (SNSE). The works are devoted to the study of the design and rules of operation of the IRT-T research nuclear reactor. The technological equipment and control and protection system of the reactor are considered, as well as operating modes and methods of determining the physical efficiency of control rods. The aim of the workshop is to form an understanding of the operation of the systems of the IRT-T research nuclear reactor, as well as the skills of nuclear reactor control.

Training at an operating reactor helps to improve the quality of training of graduates.

Chapter 1
DESIGN AND TECHNOLOGICAL FEATURES OF THE IRT-T NUCLEAR REACTOR

1.1. General description of the IRT-T reactor

1.1.1. Type and purpose of the IRT-T reactor

The IRT-T nuclear reactor is a pool-type reactor that uses demineralized water as moderator, coolant and upper biological protection. It is the only research nuclear reactor in Siberia and the Far East. IRT-T carries out research in nuclear physics, solid state physics, radiobiology, neutron activation analysis, geological and geochemical processes, and produces neutron-alloyed silicon and radiopharmaceuticals.

In 1977, due to progressive corrosion of the aluminum tank shell and corrosion of the aluminum heat exchangers, the reactor was shut down for reconstruction. In particular, a new tank made of 12X18H10T steel was installed.

Extensive modernization was carried out in 2004–2005, during which a control and protection system (CPS) based on the Mirage-MB safety modules and the Mirage-MR registration module was installed.

Modern control and measuring devices (CMD) were installed.

The reactor core is formed of fuel assemblies (FAs) of IRT-3M type, has small dimensions and is characterized by a high multiplication factor and short neutron migration length.

The use of beryllium, which has a relatively long migration length, as a reflector allows to ensure the maximum thermal neutron flux density and a high level of neutron flux in the experimental channels.

The main technical characteristics of the reactor are given in Table 1.1.

Table 1.1

Main characteristics of the IRT-T nuclear reactor

Name of characteristic	**Value**
Reactor power, MW	6
Number of IRT-3M FA in the reactor core, pcs.	20
8-tube 6-tube	11 9
Reactor core volume, l	59.3
Mass of uranium-235 loaded with "fresh" fuel assemblies, kg	5.47
Reactivity margin, % $\Delta k/k$	~ 11
Thermal neutron flux density in the center of the core, $cm^{-2} \cdot s^{-1}$	$2 \cdot 10^{14}$

The end of the Table 1.1

Name of characteristic	**Value**
Number of the rods of control and protection system (CPS), pcs.	9
emergency protection (EP) shim rods (SR) control rods (CR)	2 6 1
Total efficiency of EP, SR and CR rods, % $\Delta k/k$	~14.5
Coefficient of unevenness of energy release: along the horizontal cross-section of the core	1.78
at the height of the reactor core	1.26
Maximum energy density, kW/L	227
Maximum heat flux density, kW/m^2	427
Pressure drop across the core, kPa	35
Average coolant velocity in the fuel assembly gaps, m/s	2.88
Coolant flow rate through the core and reflector, m^3/h	700
Water temperature at the core inlet, °C	30–55
Maximum design fuel element surface temperature, °C	77
Surface boiling onset temperature, °C	123

1.1.2. IRT-reactor building and equipment

The territory of the reactor industrial site includes:

- reactor building with an annex;
- three-section cooling tower;
- transformer substation;
- three special tanks for liquid radioactive waste;
- artesian well;
- building of a booster pump station;
- workshop building;
- cryogenic station building;
- warehouses for equipment and materials.

The reactor building is a complex of technological rooms and laboratories.

The basement rooms contain pumps of the primary and secondary reactor cooling circuits, heat exchangers, water filters of the primary circuit, air filters of the special ventilation system, pipelines of the primary and secondary cooling circuits, a detention tank with a volume of 24 m^3.

On the ground (first) floor – experimental room, laboratories, water treatment system, low voltage switchboard (SchNN), special ventilation system pumps and filters, supply ventilation system pumps.

On the first (second) floor – power control panel (SchSU), laboratories.

On the third floor – reactor control room, dosimetric control room, laboratories, reactor CPS area.

On the fourth floor – the building's general exchange ventilation system, fresh fuel storage facility.

1.2. IRT-T reactor core and reflector

1.2.1. IRT-T reactor core construction

The fourth floor houses the building's general exchange ventilation system, fresh fuel storage room (Figure 1.1).

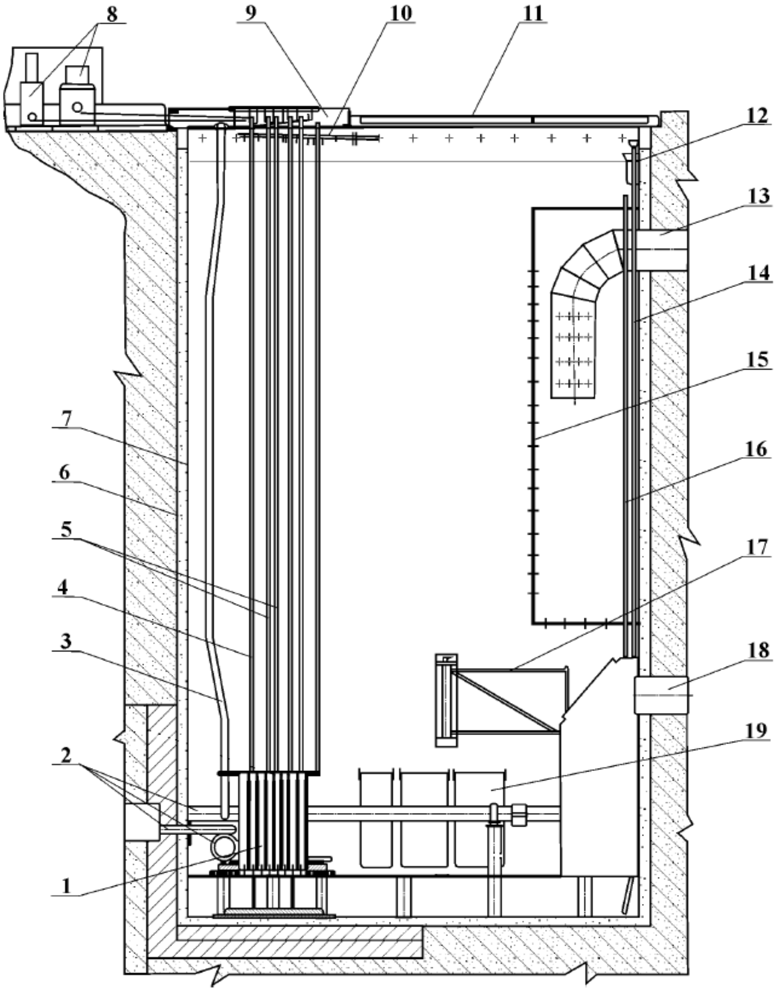

Fig. 1.1. Longitudinal section of the IRT-T reactor:
1 – reactor core; 2 – horizontal experimental channels; 3 – vertical experimental channels; 4 – channel with CPS rod; 5 – central experimental channels; 6 – aluminum tank; 7 – stainless steel tank; 8 – CPS rod drives; 9 – CPS platform; 10 – showering device; 11 – transparent decking; 12 – overflow funnel; 13 – pressure pipe; 14 – emptying pipe; 15 – distribution tank;16 – pipe for siphon disruption; 17 – fuel assembly transport device; 18 – suction pipeline; 19 – temporary storage of fuel assembly

The core is located at a depth of 6.5 meters. The core rod is made of aluminum alloy AD-1. The core rod support grid is made of SAB-1 alloy in the form of a rectangular plate with dimensions of 940×721×85 mm. The upper core rod together with the support spacing grid are mounted on a 29 mm thick stainless-steel flange. The flange is welded to the plates of the integrated retaining vessel and is additionally supported on 6 supports made of 108×5 mm diameter pipes. The supports are welded to the stainless-steel base plate from below. A 30 mm thick bottom grating for CPS channels is welded to the base plate from above. A titanium gasket is installed between the core support grid and the stainless-steel flange. The baseplate and the core bottom grill protect the concrete under the bottom of the tank from radiation heating. Titanium gaskets are installed at the contact points of aluminum alloy and stainless-steel parts to prevent corrosion of aluminum.

Fuel assemblies, beryllium reflector blocks, neutron trap blocks, and displacers are installed in the core vessel on a supporting spacing grid. The coolant passes through the core from top to bottom, which eliminates the possibility of movement of core and reflector elements. There are 56 cells in the core vessel for the installation of fuel assemblies and beryllium blocks (Figure 1.2). The four central cells are occupied by beryllium blocks, forming a neutron trap, which is designed to increase the thermal neutron flux in the center of the core by photoneutrons and to equalize the thermal neutron flux for uniform fuel burnup.

The permissible fluence of fast neutron (c E > 0.821 MeV on the surface of the support lattice) in terms of the possibility of brittle fracture is $1.6 \cdot 10^{22}$ (n/cm^2)/MW. Maximum current density of fast neutrons on the reference lattice – $0.87 \cdot 10^{12}$ (n/cm^2)/MW. Thus, the maximum fluence of fast neutrons on the support lattice will be reached in about 50 years.

Eight-tube (Figure 1.3) and six-tube (Figure 1.4) IRT-3M type fuel assemblies are used in the core. The main characteristics are given in Table 1.2.

Table 1.2

Characteristics of fuel assemblies of IRT-3M type

Characteristic	**8-tube**	**6-tube**
Fuel elements type	Three-layer, dispersive	
Fuel	UO_2	
Average burn-up depth in spent fuel assemblies, %	Not less than 40	
Fuel (uranium) enrichment, %	90	
Reactor core height, cm	60	
Uranium-235 content in fuel assemblies, g	300	265
Mass, kg	4.3	3.7

These fuel assemblies use coaxial tubular square-section fuel elements with a wall thickness of 1.4 mm. The SAB-1 aluminum alloy cladding is 0.5 mm thick each. The fuel element core consists of uranium dioxide in an aluminum matrix. A displacer with an outer diameter of 14 mm is installed inside the eight-tube fuel assembly. Either a CPS rod channel or an experimental channel with an outer diameter of 28 mm is installed inside the six-tube fuel assembly. Vertical experimental channels made of aluminum AD-1 are placed in the beryllium blocks of the neutron trap.

The eight fuel assemblies in the core and one beryllium unit in the reflector contain vertical aluminum channels that house the control and protection system rods.

The characteristics of the fuel in the fuel elements of the fuel assemblies, CPS rods and other core devices that affect reactivity preclude unplanned changes in their state that would increase reactivity or damage the fuel elements.

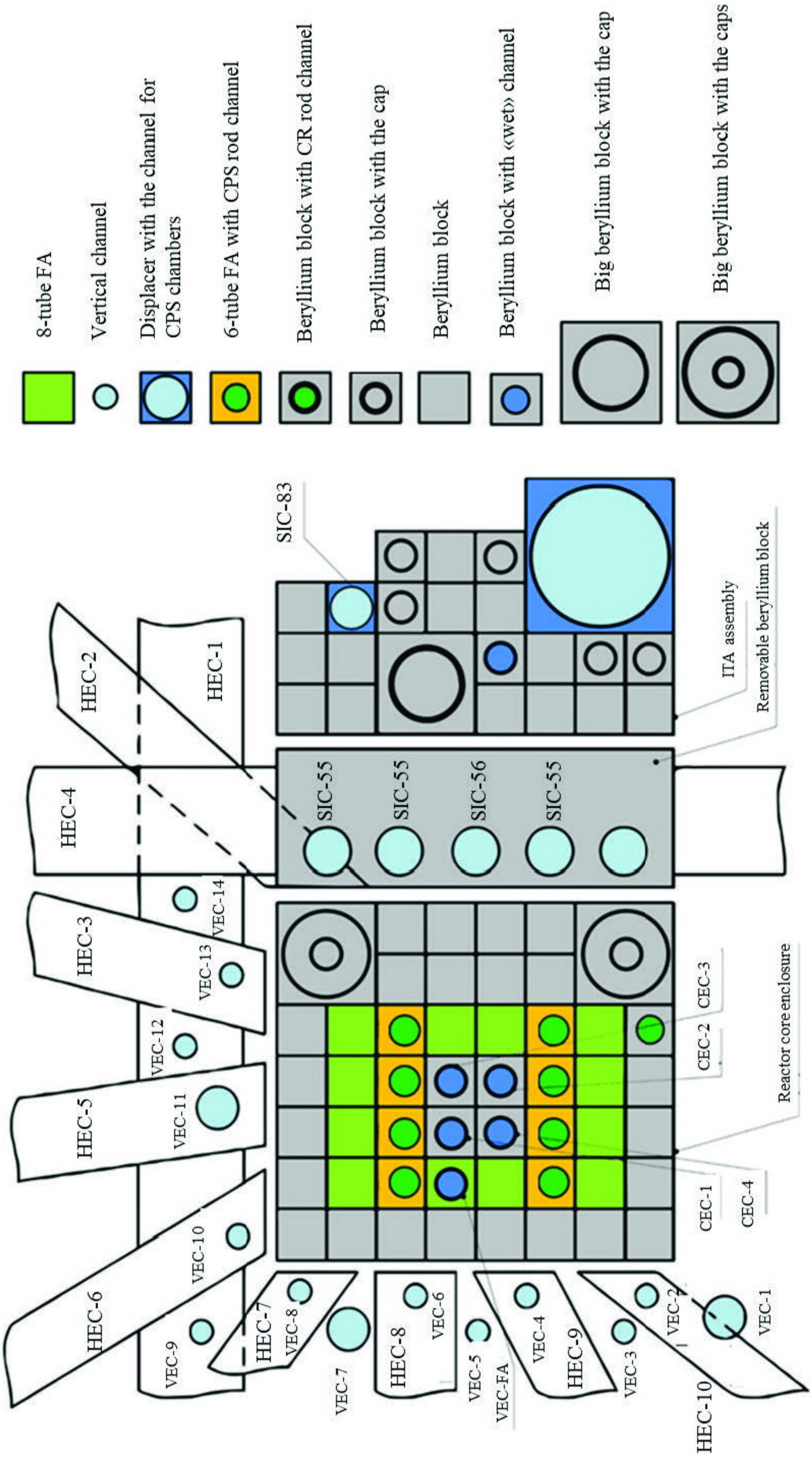

Fig. 1.2. Cartogram of the core and experimental devices of the IRT-T reactor

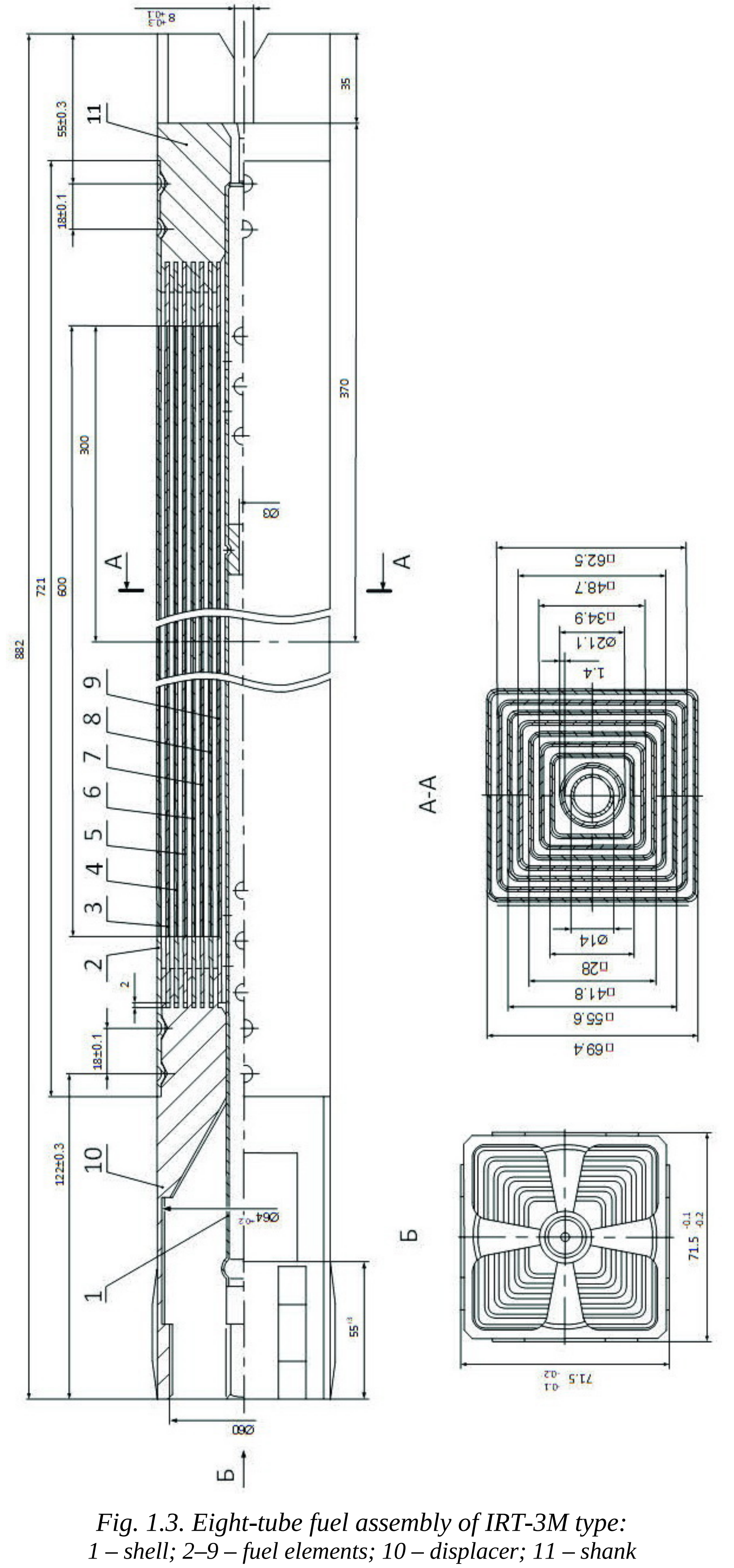

Fig. 1.3. Eight-tube fuel assembly of IRT-3M type:
1 – shell; 2–9 – fuel elements; 10 – displacer; 11 – shank

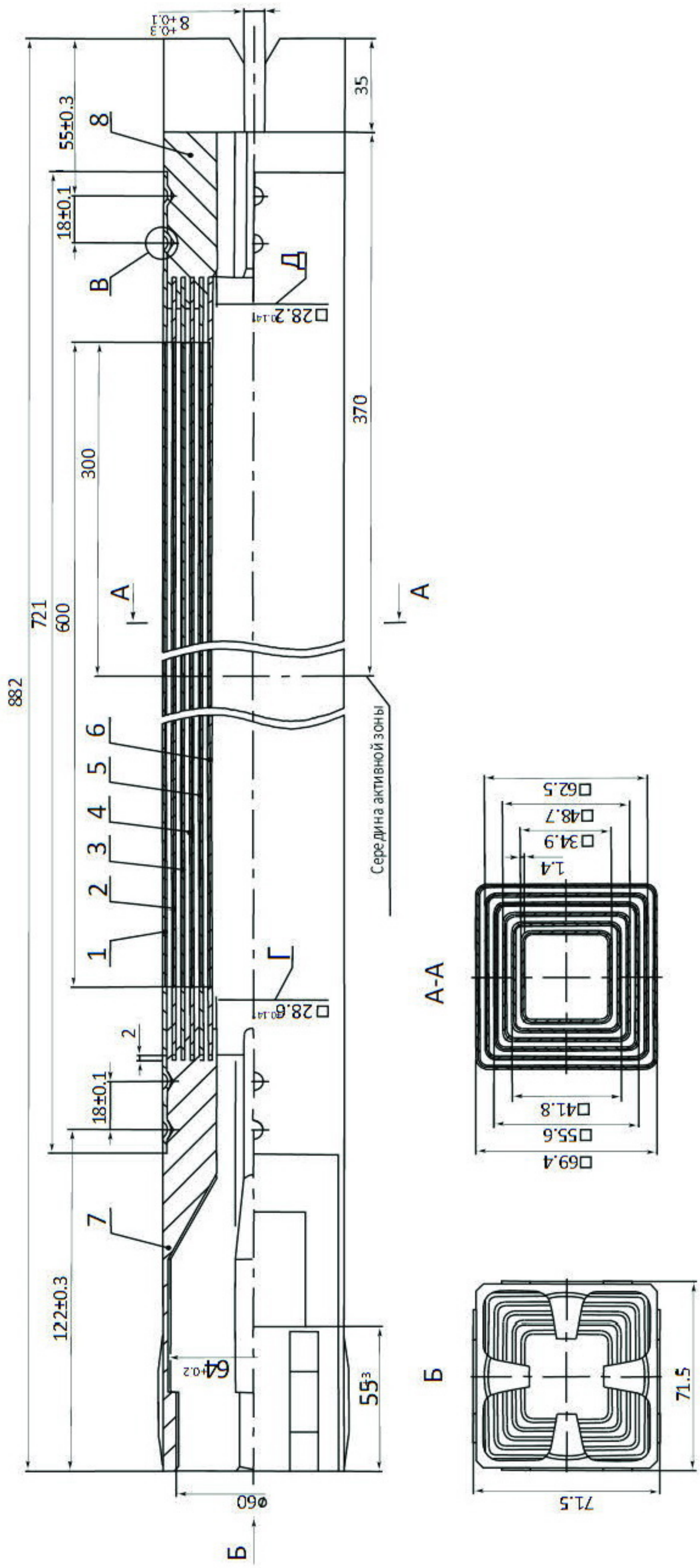

Fig. 1.4. Six-tube fuel assembly of IRT-3M type:
1–6 – fuel elements; 7 – displacer; 8 – shank

The lateral beryllium reflector is located inside the core rod and has 30 beryllium blocks, of which 28 blocks have a square cross-section of 69×69 mm and 2 blocks have a cross-section of 138×138 mm. Both solid blocks and blocks with a central hole in which a beryllium plug or an experimental channel is installed can be changed for experiments.

1.2.2. Neutron-physical characteristics of the IRT-T reactor

Neutron-physical characteristics of the reactor are determined by the use of IRT-3M type fuel assemblies, beryllium reflector blocks, as well as by the set of materials and design with a short neutron migration length.

In the core, in the reflector, in the rods of the CPS, as well as in other units of the reactor, materials with rather well studied properties are used: aluminum alloys, stainless steel, metal-ceramics, metallic beryllium.

Core loading is a certain amount of fuel assemblies so that the reactivity reserve does not exceed a certain value and at the same time sufficient campaign duration is ensured, taking into account xenon poisoning. Replacement of fuel assemblies during overloads is performed when U^{235} burn-up in the fuel assembly reaches 50 %.

Minimal critical mass of U^{235} isotope in the fuel volume – 3.01 kg. The reactor is loaded with 20 fuel assemblies, with four cells in the center of the core occupied by beryllium blocks with vertical experimental channels. An example of a typical workload is shown in Figure 1.5.

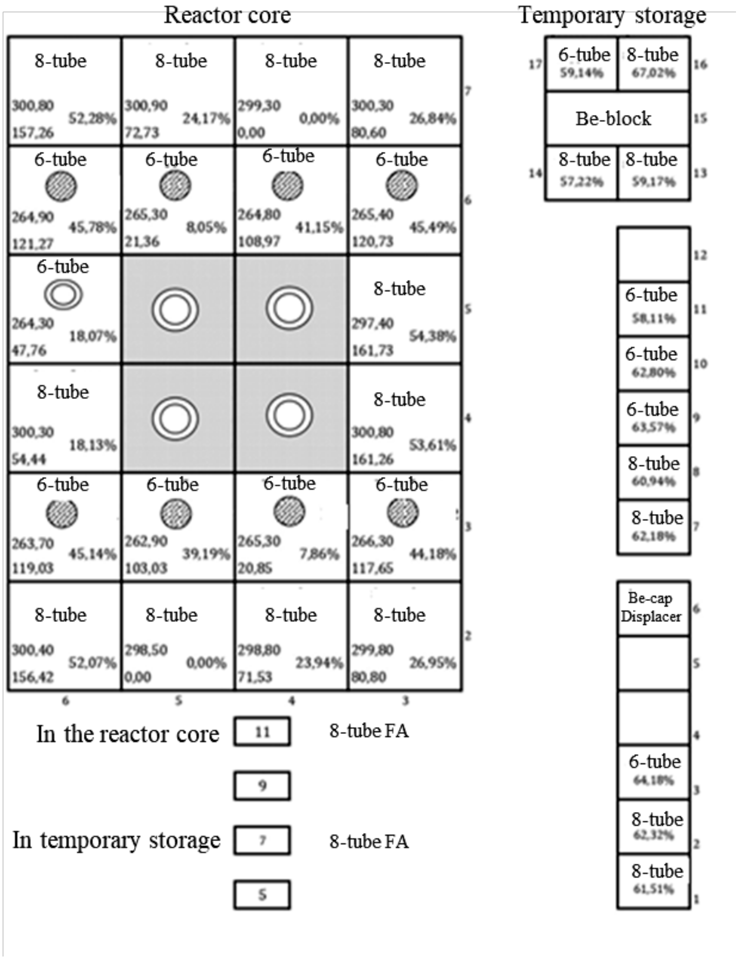

Fig. 1.5. Operating load of the IRT-T reactor

The reactor core is characterized by a sufficiently high neutron multiplication capacity $\left(k_{eff} \approx 1.07\right)$, which makes it possible to obtain high neutron-physical characteristics in experimental volumes. Some neutron-physical characteristics of the core are presented in Table 1.3.

Table 1.3

Physical parameters of the core for "fresh" loading at 20 °C

Parameter	**Cell with 8-pipe fuel assembly**	**Cell with 6-pipe fuel assembly**
U^{235} content in the assembly, g	300	265
Specific loading of U^{235}, g/liter	101.2	89.0
Cell volume occupied by water, %	62.5	54.8*
Ratio of nuclear concentrations of hydrogen and U^{235}	161	160*
Multiplication factor of the infinite lattice k_∞	1.76	1.74
Macroscopic absorption cross section Σ_a, cm^{-1} for fast neutrons for thermal neutrons	 0.004035 0.12059	 0.003643 0.10589
Product $\nu\Sigma_f$, cm^{-1} for fast neutrons for thermal neutrons	 0.005184 0.22099	 0.004606 0.19178
Macroscopic cross-section of the transition Σ^{1-2}, cm^{-1}	0.02623	0.02332
Diffusion coefficient D, cm for fast neutrons for thermal neutrons	 1.461 0.21241	 1.502 0.24457
Diffusion length square L, cm^2	1.76	2.31
Neutron age τ, cm^2	48.3	55.7

* – a channel with a displacer is installed in the center of the fuel assembly.

