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PHYSICAL ENGINEERING PROBLEMS IN SECURING THE FUNCTIONING OF THE NUCLEAR REACTOR IRT AND IMPROVING ITS USAGE

Summary of promotional study

The work is carried out in the
Salaspils nuclear reactor IRT

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1.Introduction

At the onset of operation of the Salaspils nuclear reactor, technical engineering experience with nuclear reactors and work under high levels of radiation was minimal. Use of conventional technical aids for scientific experiments was limited. As a first generation nuclear reactor, the Salaspils reactor had many unsolved technical problems and was clearly experimental in nature. The author's dissertation is the result of works and publications which analyze the reasons for the malfunction of scientifically experimental nuclear reactor IRT technology, suggest methods for the prevention of technical imperfections, discuss the modernization and increased capacity of the IRT nuclear reactor, and address the issue of nuclear and radiation safety. The Salaspils IRT- 1000 research reactor was clearly experimental in nature, it was not the result of accumulated experience and practice; the equipment had not been tested over the long term.

1.1. The topic of study and its actuality

Engineering investigations of the IRT reactor were necessary to improve operations of the nuclear reactor, to increase capacity and to enhance the safety of exploitation, adapting it to the experimental level in Latvia. In 1968 equipment damage and aluminum corrosion were detected, making it dangerous to continue. The main problems were:

In the reactor core:

- The reactor core was covered from above with a hydraulic protective shield, a fuel drop head and control servomotors;
- When turning the water flow of the coolant system on and off through the reactor core (from bottom to top), the fuel drop head and separate EK10 bars were subject to hydraulic shock and vibration, resulting in damage to the fuel assemblies. 30 damaged fuel assemblies with deformed EK-10 fuel elements were removed from the reactor core;
- The lead filter of the thermal column had been deformed (swelled), compressing the body of the reactor core and the fuel drop heads.

As a result of the aluminum corrosion:

The reactor tank, the spent fuel tank, spent fuel-lifting channels, reactor tank outlet tubs, the radiation loop casings and heat exchangers were all damaged.

Non-compliance with nuclear and radiation safety requirements was also established:

- The highly radioactive spent fuel loading system did not function in emergency situations and the stress of the overload created damage in the construction of the reactor building;
- There was nothing to prevent a meltdown in the reactor core in case of an accident;
- the change in size of the graphite of the thermal column due to radiation was not considered.

In order to operate the reactor it was necessary to increase the neutron flux at the reactor core and to automate the experimental devices.

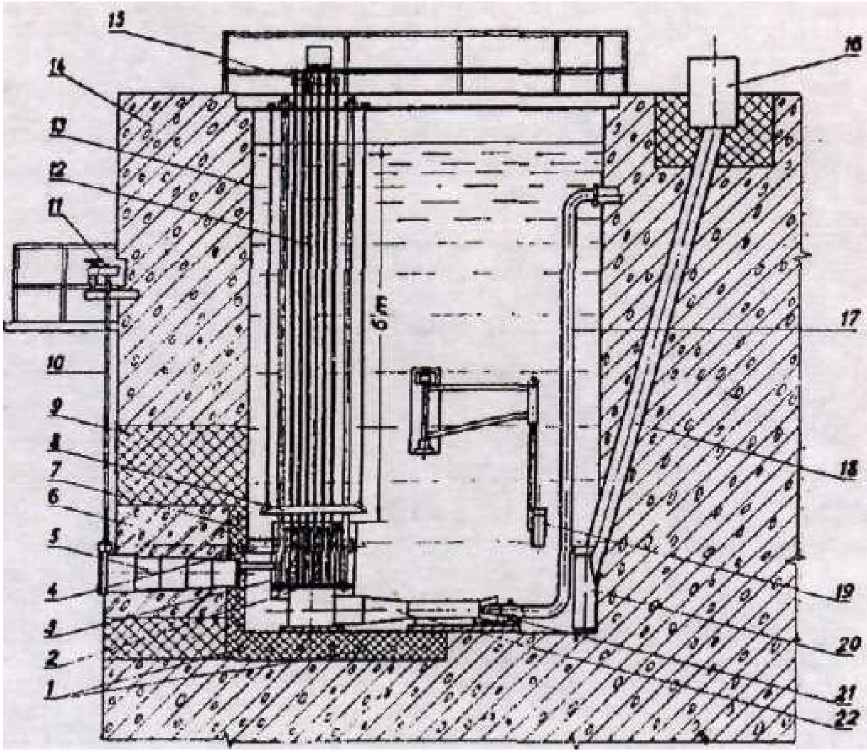


Fig. 1.1. Nuclear reactor 1RT-1000

1-biological shield cooling pipes; 2-reactor core; 3-«thermal» column; 4-tangent channel; 5-horizontal channel gate driver; 6-biological shield with density 5,2 t/m^3; 7-biological shield with density 6,5 t/m^3; 8-water reflector; 9-biological shield with density 4,5 t/m^3; 10-gate driver bar; 11-gate driver motor; 12-vertical experimental channels; 13-aluminium reactor tank; 14-concrete biological shield; 15-reactor lid with rod servodrives; 16-lead container for fuel loading; I7-cooling pipe line; 18-spend fuel loading channels; 19-spend fuel loading device; 20-conteine for spend fuel loading; 21-ejector nozzle ; 22-ejector.

1.2.Tasks and objectives of the study

1. To assess hazardous nuclear and radiation safety situations, to develop methods investigating aluminum corrosion processes under highly radioactive conditions.
2. To work out and implement IRT reactor modernization increasing its thermal capacity to 5MW, creating technologies for the replacement of damaged equipment in highly radioactive conditions.
3. To automate scientific experimental equipment and to improve the safety of the nuclear reactor.
4. To carry out testing of the cooperative functioning of the reactor after modernization determining reactor core and thermal relationships.

Structure and content of the work

The doctoral dissertation "Physical engineering problems in securing the functioning of the nuclear reactor IRT and improving its usage" is written in Latvian, it consists of an introduction and 5 chapters, 30 figures for a total of 103 pages and 31 references. The dissertation compiles the experimental results, scientific and technical innovations and their practical application, which the author was responsible for or involved in during his time of employment at the Salaspils nuclear reactor. Short summaries are given of the content of chapters 2, 3, 4 and 5.

Chapter Two (Research of modernization and technology for equipment replacement) and its subsections discuss the necessary research, physical engineering calculations, reactor equipment choice for 5MW capacity based on nuclear safety limits, biological shield measurements, increased experimental opportunities and their automation, guaranteeing high purity of the coolant water, nuclear and radiation work safety in highly radioactive conditions and equipment replacement technologies.
Analysis showed a wide range of factors favorable for modernization with capacity increasing to 5MW and opportunities for work in highly radioactive conditions.

First, calculations revealed a biological shield reserve of the reactor tank. It was possible to create a small reactor core with heightened neutron density using newly developed fuels with 90% enriched uranium 235.

Second, the reactor tank and in-tank devices were made of aluminum (with ^{28}AI Ti/$_2$ = 2,3 min), which allowed work to be done inside the reactor tank. A high-capacity device for the production of de-ionized water was placed in the reactor and it could be used for protection when performing underwater repairs. The reactor tank corrosion started from the concrete side, because water had seeped in between the biological concrete shield and the aluminum in the tank. Together with scientists from Moldavia, a unilateral diagnostic method for non-corrosive aluminum was developed. The following corrosion and damage studies were conducted:

1. Corrosion of the aluminum layer of EK10 fuel bars.
2. Mechanical damage and thermal load deformations of EK10 fuel bars.
3. Damage to the lead filter of the core.
4. Reactor tank and outlet corrosion damage.
5. Damage to the spent-fuel aluminum tank.
6. Corrosion damage to the spent-fuel lading channel.
7. Corrosion damage to the heat exchange and primary cooling system filters.

After a negative safety assessment of the equipment, the Salaspils nuclear reactor was closed down in 1968. The damaged systems were either repaired or replaced with new equipment.
The reactor tank underwent temporary repairs and the damaged aluminum was replaced with new welded aluminum and security tested.

Simultaneously a technology, equipment and method were developed for the repair of the reactor tank in case of accidental leaks. These measures enabled the reactor to function four years awaiting the design and construction of a new stainless steel tank.

Modernization of the nuclear reactor was commenced. The direction of the coolant water was reversed to flow from top to bottom by using an ejector. This solved the fuel vibration and hydraulic shock problem, removing the drop head and hydraulic return shield from the reactor core.