Reactivity balance of a working load of 20 fuel assemblies at periodic replacement of one most burned-out fuel assembly with a "fresh" one in the core (partial overload mode), % $\Delta k/k$:

- maximal reactivity margin – 11;
- equilibrium isotope poisoning Xe^{135} and Sm^{149} – 3.1;
- temperature reactivity coefficient – 0.00785;
- burnout – 1.0;
- operating margin – 1.0.

Burnout reactance reserve equal to 7 % $\Delta k/k$, allows to perform reloads after about 50 days during continuous operation of the reactor at power capacity 6 MW.

Loss of reactivity due to equilibrium poisoning with xenon-135 and samarium-149 do not exceed 3.1 % $\Delta k/k$. The time to reach maximum poisoning at the peak of the "iodine pit" is ~ 8 hours.

The temperature coefficient of reactivity is negative and its value in the operating temperature range from 20 to 50 °C is equal $0.81 \cdot 10^{-4}$ deg^{-1}. The power coefficient of reactivity cannot be measured experimentally due to its small value. According to theoretical estimates, it is negative.

Reactivity compensation is carried out by a system of rods (CPS rods) placed in six-tube fuel assemblies. With an operating load of 20 fuel assemblies, the efficiency of rods EP1 and EP2 is as follows 1.8 и 1.7 % $\Delta k/k$, SR1 rod ~ 2.63, SR2 ~ 3.54, SR3 ~ 4.34, CR ~ 0.33, total efficiency of all rods SR и CR ~ 10.84 %.

It is only possible to lift the KO1-KO3 rods out of the core in "steps". The amount of reactivity introduced per step does not exceed 0.3 β_{eff}. The rod transition speed during removal from the core of an IRT-T reactor is as follows:

- EP1 – 12.4 mm/s;
- EP2 – 12.2 mm/s;
- SR1 – 1.14 mm/s;
- SR2 – 1.14 mm/s;
- SR3 – 2.9 mm/s;
- CR in manual mode – 7 mm/s;
- CR in automatic mode – 40 mm/s.

The fall time of EP rods into the core of the IRT-T reactor is no more than 0.8 s. When the emergency protection is triggered, the SR and CR rods also plunge into the core of the IRT-T reactor at an increased speed for a time not exceeding 60 s.

Each rod is placed in an aluminum channel (tube). The channels for EP and SR rods are installed in six-tube FAs. The lower ends of these tubes are centered in a special grid. The channel for the CR rod (rod without displacer) is installed in a replaceable beryllium reflector block. The tubes of all CPS rods are "wet".

The upper ends of all channels with CPS rods are fixed in special sockets for brackets of the control and protection system platform located above the IRT-T reactor tank under the containment plate. The rods are connected by cables to the actuator drums, which are located at the periphery of the biological protection on a special platform under the containment hood.

When the reactivity reserve is reduced to a value below 1 % $\Delta k/k$ a decision is made to change the core layout by removing the fuel assemblies with fuel burn-up greater than 50 %. Next, the fuel assemblies are rearranged in the core – from the periphery to the center. Then "fresh" fuel assemblies are installed. After reloading of the new fuel assemblies from the core, the reactor is switched to 12 kW power and the position of the rods is used to determine by what value the reactivity reserve has increased.

The main technological equipment of the reactor - pipelines, primary circuit pumps, heat exchangers, retaining tank, primary circuit water purification filters, air purification filters of the special ventilation system are located in basement rooms with heavy concrete slabs up to 600 mm thick.

The spent fuel assembly storage shaft is buried to the level of –1.72 m and has a side protection made of heavy concrete. Above the fuel assemblies there is a water layer 5500 mm thick, which reliably protects the personnel from gamma radiation.

Between the water mirror and the pool deck there is a sealed sub-basement space. The operation of the special ventilation system ensures air discharge relative to the physical hall, which is controlled at the control panel. This prevents the escape of radioactive air from the underdeck space.

1.3. Biological protection of the IRT-T reactor

Biological protection is designed to create a radiation environment at workplaces and in reactor rooms that meets radiation safety standards.

The reactor biological protection system includes a layer of water in the reactor tank, a concrete array of reactor tank protection, horizontal experimental channel screens, and protective boxes for reactor technological equipment.

Above the reactor core there is a 6.5 m high water layer, which provides protection of personnel on the upper platform from ionizing radiation. From below, a 0.5 m thick layer of water and 60 mm thick steel plates provide protection from ionizing radiation.

The reactor radial protection system at the core level includes a water layer about 60 mm thick (on the ITS side – beryllium assembly about 590 mm thick), a layer of heavy concrete with densities of 6.5 and 5.2 t/m^3 – 1800 mm. Above the level of the core, the concrete array is made of ordinary concrete with density of 2.3 t/m^3.

At the bottom in the radial part there are 10 holes for placing the horizontal experimental channels. From the side of the physical hall these channels are blocked by five shielding gates providing biological protection from neutron and gamma radiation. Each gate is mounted in a staggered cylindrical casing cast in a reinforced concrete mass. Inside the casing on a common axis are installed drums (sections of the gate), assembled from steel discs, the gaps between which are filled with paraffin with boron carbide. Each drum has a cylindrical hole along its entire length, so that in the closed position of the baffle the holes of all drums were displaced relative to each other by 60°. In this position, the flow of ionized radiation does not escape from the channel. And in the open position of the gate, the openings of all drums are located on one straight line, forming a straight channel and blocking the exit of the radiation beam from the reactor core.

1.4. Experimental devices of the IRT-T reactor

The experimental facilities of the IRT-T reactor provide for a wide range of research. The reactor has 10 horizontal experimental channels (HECs) (Figure 1.6) for the output of neutron beams: 8 radial (towards the core center) channels of 100 mm diameter made of stainless steel and two tangential channels of 150 mm diameter. The tangential channel HEC-1 has one output. It is made of aluminum alloy SAB-1. The stainless-steel tangent channel HEC-4 runs through the entire tank and has two outlets, one to the physics room and one to the radiation pavilion.

The ends of radial HECs are adjacent to the core vessel with 3 mm gaps. Maximum value of fast neutron flux density ($E > 0.821$ MeV) at the end of the HEC is equal to $1.8 \cdot 10^{12}$ (n/cm^2)/MW.

On the physical hall side, the HECs are blocked by gates providing biological protection against neutron and gamma radiation. The valves are controlled from the control panels installed in the corresponding sectors of the physical hall.

Horizontal channels № 3, 5 are equipped with pneumatic conveying devices allowing to irradiate samples in pouches. The cases are supplied to the irradiation position (in HEC) from the experimental facilities located in the laboratories adjacent to the physical hall.

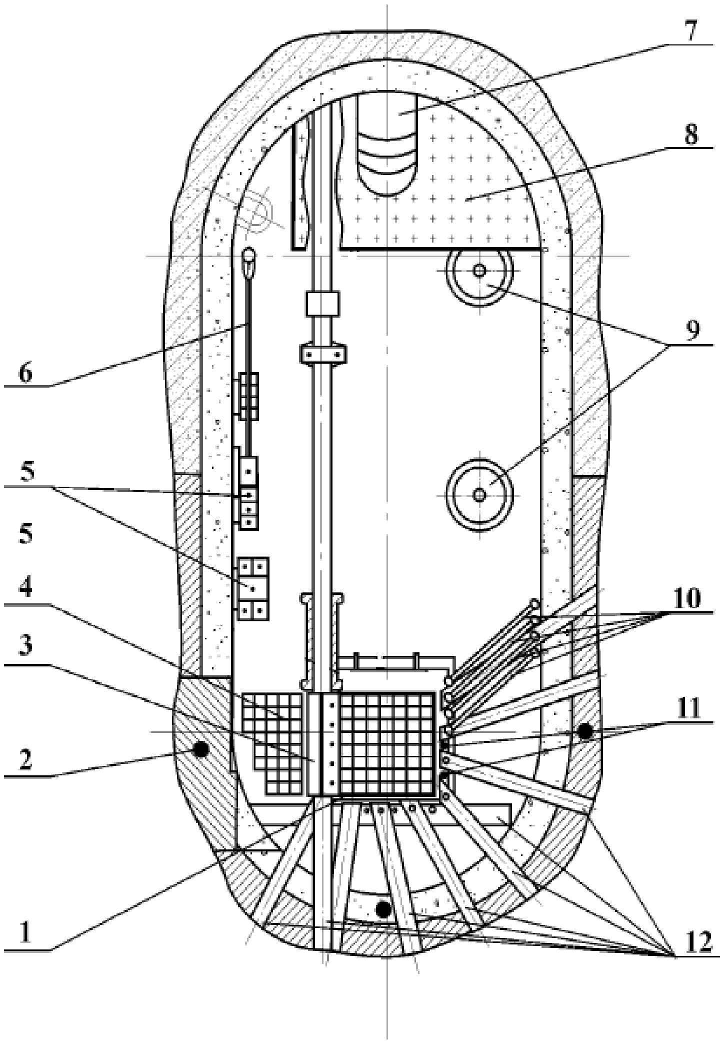

Fig. 1.6. Cross section of the reactor:
1 – core enclosure; 2 – channels for concrete temperature measurement;
3 – large beryllium block; 4 – internal thermal assembly; 5 – temporary fuel assembly storage;
6 – fuel assembly transport device; 7 – pressure pipeline; 8 – distribution tank;
9 – natural circulation valves; 10 – vertical experimental ducts with pneumatic conveying device;
11 – vertical experimental channels; 12 – horizontal experimental channels

Silicon is alloyed in HEC-4. The automated complex designed for irradiation of silicon ingots ensures uniform neutron irradiation of large volume samples.

For irradiation of products within the core, there are four aluminum channels with an outer diameter of 44 mm installed in central beryllium blocks (neutron trap). Two of them are dry and curved to exclude direct radiation penetration and one channel is straight and filled with water. The material of channel tubes is aluminum of AD-1 grade. Also, for irradiation of various samples in the fuel assemblies, a vertical experimental channel is located at numbers 5–6.

For irradiation outside the core vessel, in the water reflector, there are 10 vertical channels made of AD-1 grade aluminum alloy with outer diameters of 55 and 70.55 mm.

The total number of VECs that can be installed outside the core enclosure is 14. The dry VECs are curved, which eliminates neutron and gamma radiation shooting and makes it possible to do without protective plugs on the channels and to load and unload samples in the channels when the reactor is operating at power.

The internal thermal assembly (ITA) is assembled from beryllium blocks and is designed to form a neutron field with a cadmium-to-gold ratio of 19. ITA blocks are installed in 33 cells of the aluminium casing. Cell pitch is 71.5×71.5 mm. Thirty-one beryllium blocks are 67×67×660 mm, two blocks are 138.5×138.5×660 mm. These blocks are similar in design to the beryllium blocks installed in the core reflector.

A large beryllium block (Figure 1.6) measuring 190×550×648 mm is installed along the core edge on the HEC-4 side. The block covers the experimental channels HEC-4 and HEC-2. The purpose of the block is to generate the thermal neutron field along the cross-section of HEC-4 and in the ITA.

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Control questions and tasks

1. List the main characteristics of the IRT-T nuclear reactor.
2. What materials are used in the fuel, moderator, coolant, CPS rods?
3. What is a neutron trap?
4. Describe the construction and materials of the fuel assembly and characterize these materials.
5. Using Figure 1.5, describe the IRT-T reactor workload process.
6. List the neutron-physical characteristics of the IRT-T reactor.
7. Describe the equipment included in the IRT-T reactor biological protection system.
8. Describe the experimental devices of the reactor.

Chapter 2
TECHNOLOGICAL SYSTEMS OF THE RESEARCH IRT-T NUCLEAR REACTOR

2.1. Technological cooling systems for the IRT-T reactor

Technological reactor cooling systems (Figure 2.1) ensure removal of heat generated in fuel elements and other reactor elements during normal power operation modes, during shutdowns, as well as in abnormal (emergency) situations.

Technological systems of the IRT-T reactor include:

- primary cooling circuit;
- secondary cooling circuit;
- biological protection cooling circuit;
- leakage collection and return system;
- primary circuit coolant treatment system;
- water treatment system.

2.1.1. Primary cooling circuit of the IRT-T reactor

The primary cooling circuit, the reactor main circulation circuit, includes the following main elements:

- reactor tank with core and internal retaining vessel;
- suction pipeline;
- external retaining vessel;
- four main circulation pumps;
- emergency cooling pump (NAO);
- five heat exchangers;
- manifolds, heat exchangers and pumps inlet and outlet pipelines;
- valves located on these pipelines;
- pressure pipeline;
- distribution box;
- natural circulation valves;
- drainage pipelines with shut-off valves.

The reactor tank is a 12X18H10T polished stainless-steel vessel surrounded by concrete biological protection. The tank is 4.3 m long, 1.8 m wide, 7.725 m deep and has a volume of 56 m^3. The tank walls are 5 mm thick and the tank bottom is 10 mm thick. The level of coolant in the tank when the pumps of the primary circuit are operating is at the level of ~ 7.3 m. In the reactor tank at a depth of 6.5 m there is a reactor core in which 20 fuel assemblies (FA) and 30 beryllium reflector blocks, power and protection control and experimental channels are installed. From the core, the coolant enters the inner retaining vessel, which is formed by a 14 mm thick horizontal stainless-steel baffle. This partition is supported by 15 struts made of 108 mm diameter pipes. The volume of the internal retaining tank is 4.2 m^3, it provides reduction of water activity by isotope N^{16}.

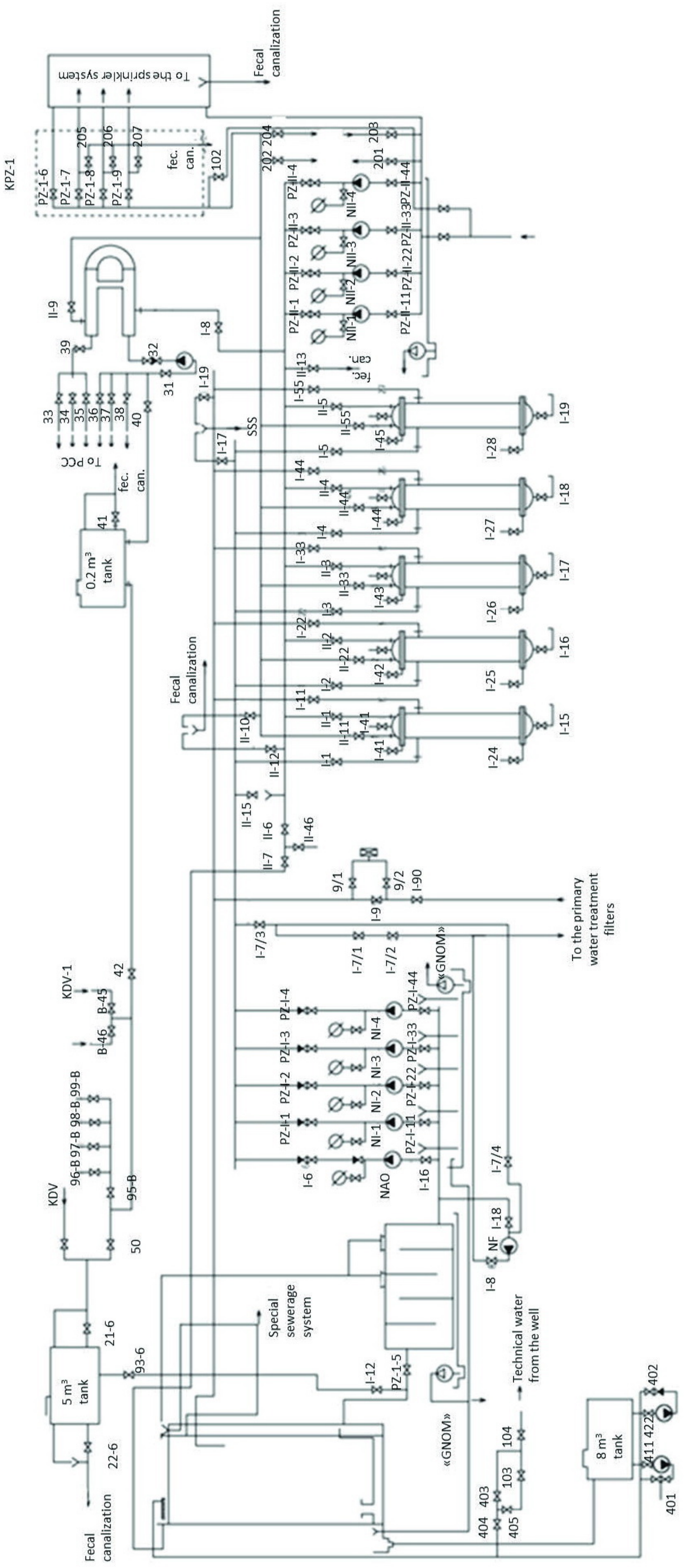

Fig. 2.1. Technological scheme of cooling of the IRT-T reactor

Then the coolant flows through the 400 mm diameter suction pipeline via the electric gate valve PZ1-5 to the external retaining tank. It is located in room 152 in the box at the level –2.5 m and is closed with protective plates. It is designed to reduce the activity of the coolant by isotopes N^{16}, N^{17} and O^{19} before entering the pump room of the primary circuit. The volume of the retaining vessel is 24 m^3, the time of coolant passing through it (at a flow rate of 900 m^3/h) is 90 seconds. Four baffles are installed in the tank to equalize the water velocity across the cross-section. To remove the "rattle" gas accumulating in the upper part of the retaining vessel, two tubes are led into the space under the reactor tank deck.

From the external retaining tank, water flows through 400 mm diameter pipework into the primary circuit pump room (room 149).

The suction pipeline consists of two parts. The first one connects the inner retaining vessel with the outer one, the upper point of which is 0.65 m higher than the upper end of the core before leaving the tank, which excludes the possibility of core exposure in case of depressurization of the suction pipeline; the second one connects the outer retaining vessel with the suction manifold and pumps.

The suction pipe passes through the rooms of the radiation pavilion (room 154), the hot chamber (room 153), the holding tank (room 152) and enters the primary circuit pump room (room 149).

Four pumps type X280/29 (Figure 2.2) – NI-1, NI-2, NI-3, NI-4 – are connected in parallel to the suction manifold located in the pump room. Pump capacity ~ 280 m^3/hour at head 0.13–0.14 MPa. Electric gate valves PZI-1, PZI-2, PZI-3, PZI-4 with remote control and check valves are installed on pressure pipelines. On suction pipelines of circulation pumps there are electric gate valves PZI-11, PZI-22, PZI-33, PZI-44 with remote control.

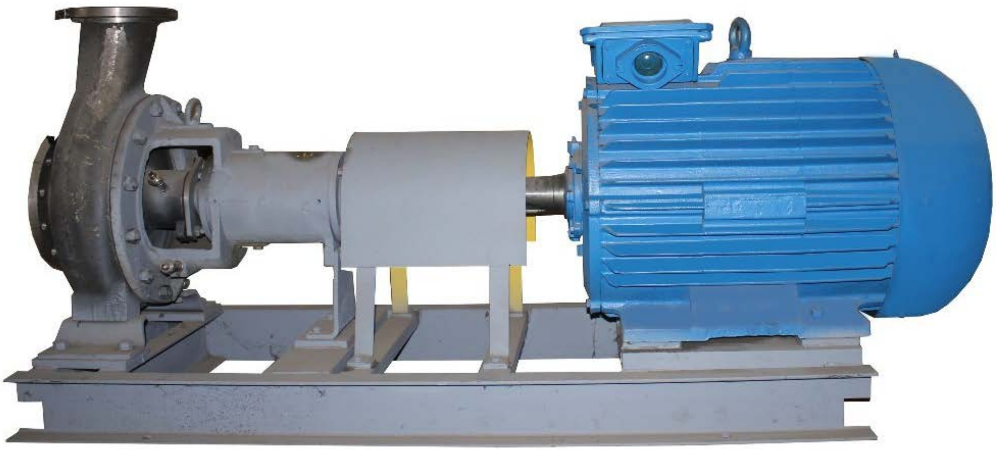

Fig. 2.2. Pump X280/29

Of the four pumps, two are in operation, two are back-up pumps. After the pumps, the coolant flows through the collector to five heat exchangers – T-1, T-2, T-3, T-4, T-5 of IRT-1000 type with heat exchange surface 200 m^2 each, designed to transfer heat from the primary circuit to the secondary circuit (located in room 148). The heat exchangers are connected in series through the collector. At the inlet pipelines of the heat exchangers there are valves I-1, I-2, I-3, I-4, I-5. After the heat exchangers the coolant is transported through the pipelines via gate valves I-11, I-22, I-33, I-44, I-55 enters the collector, which is the initial section of the pressure pipeline.

Due to the fact that the secondary circuit maintains a higher pressure (0.38–0.41 MPa) than the primary (0.13–0.14 MPa), in case of depressurization of the heat-exchange tubes, water leakage from the primary circuit into the secondary circuit is excluded.

The coolant enters the box located in the reactor basin through a pressure pipeline with an internal diameter of 350 mm. Through the perforated walls and bottom of the box the coolant enters the lower part of the reactor tank at low speed, evenly distributed over its volume.

The pressure pipeline from the pump room passes through the retaining vessel room (room 152) and the reactor biological protection and enters the reactor tank at + 6.5 m, i. e. 5.2 m above the top end of the core.

To ensure core cooling in the event of an emergency power failure of the primary circuit pumps (with simultaneous shutdown of the reactor by the emergency protection rods), an emergency cooling pump (NAO) and two natural circulation valves are provided.

The emergency cooling pump (NAO) type ESP 3/1 provides cooling of the core within 2.5 min after the primary circuit is switched off. Pump capacity 50 m^3/hour at the head of 0.22 MPa. The pump DC motor is powered from two independent sources:

- from a 3V (4V) rectifier of ZUK-155/230 type in normal operation mode;
- from the battery when operating in emergency mode (in case of AC voltage failure).

The pump is included in the cooling system in parallel with the circulation pumps. The pipelines leading to it consist of pipes of 100 mm diameter. Manually operated gate valves 1–6 and 1–16 are installed on the pipelines.

Natural circulation valves are installed in the holes of the horizontal partition of the reactor tank. During operation of circulation pumps NI-1-NI-4 and NAO the valves are closed, because the pressure in the internal retaining vessel is lower than the pressure in the reactor tank, in addition, the valves in the lower position are held by electromagnets. After 2.5 minutes after the circulating pumps stop, the NAO stops and the valves open under the action of the springs as a result of the solenoids being switched off. Due to the difference in temperature of the coolant near the core and the upper area of the reactor tank, the direction of movement of the coolant in the core changes – it rises upwards, thus further cooling of the reactor occurs due to natural circulation.

A drainage pipe is available to drain the IRT-T reactor tank and the internal retaining vessel Ø 56×3, working on the principle of a siphon. One end of the pipe is located at the bottom of the reactor tank, the other end reaches the upper water layer. The siphon pipe has a drainage pipe leading to the special sewerage tanks. In the upper part of the pipe there is a socket which is always open to prevent accidental emptying of the IRT-T reactor tank. In order to drain the water, the upper end of the siphon pipe must be closed off with a screw cap of the siphon pipe with a special screw plug and open the manually operated valve 1–20 on the drain pipe, which must always be securely closed and sealed, except in the case of repairs with water drainage from the IRT-T reactor tank.

To exclude overflow of water from the pool into the special ventilation channels of the above-reactor space, the tank has an overflow device with a pipeline outlet to the special sewerage system.

Emptying of the external retaining tank, pipelines, pump manifold is carried out through drain valves I-23/1 and I-23/2 by a portable pump, which is installed in the canyon of the pump room of the primary circuit. Water is discharged into the tank designed for draining the coolant or into a special sewerage system. Drainage of the coolant of the primary circuit from the heat exchangers is carried out with the help of compressed air through valves I-24, I-25, I-26, I-27, I-28 into the special sewerage system through connected rubber hoses. Compressed air from the main line is supplied by rubber hose to the valves of heat exchangers I-41, I-42, I-43, I-44, I-45.

2.1.2. IRT-T reactor secondary cooling circuit

The secondary circuit includes the following main elements:

- suction pipeline;
- four pumps;
- pressure pipeline;
- five heat exchangers;
- manifolds, supply and return pipes of heat exchangers and pumps;
- valves located on the pipelines;
- biological protection heat exchanger;
- cooling tower;
- Ø 400 mm, Ø 600 mm main lines;
- valve switching chamber KPZ-1;
- drainage pipelines with valves.

The secondary reactor cooling circuit provides cooling of the coolant of the primary reactor circuit, the primary cooling circuit of the biological protection system and heat removal from the water of the secondary circuit to the atmosphere. Water from the pipeline Ø 400 mm through gate valves PZII-11, PZII-22, PZII-33, PZII-44 goes to four parallel pumps type D320/50 (Figure 2.3) NII-1, NII-2, NII-3, NII-4.

Fig. 2.3. D320/50 pump

One pump flow rate capacity – 320 m^3/hour with the pressure of 0.38–0.41 MPa. Manually operated check valves and gate valves PZII-1, PZII-2, PZII-3, PZII-4 are installed on the pressure pipelines. The suction pipelines are also manually operated. Pumps with gate valves and check valves are located in the secondary circuit piping room (room 009). After the pumps, the water is piped through the Ø 350 mm pipeline flows into T-1, T-2, T-3, T-4, T-5, connected in parallel. Heat exchanger inlet gate valves II-1, II-2, II-3, II-4, II-5 outlet gate valves II-11, II-22, II-33, II-44, II-55 with manual control. Water discharge from pipelines, heat exchangers and collectors is carried out through valves II-13, II-15, II-16, II-17, II-18, II-19 into the sewerage system.

The water from the heat exchangers flows through the pressure pipeline Ø 350 mm to the pressure main pipeline Ø 400 mm, laid in the ground on the territory of the industrial site, and to the manifold of the gate valve switching chamber No. 1 (KPZ-1). Further the coolant can flow in two modes:

1. From the collector, the coolant flows through the open PZ-GO to the cooling tower basin where it is cooled. This flow pattern is appropriate at low outside air temperatures. When the temperature of the coolant does not provide sufficient heat removal, the PZ-GO is closed and the second scheme is implemented.
2. When the PZ-GO is closed, water from the collector flows through three parallel pipelines through the goosenecks into the cooling tower's distribution network of pipelines, which are equipped with spray nozzles. Under the action of centrifugal forces, the water jet breaks up into droplets. As they fall, they are cooled by the oncoming air stream and then fall into the cooling tower basin. If, even in this case, the temperature condition does not meet the operating requirements, the cooling tower fan motors are switched on.

The cooled water from the cooling tower basin then flows through the suction main pipe Ø 600 mm to the suction manifold of the secondary circuit pumps.

The sprinkler type cooling tower has three identical sections. The area of one section 64 m^2. In each of them there is a fan type VG2-50 produced by the capacity of 500.000 m^3/hour. Maximum water flow rate per one section – 350 m^3/hour.

The cooling tower basin is filled with service water through a Ø 70 mm pipeline from an artesian well located at the IRT-T reactor industrial site through gate valve 100, which is tapped into the suction pipeline of the secondary circuit upstream of the pumps. Also, the cooling tower basin is fed through gate valve 102, tapped into the secondary circuit pressure line after the heat exchangers. The gate valves are installed in room 009.

In case of well failure, the pool is fed from the water pipeline from Sputnik through gate 104.

Emergency filling of the IRT-T reactor tank in case of threat of core denudation is carried out with service water through a pipeline from the household drinking water line or the pressure manifold of the secondary circuit pumps, depending on which system has water. The water intake for the secondary circuit pumps is from the cooling tower basin. The water supply line to the IRT-T reactor tank has two series-connected gate valves II-6 and II-7 with a valve 46 between them to control leaks. All of the above gate valves are manually operated.

2.1.3. IRT-T biological protection cooling circuit

Biological protection cooling circuit includes:

- pump;
- heat exchanger;
- biological protection system pipeline;
- supply tank;
- piping and valves.

This circuit is designed to remove heat from the IRT-T reactor biological protection due to ionizing radiation. The piping of the system is filled with demineralized water. It is made of Ø 38×3 and Ø 32×3 stainless steel pipes and is located in the concrete of the bottom and walls of the tank. The coolant is fed through Ø 50 mm piping to the X20/31 type protection cooling pump located in the pump room of the secondary circuit.

The pump capacity is 20 m^3/hour at a head of 0.32 MPa. On the suction pipe of the pump there is a valve 31 and on the pressure pipe there is a check valve and a manually operated valve 32. The pump feeds demineralized water into water-water heat exchanger T-6 with heat exchange surface of 1.5 m^2, where it is cooled with technical water of the secondary circuit. The heat exchanger is fixed on the wall in the chemical-water preparation room (room 147). At its inlet and outlet valves 30 and 39 are installed.

Further, the cooled water is fed through a Ø 57×3 pipe to the protection cooling coils. Valves 33, 34, 35 are installed at the inlet of the coils and valves 36, 37, 38 at the outlet. The following valves are located in the retaining vessel room (room 152). Filling and make-up of the protection cooling circuit with desalinated water is performed from the make-up tank of 0.2 m^3, located in the water preparation room (room 147) at the + 3.1 m level. Ventilator 40 and check valve are installed on the make-up water pipeline.

2.1.4. IRT-T reactor leak collection and return systems

The system for collection and return of coolant leaks to the reactor tank in case of an accident (Accident Localization System – SLA) is designed to collect coolant leaking from horizontal experimental channels in case of depressurization of channel bottoms and return it to the reactor tank through a showering device.

The SLA system provides:

- localization of leaks within the physical hall of the reactor and thus preserves the rest of the reactor and the industrial site from radioactive contamination;
- cooling of fuel assemblies and prevention of their meltdown from residual heat release in case of core denudation.

To collect coolant leaks in the physical hall, a 48 m^3 sump is installed adjacent to the reactor biological protection. The sump consists of three parts connected by a pipeline of 80×280 mm. The first one collects coolant from HEC-1, 2; the second one collects coolant from HEC-3-5; the third one collects coolant from HEC-6-10.

The sump of the SLA system is connected by a pipeline DN 100 mm with a receiving tank with a volume of 8 m^3, which is installed at a mark –1.7 m in room 145. The throughput capacity of this pipeline is 50 m^3/hour. For pumping the coolant from the 8 m^3 tank back to the reactor tank there are two pumps of ESP-3/1 type with the capacity of 26 m^3/hour. At the pump inlet there is a valve Du 80, at the outlet there is a valve and a check valve Du 50. When the system is activated, one pump is in operation, and the second pump is a backup.

When the system is switched on, the coolant is supplied to the upper part of the reactor tank through a showering device fixed on the upper platform and is sprayed over the core through the pipeline DN 50 mm.

The pressure pipeline DN 50 mm with a showering device through two ventilators (No. 403, 404) is connected by a DN 50 pipe to the service water pipeline for emergency core cooling and reactor tank filling.

SLA system pumps provide coolant flow rate up to 20 m^3/hour during the first hour after HEC depressurization, then up to 5–8 m^3/hour during the first day and up to 2–3 m^3/hour during the following days. The total time of reactor core strangulation should be not less than 3 days. It is possible to shut down the system after a shorter time provided that the reactor tank is filled with water one meter or more above the reactor core.

The SLA system must be permanently in the ready-to-operate mode. Checking the switching on of the SLA system pumps can be carried out in three modes:

1. Switching on the SLA system pumps from the local control station. At the local control station of the first SLA-1 pump turn the key to the "On" position for 5–10 s.
2. If the pump is switched on, at the local control station of the SLA-1 pump set the key to the zero position, thus disconnecting the first pump. Repeat the same steps for pump SLA-2.
3. Remote activation of the SLA system pumps. At the local control station SLA-1 and SLA-2 in room 145 set the key to "Distant" position. At the operator panel 6 (PO6) turn the key from the zero position to the left for 5–10 s to switch on the SLA-1 pump. After checking the first pump, return the key to the zero position. Turn the key from the zero position to the right for 5–10 s to switch on the SLA-2 pump. After checking the activation of the second pump return the key to the zero position.
4. Check of automatic switching on of SLA pumps. At the local control station SLA-1 and SLA-2 in room 145 set the key to the "Auto" position. On the operator panel 6 (SO6) are located devices SPR-04 – "SLA level", simulating the presence of water in the tank volume of 8 m^3, and "SLA 60 cubic meters", simulating a decrease in the level of coolant in the reactor tank below 6 m. It is necessary to simultaneously press the test buttons on these devices for 5–10 s. In case of SLA-1 pump switching on, turn the key at the local control station SLA-1 to zero position and repeat the scheme of automatic pump switching on for SLA-2.

Except for pump operation checks or any repair work, the key must always be in the "Auto" position at the local control station SLA-1 and SLA-2.

2.1.5. IRT-T reactor ventilation system

The ventilation system of the reactor building consists of several exhaust and supply ventilation systems. The required air exchange rate is created in each room. In the rooms where the least radioactive contamination is expected, increased pressure is created compared to the rooms with higher contamination, which contributes to localization of contamination.

Exhaust ventilation of the building is divided into general and special ventilation.

2.1.5.1. RT-T reactor general ventilation system

Supply ventilation provides supply of air heated to +18 °C in cold season and consists of six systems – P1-P6. System P1 supplies air heated in calorifiers to the reactor building. Necessary air heating is provided at ambient air temperature down to –40 °C. There are two fans operating in the P1 system, one of them is a backup fan. All equipment of system P1 is located in the supply ventilation room (room 139).

Systems P2-P5 supply air to the laboratory annex of the reactor building. System P6 – to the accumulator room.

General exchange ventilation extracts air from the reactor rooms (V3) and from the annex laboratories (V7-V15).

2.1.5.2. IRT-T reactor special ventilation system

Special exhaust ventilation systems V1 and V6 are designed to remove air from places where radioactive gases and aerosols may occur, to purify contaminated air and release it through a ventilation pipe with a height of 42 m and a diameter of 1200 mm.

Air removal by special ventilation system V1 (fans V1-1 and V1-2) is performed from the following places:

- from the underdeck space (between the deck and the water surface in the reactor pool);
- the sub-basement of the spent fuel assembly storage pit;
- HEC vents;
- storage of "dry" assemblies;
- "hot chamber";
- radiation pavilion room.

The operation of system V1 creates a vacuum in them, which ensures one-way air movement from the physical room into these volumes and prevents the spread of radioactive air into the physical room. In addition, the V1 system (fans V1-3 and V1-4) removes air from the following rooms:

- rooms of the retaining tank and filters of the primary circuit coolant purification;
- rooms of the pump room of the primary circuit of the IRT-T reactor cooling circuit;
- heat exchanger room;
- maintenance room corridor.

The total amount of air removed by the V1 system is 5500 m^3/h. Gaseous products of nuclear reactor operation from the space above the pool are passed through filters FP-300 (Figure 2.4) consisting of activated carbon designed to absorb radioactive iodine-131 in case of fuel element depressurization. The rest of the V1 system air is cleaned from radioactive aerosols in fine filters FAS A-13 (Figure 2.5). The system has redundant fans and filters.

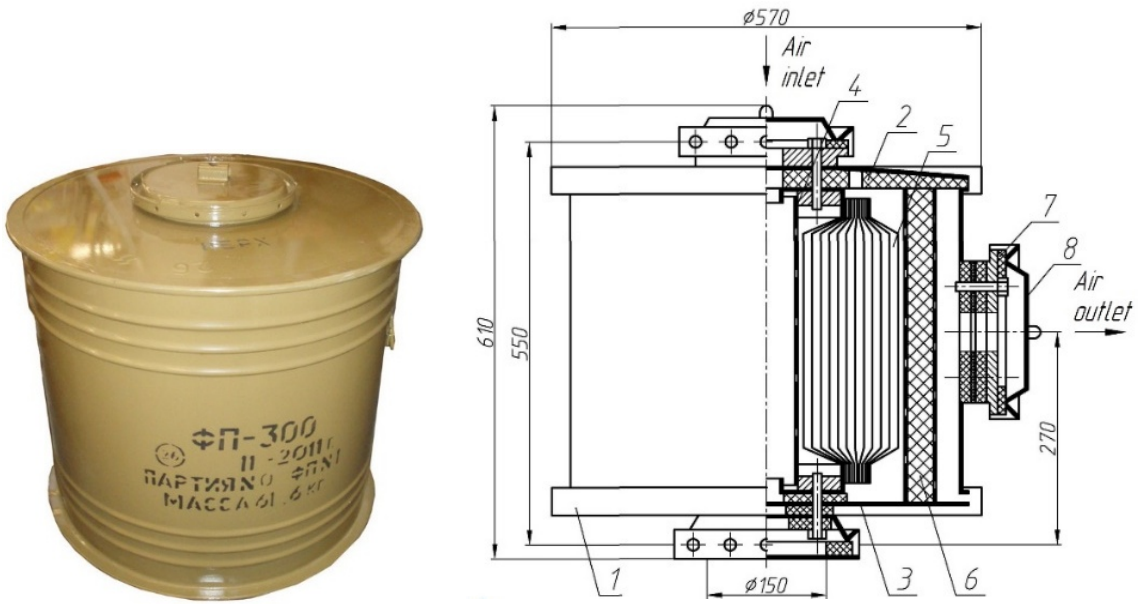

Fig. 2.4. FP-300 filter:
1 – housing; 2 – cover; 3 – bottom; 4 – gasket;
5 – anti–aerosol filter; 6 – catalyst; 7 – nipple ring; 8 – plug

Fig. 2.5. FAS A-13 filter

Ventilator V2-1 removes air from the fume cupboard of the chemistry laboratory (room 325).

General exchange ventilation system V3 removes the air:

- from the physical hall room;
- IRT-T reactor laboratories.

V4 ventilation system (ventilators B4-1 and B4-2) removes the air:

- from the secondary cooling system pumps room;
- water treatment room.

System V6 sucks air from HEC-4 to cool the silicon ingots during irradiation. The air from HEC-4 is passed through filters and discharged into the reactor ventilation stack. The radioactivity of the air discharged into the stack is continuously monitored and recorded on dosimetry equipment.

2.1.6. IRT-T reactor special sewerage system

The special sewerage system is designed to collect radioactive water into special tanks located in the reactor industrial area. This system provides:

- drainage of water from the reactor tank in case of its emptying or overflow;
- collection of demineralized water from the SFA storage pit in case of overflow;
- collection of leaks from the primary circuit pump room, heat exchanger room and external retaining vessel;
- collection of water and solutions after washing of the hot chamber, radiation pavilion, decontamination bath, sink on the upper platform, special cabinet of the radionuclide laboratory and from the tank of the nuclear silicon doping laboratory.

All liquids are discharged into three special tanks. Two tanks have a volume of 100 m^3 each, the volume of the third tank is 325 m^3. The special tanks are made of concrete, located below ground level on the industrial site and lined with stainless steel inside. The material of all pipes of the system is stainless steel.

The special sewage system operates in the mode of accumulation of radioactive effluents. Annual replenishment of special tanks is 15–20 m^3 of effluents. Every year it is possible to regenerate up to 20 m^3 of effluents. The treated special effluents are checked for compliance with make-up water quality standards and are used for make-up of the primary cooling circuit of IRT-T.

2.1.7. IRT-T reactor water treatment and purification systems

2.1.7.1. IRT-T reactor water treatment system

The water treatment system is designed to produce demineralized water used for primary filling of the IRT-T reactor tank and pipelines of the primary circuit of the IRT-T reactor core cooling, make-up of the SFA storage shaft, as well as for laboratory needs.

Ion-exchange resin is used as the main load in the filters of the water treatment system, the main purpose of which is to reduce the content of impurities in the water and normalize the pH within the specified limits. Water purification from corrosion products (mainly iron oxides) by ion-exchange resins is ineffective, so the purification system also uses a mechanical filter consisting of thermoxide, which effectively removes iron oxides and other mechanical impurities.

The water treatment system consists of eight filters and works in the following way: first, tap water passes through the mechanical filter, then alternately enters the filters with cationic and anionic resin (6 filters in total) and then into the mixed action filter consisting of cationic and anionic resin simultaneously. After passing through the water treatment system, demineralized water with electrical conductivity ~ 1–2 μS/cm goes first into a 1 m^3 tank, which is located in the room of the secondary circuit pumps, and then by the demineralized water pump (NDV) is supplied to the make-up tank of 5 m^3 of the primary circuit make-up system. The capacity of the water treatment unit is 0.4 m^3/h.

In case of deterioration of purification properties of ion exchange resins, the operation on their regeneration by passing acid and alkali through them is performed. Acid is run through the cationic resin; alkali is run through the anionic resin.

The primary cooling circuit is recharged by opening valve 93-6, located on the tank with a volume of 5 m^3. Demineralized water is fed into the pipeline of the primary circuit through the pipe-line through the gate valve I-12. The pipe from the 5 m^3 tank is connected to the primary circuit pipeline. This connection is located upstream of the gate valve PZI-5 in the room of the detention tank.

2.1.7.2. IRT-T reactor water purification system

The water treatment system is designed to remove radiolysis products as well as erosion products from the primary circuit coolant produced during IRT-T reactor operation.

The water treatment system includes 8 filters, 2 of which are mechanical and 6 mixed filters. The primary circuit coolant with conductivity value ~ 3–4 μS/cm is extracted by pumps at the outlet of the external retaining tank. Further the coolant is purified in the water treatment system to the value of conductivity ~ 1–2 μS/cm and then returns to the primary circuit through a cut-in connection in the pipeline, located after the heat exchangers. The capacity of the water treatment unit is 0.13–0.16 m^3/h.

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Control questions and tasks

1. List the components of the IRT-T reactor technological cooling system.
2. What is included in the IRT-T reactor primary cooling circuit?
3. Describe the operation of the IRT-T reactor primary cooling circuit.
4. What is the purpose of the retaining vessel?
5. What is part of the secondary cooling circuit of an IRT-T reactor?
6. What are the operating modes of the IRT-T reactor secondary cooling circuit?
7. What is included in the IRT-T reactor biological containment concrete cooling system?
8. Describe the operation of the IRT-T reactor leak collection and return system.
9. List the activation test modes of the IRT-T reactor SLA system pumps.
10. List the ventilation systems of the IRT-T reactor.
11. Which ventilation system provides air supply and in which rooms, and which provides air removal and in which rooms?
12. What is the reason for the need for a special sewerage system at the IRT-T reactor?
13. What is the difference between the water treatment system and the water purification system of the IRT-T reactor?

Chapter 3
IRT-T NUCLEAR RESEARCH RECTOR TECHNICAL SYSTEMS FOR TECHNOLOGICAL PARAMETERS CONTROL

3.1. IRT-T reactor technological parameters control system description

The technological parameter control system provides continuous monitoring of all technological systems of the IRT-T reactor and output of signals in analog or contact form in case of deviation from normal operating modes. Signals from sensors or transducers of the technological parameter control system are entered into the SCADA system of the IRT-T reactor. Signals from transducers measuring the level in the IRT-T reactor tank, pressure at the head of the IRT-T reactor core emergency cooling pump, pressure drop across the IRT-T reactor core, temperature at the core inlet and temperature drop across the core are input to the IRT-T reactor control and protection system warning and emergency signaling.

The technological parameter control system sends a signal to the blocking unit to open the natural circulation valves, and can also give signals to block the switching on of electric motors of the IRT-T reactor core primary cooling circuit pumps, the IRT-T reactor core emergency cooling pump and the IRT-T reactor primary cooling circuit coolant filter pump.

The technological parameter monitoring system measures:

- coolant flow rate in the IRT-T reactor core cooling circuits and biological protection cooling circuit;
- coolant pressure in the IRT-T reactor core cooling circuits and biological protection cooling circuit;
- coolant temperature in the IRT-T reactor tank, IRT-T core cooling circuits and biological protection cooling circuit;
- coolant level in the IRT-T reactor tank, in the make-up tank of the biological protection cooling circuit, in the make-up tank of the primary core cooling circuit of the IRT-T reactor, in the cooling tower basin, and in the tanks of the special sewerage system.

3.2. IRT-T reactor coolant flow rate measurement

To measure the coolant flow rate of the primary and secondary cooling circuits of the IRT-T reactor core, the IRT-T reactor core emergency cooling pump, primary and secondary cooling circuits of the IRT-T reactor biological protection and the coolant flow rate through ion-exchange and mechanical filters, flow meter units are installed, which include:

- diaphragm chamber DC-6 (Figure 3.1);
- Metran 150-DD transmitter (differential pressure) (Figure 3.2);
- IRT-1730 U/M universal millivotmeter (Figure 3.3).

The chamber diaphragm creates a local flow restriction. The static pressure of the flow after the orifice plate becomes lower than before the orifice plate. The difference in these pressures is greater the greater the flow rate of the flowing substance.

The Metran 150-DD converts the pressure drop into a 4–20 mA current signal. The current signal is transmitted to the process controller meter (IRT-1730 U/M), which displays the digital value of the flow rate in m^3/hour. These devices are installed on PO1 (operator control panel) and SO6 (operator panel) in the IRT-T reactor control room.

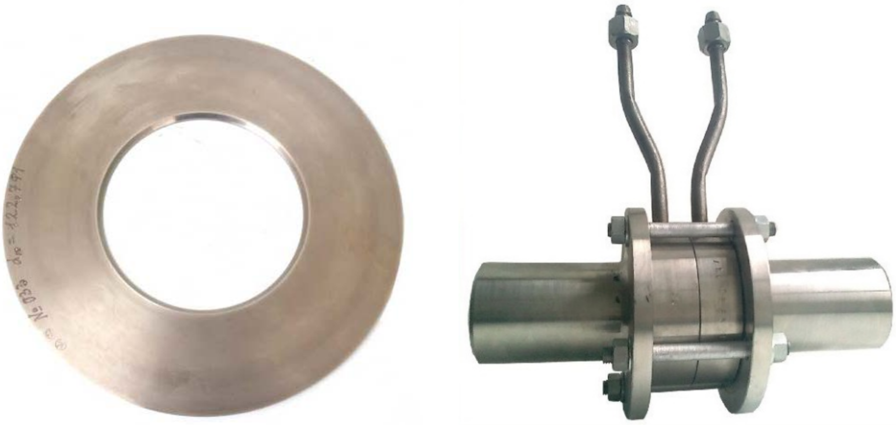

Fig. 3.1. DC-6 diaphragm chamber

Fig. 3.2. Metran 150-DD transmitter with differential pressure

Fig. 3.3. IRT-1730 U/M universal millivoltmeter

Flow rates during normal IRT-T reactor operation:

- IRT-T primary cooling circuit – 700 m^3/hour;
- IRT-T secondary cooling circuit – 850 m^3/hour;
- IRT-T reactor core emergency cooling pump – 59 m^3/hour;
- IRT-T reactor biological protection primary cooling circuit IRT-T – 2.80 m^3/hour;
- IRT-T reactor biological protection secondary cooling circuit IRT-T – 5 m^3/hour;
- IRT-T water purification system – 0.15 m^3/hour.

The IRT-1730 U/M millivoltmeter provides a notification signal when the flow rate drops by 10 % and a warning signal when the flow rate drops by 20 %, and the SCADA system located in the IRT-T reactor control room notifies the operating personnel.

3.3. IRT-T reactor coolant pressure measurement

Measurement of coolant pressure in the primary and secondary cooling circuits of the IRT-T reactor core and in the primary cooling circuit of the IRT-T reactor biological protection is carried out by overpressure transducers "Metran 150-DI" (Figure 3.4) in a set with universal millivoltmeters IRT-1730 U/M.

Fig. 3.4. "Metran 150-DI" transducer (pressure exceeded)

The value of the excess pressure of the coolant is measured by the sensor "Metran 150-DI" in the range from 0 to 0.6 MPa and converted into a current signal 4–20 mA. The current signal is transmitted to the meter-regulator technological IRT-1730 U/M, which displays the digital value of pressure in MPa. These devices are installed on PO1 in the control room of the IRT-T reactor.

Pressure values during normal operation of the IRT-T reactor:

- IRT-T reactor primary circuit – 0.13–0.14 MPa;
- IRT-T reactor secondary circuit – 0.38–0.41 MPa;
- IRT-T reactor emergency cooling pump – 222–233 kPa;
- coolant pressure drop on the IRT-T reactor core – 0–37 kPa.

Millivoltmeter IRT-1730 U/M issues a notification signal when the coolant pressure in the primary and secondary coolant circuits of the IRT-T reactor core coolant decreases by 20 kPa from the nominal pressure, and when the pressure decreases by the same parameters specified above by the value equal to 40 kPa, it issues a warning signal, and the SCADA system notifies the operating personnel about it.

Measurement of coolant pressure at the head of the IRT-T reactor core emergency cooling pump is carried out by three Metran 150-DI overpressure transducers complete with Mirage-MB safety modules.

The value of overpressure is measured by the sensor "Metran 150-DI" in the range from 0 to 0.6 MPa and converted into a current signal 0–5 mA. The current signal is transmitted to the galvanically isolated amplifier unit (BUG-02), which is an integral part of the safety module (MB) Mirage-MB (Figure 3.5).

Fig. 3.5. Mirage-MB Safety module

The Mirage-MB Safety Module is connected to a display workstation (RSO), which displays a digital pressure value in kPa, and to a narrow-profile device (UPP-01), which displays an analog pressure value in kPa. The UPP-01 is located at PO4 in the IRT-T reactor control room. RSOs are also located in the IRT-T reactor control room. When the coolant pressure at the head of the IRT-T reactor core emergency cooling pump drops to 157 kPa from the rated pressure, a warning signal is issued, and when the pressure drops to 140 kPa, an emergency signal is issued to the IRT-T reactor control and protection system, after which the emergency protection is activated and all rods are lowered into the IRT-T reactor core.

The coolant pressure drop across the IRT-T reactor core is measured by a Metran 150-DD differential pressure sensor in combination with the Mirage-MB safety module. Pressure is extracted from the top of the IRT-T reactor core (plus chamber) and from below the IRT-T reactor core (minus chamber). The Metran 150-DD sensor converts the differential pressure into a 0–5 mA current signal. The current signal is fed into the galvanically isolated amplifier unit (BUG-02), which is part of the Mirage-MB safety module. The signal from Mirage-MB is transmitted to the display workstation (RSO), which displays the digital pressure value in kPa, and to the narrow-profile device (UPP-01) located at PO4 of the IRT-T reactor, which displays the analog pressure value in kPa. When the coolant pressure drop on the IRT-T reactor core drops to 30 kPa, a warning signal is issued, and when it drops to 27 kPa, an emergency signal is issued to the IRT-T control and protection system, after which the emergency protection is activated and all rods are lowered into the IRT-T reactor core.

3.4. IRT-T reactor coolant temperature measurement

Measurement of the coolant temperature and the temperature of the concrete of the IRT-T reactor biological protection is carried out according to three schemes:

- platinum technical sensitive element (CHEPT-2) (Figure 3.6) → temperature signal conversion unit (BPTS-02) of safety module Mirage-MB → safety module Mirage-MB;
- platinum technical sensitive element (CHEPT-2) → microprocessor-based 2000NM standardizing converter (Figure 3.7) → universal millivoltmeter IRT-1730 U/M;
- resistance thermometer with unified output (TSPU-2222) (Figure 3.8) → universal millivoltmeter IRT-1730 U/M.

Fig. 3.6. Platinum technical sensitive element (CHEPT-2)

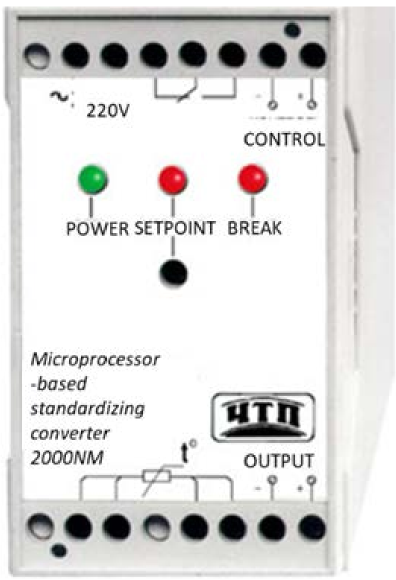

Fig. 3.7. Microprocessor-based standardizing converter 2000NM

Fig. 3.8. Resistance thermometer with unified output (TSPU-2222)

According to the first and second schemes the measured temperature is converted into current signal from 0 to 5 mA, according to the third scheme of measurement the output current signal is 4–20 mA.