The reactor core was set up with a removable part for the operation of the EK10 fuel assemblies, so that the reactor core would be operational with IRT M type assemblies if the part were removed.

The second modernization phase was realized in accordance with the 1RT-5000 project. As a result, a core heat capacity of 5 MW with a thermal neutron flux in the reactor core of 8 10^{13} n/cm s was attained. To reach this result, all devices from the inside of the reactor tanks were dismantled by using a metal electrocuting machine (see fig. 2.1.). The technological equipment and graphite cutting electrode settings were modeled on the mock-up of the bottom section of the reactor tank at full size (fig. 2.2.).

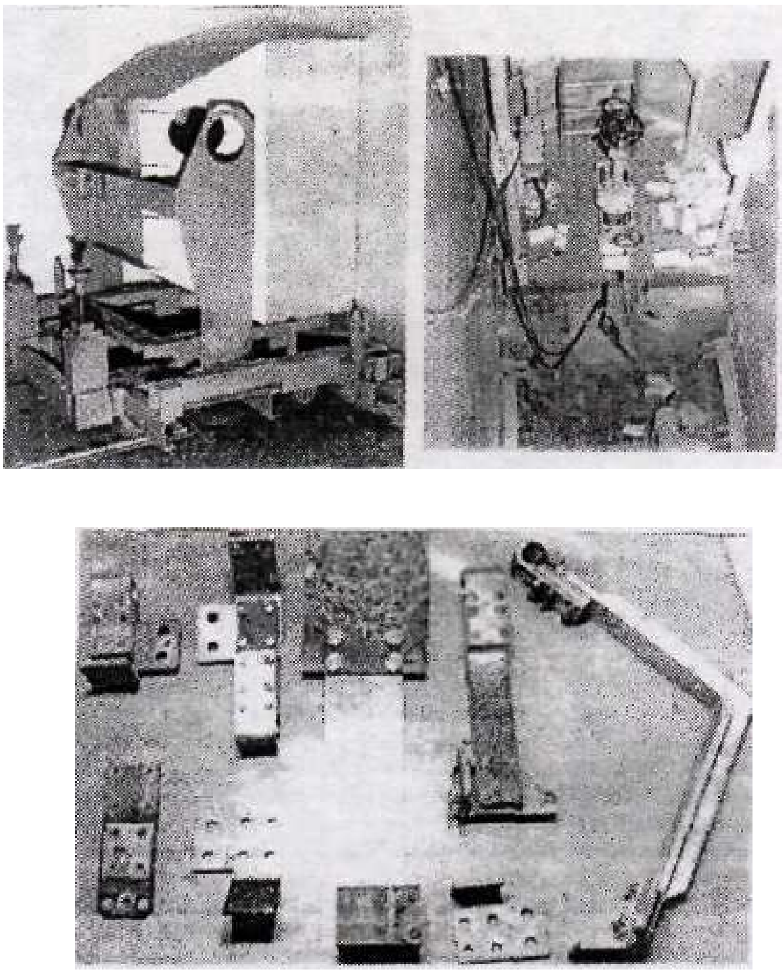


Fig. 2.1. Dismantling devices and implements for work inside the reactor tank underwater or in water-free conditions. 1. The thermal column casing device after cutting; 2. electroarc cutting platform and machine: 3. special graphite cutting electrodes.

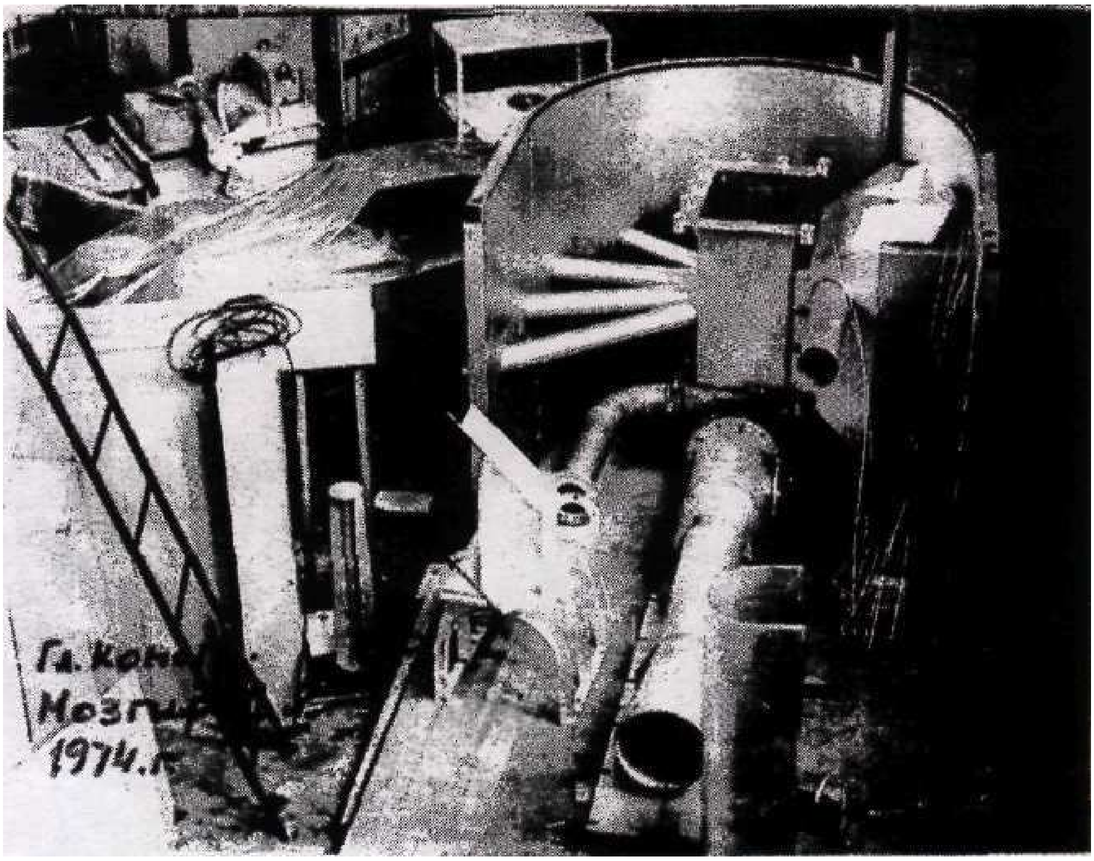


Fig. 2.2. Model of the bottom section of nuclear reactor IRT-5000.

Storage vaults were constructed at the nuclear reactor site for the safe storage of the dismantled radioactive parts.

A new stainless steel reactor tank was installed and mounted inside the aluminum vessel, new inner-tank devices were mounted, the fuel assemblies in the reactor core were changed from EK-10 with 10% uranium isotope enrichment to IRT2M and 1RT3M assemblies with 90% enrichment, the graphite reflector in the reactor core was replaced with beryllium, primary and secondary cooling cycles were developed in accordance with a 5 MW capacity.

At the same time, pneumatic mail was created for carrying radioactive samples and graphite column HEK Nr. 1 was equipped for the procurement of thermal neutrons. The HEK Nr. 4 was renovated and reworked as a device that would pass through the reactor tank and would be possible to use from both ends (the sample to be tested is inserted in one end, the measurement is taken at the other end). The HEK Nr. 7 was transformed to be tangent to the core with the original one-piece channel valve.

Chapter three (Equipment and systems of the modernized nuclear reactor IRT-5000) describes the equipment and systems of the modernized nuclear reactor IRT-5000, which is shown in fig. 3.1.

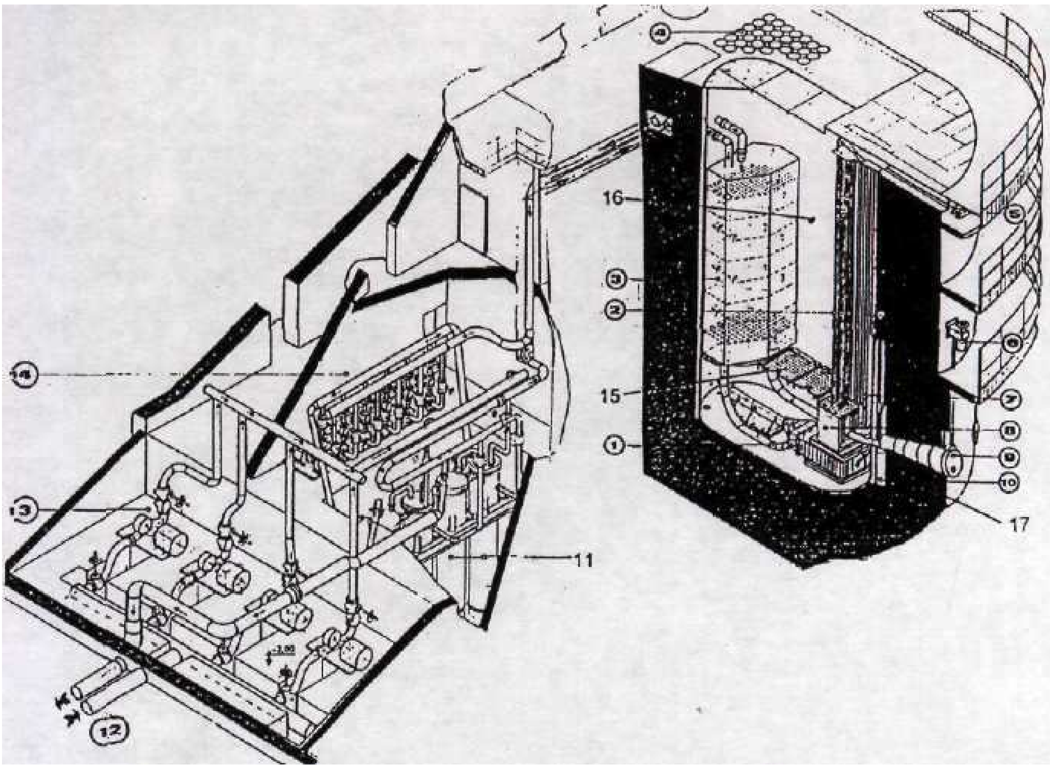


Fig. 3.1. The modernized nuclear reactor 1RT-5000, tank, and I, II cooling circuit pump rooms.

1 - cooling pipeline with ejector;
2 - control channels;
3 - coolant delay tank;
4 - dry radioactive sample storage vaults;
5 - control rod servodrives;
6 - HEK gate drives;
7 - vertical experimental channel (VEC);
8 - reactor core;
9 - horizontal experimental channel (HEC);
10 - thermal shield;
11 -heat exchangers;
12 - secondary circuit pipeline, that is connected with the cooling tower;
13 - secondary circuit pump room;
14 - primary circuit pump room;
15 - hydraulic delay grind;
16 - reactor tank;
17 - concrete biological shielding

Reactor tank. A new stainless steel tank, was installed inside the damaged aluminum tank with a 100 mm gap. The gap was filled with concrete. The reactor tank lid is the original construction and is designed to carry a lode up to 10t as a supplemental vertical biological shield.

The cooling delays system. To lessen the radioactivity of the water in the primary cooling system (fig.3.2.), a hydraulic delay system was created, consisting of two newly created mechanisms in Latvia: a hydraulic grind (12) and a hydraulic delay tank (3).

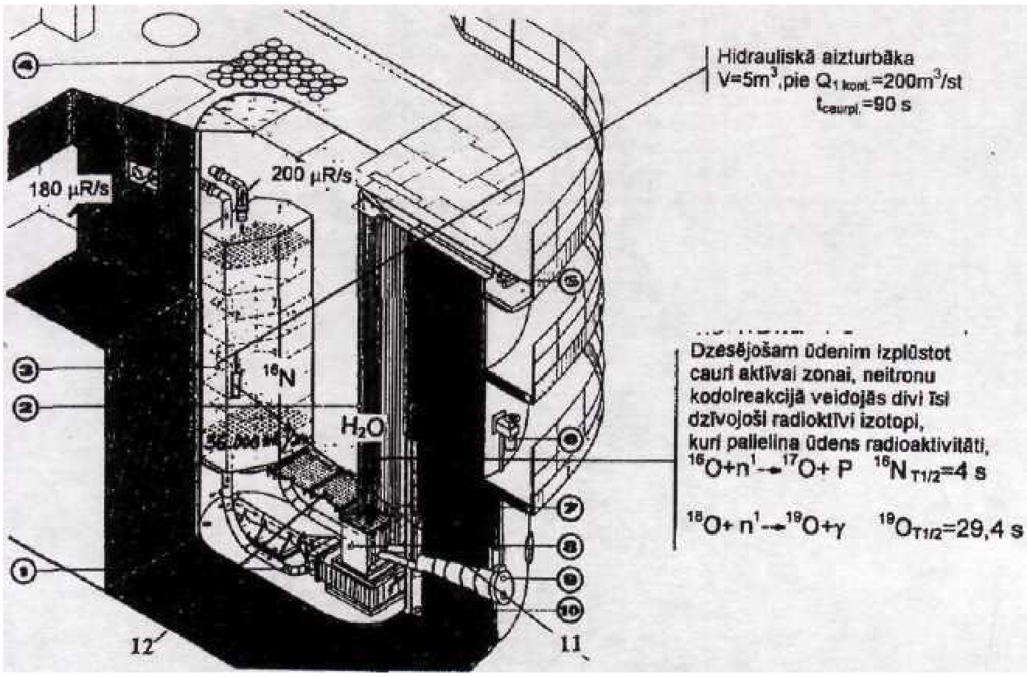


Fig. 3.2. Hydraulic delay system

1 - cooling pipeline; 2 - control channels; 3 - hydraulic delay tank; 4-radioactive sample storage; 5 - servodrivers; 6 - HEK gate drives; 7 - vertical experimental channels; 8 - reactor core; 9 - horizontal experimental channel (HEC); 10 -thermal shield; 11 - ionization chambers; 12 - hydraulic delay grind.

In the reactor core two radioactive isotopes, ^{16}N and ^{19}O are formed by a nuclear reaction of water oxygen. The main carrier of radioactivity in water is the nitrogen-16 isotope with a half life of 4s, water flows through the hydraulic delay tank at 90s. During this period ^{16}N and ^{19}O lose radioactivity by a factor of approx. 200. During the decay period the radioactivity is retained inside the tank under the biological shield of the water. Such a primary cooling plan to increase the power to 5MW was calculated and created at Salaspils during the modernization of the nuclear reactor.

The reactor core takes up little space relative to the nuclear reactor equipment as a whole; however, all of the other devices are dependent on it. The reactor core is located at the bottom of the reactor tank covered with a 7m thick layer of water (fig. 3.3.).

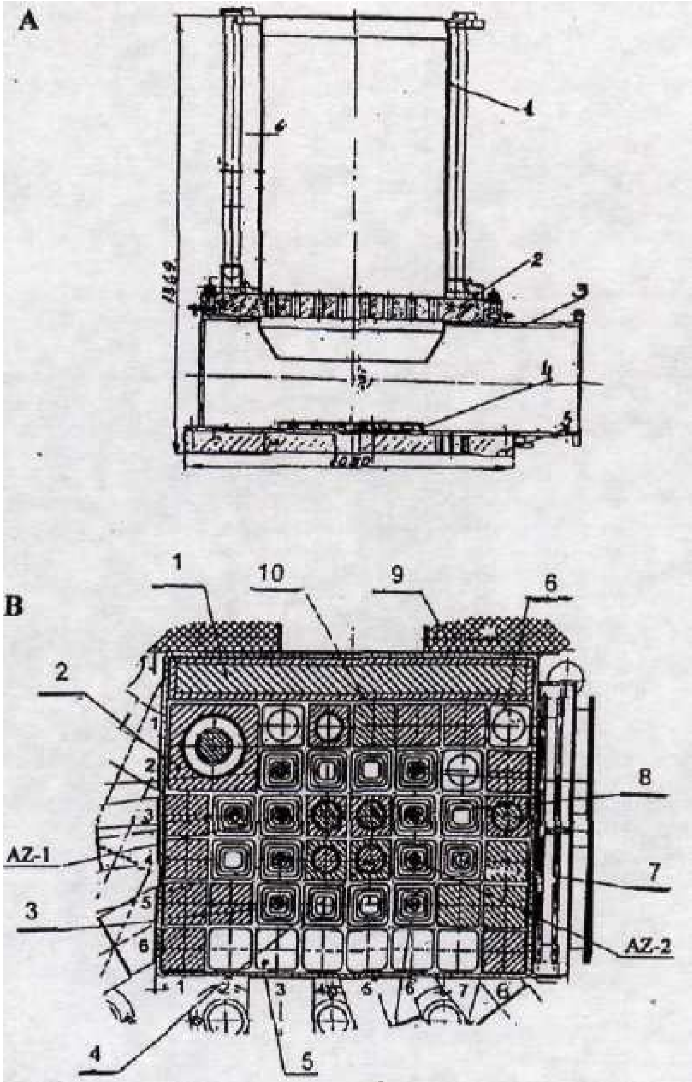


Fig. 3.3. Reactor core of reactor IRT-5000

1 - lead filter; 2 - special beryllium block; 3 - control rods; 4 - beryllium block; 5 fuel assembly imitator 6 - water press; 7 - radiation loop generator; 8 -fuel assembly; 9 - thermal column; 10 - beryllium block (reflector)