The temperature measurement interval for all channels ranges from 0 to 100 °C. IRT-T reactor biological protection concrete temperature measurement interval from 0 to 150 °C.

The coolant temperature at the inlet to the IRT-T reactor core and at the outlet from the IRT-T reactor core is measured using three CHEPT-2 sensors. The signal is then fed to the temperature signal conversion unit (BPTS-02) of the Mirage-MB safety module, then output to the display workstation (RSO), which displays the digital value of the temperature in the reactor core in °C, and to narrow-profile devices (UPP-01) located on PO3, where the analog signal is displayed. When the temperature of the coolant at the inlet to the reactor core increases to 55 °C a warning signal is issued, and when the same parameter is reached to 60 °C – emergency signal to the IRT-T reactor control and protection system, after which the emergency protection is triggered and all rods are lowered into the core of the IRT-T reactor. The signals are generated by the majoritarian logic "2 out of 3".

Measurement of the coolant temperature difference in the IRT-T reactor core is performed by calculating the difference between the coolant temperature at the inlet to the IRT-T reactor core and at the outlet from the IRT-T reactor core using CHEPT-2 sensors. The signal is then sent to the temperature signal conversion unit (BPTS-02) of the Mirage-MB safety module, and then transmitted to the display workstation (RSO), which displays the digital value of the temperature in the IRT-T reactor core in °C, and to narrow-profile devices (UPP-01) located at PO3, where the analog signal is displayed. The measurement interval of the coolant temperature difference on the IRT-T reactor core is from 0 to 10 °C. When the coolant temperature differential at the core is increased to 9.5 °C the IRT-T reactor control and protection system receives a warning signal, and when it increases to 10 °C – emergency signal, after which the emergency protection is activated and all rods are lowered into the core of the IRT-T reactor. The signals are generated using majoritarian logic "2 out of 3".

Temperature measurement is performed on single channels:

- of the IRT-T reactor core;
- IRT-T reactor biological protection concrete;
- coolant after the internal retaining vessel of the IRT-T reactor;

- coolant at the heat exchanger inlet and outlet of the heat exchangers of the primary and secondary cooling circuits of the IRT-T reactor;
- coolant in the two cooling circuits of the biological protection concrete of the IRT-T reactor.

The core temperature of the IRT-T reactor (1 sensor) and the temperature in the cooling circuit of the IRT-T reactor biological protection (3 sensors) are measured using CHEPT-2. The signal produced by the sensors is fed to the 2000NM microprocessor-based normalizing converter and converted into a current signal from 0 to 5 mA, which is fed to the IRT-1730 U/M universal millivoltmeter, where the temperature value is displayed in °C.

Temperature measurement in other points is performed by means of TSPU-2222. The measured temperature is converted into a current signal from 4 to 20 mA, which is sent to the IRT-1730 U/M universal millivoltmeter, which displays the temperature value in the °C. IRT-1730 U/M, which displays the values of eighteen temperature parameters set in the control room of the IRT-T reactor at PO1 and SO6.

Location of temperature measurement sensors:

- CHEPT-2 platinum technical thermometers (9 pieces) installed in the tank of the IRT-T reactor;
- CHEPT-2 platinum technical thermometers (3 pieces) are installed in the concrete mass of the IRT-T reactor tank wall;
- TSPU-2222 resistance thermometers (12 pieces) are installed on the technological pipelines;
- TSPU-2222 resistance thermometers (5 pieces) are installed on heat exchangers on the secondary cooling circuit;
- TSPU-2222 resistance thermometer (1 piece) is installed in the SFA storage pit.

3.5. IRT-T reactor coolant water level

The level of coolant in the IRT-T reactor tank is measured with a Metran 150-DD sensor in combination with the Mirage-MB safety module. The Metran 150-DD differential pressure sensor is installed on the second-floor balcony of the IRT-T reactor physical hall. The minus pulse line from the measuring chamber of the sensor is installed in the equalization vessel, which is located on the wall of the biological protection of the IRT-T reactor at the level of 6.0 m, and the plus pulse line is installed in the tank of the IRT-T reactor, also at the level of 6.0 m. This creates a pressure difference between the water column from the 6 m level in the reactor tank and the water level in the equalization vessel.

The Metran 150-DD sensor converts the pressure difference into a current signal from 0 to 5 mA. The current signal is measured in the galvanically isolated amplifier unit (BUG-02) of the safety module Mirage-MB, then transmitted to the display workstation (RSO), which displays the digital level value in meters, and to the UPP-01 narrow-profile devices located at PO3, where the analog signal is displayed. The IRT-T reactor tank coolant level measurement range is from 6 to 7.6 meters, with the nominal level considered to be 7.35 meters. If the level drops from the nominal level to 7.2 m, a warning signal is issued, and up to 7.0 m – an emergency signal is issued to the IRT-T control and protection system, after which the emergency protection is activated and all rods are lowered into the core of the IRT-T reactor. In addition to this, when the level drops to 7.0 m, a signal is given to shut down the electric motors of the IRT-T reactor core cooling circuit pumps, and after 140 s – to shut down the electric motor of the IRT-T reactor core emergency cooling pump. The circuit that ensures disconnection of the above-mentioned electric motors is assembled in the blocking unit in RS3 (distribution panel).

Since in the control and protection system of the IRT-T reactor the signals are formed according to the majority logic "2 out of 3" and the measurement of the true level of the coolant is carried out by one channel, 4 contact sensors S-57 (Figure 3.9) together with the resistance limit switch (SPRS2I-04V) (fig. 3.10) are placed on the top of the IRT-T reactor tank to signal the upper limit position of the coolant level in the IRT-T reactor tank. The signal of coolant level decrease in the IRT-T reactor tank by two of the four sensors in the contact form goes to the discrete signal unit (BDS) of the safety module Mirage-MB and is input to the control and protection system of the IRT-T reactor. The other two sensors are not wired into the CPS. Resistance limit switches (SPRS2I-04V), which indicate the presence or absence of coolant in the reactor tank, are located on SO6 of the IRT-T control room.

Fig. 3.9. S-57 contact sensor

Fig. 3.10. SPRS2I-04 resistance limit switch

Measurement of demineralized water level in the make-up tank of 5 m^3 is carried out by the transducer "Zond 10-GD" (Figure 3.11), which is installed directly on the make-up tank. The measuring range is from 0 to 1.6 m. The current signal from 4 to 20 mA from the transmitter Zond 10-GD goes to the universal millivoltmeter IRT-1730 U/M, mounted on SO6, which displays the level value in meters.

Fig. 3.11. "Zond 10-GD" transducer   *Fig. 3.12. Magnetic float transmitter PMP-062*

The Zond 10-GD also measures the pressure of the secondary circuit fluid after the heat exchangers. This pressure is referred to as the cooling tower pressure. The IRT-1730 U/M, which indicates the pressure value in MPa, is installed at PO1.

To detect leaks in the pits of the suction manifolds of the pipelines of the primary and secondary core cooling circuits of the IRT-T reactor, the retaining vessel, the heat exchanger canyons, the 325 m^3 special sewerage tank, the fresh fuel storage room, and the SLA tank, contact sensors S-57 complete with resistance limit switches (SPRS2I-04V) are installed to indicate the presence or absence of leaks in various pits. SPRS2I-04V are located on SO6 in the IRT-T reactor control room.

Measurement of the spent fuel level in the special sewerage tanks, in the cooling tower basin, in the make-up tank of the biological protection cooling circuit, in the SLA tank, as well as in the storage pit is performed by PMP-062 sensors (Figure 3.12) complete with IRT-1730 U/M millivoltmeters. The IRT-1730 U/M data, where the level value is displayed, are installed on SO6 of the IRT-T reactor control room.

3.6. IRT-T reactor natural circulation valves

Natural circulation valves (2 pcs.) are designed for natural circulation of the coolant. Thanks to the valves, the core of the IRT-T reactor is cooled in case of shutdown of the primary circuit pumps and the emergency cooling pump. The solenoids of the natural circulation valves are located on the IRT-T tank deck and the valves themselves are located on the internal retaining vessel. The natural circulation valves are closed when a constant voltage of 110 V is applied to the retaining coils of the solenoids and after switching on any of the electric motors of the IRT-T reactor core primary cooling circuit pumps or the electric motor of the IRT-T reactor core emergency cooling pump. The force developed by the valve solenoid retaining coil is sufficient to keep the valve closed. When any of the main pumps of the primary circuit is de-energized and after NAO operation equal to 140 s from the accumulator batteries of the previously mentioned electric motors, the valve coil is de-energized, the valve opens under the action of the spring and the natural circulation of the coolant in the IRT-T reactor tank begins. This cools the core of the IRT-T reactor.

3.7. IRT-T interlock unit

The interlock unit is located in control room 3 and is designed to shut down the electric motors of the IRT-T reactor core cooling primary circuit pumps, the IRT-T reactor core emergency cooling pump and the filter pump when:

- 110 V DC voltage is not applied to the solenoids of natural circulation valves;
- the position of gate valve PZ1-5 is "closed";
- the level of coolant in the IRT-T reactor tank has decreased to the emergency set point.

That is, if at least one of the above conditions is violated before startup, the IRT-T core primary cooling circuit pumps, the IRT-T core emergency cooling pump, and the filter pumps **will not start**.

If one of the above conditions is violated during operation, the interlock unit will shut down all of the above pumps except NAO.

References

Technical description and operating instructions of the control system (I&C) of the IRT-T reactor. – Tomsk: NR TPU, 2022. – 15 p. (in Russian).

Control questions and tasks

1. How is the flow rate of the primary and secondary coolant circuit of the IRT-T reactor measured?
2. Describe the principle of operation of the chamber diaphragm DC-6.
3. Describe the principle of operation of the Metran 150-DD transducer.
4. Describe the principle of operation of universal millivoltmeter IRT-1730 U/M.
5. How is the measurement of the coolant pressure of the primary and secondary cooling circuit of the IRT-T reactor carried out?
6. Describe the principle of operation of the Metran 150-DI transducer.

7. How is the measurement of the temperature of the coolant of the reactor IRT-T?
8. What is the principle of operation of CHEPT-2 sensing element and TSPU-2222 resistance thermometer?
9. Describe the principle of operation of the 2000NM transducer.
10. How is the measurement of coolant level in the tank of IRT-T reactor performed?
11. Describe the principle of operation of the S-57 contact sensor.
12. Describe the principle of operation of resistance limit switch (SPRS2I-04V)?
13. Compare the principle of operation of the Zond 10-GD transmitter and the Metran 150-DI transducer.
14. Describe the principle of operation of level transmitter PMP-062.
15. Describe the operation of the natural circulation valves of an IRT-T reactor.
16. How does the IRT-T reactor interlock unit work?
17. How is the IRT-T reactor technological parameter control system activated?
18. Describe the principle of operation of the pressure gauge.
19. What is a signal with unified output?
20. What is the difference between sensors with a thermistor (thermocouple) and with a thermistor?

Chapter 4
IRT-T NUCLEAR REACTOR CONTROL AND PROTECTION SYSTEM HARDWARE COMPLEX

4.1. Purpose of the complex

The complex is designed to ensure safe operation of the reactor in all modes of its operation. In accordance with its purpose, the complex provides:

- automatic and manual remote shutdown of the reactor in case of emergency situations in the reactor according to the signals of neutron flux (physical power) control detectors and according to the signals of primary or secondary transducers of reactor technological parameters control;
- manual remote reactor shutdown from the reserve control room and reactor hall room;
- automatic start-up of the reactor to a specified power level with a specified period;
- automatic maintenance of the set power level within the operating range of the automatic regulator and automatic power change with the set period;
- manual remote control of movement of reactivity impacting secondary reactor cooling circuits;
- continuous control and registration of the reactor relative physical power level;
- control of the rate (period) of change of the relative physical power of the reactor;
- control of technological parameters for which emergency protection signals are formed;
- control of the position of the CPS rods;
- control of the relative physical power of the reactor and final positions of the reactivity impacting secondary reactor cooling circuits from the back-up console;
- emergency and warning light and sound signaling in case of inadmissible deviations of controlled parameters from the set values and malfunctions in the complex;
- recording of triggering causes and sequence of events that led to emergency stop.

4.2. Main technical characteristics of the equipment complex of the IRT-T reactor control and protection system

4.2.1. Information functions of the complex

Complex performs several information functions:

- control of changes in the relative physical power of the reactor based on the neutron flux density at the ionization chamber locations through six independent channels and presentation of this information on six display devices (four at the operator's control room, two at the backup room);
- control of the rate (period) of relative changes of physical power on four independent channels and presentation of this information on four displaying devices on the operator console;

- control of water pressure drop across the core, water temperature at the core inlet, water temperature drop across the core, water level in the reactor pool, pressure at the head of the emergency cooling pump, gamma radiation dose rate at the primary circuit pipework, gas activity in the air from under the reactor pool cover on three independent channels for each parameter and presentation of this information on displaying devices on the operator console (except for water level in the reactor pool);
- control of water temperature at the core inlet by one channel, water level in the reactor pool by two channels, gamma radiation dose rate by four channels (backup console, primary circuit piping room, IRT-T reactor upper deck, fresh fuel storage) and presentation of this information on the back-up console;
- control and presentation of information on the position of six reactivity control secondary reactor cooling circuits, including end positions of EP1 and EP2 secondary reactor cooling circuits on the indicators of the operator console and the back-up console, end and intermediate positions of CR and SR1–SR3 secondary reactor cooling circuits on the indicators and position indicators on the operator console, as well as presentation of information on the end positions of all secondary reactor cooling circuits on the backup console;
- control and presentation of information on the operation of both individual units and the equipment complex as a whole;
- presentation of information (light and sound) on the causes of occurrence of warning and emergency signals with fixing the sequence of their occurrence;
- registration and displaying of controlled parameters and signals in working stations of display and information support.

4.2.2. Protection and interlocking functions of the complex

The emergency protection function is realized by emergency protection commands by de-energizing the electromagnetic clutches of the clutch in the EP rod drives, leading to the resetting of the rods into the reactor core, and automatic CR and SR.

The equipment of the complex provides formation of emergency protection commands by majoritarian logic "2 out of 3" for forced immersion of secondary reactor cooling circuit drives according to the parameters given in Table 4.1.

It also provides formation of emergency protection commands in case of disturbances in the power supply system, including loss of input power supply, and in case of malfunctions in the CPS equipment.

Formation of emergency protection commands by the operator's decision is performed by pressing any of the two "EP" buttons on the operator's console, the "EP" button on the back-up console or in the reactor hall.

The protective action initiated by the "EP" signal is performed from any position of the CPS rods until the EP1, EP2, CR and SR rods are fully entered into the reactor core.

The "EP" couplings are tightened by pressing the "Release EP" button on PO4 when the following conditions are fulfilled at the same time:

- there is no first-cause EP signal;
- no interlocking signals;
- all working elements are in the lower end positions.

Table 4.1

Warning and emergency technological parameters, which are incorporated in the IRT-T reactor control and protection system equipment complex

Parameter	Triggering event	
	Warning protection (blockage)	**Emergency protection**
Relative physical power	$\geq 1.1\ N_{stated}$*	$\geq 1.2\ N_{stated}$*
Period of change in relative physical power	≤ 20 S	≤ 10 s
Water temperature at the inlet of the reactor core	≥ 55 °C	≥ 60 °C
Temperature drop at the reactor core	≥ 9.5 °C	≥ 10 °C
Reactor tank water level	≤ 7.2 m	≤ 7.0 m
Pressure drop at the reactor core	≤ 30 kPa	≤ 27 kPa
Emergency cooling pump head pressure	≤ 133 kPa	≤ 118 kPa
Gamma radiation dose rate at the pipeline of the primary circuit	≥ 400 μR/s	≥ 500 μR/s
Activity of gases from under the reactor lid	$\geq 4\cdot10^{11}$ Bq/m^3	$\geq 5\cdot10^{11}$ Bq/m^3

Note: *N_{stated} – power stated by the operator.

Output of signals for triggering of emergency protection by power is provided in the range from 10^{-9} to 10^{-3} A (by neutron component of ionization chamber current) depending on the selected setpoint. The complex provides triggering of the emergency protection regardless of the current setpoint when the predetermined maximum power level is exceeded (by the neutron component of the ionisation chamber current).

Signals for triggering of emergency protection by the reduced rate of neutron flux increase (setpoint value – 10 s) are provided in the range from $1\cdot10^{-13}$ to $1\cdot10^{-3}$ A (by neutron component of ionization chamber current).

The complex provides triggering of interlocks for removal of reactivity impacting secondary reactor cooling circuits (reactivity increase interlocks) in case of inadmissible deviations from the controlled parameters specified in Table 4.1, in case of malfunctions in the equipment, absence of any functional or logical unit at its place, as well as in case of power supply redundancy reduction (in case of failure of one power supply unit of the rack of safety modules).

The emergency protection can only be disarmed when all CR and SR controls are in their lowest positions. When the emergency protection is activated, the above-mentioned interlocks are activated, forbidding the retraction of the EP couplings and the removal of the emergency protection rods.

The fail-safe action is only possible when all CR and SR actuators are in their lowest positions. When the emergency protection is activated, the above-mentioned interlocks are activated, which prohibits the retraction of the EP couplings and the removal of the emergency protection secondary reactor cooling circuits.

The complex provides for automatic lowering of the regulating and compensating rods to their final lower positions if the emergency protection rods are not in the upper position.

In the manual and remote-control modes of the reactivity influencing secondary reactor cooling circuits, the complex provides step-by-step introduction of positive reactivity with the step duration not more than 10 s (corresponding to the step "weight" up to 0.3 β_{eff}).

Also, in two control modes, the simultaneous removal of two or more regulating and compensating secondary reactor cooling circuits is blocked.

4.2.3. Control functions of the complex

EP secondary reactor cooling circuits are operated by manual remote control only, and CR and SR secondary reactor cooling circuits are operated by both manual and remote control.

The complex includes the path of automatic start-up and regulation of the relative physical power level, which provides the formation of signals for automatic start-up of the reactor and its transfer from one power level to another by acting on the drive of the CR secondary reactor cooling circuit with automatic connection of the SR1–SR3 working secondary reactor cooling circuits.

Automatic start-up and regulation is provided by an optimal regulator. Transition from one stationary power level to another is carried out according to the equation:

$$N = N_0 \cdot e^{t/T} \quad if \quad N_0 < N < N_{stated}, \tag{4.1}$$

where T – stated power doubling period; N – current power value; N_0 – initial power value; N_{stated} – stated power level.

The operating period of power increase is 50 s. The setpoints for the set power level lie in the range from 10^{-9} to 10^{-3} A (based on the neutron current component of the ionization chamber).

4.3. Composition of the IRT-T reactor control and protection system equipment complex

The IRT-T reactor control and protection system hardware complex consists of two sets: main and backup.

The main set includes:

- four suspensions with primary neutron flux density transducers (ionization chambers): three SIC 55 suspensions with fission ionization chambers with gamma-sensitive volume and one SIC 56 suspension with current ionization chamber of KNK-53 type;
- two device stands (SP1 and SP2);
- a set of operator console:
  - processing unit (PB1, PB2);
  - uninterruptible power source (UPS4, UPS5);
  - monitor (M1, M2);
  - keyboard (K1, K2);
  - "mouse" manipulator;
  - two interface converters (PI).

The SP1 device stand includes:

- two main units Mirage-MB (MB1-1 (EP), MB1-2 (EO));
- hardware unit BA1-1, comprising:
  - two relay units (BR1-1, BR1-2);
  - three logic units (BL1-1, BL1-2, BL1-3);
  - three servo amplifiers (SU1-1 (EP1), SU1-2 (SR1), SU1-3 (SR2));
  - two diode-resistor units (BDR1-1, BDR1-2);
- hardware unit BA1-2, comprising:
  - three signal logic units (BSL1–BSL3);
  - two power supply units (BP24 1-1, BP24 1-2);
  - power supply control unit (BCP1);
  - uninterruptible power source (UPS1).

The SP2 device stand includes:

- two main units Mirage-MB (MB2-1 (A3), (MB2-2 (AP));
- hardware unit (BA2-1), comprising:
  - two relay units (BR2-1, BR2-2);
  - three logic units (BL2-1, BL2-2, BL2-3);
  - three servo amplifiers (SU2-1 (EP2), SU2-2 (AP), SU2-3 (SR3));
  - two diode-resistor units (BDR2-1, BDR2-2);
  - two power supply units (BP24 2-1, BP24 2-2);
  - power supply control unit (BCP2);
  - uninterruptible power source (UPS2).

The appearance of device stands SP1 and SP2 is shown in Figure 4.1.

The operator console (PO) includes:

- control panel (PU);
- indication panel PI1;
- registration module Mirage-MR;
- indication panel PI2;
- indication panel PI3.

Control panel (PU) includes:

- four remote indicators-power setters (VIZM1–VIZM4);
- button "Emergency signalization sound check";
- button "Warning signalization sound check";
- button "Notification signalization sound check";
- button "Mute";
- button "Signalization unblocking";
- toggle switch "Indication extinguishing";
- toggle switch "Signalization extinguishing";
- toggle switch "UPC extinguishing";
- two buttons for triggering the emergency protection "Emergency protection";
- key "CR Automatic / Manual" to select the mode of controlling the movement of the CR rod;
- SR "SR1–SR3 Automatic / Manual" toggle switch for selecting the SR operation mode;

- four keys with non-latching positions (with self-recovery) "Rod movement" for removal or insertion of CR and SR1–SR3 secondary reactor cooling circuits;
- four toggle switches for forced disconnection of motor power supply circuits: "Prohibition of CR extraction", "Prohibition of SR1 extraction" – "Prohibition of SR3 extraction";
- toggle switch of forced disconnection of power supply circuits of clutches of EP drives;
- button "EP unblocking";
- button "EP extraction".

Indication panel (PI1) includes:

- four digital position indicators (UPCs) to provide information on the exact positions (end and intermediate) of the CR and SR1–SR3 rods in the reactor core, the values are displayed in mm;
- indication unit to provide information on final positions of EP1 and EP2 secondary reactor cooling circuits;
- four narrow-profile devices that show the relative power level from the four Mirage-MB units of the main set;
- four narrow-profile devices that show the power doubling period from the four Mirage-MB units of the main set;
- three narrow-profile devices that show the core pressure drop from three Mirage-MB emergency protection units;
- three narrow-profile devices that show the head pressure of the emergency cooling pump from three Mirage-MB emergency protection units.

Indication panel (PI2) includes:

- three light signaling units of emergency signaling (BSS2-1–BSS2-3);
- four light signaling units of warning signaling (BSS2-4–BSS2-7);
- a narrow-profile device showing the water level in the swimming pool from the third Mirage-MB emergency protection unit;
- three narrow-profile devices showing the water temperature from three Mirage-MB emergency protection units;
- three narrow-profile devices showing the difference in core inlet and core outlet water temperature from three Mirage-MB emergency protection units;
- three narrow-profile devices showing the gamma dose rate at the primary circuit pipework from three Mirage-MB emergency protection units;
- three narrow-bore devices showing the activity of gases in the air from under the reactor tank cover from three Mirage-MB emergency protection units.

Indication panel (PI3) includes:

- four light signaling units for notification signaling (BSS3-1–BSS3-4);
- two sound signalization units (BZI);
- two loudspeaker units (BGr1, BGr2).

The backup part of the IRT-T reactor control and protection system hardware complex includes:

- two suspensions (SIC 55 and SIC 83) with primary neutron flux density transducers (fission ionization chambers);
- device stand (SP3);

- display workstation (RSO3), comprising:
  - processing unit (PB3);
  - uninterruptible power source (UPS6);
  - monitor (M3);
  - keyboard (K3);
  - "mouse" manipulator;
  - interface converter PI.

Device stand (SP3) includes:

- two main units Mirage-MB (MB3-1, MB3-2);
- hardware unit (BA3-1), comprising:
  - indication unit;
  - two narrow-profile display units, which display power signals from the main Mirage-MB units of the backup set;
  - a narrow-profile device showing the water temperature from the fifth Mirage-MB unit of the backup set;
  - button "Emergency protection";
- hardware unit (BA3-2), comprising:
  - four narrow-bore devices that indicate the gamma dose rate from the Mirage-MB units of the backup set;
  - power supply unit (BP24 3-1);
  - power control unit (BCP3);
  - uninterruptible power supply unit (UPS3).

Appearance of the SP3 dashboard rack is shown Figure 4.1.