Upper unit fig 3.3. A (1) and B aerial view; the unit contains everything connected with the cause and control of chain reactions. The working reactor core components are 30 fuel assemblies (8), assemblies containing test samples (5), a special beryllium block with a thermal neutron trap (2). Beryllium neutron reflective blocks (up to 20) (2,4), water press assemblies (6), control rods (3) and defense rods AZ-1 and AZ-2 were installed in the remaining sockets. Lower unit fig. 3.3. A (3). A reactor core support grid was installed between the upper and lower units. This is one of the most important and precise components of the nuclear reactor. Fig. 3.3. A (2). An ejector with a nozzle and diffuser was attached at the four-cornered fold in the lower unit (Fig. 3.1.(1). This guarantees that considerably more cooling water flows through the reactor core than through the primary cooling cycle, ejection coefficient 4. The ejector ensures heat diversion from the radioactive assemblies in the event that the primary cooling cycle pumps cease functioning.

Nuclear fuel. After modernization the Salaspils nuclear reactor used Soviet produced nuclear fuel: assembly IRT-2M (three elements), IRT-2M (four elements), IRT-3M (six elements), 1RT-3M (eight elements) fig. 3.4.

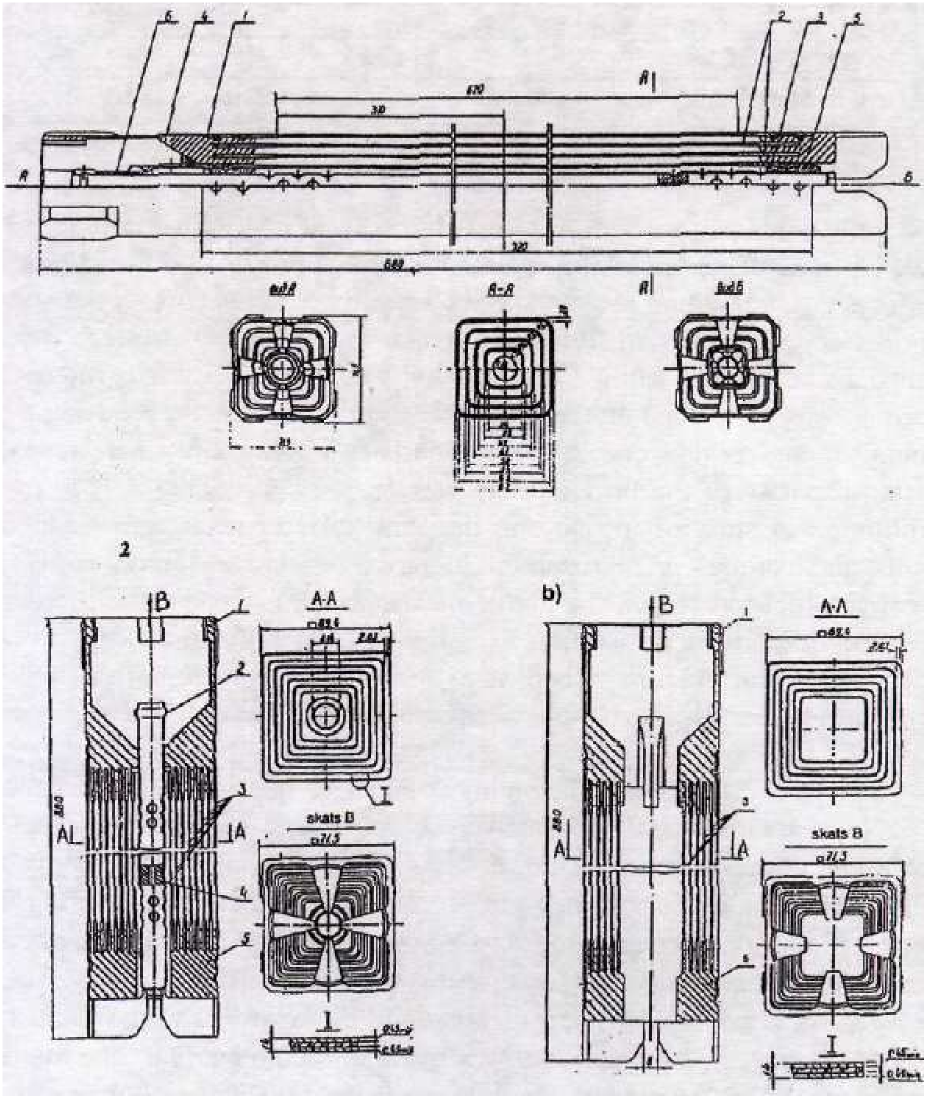


Fig. 3.4. Reactor IRT-5000 fuel assemblies

1) IRT-2M four-tube assembly: 1 - external element; 2 - middle element; 3 - pull-out inner element; 4 - assembly head; 5 - assembly tail; 6 - displacer 016mm;

2) IRT-3M. a) 8-tube assembly; b) 6 - tube assembly: 1,5-assembly aluminum ends; 2,4-waterflow regulator; 3-four-angle fuel tube.

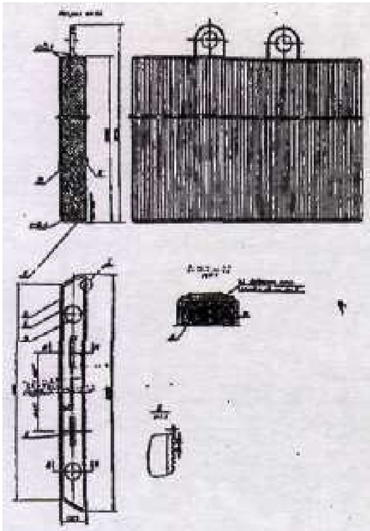
Reactor core and fuel date

	IRT-2M		IRT-3M	
Tubs in asse nbly	3gab.	4gab.	6gab.	8gab.
Enrichment with U-235	90%	90%	90%	90%
Amount of L-235 , g	148,3	173,0	269,3	305,0
Amount of L-238 , g	16,5	19,2	29,9	33,9
Amount alur inum in core g	566	661	977	1112
Assembly ste p, mm	71,5	71,5	71,5	71,5
Length of as embly, mm	880	880	880	880
Total weigh g	2800	3300	3800	4300

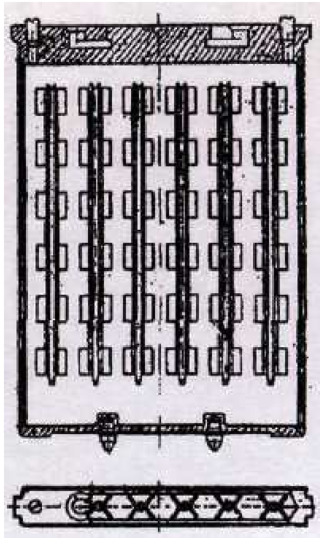
The semi-automatic unloading system of highly radioactive spent fuel [9]. Up to 200 fuel assembly unloading operations are performed annually using this system, unloading the assemblies from the reactor core to the spent fuel tank and vice versa. The 1RT-I000 reactor's unloading system was defective (unbalanced load, inability to function when electricity is switched off). Fuel loading was performed on the upper platform of the reactor by using a special lead container and bridge crane. The weight of the lead container was 5,2t, but the lifting capacity of the bridge crane was 5t. thus producing a 10% overload. The building was stressed in one and the same place causing cracks in the building wails and ceiling. As a result of the investigation an autonomous system was created which prevented the above mentioned imperfections and reduced loading operation time from 60 minutes to 5 minutes. Operational and security capabilities are determining factors when it is necessary to accomplish fuel evacuation procedures from the reactor core in case of accident or unforeseen circumstances.