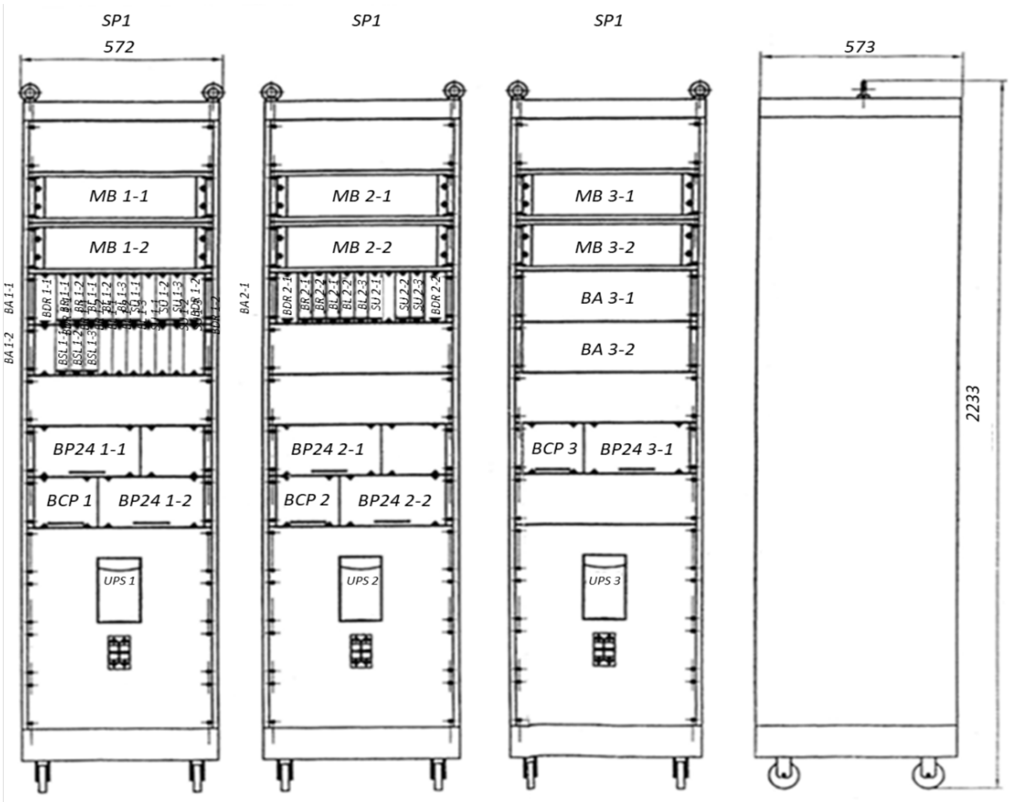

Fig. 4.1. CPS device stands of the IRT-T reactor

4.4. Design and operation of the components of the control and protection system complex IRT-T reactor control and protection system

4.4.1. Mirage-MB CPS Main Unit of the IRT-T Reactor

The Mirage-MB basic unit is a computer system consisting of linked microprocessor-based processing units and peripheral equipment, which is controlled by internally stored programs.

Mirage-MB has a unit-modular design. It is a cage with rails for mounting up to 14 interchangeable units. The units are electrically connected to each other via a distribution board, on which the mating parts of the unit connectors are installed. To the distribution board the indication, signaling and keypad panel (PISK) is attached, which is closed with a front false panel.

On the rear side of the Mirage-MB main unit there are various interchangeable signal processing units. It is not allowed to change the installation positions of these units. Listed below are the interchangeable signal processing units included in the Mirage-MB main unit:

- control controller unit (BUK-02) – microprocessor-based processing unit designed to perform the following functions:
  - reception, normalization and conversion into digital codes of signals from technological parameter input units;
  - processing of information in accordance with specified algorithms, generation of signals for emergency protection, interlocks, signaling and automatic control of physical power;
  - information exchange with the auxiliary controller unit (BVK-02), indication, signalling and keyboard panel and remote power setter indicator (VIZM) in accordance with the accepted exchange protocol;
- auxiliary controller unit (BVK-02) – microprocessor-based processing unit designed to fulfil the following functions:
  - receiving data from the control controller, processing them in accordance with the specified algorithms;
  - storage of archive data;
  - transfer of information to external devices (workstations) via two serial communication channels in accordance with accepted protocols;
- indication, signaling and keypad panel (PISK-01) is a microprocessor-based processing unit and provides for:
  - input from the built-in keyboard and display of emergency and warning settings on the built-in display;
  - digital display of measured and calculated values;
  - indication of light emergency, warning and notification signaling when the controlled parameters exceed the set points.

The following units are peripheral equipment used for signal input/output:

- unit of analogue IR signal processing (BAO-05) is controlled from BUK-02 and is designed to receive signals from pendants with fission ionization chamber with gamma-sensitive volume;
- current amplifier unit (BUT-02) is controlled from BUK-02 and is designed to receive signals from current ionization chamber;

- unit of resistance thermometer signal converters BPTS-02 is designed to receive signals from resistance thermometers (TS) used for temperature control;
- unit of galvanically isolated amplifiers (BUG-02) is controlled by BUK-02 and is designed to receive analogue signals (voltages, currents) from devices that measure technological parameters;
- discrete signal output unit (BDV-02) is controlled by BUK-02 and is designed to generate and output to external circuits discrete signals for control and signaling units;
- discrete signal input unit (BDS-02) is controlled by BUK-02 and is designed to receive discrete signals, which are formed by technological parameter measuring devices from devices with potential output or "dry contact" type and provides galvanic isolation of signals;
- analogue signal output unit (BAV-02) is controlled by BUK-02 and is designed to generate and output voltage and current signals to external circuits to display devices for indication of the main controlled parameters. In addition, BAV-02 contains a channel for forming and outputting into external circuits a voltage signal, which is used as a signal of automatic power control;
- radiation monitoring unit (BRK-01) is controlled by BUK-02 and is designed to receive signals from detection units (BD) of primary circuit coolant activity and activity of gases from under the IRT-T reactor lid;
- low-voltage power supply unit (BPN-06) is designed to convert the DC network voltage of 24 V ± 15 % into a constant stabilized voltage from + 5 to ± 15 V required to power the Mirage-MB units;
- high voltage power supply unit (BPV-06) is designed to convert the DC mains voltage of 24 V ± 15 % into a constant regulated voltage from 0 to +500 V required to power the IC suspension units.

The front panel of the PISK contains the LED display, LCD and keypad. The LED display is divided into three zones:

- emergency signaling (ES);
- warning signaling (WS);
- notification signaling (NS).

The emergency and warning alarms are triggered by deviations from normal values of the following parameters:

- "N" – physical power (neutron component of the ionization chamber current);
- "A" – the reduced rate of change of physical power (period);
- "P" – core pressure drop;
- "H_t" – reactor tank water level;
- "P_{NAO}" – water pressure at NAO head;
- "T_{in}" – core inlet water temperature;
- "ΔT" – water temperature drop at the reactor core;
- "$D_т$" – γ-radiation dose rate at the suction pipe of the primary circuit;
- "D_c" – β-activity of gases in the air removed from under the reactor lid;
- "Failure" – "Mirage-MB" failure.

4.4.2. Hardware CPS unit of the IRT-T reactor

Hardware unit (BA) is designed for logic processing of signals and organization of RO control. It represents a unit frame of "Vishnya" design and consists of three logic units, two relay units, two diode-resistor units and three servo amplifiers (Figure 4.1). Its functions are described in detail below, in sections 4.4.3–4.4.11.

4.4.3. IRT-T reactor CPS logic unit

The logic unit is designed for logical processing of input discrete signals and outputting a discrete signal for subsequent formation of interlocking or emergency protection commands.

The logic input signals of the logic unit are defined as follows:

- "normal" or "serviceable" – 0 to + 3.0 V – "logic zero";
- "accident" or "failure" – from + 6.0 to + 40.0 V – "logical one".

The input signals of the logic unit are divided into two parts: the first part includes the so-called group signals with three signals in each group, the logic processing of the signals of each group is carried out by the logic "2 out of 3"; the second part includes the so-called single signals, the logic processing of which is carried out by the logic "OR".

The output signal is taken from the open drain of the output transistor. The input signal processing logic is as follows. The "output transistor" is closed if at least two signals in any of the nine groups have a value of "log.1" ("2 out of 3" logic) or any of the seven single signals has a value of "log.1" ("OR" logic).

Connector pins 1th to 27th inclusive are designed to receive nine groups of signals, which are processed by majoritarian logic "2 out of 3".

Connector pins from 28th to 34th are designed to receive single logic signals of the second group. The output signal is taken from pin 28 of the "Output" connector.

On the front panel of the logic unit there is a green LED indicator. A lit LED indicates that the output transistor is open and current is flowing through it.

The output signal ("Output") of the logic unit is defined as follows. The open state of the output transistor corresponds to the absence of the "EP" command, the closed state corresponds to the presence of the "EP" command.

Also, on the front panel there is a button "AOS", pressing which switches the output transistor to the closed state, even in the absence of input signals such as "failure" or "fault". The button is used for individual resetting of the emergency protection secondary reactor cooling circuit. The details of this button are described below in the subsection "CPS Relay Unit of the IRT-T Reactor".

The generation of an emergency protection command or interlock command by the logic unit is determined by the unit where the logic unit is installed.

For formation of commands for emergency protection the logic units BL1-1, BL1-2, BL2-1, BL2-2 are intended.

Logic units BL1-1 and BL1-2 are installed in BA1-1 of SP1 rack on the fourth and fifth (counting from left to right) units; logic units BL2-1 and BL2-2 are installed in BA2-1 of SP2 rack also on the fourth and fifth units.

The input signals of each logic unit are as follows:

- "AZMS", "AZTPT", "AZDP", "AZUB", "AZAO", "AZPD" from three Mirage-MB units of emergency protection, connected to the groups of inputs "2 out of 3";
- "APNAO" (two circuits), "APS", "ARP", "AOP" are connected to single inputs;
- emergency signals "KAZPO", "KAZRP", "KAZRZ" are connected to the relay units (see below) and are not input to the logic units.

For the formation of the command "WP", blocking the extraction of EP, CR and SR secondary reactor cooling circuits, the logic units BL1-3 and BL2-3, installed, respectively, on the sixth unit-seat of the hardware unit BA1-1 of the rack SP1 and on the sixth unit-seat of the hardware unit BA1-1 of the rack SP2, are intended.

The input signals of these units are as follows:

- "Interlock E" from three Mirage-MB emergency protection units, wired to single inputs;
- "Interlock P" from three Mirage-MB units of emergency protection, connected to the group of inputs "2 out of 3";
- "OVB", "OF", "OPIBP", "OPC", "ORRP", connected to single inputs.

The missing single inputs are obtained from the "2 out of 3" inputs by not connecting one of the three inputs, then the two remaining inputs behave the same way as single inputs.

The output signal from BL1-3 "Prohibition to EP rods extraction" from the contact "Diagn" is fed to two relay blocks BR1-1 and BR1-2, and from the logic unit BL2-3 (also from the contact "Diagn") to the relay units BR2-1 and BR2-2.

4.4.4. IRT-T reactor CPS relay unit

The relay unit (BR) is a unit unified within this CPS, which is used to control electromagnetic coupling clutches (EMS) installed in the drives of the rods of the EP and to organize blocking of the EP rods extraction.

The main functions of the set of relay units installed in the hardware units BA1-1 and BA2-1 are as follows:

- unlocking of the protection and extraction permission of EP;
- fixing the end of the protection rods and the removal of CR and SR rods permission;
- bringing the initiated defense action to the end;
- formation of a command for emergency lowering of CR and SR rods when at least one EP rod leaves the upper end position in case of emergency protection activation;
- ensuring individual resetting of EP1, EP2 rods during experiments on determination of rods efficiency by the resetting method.

The IRT-T reactor's CPS relay unit connector pins receive signals:

- "PRA" – signal from the operating mode selection key "CR Automatic / Manual" located on the operator panel, "log.1" = "Manual", "log.0" = "Automatic";
- "Interlock 1" – "Interlock 4" – unlocking prohibition signals, "Interlock 1" is connected to the "Diagn" output of the locking logic unit, "Interlock 2" – "Interlock 4" – backup, always "log.0";
- "Unlock button" – signal from the "Unlock EP" button located on the operator panel;
- "Drop EP1" – "Drop EP6" – signals of Drop EP, inputs "Drop EP1" – "Drop AZ3" are used for signals "KAZPO", "KAZRP", "KAZRZ" from buttons of Drop AZ, inputs "Drop AZ4" – "Drop AZ6" – backup, always "log.0";

"BAOS" – a signal prohibiting the clutch release and output of the "AOS" signal when at least one of the EP secondary reactor cooling circuits moves from the upper position, it operates only when the "BAOS" button on the front panel of the unit is pressed, described in detail below.

In turn, the CPS relay unit of the IRT–T reactor generates the following signals:

- "AOS" – signal of emergency lowering of CR and SR, formed when at least one of the rods of the EP from the upper position;
- "Ready for extraction" – a signal about readiness of the EP for extraction;
- "RIS R" – signal that CR and SR rods can be extracted and the EP is ready for triggering.

The "Ready for extraction" signal indicates that the safety relay can be armed and is input to the "EP readiness for extraction" LED on the operator panel. This signal is also the input signal for the relay unit.

On the front panel of the unit there is an LED indicator to provide visual control of the closed state of the EMS power supply circuits, as well as the "BAOS" button used to provide the individual Drop rod mode.

Functioning of the relay unit for rods EP1 and EP2 actuators

In the initial state, all rods are in the final low positions, the "CR Automatic / Manual" operating mode switch is in the "Manual" mode, there are no warning and emergency signals, "PRA", "Unlock button", "Ready for extraction", "BAOS" inputs have "log.1", and "Interlock 1" – "Interlock 4", "Drop EP1" – "Drop EP6" inputs have "log.0" value.

Even in the absence of emergency protection signals, no current flows through the output transistors in the logic units and, accordingly, the "Hold" signal has the value "log.1".

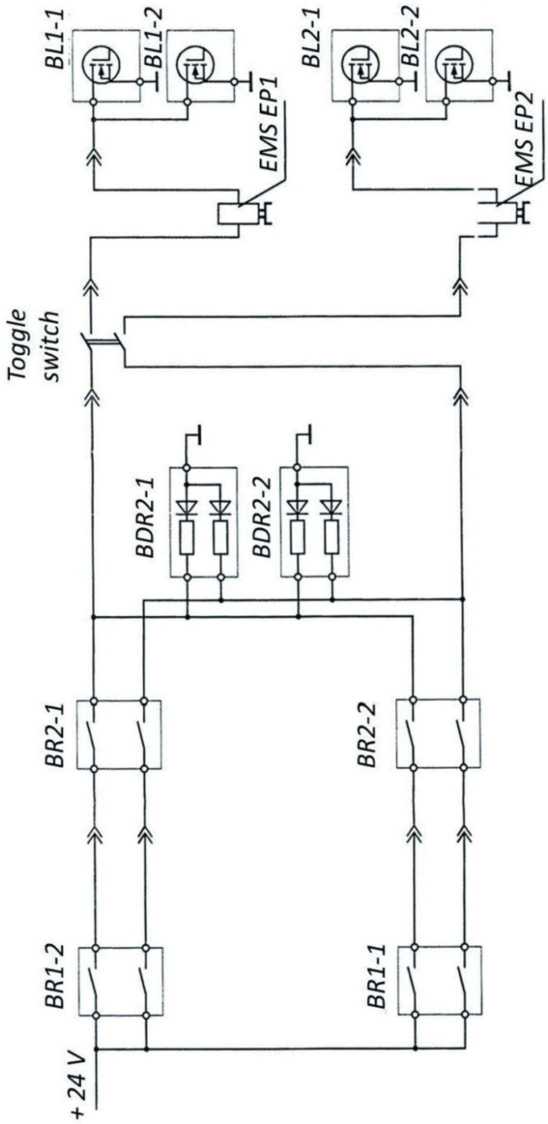

Fig. 4.2. Control scheme of electromagnetic clutches of actuators EP1 and EP2 of the CPS of the IRT-T reactor

When pressing the button "Unlock EP" on all inputs of the element "OR" is "log.0", as a result of which the power relays are switched on and there is "log.0" on the output "Ready for extraction". Since the power transistors of the logic units are open, the power supply circuit of the coupling is closed (Figure 4.2) and a current sufficient to open the "Diagn" contact of the logic units occurs. The relay unit "Hold" input receives "log.0". The "Ready for extraction" and "Hold" signals are collected by the "OR" signal and create a new circuit for switching on the power relays. The "Unlock EP" button can now be released. The couplings are pulled up and thus the emergency protection is unlocked.

After unlocking of the emergency protection on the operator panel by the signal "Ready for extraction" LED from the relay units lights up. At the same time the same signal comes to the control input of the diode-resistor unit and power is supplied to the excitation windings of EP drive motors. Then it is necessary to press the button "EP extraction" to cock rods EP1 and EP2 to their final upper positions. When the EP1 and EP2 rods are extracted to the final upper positions, the "Ready for extraction" signal disappears, the "Ready for extraction" LED goes out and the excitation windings of the EP drive motors are de-energised.

The wiring diagram of relay and logic units providing individual Drop rods EP1 and EP2 is shown in Figure 4.3.

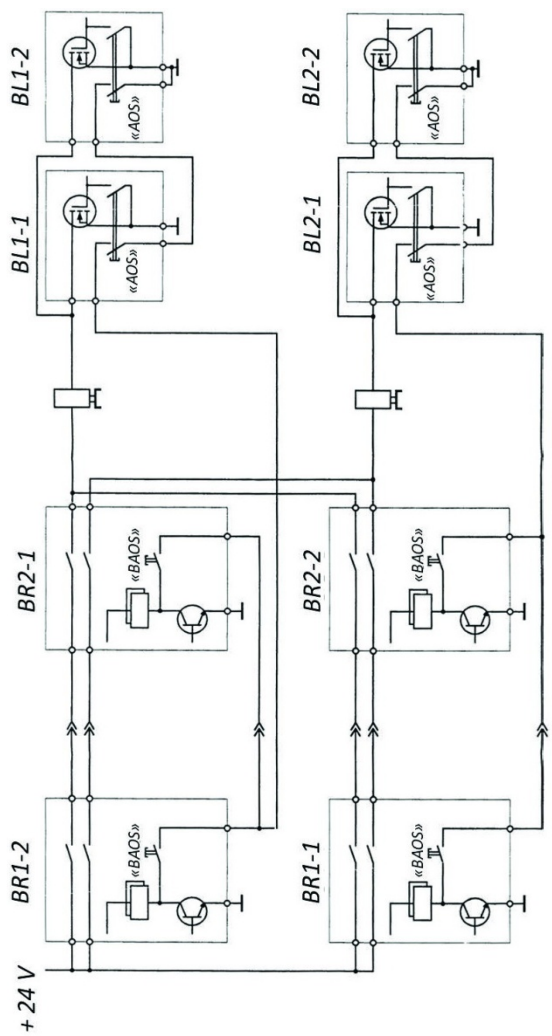

Fig. 4.3. Scheme for separation by EMC of EP1 and EMC of EP2 CPS of the IRT-T reactor

After the EP rods have been extracted to their final upper positions, the individual Drop of each EP rod can be performed. To drop rod EP1 it is necessary to press the "BAOS" buttons on the relay unit BR1-2 and on the relay unit BR2-1, as well as the "AOS" buttons on the logic units BL1-1 and BL1-2.

Pressing the "BAOS" buttons in the relay units BR1-2 and BR2-1 units the disconnection of relays in them, which provide power supply to the electromagnetic clutch of the rod EP2 drive and the output of the CR and SR lowering signal, and pressing the "AOS" buttons on the logic units BL1-1 and BL1-2 leads to the closure of the output transistors in these logic units and the opening of the power supply circuits of the electromagnetic clutch of the rod EP1 drive.

All four buttons should be held down until the end of the experiment to determine rod efficiency using the "Drop" method. Releasing any one of these buttons will cause another rod EP to Drop another rod EP2.

To Drop rod EP2, press the "BAOS" buttons on relay unit BR1-1 and on relay unit BR2-2, as well as the "AOS" buttons on logic units BL2-1 and BL2-2.

4.4.5. IRT-T reactor diode-resistor CPS unit

The diode-resistor unit (BDR) is designed to provide the following auxiliary functions:

- redundancy of the DC power supply required for the respective consumers with a nominal value of plus 24 V, minus 24 V, obtained from two power sources;
- shunting of voltage surges arising at switching off the electromagnetic clutches of the clutch installed in the EP drives;
- switching on and switching off the power supply of excitation windings of electric motors of rods drives;
- switching on and switching off the power supply to the indicating devices on the operator panel.

For redundant power supply, the BDR is equipped with pairs of diodes, which are supplied with voltages from two BP24 power supplies. The redundant plus and minus 24 V voltages are supplied from the BDR for internal consumption in the hardware unit in which it is installed. These voltages are also supplied to the operator console via two lines. One line is used to supply the components located on the console, which operate only with the device rack in which the BDR is located. The other line supplies the components on the console that are common to both racks. Each line is protected by a resistor and fuse connected in series (4 Ohm, 8 W resistor and 1 A fuse on the first line, 2 Ohm, 16 W resistor and 2 A fuse on the second line). In case of a short-circuit on one of the lines, the voltage remains on the other line and on the internal consumers of the apparatus unit. Two BDR units connected in parallel are installed in each equipment unit.

Voltage surges are bypassed by a diode-resistor chain connected in parallel to the winding of the electromagnetic coupling.

4.4.6. IRT-T reactor CPS servo amplifier

The servo amplifier (SU) is a unit used to control the anchor winding of the work rod drive motor.

A positive voltage of up to 9 V on the anchor winding corresponds to an upward movement of the rod, while a negative voltage of up to 9 V corresponds to a downward movement of the rod. The higher in modulus the voltage given to the anchor winding of the electric motor of the working rod drive, the higher the speed of raising or lowering of the working rod.

Logic circuit converts input logic signals, selecting the mode of operation of the control system, and generates output logic signals to control the actuators.

Operating modes of the SU:

- **Regime A.** Proportional control between inputs "AU", "UBZ1", "UBZ2", "UBZ3". The voltages coming from these inputs are averaged using resistors. In the circuits of inputs "UBZ1", "UBZ2", "UBZ3" there are diodes, so that when controlling these inputs, the output voltage of the control system can only be negative. The output voltage of the control system is proportional to the input voltage (averaged from "AU", "UBZ1", "UBZ2", "UBZ3") and coincides with it in sign. The sensitivity is regulated by the adjustment resistor "↕" on the front panel and can be monitored with a voltmeter connected to the sockets "↕" and "0".

This mode is activated when "log.0" is present at the "PRA" input, i. e. mode A controls the reactor in Automatic mode.

- **Regime B.** Supply of the set positive voltage. The output voltage is regulated by the "↑" adjustment resistor on the front panel and can be monitored by a voltmeter connected to the "↑" and "0" sockets.

This mode is enabled when "log.0" is present at the "IC" input. It is switched on only for a certain period of time – 3–5 s, after which the Automatic mode is switched off.

- **Regime C.** Supply of the set negative voltage. The output voltage is regulated by the adjustment resistor "↓" on the front panel and can be monitored by a voltmeter connected to the sockets "↓" and "0".

This mode is switched on when "log.0" is present at the "OS" input, as well as by feeding "log.0" to the "AK80" input, at that the switching on of the mode is memorized on the trigger present in the control system. To switch off the mode in this case it is necessary to input "log.0" to the input "AK50".

- **Regime D.** Supply of the maximum modulo negative voltage possible.

This mode is activated when "log.1" is present on the "AOS" input and has priority over all other modes.

The "log.0" on the "VK" input means that the rod has reached the upper end position and is also indicated by the "VK" LED on the front panel of the unit.

In all modes the presence of "log.0" on the "VK" input units the possibility of positive output voltage.

In mode B, a voltage of more than 1.5 V on the "KIS" line units the possibility of positive output voltage supply.

The "KIS" line is designed to limit the number of rods that can be extracted simultaneously. All SUs are connected to this line. From here voltage is applied to the common wire, which is connected to a load resistor installed in the SU between the "log.1" and "Block" pins. When the SU generates a positive output voltage, it also energizes the "KIS" line. When more than one servo amplifier supplies current to the "KIS" line at the same time, the line voltage exceeds the limit and the rod extraction is blocked.

In order to block the rod extraction when the warning protection is activated, the load resistor of the "KIS" line on the common wire is disconnected and the line voltage is increased by the resistor of the control system between the "log.1" pin and the 9 V supply.

"log. 0" on the "NK" input means that the rod has reached the lower end position and is also indicated by the "NK" LED on the front panel of the unit.

The presence of "log.0" on the "NK" input units the possibility of negative output voltage.

4.4.7. CPS power supply unit 24 of the IRT-T reactor

Power supply unit 24 (BP24) is designed to supply all functional units of the CPS equipment.

Functionally, the BP24 consists of two bridge rectifiers for plus 24 V, minus 24 V and plus 9 V voltages. Each rectifier has a trans-former and a capacitive filter.

The presence of output voltages is induced by an LED mounted on the front panel. It is illuminated only when all output voltages are present and is not illuminated when at least one is absent. There is also an electronic relay for monitoring the output voltages. It has five equivalent dry monitoring contacts, of which two are connected by the minus terminal to the common wire. Each of them is closed when all output voltages are present and open when at least one of them is absent.

The unit also contains an intermediate electronic relay designed to receive and reproduce the failure signal of the BP24 unit located in another device rack.

The normally open contacts of these relays are used to ensure control of the BP24 unit operability as part of the entire power supply system.

4.4.8. IRT-T reactor CPS power control unit

Power control unit (BCP) is designed to control the presence of voltage on each of the two feeders, on the output of the uninterruptible power supply, switching the power supply of consumers, uninterruptible power supply from the "main" feeder to the backup feeder in the absence of voltage on the "main" feeder and back to the "main" feeder when the voltage is restored on the main feeder.

The BCP unit includes three electronic relays, whose normally open contacts are used to monitor the presence of voltages on both feeders and the output of the uninterruptible power supply in order to form signals of faults in the power supply system. There are also two intermediate electronic relays in the unit. One of them is designed to receive and multiply the signal of failure of the uninterruptible power supply located in another rack, the other is a backup.

BCP units are part of all device racks, and the external power supply of 220 V, 50 Hz is supplied to the device racks via feeder 1 and feeder 2, so that feeder 1 is the "main" feeder and feeder 2 is the "backup" feeder in rack SP1 and rack SP3 (backup console). In rack SP2, feeder 2 is the "primary" feeder and feeder 1 is the "back-up" feeder.

4.4.9. IRT-T reactor CPS signaling equipment

The signaling equipment consists of a hardware unit (BA1-1) and indication panels (PI2 and PI3) designed for recording and audiovisualization of logic device activations (caused by both deviations in the nuclear reactor operation and malfunctions in the CPS equipment itself), as well as for recording and audiovisualization of external commands requiring activation of the emergency protection, and erroneous actions of the operator.

Indication panel PI2 is intended for fixation and visualization of emergency and warning signals. Indication panel PI3 is used for fixation and visualization of notification signals and sound signals. Hardware unit BA1-1 – for collecting signals from three main Mirage-MB units.