Reconstruction of the highly radioactive spent fuel storage tank (27). There is a high incidence of radioactive isotope decay in the spent fuel assemblies releasing a large amount of heat. For this reason they are kept under water for 5 - 6 years. During this period they are stored in a special vault and are cooled with water. If the assemblies come into contact with the atmosphere, the situation is viewed as a nuclear disaster because it is possible for the hermetic aluminum cover to melt. As many as 100 spent fuel assemblies are stored in the vault. In the initial IRT-I000 project, the spent fuel was made of aluminum and, like the reactor tank, was damaged by corrosion. The new spent fuel tank was constructed of stainless steel 321H by the Swedish company ABB Alstrom Power.

Reactor core lead filter. In the IRT-1000 project the lead filter (fig. 3.5. A) was located in the gap between the body of the reactor core and the plane of the thermal column. As the result of neutron seizure, the temperature of the lead shield reached 90° C. The shield swelled creating micro cracks in the aluminum casing. The swelling deformed the filter by 15 mm, thus deforming the reactor core by 10 mm, compressing the fuel assemblies.



A



B

Fig. 3.5. Reactor core lead filters

A - Reactor IRT-1000 lead core filters; B - Reactor IRT-5000 lead core filters

It was necessary to find significant solutions to this extremely dangerous problem. In the modernization project of reactor IRT-5000, the lead filter (Fig. 3.5. B) was situated in the reactor core and subjected to intense forced cooling. Moving the lead filter to the reactor core and subjecting it to intense forced cooling solved all the prior problems. The construction of the new lead filter (Fig. 3.5.B) included side panels thus enlarging the cooling surface. Additional crenellation of the surface also was done. The inside of the structure was fitted with loop-shaped side elements to absorb the force of the pressure.

Reactor core emergency cooling system. Analysis of hypothetical emergency situations lead to the development of a reactor core emergency cooling system which did not allow meltdowns. The emergency system consists of water collection and feeder pipelines. The reactor core cooling system's shower was installed in the upper part of the reactor tank above the core.

The cooling system of the modernized reactor [18;20]. Water circulates through the reactor core from top to bottom. The cooling system of nuclear reactor IRT-5000 is shown in Fig. 3.6.

The primary cooling circuit cools the fuel in the reactor core, the system is radioactive and hermetic, it consists of: an ejector (3), a cooling delay tank (2), a hydraulic repulsion grid and six pumps (9), four heat exchangers (11), six water filters (13), producing desalinated water at 280 m^3/h.

The secondary cooling circuit is filled with technical water; it cools the water from the primary cooling circuit in heat exchangers and consists of: four heats exchangers (II), four circulation pumps (9), a cooling tower with six ventilators (15), productivity is 1000 m^3/h.

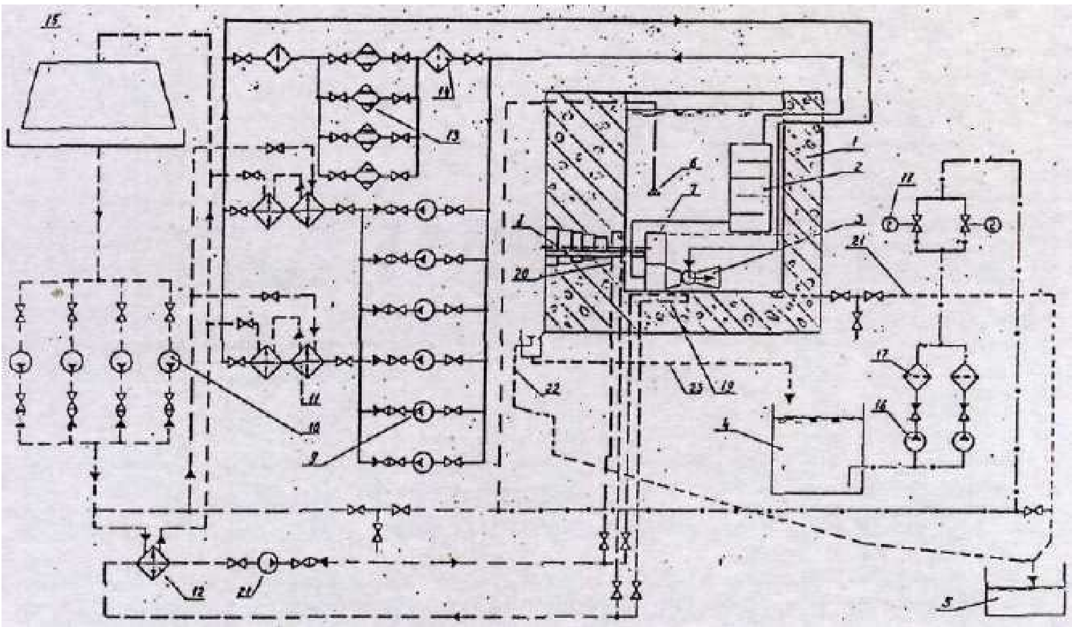


Fig. 3.6. The cooling system of the modernized IRT-5000 nuclear reactor

1 - biological shield; 2 - cooling delay tank; 3 - ejector; 4 - leached water collecting tank; 5- a 100m 3 tank for collecting radioactive leached water; 6 -emergency shower; 7 - reactor core; 8 - first channel; 9 - primary circuit pumps; 10 - secondary circuit pumps; 11 - heat exchangers; 12 - third circuit heat exchanger; 13 - ionic filters; 14 - mechanical filter; 15 - cooling tower; 16 -pumps: 17 - mechanical filters; 18 - control program valves; 19 -third circuit heat exchanger: 20 - inter-tank cooling device; 21 - third circuit pump; 22 -gathering collector; 23 - drain pipeline.

Chapter Four (Experimental use of nuclear fusion from the modernized reactor) explores modern experimental technologies and their use in nuclear fusion experiments.

Safety became a crucial issue when the reactor was constantly operational for a week, making it impossible to open experimental channels due to high levels of radiation.

Unique semi-automatic vertical channels were successfully developed in Latvia: electromagnetic mail, vertical pneumatic mail, horizontal pneumatic mail, a floating vertical experimental channel and curved vertical channels. These constructions will be reviewed individually.

Electromagnetic mail serves as quick transport of irradiated substances from the reactor core to the hot chamber. The transport container travels through a pipeline lined with electro conductors that create a vertically running magnetic field. The distance from the reactor core to the hot chamber is 15 m.

Pneumatic mail

Vertical pneumatic mail (fig. 4.2.) (a) [5], installed at the reactor core, distance 052 mm, cartridge volume 0,125 liters, transport velocity up to 10 m/s. cartridge weight up to 0,3 kg, works with compressed air. Speed of the transport system ensures experimentation with isotopes that have short half-lives, transporting them quickly to the measurement site. The closed pipeline system eliminates radioactive gas leaks and the automated features eliminate the necessity for personnel to come in contact with radioactive samples.

Horizontal pneumatic mail (fig. 4.2.) (b). Pneumatic pipelines ∅11 mm. Transport time to the reactor core is 1.5 sec. pressure is less than 1 arm. compressed CO2 gas is used for transport. The transport container is made of high pressure polyethylene. Pneumatic mail is used for the study of short-lived isotopes and isotope activity, set up in the fifth horizontal experimental channel.

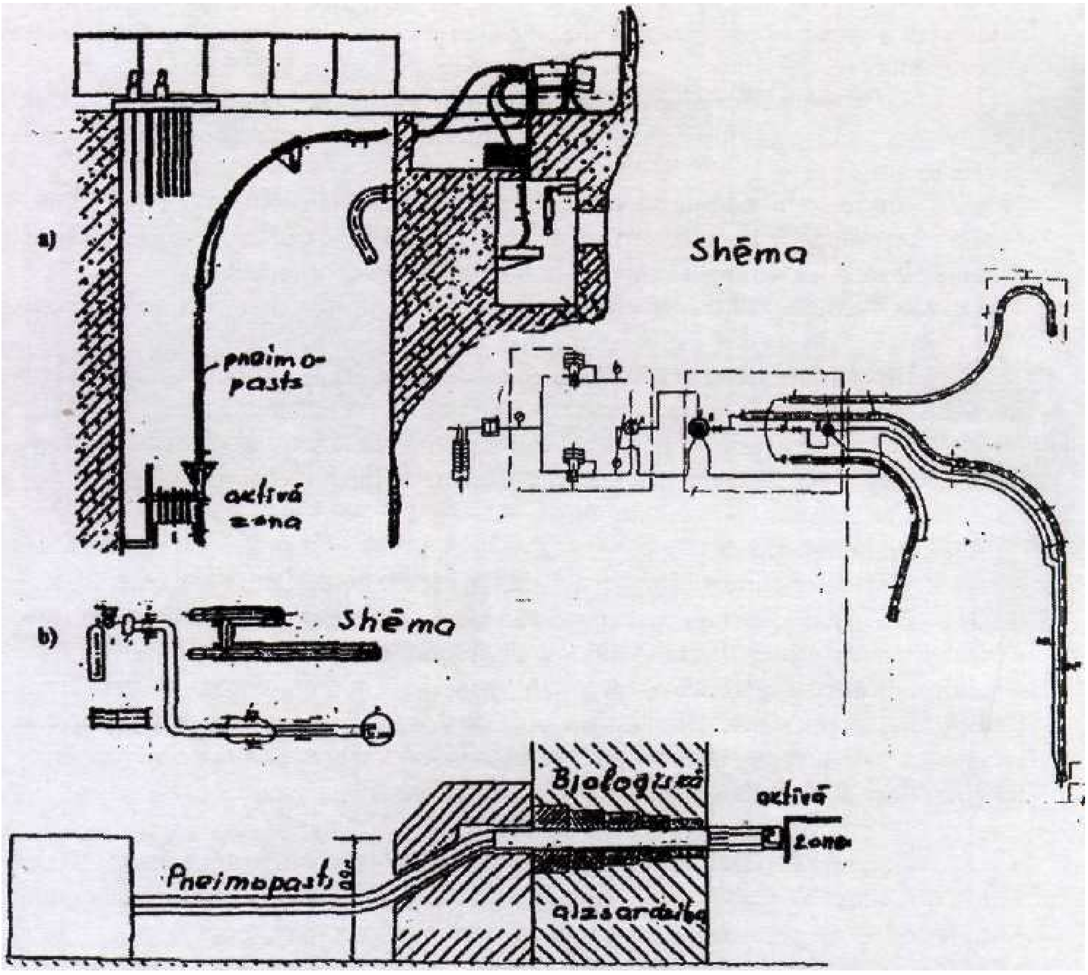


Fig. 4.2. IRT-5000 reactor pneumatic mail

a - vertical pneumatic mail, for radiation technology experiments in the reactor core; b - horizontal pneumatic mail for activity analysis experiments in the fifth horizontal experimental channel.

Conclusion. Pneumatic mail provides a slew of advantages under nuclear reactor conditions: complete automation of the radiation process; ability to transport highly radioactive substances without the need for heavy biological shielding the entire length of the pneumatic pathway.

Floating vertical experimental channel (VEK) fig. 4.3. is unique in that the technological water from the reactor tank is used as a shield against reactor core radiation. Functioning of the floating vertical experimental channel is shown in fig.

4.4. Construction of the channel (0 52 mm) is relatively simple, making it possible to conduct measurements during irradiation.

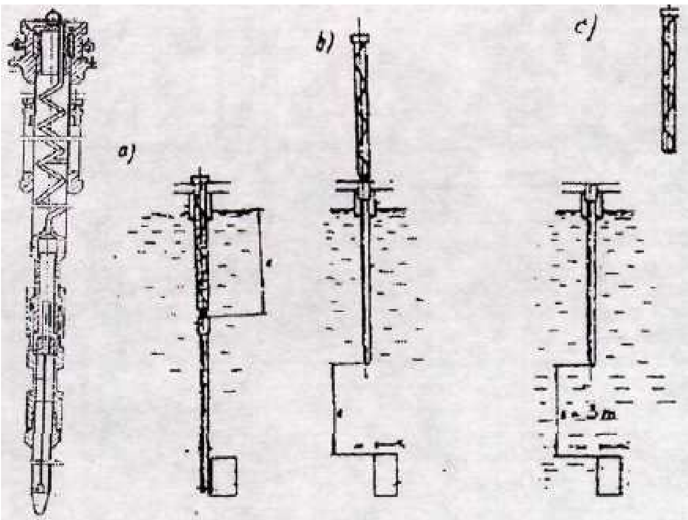


Fig.4.3. Floating vertical experimental channel (VEK) 052 mm

Curved vertical channels (fig. 4.4.). They are unique in that they do not require heavy biological shielding; they are filled with technological water from the reactor tank. The curved part is covered with a 4 m thick layer of pool water that forms a shield against direct reactor core radiation.

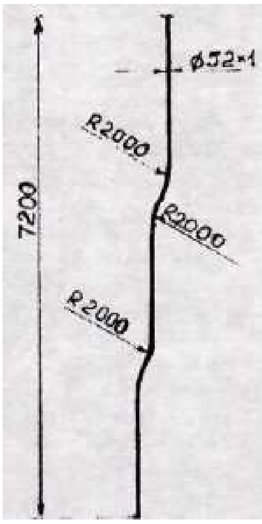
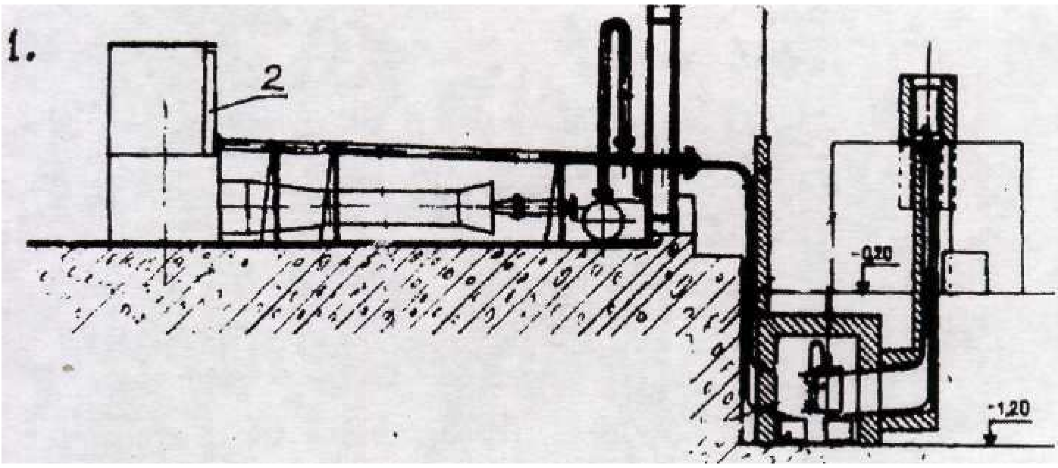


Fig.4.4. Curved vertical channels

The radiation loop (RK) is a source of pure gamma rays in the original construction, fig. 4.5. (1,2,3) and is connected to the reactor core. The author, working with physicists, created the metal construction of the radiation loop (1). connections with valves and mixing chambers as well as devices for the radiation loop. The radiation loop consists of magneto hydrodynamic pumps that pump a liquid metal alloy (indium-gallium-tin) from the reactor core generator (2) to the hot chamber, in which gamma ray sources are located (3) for fusion samples. Their work capacity is l,8PBq, but ray intensity is up to 190Gy/h.



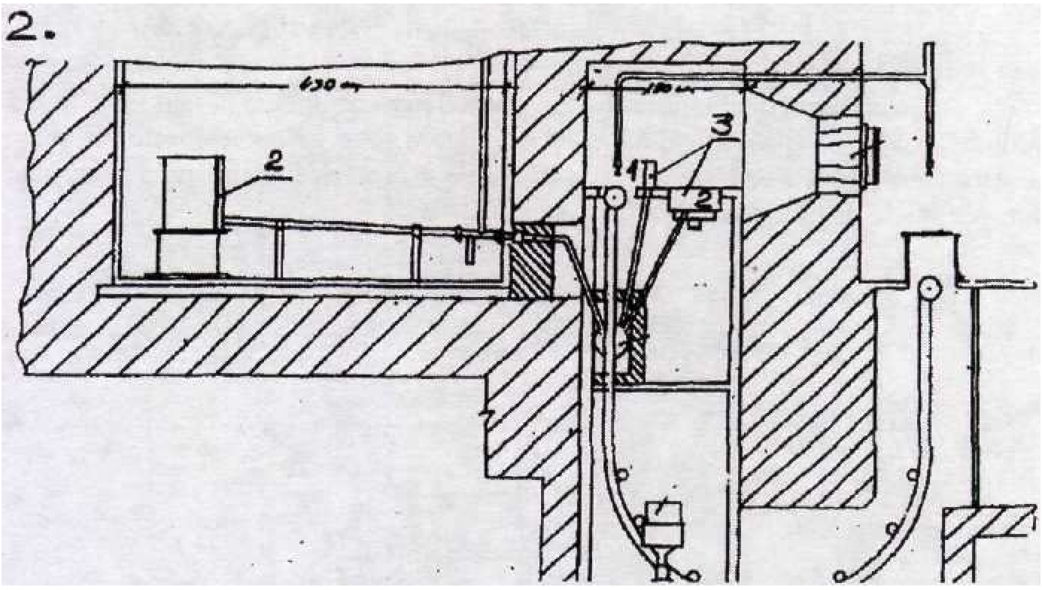


Fig. 4.5. Radiation loop (RK)

1 - overview with reactor and hot chamber; 2 - activation generator; 3 -fusion chamber; (1) - 6 Mrad/h; (2) - 19 Mrad/h; 2 - radiation loop lift

First experimental channel (thermal column) [7].