The output signals of the signaling units are divided into three groups:

- emergency – seven-segment single-digit indicators, closed, together with nameplates, light filters of red color; intermittent sound signal with frequency of about 800 Hz;

- warning – seven-segment single-digit indicators, closed, together with nameplates, light filters of yellow color; intermittent sound signal with frequency of about 500 Hz;
- notification – seven-segment single-digit indicators, closed, together with nameplates, with green-colored light filters; intermittent sound signal with a frequency of about 300 Hz.

A number of signals, which are input to the signaling equipment, are processed in the BSL signal logic units and the Mirage-MR registration module before reaching the light signaling units. Other signals are not subjected to such processing and go directly to the BSS units.

The sound notification unit BZI consists of three controllable generators operating on a power amplifier. The generators are controlled via the buses "Sound ES", "Sound WS", "Sound NS" and the input "Sound Capture".

Additional units providing processing and transformation of input signals are three units of signal logic – BSL1–BSL3, installed in the hardware unit BA1-1.

BSL contains:

- seven "2 out of 3" logic elements;
- the "4OR" logic element;
- the "3OR" logic element.

The BSL input signals are groups of three emergency or warning signals of the same name from three Mirage-MB emergency protection units. For each such group BSL executes the logic "2 out of 3" or "OR" according to the signal description. The results of the logic processing are fed to the BSS.

The signals of the signal logic units processed by the "2 out of 3" majority logic are as follows:

- BSL1 – "AZM", "AZS", "AZT", "AZPT", "AZD1", "AZPD";
- BSL2 – "AZAG", "AZUB", "AZAO", "PM", "PS", "PPD";
- BSL3 – "PT", "PPT", "PD1", "PAG", "PUB", "PAO", "NSM".

The signals to be processed by BSL units using "OR" logic are as follows:

- BSL1 – "BPM", "APNAO";
- BSL2 – "BAM";
- BSL3 – "UBD".

The Mirage-MR registration module is another additional unit for processing and converting the input signals. This module receives all warning and notification signals from other systems, where they are galvanically isolated and outputted.

It receives all warning and notification signals from other systems, where they are galvanically isolated and output from it to the BSS. The internal CPS signals are connected to the inputs of the Mirage-MR and the BSS in parallel without galvanic isolation.

The input signals of the BSS are:

- BSS2-1 – "EP", "AZM", "A3S", "AZT", "AZPD";
- BSS2-2 – "AZPT", "AZD1", "AZAG", "AZUB", "AZAO", "APNAO";
- BSS2-3 – "APS", "ARP", "AOP", "KAZPO", "KAZRP", "KAZRZ";
- BSS2-4 – "WP", "PM", "PS", "PT", "PPD";
- BSS2-5 – "PPT", "PD1", "PAG", "PUB", "PAO", "BAM";
- BSS2-6 – "UBD", "NSM", "OF", "OIBP", "OPS";
- BSS2-7 – "ROM", "OAP", "OVB", "ORP", "OCV", "P1K";
- BSS3-1 – "BPM";
- BSS3-2 – "U2K", "OVG", "ODNV", "O110", "VUVB", "VP1";
- BSS3-3 – "VP2", "VPZE", "VPTO", "U1K3", "U2K3", "URF".

The unused BSS and BSS3-4 inputs are backups. The hardware units provide connectors for input signals that can be applied to these backup connectors. The need for these backup signals can be determined during product operation.

4.4.10. IRT-T reactor digital CPS position indicator

The digital position indicator (UPC) is designed to provide digital and analogue information on the position of the rotor of the bellows and the associated control rod.

UPC provides:

- display of rod position on the four-digit seven-segment indicator within the range from 0 to 8191;
- duplication of information presented on the seven-segment indicator in analogue form in the form of a luminous bar;
- indication of actuation of limit switches of servo drives using LEDs;
- indication of the direction of rod movement using LEDs;
- transmission to external circuits of information on rod position, state of limit switches and RO movement using serial interface.

The UPC works in combination with a selsin of type BD 404. It can be said that the UPC is a functional equivalent of the receiver and provides tracking of the phase shift change of the sensor bellows within one or many revolutions of its shaft, depending on the settings of microswitches.

The most complex part of the device is the phase shift tracking circuit between the single-phase and three-phase windings of the selsin. The principle of conversion is based on a rigid connection between the position of the RO and the angle of rotation of the selsin shaft. A change in the angle of rotation of the bellows leads to a relative phase shift of the signals on its single-phase and three-phase windings. The phase shift is converted into binary and binary-decimal numerical codes. The resulting number is also converted into an analogue signal by means of a pulse-width DAC and displayed on an analogue indicator in the form of an LED bar. The luminous bar consists of 14 LEDs.

The full stroke of the RO is from 0 to 81.91 mm, the movement of the rods per one turn of the selsin is 0.40–40.96 mm. The length of the connecting line between the UPC and the selsin is not more than 1 km.

On the front panel of the UPC are located:

- four seven-segment indicators;
- 14 analogue indicator LEDs;
- indicators of operation of upper and lower limit switches;
- indicators of the direction of movement of the rods;
- button for setting the indications "RU";
- button forbidding the processing of limit switch signals "OK";
- slit of the tuning resistor for zero adjustment "0".

At the rear of the UPC are micro-switches for setting actuator parameters.

4.4.11. IRT-T reactor CPS remote power indicator-sensor

The remote power indicator-sensor (VIZM) is designed to provide the operator with the possibility to set the reactor power in fractions of the nominal power and to indicate the mismatch between the measured and set power.

Four program switches are used to set the power setting, each of which allows setting one digit from 0 to 9. Three digits set the mantissa; one digit sets the order.

If the digits set on the switches are labelled A, B, C, D, counting from left to right, the ratio of installed and rated power is equal to:

$$(0.1\cdot A+0.01\cdot B+0.001\cdot C)\cdot 10^{-D}. \qquad (4.2)$$

A linear scale of 160 LEDs is used to display the ratio of measured to set power. The range is from 10^{-6} to 1.25. In the range from 10^{-6} to 0.9 the scale is logarithmic and 90 LEDs are allocated to this section. In the range from 0.9 to 1.25, the scale is linear on 70 LEDs. One LED is lit on the scale and the number of distinguishable levels is 160. The counting error does not exceed 0.32 % of the scale.

The information exchange between the control controller unit, which is part of the main Mirage-MB unit, and the VIZM (Figure 4.4) is performed via a serial link with the following characteristics:

- interface type: RS 485;
- operating mode: half-duplex;
- data transfer rate: 250 kbps.

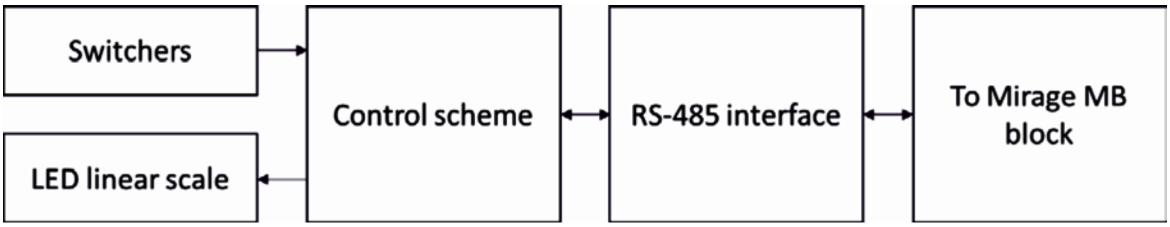

Fig. 4.4. Structural diagram of the VIZM CPS reactor IRT-T

4.5. Design and operation of the control system equipment complex IRT-T reactor control and protection system

4.5.1. Realization of IRT-T reactor CPS information functions

The IRT-T reactor control and protection system hardware complex provides:

- monitoring, recording and outputting of parameter information to the display units in accordance with Table 4.1;
- control of intermediate and end positions of rods SR, CR;
- control of end positions of rods EP;
- emergency, warning and notification signaling with fixing the sequence of signals occurrence.

The main set of the IRT-T reactor control and protection system complex transmits information to the operator about the controlled parameters.

Analogue output signals from four Mirage-MB units of the main set are output to narrow-profile display device located on the operator's console.

The main set of the IRT-T reactor control and protection system equipment complex provides for registration of controlled parameters at two workstations (computers) of the main set and display of information on monitors.

In addition, the relative physical power signal from each unit of the main Mirage-MB is fed to the corresponding VIZM, which has a "RELATIVE LEVEL" indicator.

The backup set of the IRT-T reactor control and protection system hardware complex transmits information to the operator about the controlled parameters.

Analogue output signals from two Mirage-MB units of the backup complex are output to the display devices located on the device rack of the backup control panel.

The backup IRT-T reactor control and protection system equipment set provides for registration of controlled parameters on the workstation (computer) of the backup set and display of information on the monitor. The following indicators are displayed on the emergency panel of the operator console:

- "VK EP1" – signaling that the EP1 operating rod is on the upper limit switch;
- "NK EP1" – signaling that the EP1 operating rod is on the lower limit switch;
- "VK EP2" – signaling that the EP2 operating rod is on the upper limit switch;
- "NK EP2" – signaling that the EP2 work rod is on the lower limit switch;
- "EP readiness for extraction" – signal that the EP working rods can be picked up.

There are also four digital position indicators (UPC) rods on the operator panel – CR, SR1, SR2, SR3. On their front panels there are four-digit seven-segment indicators, which display digital values of intermediate positions of control and compensation rods, single indicators of end positions, as well as indicators of rods movement direction. The signal to the UPCs comes from a selsin located in the actuator of the respective rod. In addition, each UPC has an LED bar that displays information about intermediate positions of the rod affecting the reactance.

The IRT-T reactor control and protection system equipment complex includes light and sound signaling units, which receive emergency, warning and notification signals.

The signaling equipment includes:

- three light signaling units – BSS2-1–BSS2-3 – for indication of emergencies (displayed as red colored digits);
- four units of light signaling devices – BSS2-4–BSS2-7 – for indication of warning signals (displayed as yellow-colored digits);
- four units of light signaling devices – BSS3-1–BSS3-4 – for indication of notification signals (displayed as green colored digits);
- two units of sound notification units (BZI), producing different tones of signals (emergency signal with frequency of approximately 800 Hz, warning signal with frequency of approximately 500 Hz, and notification signal with frequency of approximately 200 Hz) to BGr1, BGr2 loudspeaker units.

Units of light signaling devices, besides indication of alarms and / or preconditioning signals, also provide fixation of the sequence of their occurrence (with fixation depth from 0 to 9), which makes it possible to fix the prehistory of triggering of emergency protection.

The following signals are output on the emergency BSS:

- "AZ" ("EP") – tripping of the emergency protection;
- "AZM" – exceeding of the emergency power setpoint for two of the three Mirage-MB main units;
- "AZS" – speed emergency setpoint exceeded on two of the three Mirage-MB main units;
- "AZT" – water temperature emergency setpoint exceeded on two of the three control channels;
- "AZPD" – reduction below the emergency setpoint of the pressure drop on the reactor core on two of the three control channels;

- "AZPT" – exceeding the emergency setpoint for the difference between the water temperature at the outlet and inlet of the reactor core on two of the three monitoring channels;
- "AZD1" – exceeding of the emergency setpoint for gamma radiation dose rate at the primary circuit pipeline in two out of three monitoring channels;
- "AZAG" – exceeding of the emergency setpoint for the activity of gases in the air from under the reactor pool cover on two out of three monitoring channels;
- "AZUB" – decrease below the emergency set point of the water level in the pool on two out of three control channels;
- "AZAO" – decrease below the emergency set-point of the emergency cooling pump head pressure on two out of three control channels;
- "APNAO" – power failure of the emergency cooling pump on any of the two control circuits;
- "APS" – rack power supply failure: failure of two SP1 and / or SP2 rack equipment power supply units switched on in parallel;
- "ARP" – power redundancy failure: simultaneous absence of power supply on one of the feeders and failure of uninterruptible power supply units in both racks;
- "AOP" – power failure of the IRT-T reactor control and protection system equipment complex: a signal of simultaneous absence of power supply on both feeders;
- "KAZPO" – signal about issuing of emergency protection command by the operator from any of the two buttons "EP" located on PO4;
- "KAZRP" – "EP" signal received from the "EP" button from the backup panel;
- "KAZRZ" – "EP" signal received from the "EP" button of the reactor hall.

The following signals are received by the BSS warning emergency units:

- "PZ" ("WP") – blocking operation;
- "PM" – exceeding the power warning setpoint on two of the three Mirage-MB main units;
- "PS" – speed warning setpoint exceeded on two of the three Mirage-MB main units;
- "PT" – exceeding the water temperature warning setpoint on two of the three control channels;
- "PPD" – drop below the warning setpoint of the pressure drop on the reactor core on two of the three control channels;
- "PPT" – exceeding the warning setpoint for the water temperature difference between the outlet and inlet of the reactor core on two of the three monitoring channels;
- "PD1" – exceeding of the warning set point for gamma radiation dose rate at the pipeline of the primary circuit in two out of three monitoring channels;
- "PAG" – exceeding the warning set point for the activity of gases in the air from under the reactor pool cover on two out of three monitoring channels;
- "PUB" – decrease below the warning set point of the water level in the pool on two of three monitoring channels;
- "PAO" – decrease below the warning set point of the pressure at the head of the emergency cooling pump on two out of three monitoring channels;
- "BAM" – emergency signal of one of the Mirage-MB main units (Interlock E signals);
- "OAR" – failure of automatic regulator;

- "UBD" – (setpoint greater than permissible) – setting by the operator of a setpoint exceeding the permissible value on any power setpoint;
- "ROM" – reactor power limitation mode by protection channels;
- "OVB" – signal about absence of proper electrical connection of any of the plug-in units in the racks and operator panel, except for the main Mirage-MB units, power supply units and indicators of power setters;
- "OF" – absence of power supply on one of the feeders;
- "OIBP" – lack of power supply at the output of at least one of the uninterruptible power supply sources in the racks of device SP1 and SP2;
- "OPS" – signal of failure of any of the four power supply units of racks SP1 and SP2;
- "ORP" – a generalized signal about the failure of the backup console equipment, including due to the lack of power supply, or exceeding the emergency parameter control settings of at least one of the main Mirage-MB units of the backup console;
- "OSV" – stopping of special ventilation motors;
- "P1K" – reduction of pressure or flow rate of the primary circuit below the warning setpoint;
- "NSM" – unscheduled power reduction (power less than 0.95 of the set point) on two of the three control channels.

Note: the purpose of organizing the "BAM" signal is to provide timely warning of failures in the emergency protection circuits of any Mirage-MB channel and thus prevent the accumulation of such failures in the system.

The following signals are received by the BSS notification emergency units:

- "BPM" – warning signal of at least one of the main units Mirage-MB (signals "Interlock W");
- "U2K" – drop below the warning set point of the pressure or flow rate of the secondary circuit;
- "OVG" – cooling tower fan stop;
- "ODNV" – pump or fan motor stop;
- "O110" – no = 110 V from backup batteries;
- "UPWB" – upper water level in the basin;
- "VP1" – water in the pit of the primary circuit;
- "VP2" – water in the pit of the secondary circuit;
- "VPZE" – water in the pit of the retaining tank;
- "VPTO" – water in heat exchanger pits;
- "U1KZ" – decrease of flow rate or decrease of pressure of the primary cooling circuit of the biological protection concrete;
- "U2KZ" – reduction of flow rate of the second biological protection concrete cooling circuit;
- "URF" – reduction of flow rate through filters.

Indicator type information includes signals displayed on LED indicators located both on the operator panel and directly on the units. The power control unit in each rack and the back-up operator panel have LED indicators signaling the presence of power on each of the two feeders.

Formation of an emergency or warning signal by the main Mirage-MB units is signaled by indicators on their front panels.

The structural diagram of the parameter registration system is presented in Figure 4.5.

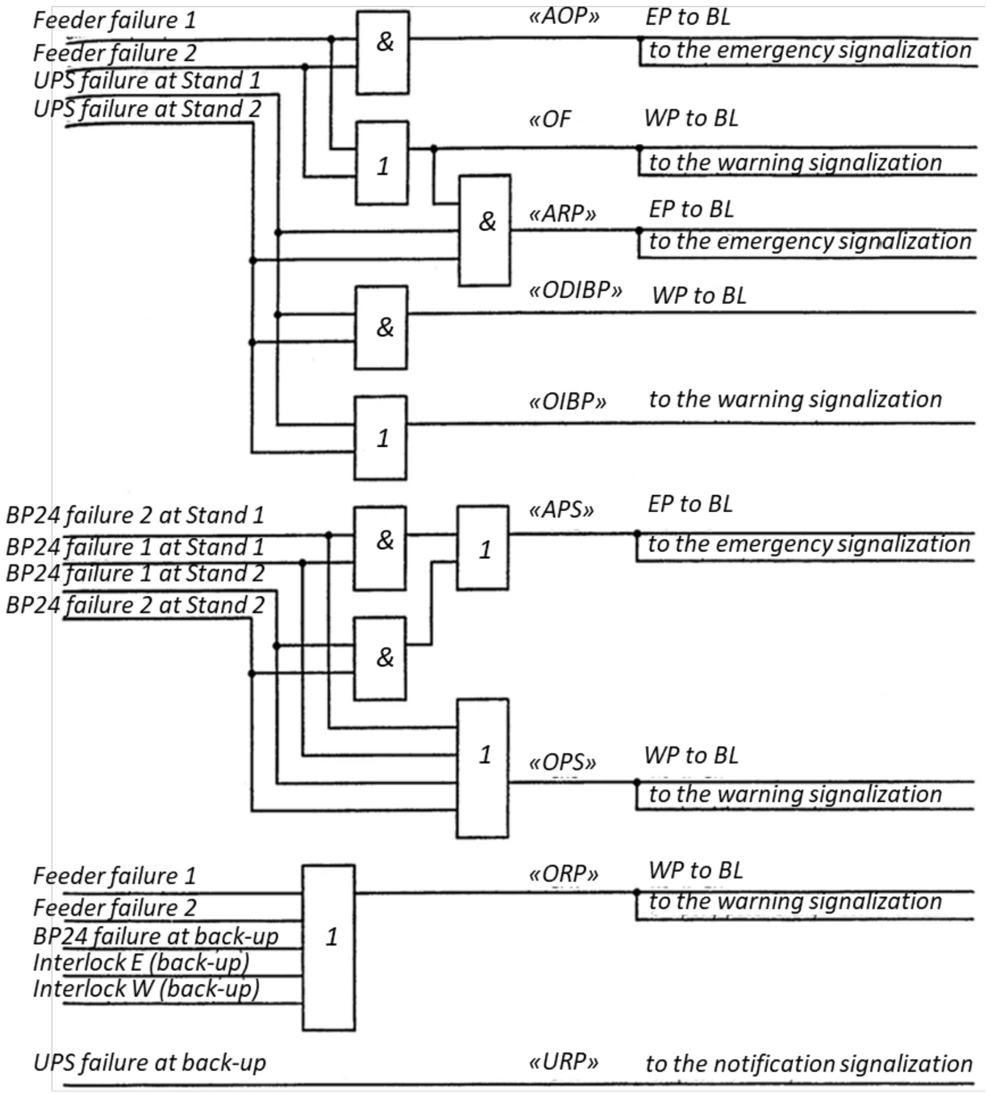

Fig. 4.5. Functional diagram of command generation for CPS power failures of the IRT-T reactor

4.5.2. Realization of CPS protection and interlocking functions of the IRT-T reactor

As mentioned above, the emergency protection channels include three Mirage-MB safety modules, each of which operates with a SIC 55 pendant (fission ionization chamber) and contains the main MB unit, remote power indicator-sensor VIZM, two units of logic (BL1-1, BL1-2) and two units of relay (BR1-1, BR1-2) from hardware unit BA1-1 and two units of logic (BL2-1, BL2-2) and two units of relay (BR2-1, BR2-2) from hardware unit BA2-1.

The emergency protection control paths contain, in addition, logic units BL1-3, BL2-3 and servo amplifiers SU1-1, SU2-1.

The units forming the emergency protection paths provide the following functions:

- bringing the initiated protection action to an end;
- individual Drop rods of EP1 and EP2 protection (e. g., when determining the reactivity of rods by the Drop method).

The protection function is achieved by de-energizing the electro-magnetic clutches (EMS) in the EP1 and EP2 protection rods and then dropping these rods by gravity. The units responsible for triggering the protection are redundant, so that failure of any one of them does not cause a failure of the protection function. The electromagnetic clutches (EMS) in the EP1 and EP2 protection rods are de-energized only by the emergency protection signals.

In case of power failure, the initial signals of power failure are formed in the power control units, as well as in the integrated control circuits in the units providing secondary power supply.

Functional scheme of organization of emergency protection and blocking on power supply failure is shown in Figure 4.5.

Switching (connection between actuators) of EMS actuators rods EP1 and EP2 is carried out both on the "plus" side of the power supply and on the "zero" side.

For switching on the plus side of these EMS, four relay units are used – BR1-1, BR1-2, BR2-1 and BR2-2, switched according to the logic "two or three out of four" (except for two combinations).

For switching on the neutral wire side of these EMSs, four logic units (BL1-1, BL1-2, BL2-1 and BL2-2) are used, switched in pairs by "OR" logic.

Such inclusion of relay units and logic units allows, if necessary, carrying out routine checks of these units or their replacement without triggering the emergency protection or interruptions in operation of protection paths.

EMS activation of EP1 and EP2 protection rods actuators is possible only in the following cases:

- no alarms listed above;
- CR and SR rods in their final lower positions;
- no EP extraction interlock signals;
- "CR Automatic / Manual" key is in "Manual" position;
- pressing the "Unlock Automatic / Manual" button located on the operator panel.

The emergency protection is raised by pressing the "EP extraction" button on the operator panel, while raising the rod protection only when the "EP extraction" button is pressed. Firstly, rod EP1 is completely removed, and then – EP2 (realized in a schematic way). When rod EP1 is displaced from its lower position on the operator panel, the red indicator "NK EP1" goes out, and when rod returns to its final upper position, the green indicator "VK EP1" lights up. When rod EP2 is displaced from its lower position, the red indicator "NK EP2" goes out, and when rod returns to its final upper position, the green indicator "VK EP2" lights up and simultaneously the indicator "EP readiness for extraction" goes out.

During the entire retrieval period of rods EP1 and EP2, both the emergency protection mode and the retrieval interlock mode are in effect.

Signals of the EP lockout are generated by the logic units BL1-3 and BL2-3 when the following initiating signals appear:

- "Interlock E" – signal at the output of any Mirage-MB unit of the basic set;
- "Interlock W" – a signal at the outputs of two or more Mirage-MB units of the main set;
- "OVB" – a signal that there is no proper electrical connection of any of the plug-in units in the racks and operator panel;
- "OF" – absence of power supply on one of the feeders;

- "ODIBP" – absence of power supply at the output of both uninterruptible power supply sources in the SP1 and SP2 device racks;
- "OPS" – signal of failure of any of the four power supply units of racks SP1 and SP2;
- "ORP" – a generalized signal of failure of the backup panel equipment, including its power supply.

When EP signal is received, BL1-1, BL1-2, BL2-1, BL2-2 blocks break the power supply circuits on the common wire side and BR1-1, BR1-2, BR2-1, BR2-2 blocks break the power supply circuits of the couplings on the plus side and Drop rods EP occurs.

After both rods EP1 and EP2 have reached their final upper positions, the CR and SR extraction authorization signal is generated and reactor startup and power control become possible. In case at least one of the rods AZ comes down from its final upper position, a signal is generated to lower the rods EP and SR1–SR3.

If during Drop rods EP the emergency signal is lost, the "protective action" will manifest itself to the end, as the subsequent EP rods EP can only be taken up after all EPs have been returned to the lower limit switches and the "Unlock EP" button has been pressed.

4.5.3. IRT-T reactor control

To realize reactor control, the CPS IRT-T provides four reactivity impact rods actuators: one CR rod actuator and three rods actuators SR1, SR2, SR3.

The complex provides formation of signals of rods CR and SR1, SR2, SR3 movement both in the mode of automatic and manual remote control.

For the formation of signals of automatic start-up and regulation of physical power of the reactor the regulation path is designed, which consists of the suspension SIC 56 (boron ionization chamber KNK 53), current amplifier unit (BUT-02), which is a part of the main Mirage-MB, remote power indicator-sensor VIZM and servo amplifier.

Two switches – "CR Automatic / Manual" and "SR1–SR3 Automatic / Manual" – are provided on the operator panel for selecting the mode of controlling the movement of reactivity impact rods (CR and SR1–SR3 rods).

When the switch "CR Automatic / Manual" is in the position "Automatic", the start-up and control of the reactor power is performed by the Automatic regulator, which transitions from one stationary power level to another according to the law (4.1).

The setpoint values for a given power level lie in the range from 10^{-9} to 10^{-3} A (according to the neutron component of the ionization chamber current).

The range of CR movement in the Automatic Regulation mode is from 20 to 80 % of immersion in the reactor core.

The operating range of the Mirage-MB unit interacting with the current ionization chamber is limited to five orders of magnitude of power change, since the boron current ionization chamber is blind at low neutron fluxes due to significant γ-background, especially in a reactor already operating at power. Therefore, in order to extend the range of the automatic startup to eight to nine decimal orders of magnitude, in addition to the control signal generated by the Mirage-MB unit in the automatic control path, the control signals generated by the Mirage-MB units in the control and emergency protection paths were introduced into the servo amplifier of the rod CR drive.

At the initial stage of the automatic startup of the reactor and its start-up, when it is actually necessary to keep constant the reduced rate (period) of physical power change, the fission ionization chamber does not sense neutron flux changes and the control signal at the output of the Mirage-MB unit connected to it has a maximum positive value and does not change. However, the Mirage-MB units in the protection paths connected to the fission ionization chambers monitor these neutron flux changes and generate control signals at their respective outputs – "Control from Protection Unit" ("UBZ1", "UBZ2", "UBZ3").

When the controller introduces excess reactivity causing the reduced rate to exceed the setpoint value (period reduction relative to the entered operating setpoint), these control signals ("UBZ1", "UBZ2", "UBZ3") take negative values. In the presence of two or three negative signals "UBZ" rod CR will be injected into the reactor core so as to maintain the set value of the reduced rate (period) of change of the relative physical power. Such joint operation of four Mirage-MB units allows to extend the range of Automatic start to eight or nine decimal orders.