The first experimental channel (thermal column) was erected:

l. To obtain maximal thermal neutron flux;
2. To carry out thermal neutron irradiation of large samples, channel 0230mm;

3.To work in very low temperatures (-188° C).

The thermal column consists of two main parts, graphite and biological shields. The graphite part of the thermal column is connected to one side of the reactor core and receives 1/6 of the fusion from the reactor core. This graphite part of the thermal column is a rectangular prism (4) and is composed of graphite blocks (one block measures 0,2m x 0,2m x 0,5m), total weight of the graphite pile (1m x 1m x 1,5m) is 5t.

The task of the graphite is to slow the neutrons from the reactor core flux to the rate of the thermal neutron energy, thus resulting in an increase of the graphite radiation level (Vigners energy accumulation). To prevent cracking of the outer layer of the thermal column, graphite thermal annealing is provided for, heating the graphite pile with I4KW and creating an elastic construction (expander) compensating the growth of the graphite pile (6). During use the graphite is cooled by a heat exchanger, which is located between the graphite pile and the biological shield and connected to the reactor's primary cooling circuit.

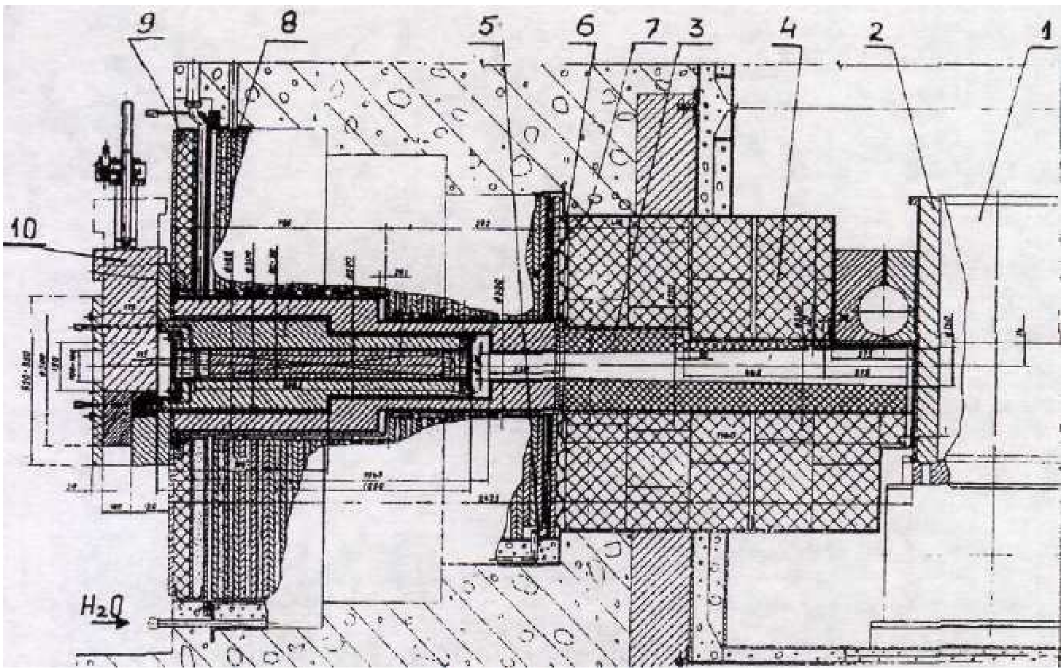


Fig.4.6. First experimental channel (thermal column)

1 - reactor core; 2 - lead filter; 3 - channel; 4 - graphite blocks; 5 - cooling pipe; 6 - expander; 7 - iron sheets; 8 - layered shielding blocks; 9 – paraffin shielding blocks; 10 - lead shield

Chapter Five (Approbation of the Salaspils nuclear reactor after modernization) **[21;23;25;]** describes the cooling approbation of the reactor core, the overall approbation of the equipment after 25,000 work hours and total approbation after 35,000 work hours with laboratory investigation of irradiated sample 112X18H10T.

Cooling approbation of the reactor core was performed as the first investigation immediately following the turning on of the reactor with the aim of determining the size and heat distribution of the neutron flux. The size of the neutron flux is directly proportional to the size of the heat distribution. The distribution of the reactor neutron flux on a horizontal plane is shown in fig.5.1., but the spatial distribution φ_T (x,y,z) is shown in fig. 5.2., leading to the conclusion that the most heavily loaded fuel assemblies are situated in the reactor core central sockets.

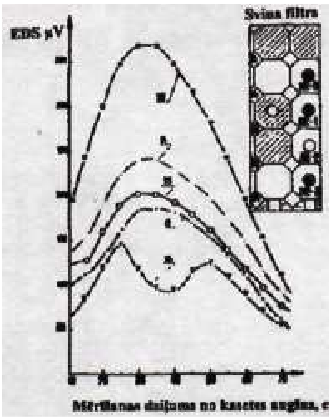


Fig. 5.1. Vertical distribution of thermal neutrons

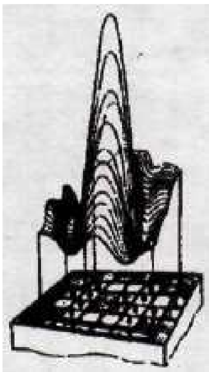


Fig. 5.2. Thermal neutron density in the reactor core

These sockets were outfitted with a fuel assembly with 10 thermoelectric transformers to measure the dynamics of water heating temperatures. Hypothetically the most dangerous moment during cooling of the reactor core occurs when cooling of the reactor core becomes the function of the water convection circulation of the reactor tank, cooling the remaining heat to 300 KW.

Conclusion. It was determined that the critical situation occurs 9 seconds after the reactor is turned off, when the water flow stops and changes direction. Reactor core cooling is then totally the function of the water conventional circulation in the reactor tank, flowing through the reactor core and lowering the temperature to lower 50°C.

The second reactor core temperature approbation was carried out without forced cooling of the reactor core. Reactor capacity was increased every 100KW. registering temperature changes in the fuel assembly casing. Convection circulation measurement results are shown in fig. 5.3., with the reactor working at a capacity of 100 - 600 KW. In measuring the heating of the most highly loaded fuel assemblies, the data show that at a capacity of 600 KW the temperature of the fuel assembly casing does not exceed the 80° C limit.

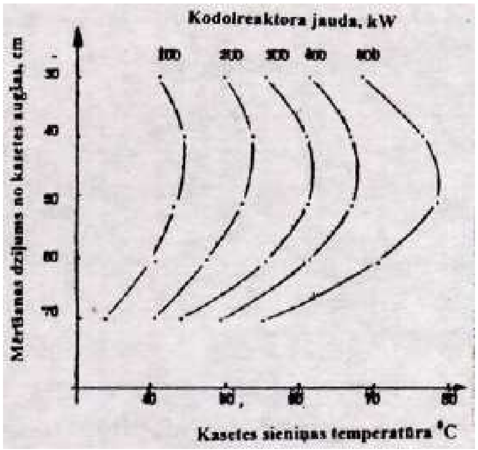


Fig. 5.3. Fuel assembly casing temperature without the primary cooling system, the reactor core is cooled by convection circulation of the reactor tank water.

With the reactor working at a capacity of 5MW, the primary circuit pumps provide cooling of the reactor core (fig. 5.4.). temperature of the fuel assembly casing does not exceed 90° C.