The complex provides the possibility of Automatic joint operation of rod CR with rods SR1–SR3. For this purpose, the switch "SR1–SR3 Automatic / Manual" should be switched to the position "Automatic".

The algorithm of Automatic operation of SR1–SR3 is as follows.

After the CR has reached 20 % dip in the reactor core, if there is no "VK SR3" signal, SR3 is connected to move up. When the signal "VK SR3" is present, SR1 and SR2 are lifted alternately for a fixed period of time each in the upward movement mode.

The SR movement ends when CR returns to the middle of the reactor core (signal "CR60").

When CR is lowered and its 80 % immersion in the reactor is reached in the absence of at least one of the signals – "NK SR1", "NK SR2" – SR1 and SR2 are lowered alternately for a fixed time interval each in the moving down mode. If both signals "NK SR1", "NK SR2" are present – SR3 is connected for downward travel.

The SR movement is terminated when CR returns to the middle of the operating characteristic (signal "CR40").

The following signals are input to the Mirage-MB controller to control the SR movement:

- "VK SR1", "VK SR2", "VK SR3" – signals of SR1–SR3 location on the upper limit switch;
- "NK SR1", "NK SR2", "NK SR3" – signals of SR1–SR3 on the lower limit switch;
- "CR20" – CR is immersed 20 % in the reactor core;
- "CR40" – CR is immersed 40 % in the reactor core;
- "CR60" – CR is immersed 60 % in the reactor core;
- "CR80" – CR is immersed 80 % in the reactor core.

The following signals are connected from the Mirage-MB controller to the SR1–SR3 servo amplifiers:

- "Up SR1", "Up SR2", "Up SR3" – movement Up SR1–SR3;
- "Down SR1", "Down SR2", "Down SR3" – movement Down SR1–SR3;
- "Stop SR" – stop movement.

The signals are coming in:

- "Up SR1", "Up SR2", "Up SR3" – to inputs "AK20" of "SR1–SR3" servo amplifiers;
- "Down SR1", "Down SR2", "Down SR3" – to inputs "AK80" of "SR1–SR3" servo amplifiers;
- "Stop SR1", "Stop SR2", "Stop SR3" – to inputs "AK50" of "SR1–SR3" servo amplifiers".

If the "CR Automatic / Manual" switch is in the "Manual" position, the operator can manually remotely control the movement of rod CR.

Regardless of the "SR1–SR3 Automatic / Manual" switch position, manual remote control of the SR1–SR3 rods movement is possible.

Four control keys with non-locking positions are provided on the operator panel to control the rods movement.

In the mode of manual remote control of rods movement, technical means provide step-by-step (with step weight not more than 0.3 β_{eff}) retrieval of the selected rod.

If the operator turns the control keys of the rods SR, when the switch "CR Automatic / Manual" is in the position "Automatic", the Automatic regulator will track the reactivity changes introduced by the operator and will maintain the set value of the reactor power.

The same input signals are used to generate the CR and SR rods extraction interlocks as for the EP rods extraction interlock.

An Interlock is also provided for simultaneous removal of more than one of the CR and SR1–SR3 rods, except for the case when the CR rod is removed by the Automatic controller and one of the SR1–SR3 rods is removed automatically or manually.

Lowering of working rods is possible both one by one and simultaneously several rods without limitation in number.

With a working period of 50 s (speed 0.055 s^{-1}), the maximum rate of reactivity injection by the CR working rods is 0.055 β_{eff}/s, the maximum rate of reactivity injection by each of the working rods is 0.017 β_{eff}/s. The maximum rate of reactivity injection by each of the working rods EP 0.07 β_{eff}/s.

The specified data on rods movement speeds are provided by setting the corresponding servo amplifiers.

An example of start-up timing diagrams is shown in Figure 4.6. The start-up process consists of the following steps:

1 – extracting CR up to the upper limit of the linear part of its characteristic;

2 – extracting the SR with the CR stationary until the reduced power increase rate reaches the set value;

3 – power increase at the preset rate, within the zone of constant period in the control path speed, while SR extraction continues. The SR displacement in this section is a disturbing influence;

4 – increase of power with the set speed when SRs are stationary;

5 – increase of power with the set speed at stationary CR and SR;

6 – increase of power with the set speed in the energy range, the speed constancy is provided by the automatic movement of CR, compensating the power effect of reactivity;

7 – stabilization of the set power level.

The start-up process is characterized by a smooth output of the reactor to the set value of the reduced rate of power increase. In this case reactivity smoothly increases up to the asymptotic value associated with the value of the reduced speed.

Then the power increases at a given rate up to a given level, upon reaching which the power change stops, and the latter stabilizes at a given level without overshooting.

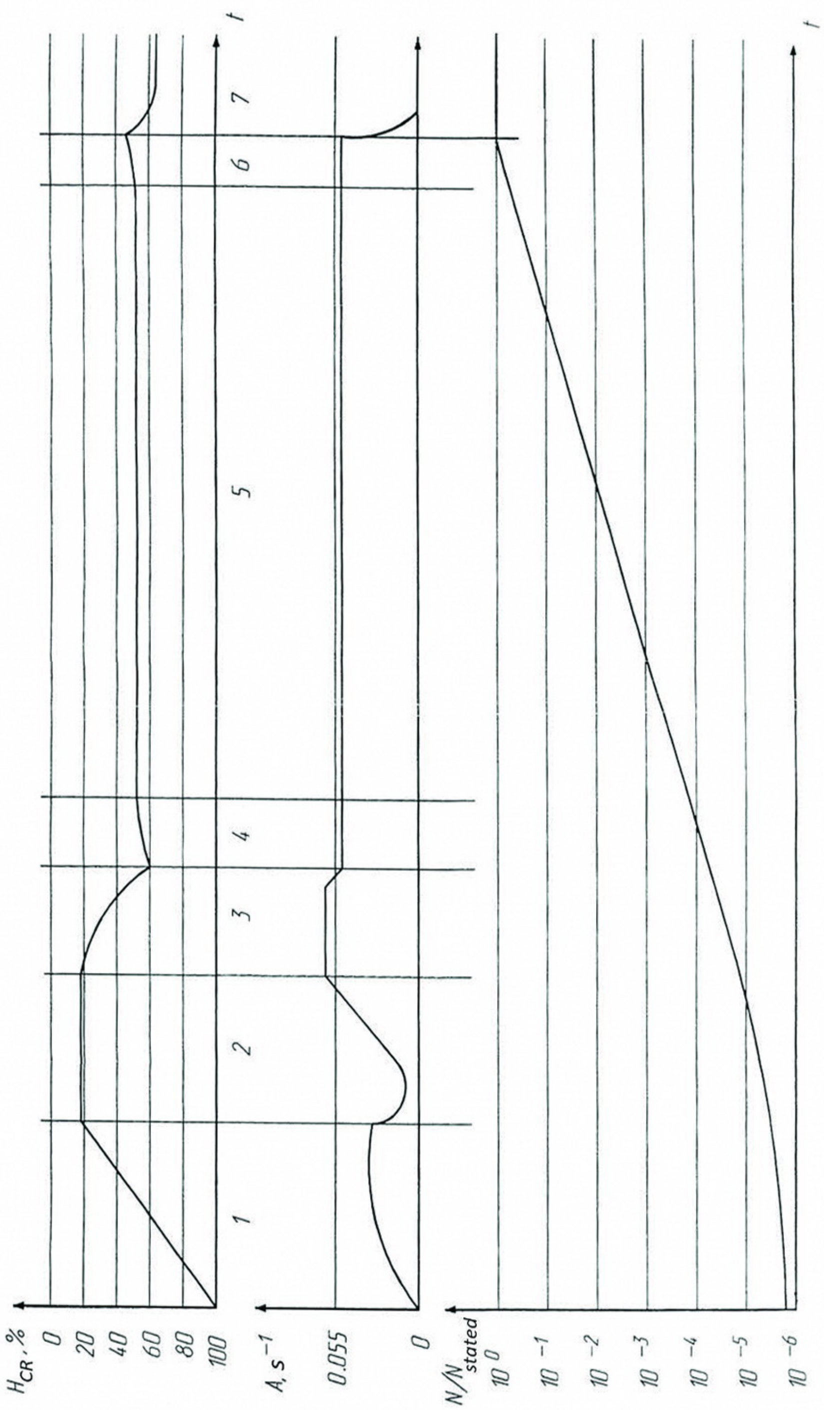

Fig. 4.6. IRT-T reactor start-up timing diagram

References

Instructions for operation of the IRT-T reactor control and protection system hardware complex. – Tomsk: NR TPU, 2023. – 66 p. (in Russian).

Control questions and tasks

1. What is the purpose of the IRT-T reactor control and protection system equipment complex.
2. List the main technical characteristics of the IRT-T reactor control and protection system equipment complex.
3. What is included in the IRT-T reactor control and protection system hardware complex?
4. Describe the Mirage-MB basic unit and the Mirage-MR recording module of the IRT-T CPS.
5. What is included in the IRT-T reactor relative power measurement channel?
6. What is the purpose of the IRT-T reactor CPS logic unit?
7. Describe the operation of the IRT-T reactor CPS relay unit.
8. What is the purpose of the diode-resistor CPS unit of the IRT-T reactor?
9. How many modes of operation does the IRT-T reactor CPS servo amplifier have?
10. What is the purpose of the IRT-T reactor CPS signal logic unit?
11. Describe the operation of the IRT-T reactor's 24 CPS power supply.
12. What equipment does the IRT-T reactor CPS power control unit monitor?
13. List the signaling components of the IRT-T CPS reactor.
14. Describe the operation of the IRT-T digital CPS reactor position indicator.
15. Describe the operation of the IRT-T reactor CPS remote power sensor indicator.
16. How the information function of the IRT-T reactor CPS is realized.
17. How is the protection and interlocks function of CPS of IRT-T reactor realized?
18. Describe the control principle of the IRT-T reactor.
19. Describe the IRT-T reactor back-up panel.

Chapter 5
OPERATION AND EFFICIENCY DETERMINATION OF CPS OPERATING RODS OF IRT-T NUCLEAR REACTOR

5.1. Work performed at the IRT-T reactor

Research and experimental work related to irradiation of samples is carried out at the IRT-T reactor. They must be carried out according to working programs defining the irradiation procedure. Measures to ensure nuclear and radiation safety must also be taken. The accounting and issuance of samples should be organized in accordance with the "Instruction on Radiation Safety during work at the IRT-T research nuclear reactor".

Nuclear hazardous activities at the IRT-T reactor are as follows:

- reloading activities associated with the IRT-T reactor core;
- work performed in the IRT-T reactor tank;
- repair work performed on the CPS rod drives;
- work performed in the SFA storage pit.

"Fresh" fuel assemblies at the IRT-T reactor are kept in the fresh fuel storage facility. The storage facility is equipped with security and fire alarms, water alarms, and an emergency alarm system for SSCR occurrence.

SFAs are stored in the storage shaft and temporarily in the IRT-T reactor pool in a temporary storage facility equipped on the lower section of the IRT-T reactor tank.

5.1.1. General organization of work at the IRT-T reactor

The IRT-T reactor and its experimental devices are operated by personnel trained in appropriate individual programs and allowed to work independently.

All IRT-T reactor operating personnel are organized into services:

- operation service;
- nuclear safety service;
- radiation safety service;
- safety service.

Work on the IRT-T reactor (IRT-T reactor operation at power, experimental and preventive maintenance work, etc.) is carried out in accordance with the annual IRT-T reactor operation schedule, which is approved by the SNSE Director.

The IRT-T reactor at power is operated in weekly cycles (5 days after 2 weekends). Work on the IRT-T reactor must be carried out strictly according to a non-weekly schedule, which is coordinated with the service managers and approved by the chief engineer of the IRT-T reactor. The plan-schedule reflects the operation mode of the IRT-T reactor, works performed during the week on the IRT-T reactor and its experimental devices.

A "Passport for radioactive source-isotope" is prepared by the customer for the sample irradiated according to the work program. The passport is signed by the chief engineer of the IRT-T reactor or the deputy chief engineer for operation.

5.2. Preparing the IRT-T reactor for start-up

Preparation of IRT-T reactor for start-up starts after receiving a written order from the chief engineer of IRT-T reactor or his substitute in the operational log of the shift supervisor in the form of a corresponding entry.

Preparation of the IRT-T reactor for startup consists in checking and activation of technological systems of the IRT-T reactor, which were not functioning at the shutdown reactor.

IRT-T reactor, and pre-startup testing of the operating systems.

Before starting the preparation of the IRT-T reactor for startup, the shift supervisor must familiarize himself with the entries made in the operational logbook by the last shift and with the IRT-T reactor core loading chart.

If there are no records prohibiting the startup of the IRT-T reactor and all electrical circuits are in good working order, the shift supervisor gives an order to the shift personnel and makes a corresponding entry in the operational logbook, about the beginning of testing and switching on the technological systems of the IRT-T reactor.

The systems are checked and put into operation in the following sequence:

- power supply system;
- radiation and dosimetric control system;
- ventilation system;
- IRT-T reactor control and protection systems;
- control system for technological parameters and automation (instrumentation);
- IRT-T reactor cooling system and other related systems;
- leakage collection and return system.

It is prohibited to enter the rooms until the radiation situation in all technological rooms of the IRT-T reactor and the physical hall is checked and the absence of radioactive gas and aerosols is verified.

Upon completion of the check and after all technological systems have been put into operation, each performer must report to the shift supervisor on their readiness to start up the IRT-T reactor and make a corresponding entry in the "Pre-startup Preparation Log".

5.2.1. Conducting a pre-startup check of the IRT-T reactor CPS hardware complex

The CPS pre-startup check is performed before each startup of the IRT-T reactor, but not more often than once a week, as well as before the startup of the IRT-T reactor after the elimination of a malfunction in the CPS.

During the CPS pre-startup check, the neutron flux density registered by the Mirage MB protection units should be at least 100 $n/s \cdot cm^2$.

While performing the CPS pre-start check, it shall be confirmed that the keys, toggle switches and switches used are clearly locked in their different positions.

During the pre-start test, the first thing to be checked is the audible alarm. By pressing the appropriate buttons, the following signals are tested:

- notification signal (NS);
- warning signal (WS);
- emergency signal (ES).

After each sound signal appears, the sound is removed by the "Mute" button.

Next, the "Mirage MB" unit is prepared for operation.

Press the "↑" button on the "Mirage MB" unit to remove all inactive signals – "AC", "SAR", "RS". Color of switched on signaling LEDs depends on the state of IRT-T reactor.

The Mirage MB unit is controlled by means of the indicator and PISK buttons.

The following basic modes (functions) are realized in the "Mirage MB" unit:

1st mode – indication of the screen saver;

2nd mode – indication of current values of controlled signals;

3rd mode – equipment setting;

4th mode – indication of current values, time and date;

5th mode – input of parameter settings;

6th mode – pre-start check.

To select the mode press the "MODE" button and the display will show "Mode No. 1". Use buttons "˄" and "˅" to select the desired mode, and by pressing the "Enter" button the "Mirage MB" unit switches to the selected operating mode.

In mode No. 2 (indication of monitored signals) the upper line shows the current value of the parameter entered into the emergency protection system, the lower line shows the emergency setpoint of this parameter.

Pressing the "Enter" button switches the lower line to the indications corresponding to the emergency setpoint of the parameter. When pressing the "Enter" button again, the nominal values of the parameter will be displayed.

To exit to the menu of selection of operating modes it is necessary to press the button "MODE".

Mode No. 3 is intended for setting the types of secondary converters used in radiation parameters control channels, as well as setting the current time and date. When entering this mode, the message "Enter password" is displayed. The password for entering the mode is a combination of the following keys: "DOWN", "ENTER", "UP", "MODE". After entering the correct combination of digits, the display shows one of the following messages: "channel BRK 1", "channel BRK 2", "channel BRK 3", "time and date setting". Use the "UP" and / or "DOWN" buttons to select the desired item in the menu and press the "ENTER" button. If the current time and date on the "Mirage MB" unit do not correspond to the actual time and date, it is necessary to set the correct time and date on the "Mirage MB" unit. After switching to the "Time and date setting" mode, the current time readings will be displayed on the indicator, and the values will blink. Use the "UP" and (or) "DOWN" buttons to set the desired value of time and date and press the "ENTER" button.

Mode No. 6 is intended for setting values of emergency, warning and nominal settings of parameters used in the mode of pre-start checks. This mode differs from mode No. 5 in appearance by the fact that the values of the set settings of the pre-start tests are not stored in the memory of "Mirage MB" unit memory when exiting the mode.

Transition to this mode is allowed provided that the reactor power (in terms of IC current) does not exceed 0.1 % of the nominal value.

(IR current) does not exceed 0.1 % of the nominal value. If this condition is not fulfilled, the following message is displayed on the display when switching to this mode: **TEST FORBIDDEN**.

To exit to the menu of operation modes selection it is necessary to press the "MODE" button. If the reactor power (by IR current) does not exceed 0.1 % of the nominal value, when switching to this mode, the message: **ENTER PASSWORD** is displayed on the indicator.

After entering the correct key combination, the "Mirage MB" unit allows access to the selection of setting types, as in mode No. 5. Using buttons "˄" and (or) "˅" select the type of setpoint to be entered and press the "ENTER" button. The display will show the value of the parameter and the entered setpoint of the pre-start test.

The value of this setpoint will be valid until the "MODE" button is pressed. After that, return to the previous menu item and the value of the corresponding pre-start setpoint is replaced by the value of the operating setpoint. In mode No. 6 the following menu item is available: **No. 30 LED TEST**.

When this menu item is selected, all LEDs on the display should blink with a period of 1 s, and the display will show the message: **BLINKING**.

Pressing the "MODE" button returns to the previous menu item. After switching to mode No. 6, the "Mirage MB" unit generates the signals "INTERLOCK E" and "INTERLOCK W" and forcibly holds them until exiting the mode.

After all the above actions have been performed, the pre-start check is considered to be completed.

5.3. IRT-T reactor start-up

IRT-T reactor startup is a very responsible operation, since the power level of the IRT-T reactor in the subcritical state is lower than the rated power by a factor of about 10^6–10^8, depending on the duration of the shutdown.

The IRT-T reactor startup is performed by the shift supervisor by written order of the IRT-T Chief Engineer or his substitute.

During IRT-T reactor startup, the shift supervisor, control engineer and shift dosimetrist must be present in the control room.

All entries in the shift supervisor's operational logbook during IRT-T startup should be made only by the shift supervisor.

Only the chief engineer of the IRT-T reactor or a substitute may give any instructions to the shift supervisor during the startup of the IRT-T reactor.

The shift supervisor must assess the reactivity reserve of the IRT-T reactor core before starting the IRT-T startup operation. If no changes have been made to the core and reflector during an IRT-T shutdown (installation or unloading of fuel assemblies, beryllium blocks and other assemblies, experimental channels, and irradiated sample containers), the reactivity reserve is based on the reserve available before the previous startup of the reactor, taking into account its change (reduction) due to fuel burnup. The value of the assumed reactivity reserve obtained in this way is increased by 0.3 % for safety purposes. Based on the determined reactivity reserve of the IRT-T reactor core, the shift supervisor must estimate the positions of the SR and CR rods at which the critical state of the IRT-T reactor will be reached. In doing so, he should take into account the change in the reactivity margin due to the IRT-T core "poisoning" that occurred after the IRT-T shutdown (based on the "poisoning" curve). The assumed positions of SR and CR rods corresponding to the "critical" state of the IRT-T reactor core should be recorded in the shift supervisor's operating log.

Immediately before the IRT-T reactor startup operations, a visual inspection of the IRT-T reactor core and reflector must be performed, and the position of the HEC gates must be checked. All screens must be in the "closed" position, unless their opening is stipulated by a special order.

The startup of the IRT-T reactor is considered to be initiated by extraction of the emergency protection rods to check the operability of the actuators and the time of fall of the emergency protection rods into the core of the IRT-T reactor.

The rate of reactivity increase should not exceed 0.07 β_{eff}/s when all control and EPS rods are extracted. For CPS operating rods with an efficiency of more than 0.7 β_{eff}, the positive reactivity input shall be stepped with a step efficiency of no more than 0.3 β_{eff}. This input of positive reactivity is provided by CPS equipment.

5.3.1. Verification of CR, SR1–SR3 rods movement and IRT-T reactor CPS equipment complex emergency protection operation

In order to check the emergency protection of the CPS equipment complex of the IRT-T reactor, the following actions should be performed:

- press the "Unlock EP" button, at that all warning and emergency indicators of BSS units on the display panels should go out, except maybe "OSV", "P1K" and "NSM". If any of these indicators are still on, the reasons should be found and eliminated, otherwise further operation is impossible;
- switch on the toggle switch "EP couplings", "AR", "SR1–SR3", if they were switched off;
- make sure that the "CR Automatic / Manual" switch is set in "Manual" position;
- press the button "Unlock EP", after which the LED "Ready for EP" should light up;
- press the button "EP extraction" and hold it until the LEDs "VC EP1" and "VC EP2" and the LEDs "on" on the units BR1-1 and BR1-2 in the device racks PS1 and PS2 light up. It is allowed to release and re-press the "EP extraction" button any number of times.

After EP have reached the upper limit switch, it is necessary to check the stroke of rods CR, SR1–SR3. Using the CR manual control key raise the CR rod by 3–4 cm with subsequent dipping by 1–2 cm. Using the manual control key KO, alternately raise SR1–SR3 by 3–4 cm with subsequent dipping by 1–2 cm. After moving the key to the "Up" position, the extraction takes place within 3–5 s, after which the RO should stop.

To continue extraction, return the key to the neutral position and then again to the "Up" position. At the same time check:

- rod movement speed;
- step movement of SR rods with step duration of 3–5 s;
- operation of indexers and rod positions;
- operation of indicating signaling;
- operation of existing interlocks in rod servo control circuits.

After these checks, press the "Emergency Protection" button on the control panel and make sure that the EP1, EP2 CR, SR1–SR3 booms are lowered to their lowest position. Verify that the UPC and RSO are displaying the information correctly. The lowering time of EP rods should be ~ 0.8 s.

5.3.2. IRT-T reactor start-up in Automatic mode

Before the IRT-T reactor can be energized, it is necessary to set the VIZM "Protection Channels" power setpoints to 20 % more power than the power to which the IRT-T reactor is to be energized. The IRT-T reactor can only be energized in Automatic mode after the emergency protection rods have been activated as described in the above paragraph. After the emergency rods have been activated, the following must be done:

- announce by loudspeaker the forthcoming power start-up of the IRT-T reactor;
- set the set point on VIZM "Regulator Channel" corresponding to the required power level, to which the output will be carried out;
- switch "CR Automatic / Manual" switch to "Automatic" position.

From this point on, the Automatic control channel will drive the IRT-T reactor to the set power level in Automatic mode. The power level setpoints range from 10^{-9} to 10^{-3} A (based on the neutron component of the ionization chamber current).

When the "CR Automatic / Manual" key is turned to the "Automatic" position, the CR bar starts to rise up to the "20 %" limit switch. After CR reaches this value and if the set power is not reached and the reactor period is more than 50 s, SR3 starts to rise.

If SR3 reaches the upper limit switch and the power remains less than the set power, SR1 and SR2 start the Up movement alternately for a fixed time interval each. SR1 and SR2 are switched on to move Up in turn until the signals "VC SR1" and "VC SR2" are activated respectively. When the reactor period decreases below 50 s, CR starts Down movement, maintaining an acceleration period of 50 s.

When CR reaches the "60 %" end switch, SR1 and SR2 stop the Up movement, the IRT-T reactor accelerates, and CR maintains the acceleration period of 50 s.

The power output ends when the "Relative level" display of the "Regulator channel" power set point displays a value of 1. When the set power level is reached, the CR rod, descending into the core, stops the IRT-T reactor acceleration and continues the power control, thus maintaining the set power of the IRT-T reactor.

At the final stage, the IRT-T reactor is to be reported to power by loudspeaker. A record is made in the operational logbook about the achievement of the "critical" state, the position of the CR and SR rods, the calculation of the reactivity reserve, and the readings of the power control devices.

5.3.3. IRT-T reactor start-up in Manual mode

Before powering up the IRT-T reactor, it is necessary to set the VIZM "Protection Channels" to a power setting 10 % higher than the power to which the IRT-T reactor is to be powered up. The IRT-T reactor can be manually energized only after the emergency protection rods have been activated as described in section 5.3.1. After the emergency protection rods have been activated, the following actions must be performed:

- announce by loudspeaker the upcoming power start-up of the IRT-T reactor;
- switch "CR Automatic / Manual" switch to "Manual" position;
- set the set point on VIZM "Regulator channel", which corresponds to the required power level, to which the output will be carried out;
- use the control key to raise the CR rod by 30 cm according to the UPC reading;
- then start removing the SR3 rod, at the same time it is necessary to constantly monitor the power level and the reactor period by UPP-01 and RSO narrow-profile devices;
- if the critical state is not reached during SR3 rod removal, remove SR1 and SR2 rods evenly and alternately with respect to each other; rod removal is stopped as soon as the power increase is observed on any of the power control channels or the acceleration period becomes less than 50 s;

- to reduce the acceleration rate, lower the CPS RO by 5–7 mm using the keys CR, SR1–SR3, by moving these keys to the "down" position;
- by moving the CR, SR rods, achieve the exact "critical" state;
- when approaching the set power level, compensate the positive reactivity by dipping the CR rod;
- as soon as the IRT-T reactor power reaches the set power level, i. e. the indication on the indicator "Relative level" of the power set point "Regulator channel" reaches the value 1, switch the switch "CR Automatic / Manual" to the position "Automatic".

At the final stage, an announcement is made over the loudspeaker to bring the IRT-T reactor to power. The operational logbook records the achievement of the "critical" state, the position of the CR and SR rods, the calculation of the reactivity reserve, and the readings of the power monitoring devices.

5.3.4. IRT-T reactor power change

The reactor power is changed in the Manual or Automatic mode, the control rods and indicators used are the same as when the reactor is brought to power.