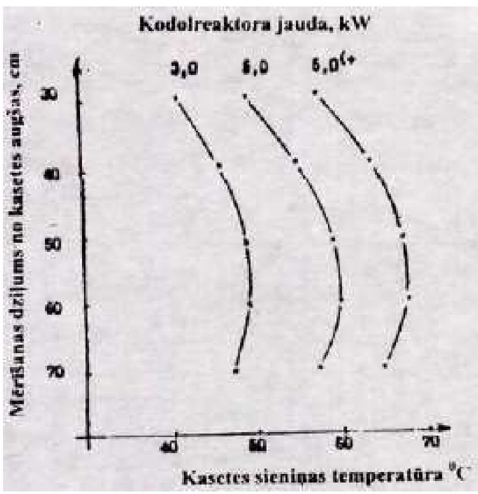


Fig. 5.4. Fuel assembly casing temperature with a functional primary cooling system.

Vibration experiments of the reactor core were conducted at a capacity of 5MW and a maximum cooling circuit workload. Measurements do not exceed normal vibration limits.

Total equipment approbation after 25,000 work hours **[25].** The equipment was tested during operation, partially dismantling it once a year. A total inspection of the equipment and all metal components was performed after 25,000 work hours, using color fault detection, ultra sound testing for hidden defects, density testing of the radioactive leach water and inspection of irradiated samples.

Underwater inspection of the reactor tank was carried out by periscope at an enlargement of 200 times. Special attention was paid to the reactor core, the lower section of the reactor tank, the HEK ends and tangential channel, and the outer casing of the thermal column graphite pile. It was established that:

1. No metal corrosion or damage was discovered in the body of the reactor core (aluminum ADI), the walls of the reactor tank (non- corroding steel 12X18H10T), nor any of the equipment.
2. 2.Traces of pitting were noticed on the surface of the neutron reflector beryllium blocks.
3. 3.No damage was determined to the aluminum oxide covered ends of the horizontal experimental channel.
4. 4.Upon inspection of the of the reactor core fuel assembly support grid, no corrosion or damage was determined neither on the top or bottom of the grid. 5.The hydraulic delay tank and hydraulic grid plate, the surface of the ejector and pipelines (aluminum ADI) were all evenly covered with a layer of aluminum oxide.

Color fault detection of the welded seams indicated that the quality of the welded seams of the pool tank had not changed.

Initial thickness fault detection of the pool tank walls was performed by ultrasound conducting 270 test measurements of previously designated spots. The measurements are plus-minus 0,1 mm of the original nominal measurements of the material. This fluctuation is well within the measurement margin of error. Upon inspection of irradiated samples, it was determined that construction corrosion under highly radioactive conditions occurs at 0,001 mm/year.

Conclusions:

1. Upon total approbation of the modernized IRT-5000 nuclear reactor after 25,000 work hours, no hazardous nuclear safety or radiation safety situations were determined in the reactor core or its components, the pool and inner tanks, or the cooling circuit.
2. Equipment testing and assessment did not indicate the need for radical changes; it was suggested that a follow-up inspection be conducted after 5 years of operation or 35,000 work hours at capacity.

Approbation of equipment after 35,000 work hours and inspection of 12X181110T samples [22;23] was carried out according to the following program in addition to the 25,000 testing program:

1. Thickness measurements of the reactor pool tank walls were conducted using ultrasound; inspection of the horizontal experimental channel ends and welded seams was performed with the help of an optical periscope.
2. Inspection of the reactor core support plate dimension 70_{-0} ,4 was performed.
3. Detailed examination of all equipment in the open position, using enlargement by 8 times.
4. Hazardous equipment pressure testing.
5. Laboratory inspection of pool tank material.

Upon visual inspection of the equipment, it was noted that:

1. Inspection of the reactor pool tank walls, the end of the horizontal experimental channel, the body of the reactor core, and the fuel support grind plate by optical periscope under enlargement 18 times led to the conclusion that there is no evidence of material defects, corrosion damage or cracking.
2. Thickness measurements of the reactor core support plate to assure 70. 0.4 thickness were performed in 6 different spots, obtaining a face value of 70mm. an increase of 0,1 mm. The increase is due to the increase of the aluminum oxide layer under pool water conditions, since the support grind plate is made of aluminum ADI. Visual inspection of the support grind plate from the top and bottom showed no damage or structural change, the inspection was conducted by underwater optical periscope.
3. A detailed examination of all equipment in an 'on' position was performed using an enlargement of 8 times.

Laboratory strength testing of pool tank material 12X18H10T [22], Characterization of irradiated samples:

$F=5x10^{20}$ n/cm^{2}at E>2,6 MeV

Where F-fluens, with a full neutron number, that affects the area at full exposure. the dimension n/cm2 characterizes the brittleness of the material. Laboratory tests yielded characteristic mechanical size measurements, based on initial parameters:

Material State	σ_b Mpa	$\sigma_{0.2}$ MPa	δ_P %	KC_V J/cm^2	K_c MPa/m	δc x10^{-3}m
Initial	668	375	40.8	52.8	67.3	0.491
Irradiated	747	590	25.2	39.3	80.2	0.236

σ_b - temporary resistance minimum value. MPa

$\sigma_{0,2}$ - minimal flow limit value, MPa

δ_p - relative extension, %

Kc_v -hit viscosity, J/cm^2

K_c - critical value of intensity, comparable to maximum load Po, PAVm

δ_t - crack width of maximum load, mm.

The test results show that mechanical hardening has taken place (as = from 668MPa to 747 MPa, δ_p = from 40,8% to 25,2%); weak traces of corrosion (iron oxide) are evident in some places. The rate of corrosion is 0,001 mm/year.

Conclusion: Condition of the equipment after 35,000 work hours is defect free. Operation was approved until the next inspection in 2003.

Public presentation of results

The results set forth in this work have been presented at the following seminars and conferences:

1. Conference on the physics and technology of nuclear reactors, Joint Nuclear Research Institute, Prague, 1963 [2].
2. Union-wide conference on the coordination of scientific efforts conducted at research reactors, Riga, 1966 [1;2].
3. Fifth conference on the physics of research reactors, Warsaw, 1968 [6;].
4. Pneumatic mail for the IRT-1000 nuclear reactor, Riga Polytechnic Institute, Riga, 1978 [4;].
5. On the corrosion in the vessel of the nuclear research reactor, Multilateral symposium on safety research for WER reactors, Cologne, September 28-30, 1993 [3;5;7;9;12;14;].
6. The nuclear reactor and experimental physics equipment, University of Latvia, Faculty of Physics and Mathematics, Riga, 1999 [29].
7. Ecological problems in dismantling nuclear facilities in Latvia, International conference EcoBalt2003, Riga, May 15-16, 2003 [26;1- 42,14-3].
8. Modernization of the Salaspils nuclear reactor 1973-1975, University of Latvia conference, Riga, January 24, 2005 [31;].

Results of the study

1. 1 .Thorough investigation conducted of the Salaspils nuclear reactor IRT-1000, a modernization project was designed to increase capacity to 5MW.
2. 2.New reactor core created with a transformed cooling system and an increased neutron flux of 7 x $l0^{13}$ n/cm^2 s.
3. 3.Total approbation of equipment after 25,000 and 35,000 work hours determined that the IRT-5000 reactor can operate safely for the next 20 years.

Scientific novelty

Several innovations have been introduced in IRT nuclear reactor modernization:

1. A new biological shield was produced in Latvia with cement injected iron blocks.
2. New reactor core construction with a transformed cooling system was developed.
3. A new delay system was developed for radioactive water in the reactor pool, decreasing radioactivity by a factor of 200.

4. New mechanisms for the fault detection and damaged equipment replacement technology were developed.
5. An emergency cooling system was developed to prevent melting of nuclear fuel.
6. A new semi-automatic independent fuel loading and evacuation system was developed.
7. Semi-automatic electromagnetic and pneumatic transport equipment and uniquely constructed channels were developed for the irradiation process.
8. Nuclear fuel quality improved as a result of investigations of fuel damage.

Practical significance

The experience gained during the modernization process was put to use in the construction and modernization of other nuclear reactors: Tbilisi in 1974, Minsk in 1977 and later Tomsk and the Moscow MIF1 nuclear reactor and abroad -Korea in 1974, Iraq in 1978, Libya in 1981 and Bulgaria in 1988. Latvian specialists assisted on site in Libya and Iraq sharing the experience gained during the modernization of the Salaspils reactor.

The modernization of the Salaspils nuclear reactor is the Latvian engineering contribution to the development of nuclear energy and serves as the foundation for further research reactor modernization and safety and security implementation.

The Salaspils reactor modernization model is an economically feasible one, because there is no need to enlarge the existing buildings and biological shielding.

Work in areas of high radioactivity is best organized in small, but highly qualified and trained groups allowing for a notably longer time period. Dismantling highly radioactive devices should be done from a distance.

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