Sequence of operations when changing the power of the IRT-T reactor:

- announce by loudspeaker the forthcoming power change of the IRT-T reactor;
- when increasing or decreasing the power, the switch "CR Automatic / Manual" must be switched to "Manual" position;
- switch "CR Automatic / Manual" to the "Manual" position;
- the new value must be set on the VIZM "Protection channels" before the power increase;
- VIZM "Protection channels" should be set to a new value after the power has decreased;
- at VIZM "Regulator channel" set the setpoint that corresponds to the required power level and to which the output will be set;
- after reaching the required power level, switch the "CR Automatic / Manual" switch to the "Automatic" position;
- announce by loudspeaker the IRT-T reactor to be brought to power.

In the operational logbook, a record is made of the achievement of the "critical" state, the position of the CR and SR rods, the calculation of the reactivity reserve is made, and the readings of the power control devices are recorded.

At the same time, due to the limitation of delayed neutron reduction rate, it is recommended to set the power reduction setpoint value not more than 100 times in one go when operating in the Automatic mode. Otherwise, significant overshoot may occur. Further power reduction is recommended after completion of transients caused by the previously performed power reduction, i. e. 5–7 minutes after power stabilization.

5.3.5. System control when the IRT-T reactor is operating at capacity

When the IRT-T reactor is operating at power, the system is monitored by reactor personnel.

Shift operation personnel controls:

- presence and type of graphs of parameter changes on RSO screens;
- serviceable condition of indicating devices by visual observation;
- equipment serviceability and absence of failure signals on the front panels of the units;

- mutual deviation of similar parameters, as well as frequencies, amplitudes and nature of fluctuations of parameter values;
- deviation of current values of parameters from the predicted ones;
- correct state of sound signaling by pressing the test buttons.

5.3.6. IRT-T reactor planned shutdown

The shift supervisor shall notify the experimenters and all personnel by loudspeaker 5 minutes prior to shutdown of the IRT-T reactor.

The shift supervisor and control engineer shall make entries in the operating logs of all technological parameters required for the pre-startup check for the next startup.

A reactor shutdown consists of two actions:

- switching the "CR Automatic / Manual" switch to the "Manual" position;
- drop EP by pressing the "Emergency protection" button located on the control panel.

It is also allowed to press other buttons "Emergency protection": "KAZ RZ" located on the upper platform of the IRT-T reactor, or "KAZ RP" – on the backup control panel. The operating personnel must make sure that all rods (EP1, EP2, CR, SR1–SR3) have reached the lowest position.

Once the temperature of the demineralized water at the core inlet reaches 25 °C, the primary cooling circuit pumps and the emergency cooling pump (NAO) should be shut down, followed by the secondary cooling circuit pumps and the biological protection concrete cooling circuit pump (NOZ). In winter, immediately after shutdown of the IRT-T reactor, the cooling tower fans should be shut down and the "PZ-GO" gate valve should be turned to the "open" position.

5.3.7. IRT-T reactor unplanned shutdown

The IRT-T reactor can be shut down unscheduled as a result of an emergency protection system activation or as a result of actions of the shift personnel. Unplanned (emergency) shutdown of the IRT-T reactor can be performed by any person from the shift personnel if the situation threatens the safety of the IRT-T reactor "and" its personnel. The shutdown is performed by pressing the emergency protection button "KAZ PO" on the control panel of the IRT-T reactor, or the button "KAZ RZ" on the upper platform of the IRT-T reactor, or "KAZ RP" on the back-up control panel. After pressing the emergency protection button, make sure that all rods – EP, SR, CR – have reached the lower end forks. After an unscheduled shutdown of the IRT-T reactor, the shift supervisor makes a corresponding entry in the operating log.

Except for the cases of emergency protection operation, unscheduled shutdown of the IRT-T reactor must be carried out:

- in case of failure of the automatic emergency protection;
- malfunction of EP, SR, CR servo drives and position indicators of compensating rods or the Automatic Regulator rod;
- 2-fold increase of gamma radiation dose rate at the suction pipe of the primary core cooling circuit of the IRT-T reactor core;
- increase of β-activity of gases in the air removed from the above-reactor space by more than two times compared to the normal value;
- more than twofold increase of gas activity release to the atmosphere through the special ventilation pipe;

- detection of water leaks:
  - through horizontal experimental channels;
  - from the pipelines of the primary reactor core cooling circuit of the IRT-T reactor;
  - from the demineralized water treatment pipelines of the primary core cooling circuit of the IRT-T reactor;
- when notified of an impending power outage;
- failure of the radiation and dosimetry control system;
- malfunction of two process control devices measuring:
  - pressure drop across the IRT-T reactor core;
  - head pressure of the IRT-T reactor core emergency cooling pump;
  - temperature of demineralized water at the inlet to the IRT-T reactor core;
  - temperature difference on the IRT-T reactor core;
  - the level of demineralized water in the IRT-T reactor tank;
- when the 110 V voltage from the batteries is lost;
- both fans of the special ventilation system are switched off B1 to B1-1 or B1-2;
- malfunction of the biological protection concrete cooling pump and HEC gates;
- all other cases, which are not stipulated by this instruction, but which jeopardize the safety of the IRT-T reactor or its personnel.

5.4. IRT-T reactor normal operating limits and parameter values for triggering the emergency protection

In order to improve the safety of IRT-T reactor operation, the normal operation limits and safe operation limits of the IRT-T reactor have been established. The IRT-T reactor normal operation limits in terms of power level are power values equal **to 1.1 of the stated power**. These values are the emergency setpoints.

The power level setpoints for triggering the emergency protection are set **to 1.2 of the stated power**.

The IRT-T reactor period equal to 20 s is the limit of normal operation in terms of power start-up rate. This value is the setpoint for triggering the warning alarm. To activate the emergency protection by the reactor power doubling period, the setpoint value should be equal to 10 s.

5.5. Calibration of neutron flux density control channels thermal power

5.5.1. Determination of CR rod efficiency by IRT-T reactor power doubling period

Before starting the IRT-T reactor, the emergency cooling pump (NAO) must be activated to maintain the coolant temperature during operation. The IRT-T reactor is then brought to a critical state. After the IRT-T reactor has reached the target power level, it is necessary to:

- set the "CR Automatic / Manual" switch to the "Manual" position;
- set the automatic protection tripping limits on VIZM-1-4 to 20 times the initial power level of the IRT-T reactor;

• recompensate the position of the operating rods CR and CR so that the operating rod CR is lowered to the lowest position, while it is important to maintain the reactor in the critical state at the initial power level;

• remove a part of the CR work rod from the core so that the injected positive reactivity does not exceed the value of 0.3 β_{eff}. The IRT-T reactor with the new position of the working rod CR is held for the time required to increase the power to 100 kW;

• time the power increase of the IRT-T reactor by a factor of 2 using the four relative power measurement channels on the RSO;

• when the power level reaches a value about 20 % less than the emergency protection trip limit, compensate the excessive positive reactivity introduced during the removal of the working rod CR by some working rod CR. Then, by further immersing the working rod CR into the core, reduce the power level of the IRT-T reactor to the initial level and bring the IRT-T reactor to a critical state;

• determine the efficiency of the part of the working rod CR that corresponds to the recorded power doubling time (Figure 5.1);

• repeat the previous steps until the rod CR is completely removed to determine the efficiency of the next section of the working rod CR;

• construct an integral characteristic of the working rod CR based on the results of determining the efficiency of its individual sections.

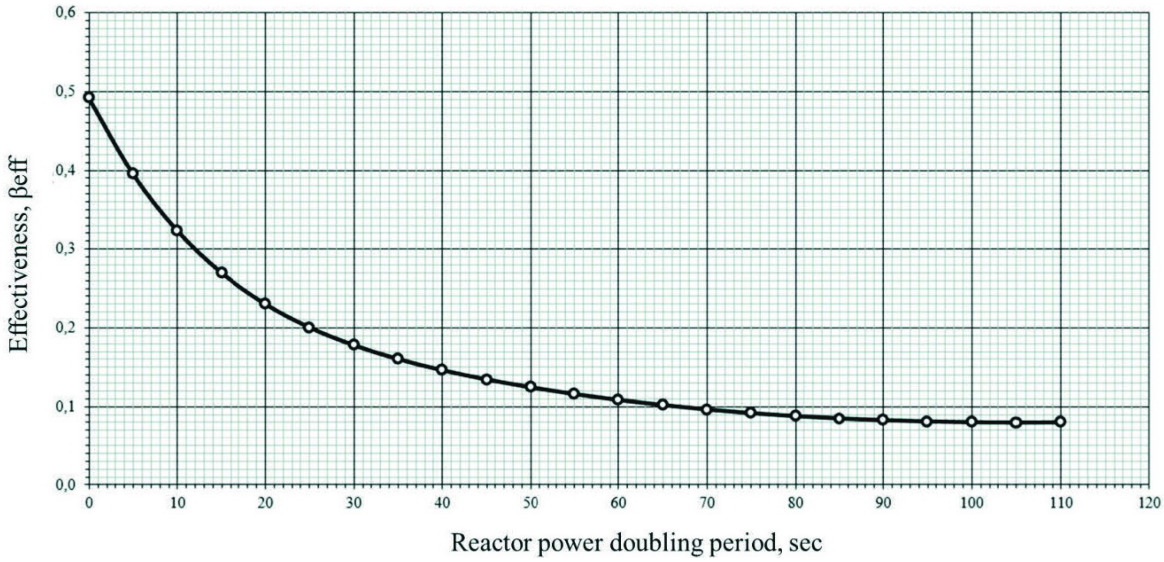

Fig. 5.1. Dependence of CR operating rod efficiency on the doubling time of the IRT-T reactor capacity

5.5.2. Determination of the efficiency of the working rods SR of the IRT-T reactor overcompensation method

After determining the rod efficiency, the CR and SR-2 work rods must be completely immersed in the core, the SR-3 work rods must be completely removed from the core, and the critical state of the IRT-T reactor must be maintained with the SR-1 work rods.

To determine the efficiency of the IRT-T reactor SR work rods by the recompensation method, the following operations are performed:

• the position of SR-3 and CR working rods corresponding to the critical state of the IRT-T reactor is fixed;

- the CR working rod is removed from the core to the upper extreme position, in this case the introduced positive reactivity is compensated by SR-3 working rods and the position of SR and CR working rods is recorded;
- the working rod CR is lowered to the lowest extreme position in the reactor core, in this case the introduced negative reactivity is compensated by working rods SR-2 and the position of working rods SR and CR is recorded;
- the previous actions are repeated until complete removal of SR-2 working rods from the core and complete immersion of SR-3 working rods into the core.

After carrying out the above manipulations it is necessary to completely immerse working rods CR and SR-3 into the core, and working rods SR-1 are completely removed from the core, the critical state of the IRT-T reactor is maintained with the help of working rods SR-2. Next, the position of the SR and CR work rods corresponding to the critical state of the IRT-T reactor is recorded.

Upon completion, the same manipulations are performed as before, only with other rods:

- working rod CR is removed from the core up to the upper extreme position, at that the introduced positive reactivity is compensated by working rods SR-1 and the position of working rods SR and CR is recorded;
- working rod SR is lowered to the lowest extreme position in the reactor core, in this case the introduced negative reactivity is compensated by working rods SR-3 and the position of working rods SR and CR is recorded;
- the previous steps are repeated until the working rods SR-3 are completely removed from the core and the working rods SR-1 are completely immersed in the core.

Integral characteristic of each of the SR working rods is built on the results of determining the efficiency of its individual sections.

5.6. Actions of operating personnel in emergency situations

5.6.1. General instructions

If a malfunction is detected in the system, a decision is made as to whether the reactor can continue to operate, change the mode or shut down. Measures must be taken to eliminate the malfunction.

If failure or breakdown of devices and equipment of the control and protection system apparatus has led to the activation of emergency protection or forced shutdown of the reactor, an additional pre-startup check is carried out after the repair work is completed.

After failure or malfunction of other devices and equipment, the necessity of an additional pre-startup check is determined by the instructions issued by the operating organization.

5.6.2. Procedure of actions of shift personnel in case of violation of limits and conditions of normal operation of the IRT-T reactor

Table 5.1 shows the algorithm of actions of shift personnel in case of deviations from normal operating conditions of the IRT-T reactor.

Table 5.1

Actions of shift personnel in case of violation of limits
and conditions of normal operation of the IRT-T reactor

1	Leakage of gland seals of pumps of the primary and (or) secondary cooling circuits	Check for leaks. Repair the leak. Report to the IRT-T Reactor Chief Engineer or his deputy for operations
2	Presence of water in the pits of the primary and secondary cooling circuits, heat exchangers, external retaining tank	Find out the cause of the water. Eliminate the fault. Pump out the water: • from the pits of the primary circuit, retaining tank and heat exchangers to the special sewerage system; • from the pits of the secondary circuit to the fecal sewage system
3	Temperature rise at the core inlet of the IRT-T reactor core	Reduce the power level until the signal disappears. Determine whether the power level corresponds to the set power level by means of the temperature and flow rate control devices. Check that the operating mode of the primary and secondary cooling circuits corresponds to the set power level. Check the compliance of the parameters of the primary and secondary cooling circuits with the normal values specified in paras. 3.2, 3.3. Check the cooling tower operation mode, if necessary, change the mode to increase heat exchange
4	Increase in the temperature difference between the inlet and outlet of the IRT-T reactor core by 10 %	Reduce the power level until the signal disappears. Check that the power level corresponds to the set power level. Check that the operation parameters of the primary and secondary cooling circuits correspond to the given power level. In case of non-compliance of the cooling circuits operation parameters with the given power level, adjust the cooling circuits operation. If the temperature control channels are not functioning properly, shut down the IRT-T reactor. Report to the Chief Engineer of the IRT-T reactor or his deputy for operation
5	IRT-T reactor tank water level below 7.20 m	Determine and correct the cause of the low level. Refuel the IRT-T reactor tank. *Note:* The level of demineralized water in the IRT-T reactor tank can drop by natural entrainment by no more than 2 cm in 12 hours
6	Overflow of water in the IRT-T reactor tank	Check whether the make-up gate valves are closed. Check the level according to the gauges. Check the quality of demineralized water in the IRT-T reactor tank. If it is determined that process water has entered the IRT-T reactor tank, shut down the IRT-T reactor. Verify that the emergency filling of the IRT-T reactor tank with service water has been stopped. Report to the IRT-T Reactor Chief Engineer or his deputy for operation

7	The vacuum under the top deck of the IRT-T reactor tank is 10 % below the normal value	Check that the device and the special ventilation system B1-1, B1-2 are in good working order. Check whether the openings on the upper deck of the IRT-T reactor tank are closed. If the required vacuum cannot be restored, shut down the IRT-T reactor. Report to the IRT-T Reactor Chief Engineer or his deputy for operation
8	Reduction of pressure in the secondary cooling circuit	Verify that the device readings are correct and that the pumps are operating properly. Check the condition of the intake screen on the cooling tower, clean the screen if necessary
9	Reduction of water consumption in the secondary cooling circuit	Check that the device readings are correct and that the pumps in the secondary cooling circuit are working properly. The condition of the valves must correspond to the set mode. In case of pump malfunction, switch to the reserve pump
10	Reduction of demineralized water level in the SFA storage pit	Make sure that the alarm is correctly activated. Supply the SFA storage shaft with demineralized water up to the nominal level. Deactivate the low-level alarm light. Ensure that the light signal is released
11	Increase of β-activity of gases in the air removed from the above-reactor space and rooms	Determine in which room the increase in β-activity of the air. Determine the cause of the increase β-activity of the air. Take measures to protect personnel from β-active air by removing personnel from the room. If possible, eliminate the cause of increased β-activity of the air. If β-activity in the air removed from the above-reactor space increases more than twofold, shut down the IRT-T reactor. Report to the IRT-T Reactor Chief Engineer or his deputy for operation
12	Increase in gamma radiation dose rate	Determine the room and the place of increase of γ-radiation dose rate. Take measures to protect personnel from overexposure by removing personnel from the hazardous area. Determine the cause of γ-radiation dose rate increase and eliminate it. In case of γ-radiation dose rate increase from the suction pipe of the primary cooling circuit by 2 times, shut down the IRT-T reactor. Report to the IRT-T Reactor Chief Engineer or his deputy for operation
13	Shutdown of fan of special ventilation system B1-1, B1-2 of IRT-T reactor building	Turn on the backup fan of the special ventilation system B1. If the special ventilation system B1 cannot be switched on, shut down the IRT-T reactor. Switch the supply ventilation system P1-1,2 to emergency operation mode. Report to the Chief Engineer of the IRT-T reactor or his deputy for operation

14	Fuel assembly depressurization in the core of an IRT-T reactor. *Signs of fuel assembly depressurization are as follows:* • increase in radioactivity of demineralized water of the primary circuit of the IRT-T reactor core cooling loop detected by measuring the activity of the "dry" sample residue; • an increase in the γ-radiation dose rate at the IRT-T reactor tank lid; • increase in β-activity of the air removed from the above-reactor space; • increase in the γ-radiation dose rate from the suction pipe of the primary core cooling circuit of the IRT-T reactor core	In case of fuel assembly depressurization in the IRT-T reactor core: • shut down the IRT-T reactor; • strengthen control over the content of aerosols and β-activity in the air removed from the above-reactor space

References

1. Operating Instructions for the IRT-T Reactor Control and Protection System Instrumentation Complex. – Tomsk : NR TPU, 2023. – 66 p. (in Russian).

2. Operating instructions for the IRT-T research reactor. – Tomsk : NR TPU, 2023. – 66 p. (in Russian).

Control questions and tasks

1. What work is performed on the IRT-T reactor?
2. Describe the process of pre-startup testing of the IRT-T CPS suite.
3. How is the IRT-T reactor started up?
4. How is the CR, SR1–SR3 rod travel and emergency protection of the IRT-T reactor CPS equipment complex tested?
5. How is the IRT-T reactor brought to power in the Automatic mode?
6. How is the IRT-T reactor brought to power in the Manual mode?
7. How is the IRT-T reactor power changed?
8. How is the system monitored when the IRT-T reactor is operating at power?
9. What is the procedure for planned and unplanned shutdown of an IRT-T reactor?
10. How is the efficiency of the CR rod determined by the power doubling period of the IRT-T reactor.
11. Describe the process of determining the efficiency of the IRT-T reactor SR operating rods by the overcompensation method.
12. What is the procedure to be followed by the shift personnel in case of violation of limits and conditions of normal operation of the IRT-T reactor?

Abbreviations and designations

Abbreviations used:

CEC	Central experimental channel
CMD	Control and measuring devices
CPS	Control and protection system
CR	Automatic control rod or AR
DNFC	Division for Nuclear Fuel Cycle
EP	Emergency protection (rod) or AZ
ESP	Electric submersible pump
FA	Fuel assembly
FSAEI	Federal state autonomous education institution
HE	High education
HEC	Horizontal experimental channel
IRT-T	Tomsk Type Research Reactor
ITA	Internal thermal assembly
NP	Nuclear physics
NR	National research
NTC NRC	National technical center on Nuclear Radiation Safety
PCC	Protection cooling coils
SFA	Spent fuel assembly
SIC	Suspension of the ionization chamber
SNSE	School of Nuclear Sciences & Engineering
SR	Shim rods KO-1, KO-2, KO-3
SSCR	Self-sustainable chain reaction
TPU	Tomsk polytechnic university
UPS	Uninterruptible power source
VEC	Vertical experimental channel
WP	Warning protection

Designations used:

1–6, 1–16	Valves at the inlet and the outlet of NAO respectively
1–20	Valve at the reactor drainage pipeline
2000NM	Microprocessor-based standardizing converter used in coolant temperature measurement
AD-1	Aluminum treated with pressure and with low quantity of impurities
AOS	Button, pressing which switches the output transistor to the closed state in the logic unit
AOP	Power failure of the IRT-T reactor control and protection system equipment complex: a signal of simultaneous absence of power supply on both feeders
APNAO	Decrease below the emergency set-point of the emergency cooling pump head pressure
APS	Rack power supply failure: failure of two SP1 and / or SP2 rack equipment power supply units switched on in parallel

AU	Automatic control
AZAO	Emergency pressure of NAO
AZAG	Emergency level of radioactive aerosol activity from under the reactor pool cover
AZD1	Emergency level of γ-radiation dose rate on the primary circuit
AZM	Emergency reactor power level
AZPD	Emergency pressure drop on the reactor core
AZPT	Emergency temperature drop on the reactor core
AZS	Emergency reactor period
AZT	Emergency temperature at the inlet into the reactor core
AZUB	Emergency reactor tank water level
BA1-1	Hardware unit
BAM	One emergency signal appearance
BAOS	Signal prohibiting clutch release and issuing of the "AOS" signal
BAV-02	Analogue output unit
BCP1	Power supply control unit
BD	Detection unit
BDR1-1	Diode-resistor unit
BDS	Discrete signals unit
BDV-02	Discrete input unit
BGr	Loudspeaker units
BL1-1	Logic unit
BP24	Power supply unit
BPM	One warning signal appearance
BPN-06	Low-voltage power supply unit
BPTS-02	Temperature signal conversion unit
BPV-06	High-voltage power supply unit
BR1-1	Relay unit
BRK-01	Radiation control unit
BSL-1	Signal logic unit
BSS2-1	Light signaling unit
BUG-02	Galvanically isolated amplifier unit
BUK-02	Control controller unit
BUT-02	Current amplifier unit
BVK-02	Auxiliary controller unit
BZI	Sound indication unit
CHEPT-2	Platinum technical sensitive element for coolant temperature measurement
D-320/50	Pump with the flow rate of 320 m^3/hour and the head of 50 m
DC-6	Diaphragm chamber at nominal pressure up to 6 MPa
EMS	Electromagnetic clutches
FAS A-13	Cellular pleated filter of A-13 group
FP-300	Filter-absorber with the capacity of 300 m^3/hour
GNOM	Mud single stage monoblock pump
I-1	Valve at the primary circuit inlet of the heat exchanger No. 1
I-11	Gate valve at the primary circuit outlet of the heat exchanger No. 1
II-1	Valve at the secondary circuit inlet of the heat exchanger No. 1
II-11	Gate valve at the secondary circuit outlet of the heat exchanger No. 1

I-23/1, I-23/2	Valves for external retaining vessel drainage
I-24, I-25, I-26, I-27, I-28	Valves for primary circuit coolant drainage by compressed air
I-41, I-42, I-43, I-44, I-45	Valves for heat exchangers compressed air supply
IRT-1730 U/M	Technological regulator meter universal millivoltmeter
KAZPO	Emergency protection button in the reactor control panel
KAZRP	Emergency protection button in the reactor backup control panel
KAZRZ	Emergency protection button in the reactor hall
KDV	Demineralized water complex
KNK-53	Suspension of the ionization chamber designation
KPZ-1	Valve switching chamber
Metran 150-DD	Pressure difference and flow rate meter (pressure differential)
Metran 150-DI	Pressure meter (pressure exceeded)
NAO	Emergency cooling pump
NDV	Demineralized water pump
NI-1	First primary cooling circuit pump
NII-1	First secondary cooling circuit pump
NF	Filter pump
NK	Lower position of the rod
NSM	Unplanned power decrease
NOZ	Biological protection cooling pump
O110	110V power supply from batteries failure
OAR	Automatic regulation control failure
ODNV	Pump or fan drive failure
OF	Feeder dailure
OIBP	UPS failure
OPS	Stand power supply failure
ORP	Backup stank power supply failure
OSV	Special ventilation drives failure
OVB	Insert unit failure
OVG	Cooling tower fan failure
P1K	Pressure or flow rate of the primary circuit drops below the warning set point
PAG	Warning level of radioactive aerosol activity from under the reactor pool cover
PAO	Warning level of NAO pressure
PB	Processor unit
PD1	Warning level of γ-radiation dose rate on the primary circuit
PI1	Indication panel
PISK	Indication, signaling and keypad panel
PM	Warning reactor power level
PMP-062	Magnetic float transmitter for coolant level measurement
PO	Operator console
PPD	Warning reactor core pressure drop
PPT	Warning temperature drop on the reactor core
PS	Warning reactor period
PT	Warning temperature at the inlet into the reactor core

PU	Control panel
PUB	Warning reactor tank water level
PZ	Valve position (Name of the valve in the Technological Scheme)
PZ-GO	Valve position when the secondary circuit coolant flows directly into the cooling tower
ROM	Power restriction regime
RSO	Display workstation (PC and monitor for control)
S-57	Contact sensor for coolant level measurement
SAB-1	Aluminum deformable alloy of Al-Mg-Si ternary system
SchNN	Low voltage switchboard
SchSU	Power control panel
SLA	Accident leaks localization system
SPRS2I-04V	Resistance limit switch
SU1-1	Servo amplifier
T-1	Heat exchanger No. 1
TS	Resistance thermocouples
TSPU-2222	Resistance thermometer with unified output
U2K	Pressure or flow rate of the secondary circuit drops below the warning set point
U1KZ	Reducing the flow rate or reducing the pressure of the primary cooling circuit of the biological protection concrete
U2KZ	Reducing the flow rate or reducing the pressure of the secondary cooling circuit of the biological protection concrete
UBD	The setpoint is greater than the permissible setpoint
UBZ	Control from protection unit
UFFA	Transfer container for SFA
UPC	Digital position indicator
UPP-01	Narrow-profile device
URF	Filter flow rate reduction
VG2-50	Cooling tower fan
VIZM	Remote power setter indicator
VK	Upper position of the rod
VP1	Water in primary circuit sump
VP2	Water in the secondary circuit sump
VPTO	Water in heat exchanger sump
VPZE	Water in retaining vessel sump
VUVB	The highest level of water in the reactor tank
Zond 10-GD	Transducer for coolant level measurement
ZUK-155/230	Charging device with maximum charging current of 155 A and the 230 V output voltage

Educational Edition

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СИСТЕМЫ И ЭЛЕМЕНТЫ ИССЛЕДОВАТЕЛЬСКОГО ЯДЕРНОГО РЕАКТОРА ИРТ-Т

Практикум

Учебно-методическое пособие

Издательство Томского политехнического университета, 2025

На английском языке

Published in author's version

Typesetting *A.I. Sidorenko*
Cover design *I.I. Lebedev*

Signed for the press 06.05.2025. Format 60x84/8. Paper "Snegurochka".
Print CANON. Arbitrary printer's sheet 10,24. Publisher's signature 9,26.
Order 213-25. Size of print run 100.

PUBLISHING HOUSE
TOMSK POLYTECHNIC UNIVERSITY