

NON PROPRIETARY

FINAL CRADA REPORT

Date: 2 October 2009

CRADA Number: 0000401

CRADA Title: Technology development for Sr-89 production with 100kW medical isotope production system ("MIPS-100")

CRADA Start/End Date: 26 September 2000/25 September 2003

Argonne Dollars: \$1,348,000

Participant Dollars: \$1,348,000

Argonne PI: George Vandegrift

Industrial Partner: TCI (Albuquerque, NM; no longer in business)
(complete address)

DOE Program Manager: Regina Carter

Summary of Major Accomplishments: Preliminary design of a solution reactor at the Kurchatov Institute (Moscow, RF), ARGUS, which could be converted to operation for production of medical isotopes, Mo99 and Sr 89.

Summary of Technology Transfer Benefits to Industry: If funding were available this Russian research reactor could be a proof-of-principle operation. A larger scale production facility could use the R&D from this operation as a basis for an economical design.

Other Information/Results: (Papers, Inventions, Software, etc.)

R. W. Brown, L. A. Thome, V. Y. Khvostionov, "Mo-99 production on a LEU solution reactor," presented at RERTR 2004 International Meeting on Reduced Enrichment for Research and Test Reactors, Vienna, Nov. 2004.

Attachments-results (Word Documents):

5.2-Report-eng-new

K-18a-MIPS-100-Eng

K-18a-Sr89-SR

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					MIPS100.00.00-OP							
<i>Change</i>	<i>Sheet</i>	<i>Document №</i>	<i>Signature</i>	<i>Date</i>	Recovery, purification and quality control of ⁹⁹ Mo. Process description			<i>Character</i>	<i>Sheet</i>	<i>Sheets</i>		
<i>Developed</i>										2	21	
<i>Checked</i>								RSC "KI"				
<i>Control</i>												
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1. General provisions.

- 1.1. A description of ⁹⁹Mo recovery, purification and quality control process is an integral part of the MIPS-100 Reactor Facility Preliminary Technical Design [1].
- 1.2. The basis for the process development is Master Contract №DE-AC01-00NN40184 Modification “D and/or 4” to DE-AT01-00NN40184, Para. 5.2.
- 1.3. The process of ⁹⁹Mo recovery (absorption) from the solution fuel (UO₂SO₄·3H₂O), as well as purification and quality control, is developed based on the experimental results submitted by the RSC “Kurchatov Institute” and Urals State Technical University (USTU) [2].
- 1.4. Grade “Thermoxide-52” (T-52) was used as the main sorbent for ⁹⁹Mo recovery from the irradiated fuel solution with high uranium concentration. The sorbent was developed jointly by the Scientific and Production Firm “Thermoxide” and USTU at the order of TCI Medical, USA.
- 1.5. The technology of ⁹⁹Mo removal from the MIPS-100 solution reactor core is described in Section 4.5 of the Preliminary Technical Design [1].

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2. Characteristics of the manufactured product.

2.1. Technical requirements (specification).

2.1.1. Product name: Molybdenum-99 free of carrier – alkaline solution.

2.1.2. Appearance: transparent colorless solution.

2.1.3. Medium: 1 n water solution of sodium hydroxide.

2.1.4. Chemical formula: ^{99}Mo as sodium molybdate Na_2MoO_4 .

2.1.5. Volume activity: ^{99}Mo – ≥ 350 mCi/ml.

2.1.6. Specific activity of ^{99}Mo (free of carrier): ≥ 5 Ci/g Mo.

2.1.7. Content of impurity radionuclides:

^{131}I $< 5 \cdot 10^{-5}$ Ci/Ci ^{99}Mo

^{103}Ru $< 5 \cdot 10^{-5}$ Ci/Ci ^{99}Mo

The rest of γ -emitters: $< 5 \cdot 10^{-5}$ Ci/Ci ^{99}Mo

^{89}Sr $< 6 \cdot 10^{-7}$ Ci/Ci ^{99}Mo

^{90}Sr $< 1.5 \cdot 10^{-8}$ Ci/Ci ^{99}Mo

All α -emitters: $< 1 \cdot 10^{-10}$ Ci/Ci ^{99}Mo

2.1.8. Dispensing.

The finished product of ^{99}Mo is ordinarily dispensed in 20-ml portions into standard medical vials (if not otherwise required by the Customer).

2.1.9. External package (container).

The vials containing the finished product are tightly sealed and installed into the transport protection containers for further delivery to the Customer.

2.2. Main characteristics of the product.

Radioactive isotope of ^{99}Mo has a half-life of 2.75 days. About 86.3% decays of ^{99}Mo result in the formation of $^{99\text{m}}\text{Tc}$ (half-life – 6.05 h), which is converted into ^{99}Tc ($2 \cdot 10^5$ years).

Characteristics of the main (most intensive) radiation are summarized in Table 1.

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Table No.1.

Corpuscular radiation, MeV and (yield per fission, %)	Gamma radiation, E γ , MeV and (yield per fission, %)
β^- radiation, E max.	0.0406 (1.15)
1,214 (81,96)	0.140 (line ^{99m}Tc ; 90,63)
0.847 (1.17)	0.191 (6.06)
0,436 (16,55)	0.366 (1.19)
Conversion electrons	0.739 (12.19)
0.0016 (83.63)	0.778 (4.32)
0.0195 (3.77)	0.823 (0.133)
0.1196 (0.49)	0.916 (0.099)
Oge-electrons 0.00217 (15.4)	X κ 0.0187 (11.6%) – equilibrium intensity

Ionization constant for $^{99}\text{Mo} + ^{99m}\text{Tc}$ is $1.675 \text{ f}\cdot\text{cm}^2/\text{mCi}\cdot\text{g}$.

2.3. Application areas.

The radionuclide ^{99m}Tc , which is a daughter isotope of ^{99}Mo , is a very important and widely used product in nuclear medicine. The applications of radiopharmaceuticals based on ^{99m}Tc are diverse and include diagnostics of numerous diseases of heart, brain, bone tissue, kidneys, liver, etc. About 80% of all the diagnostic procedures around the world are based on ^{99m}Tc . Daily use of ^{99}Mo - ^{99m}Tc generators is close to 60 thousand. Wide application of ^{99m}Tc is determined by a short half-life (6.05 h) and soft gamma radiation with the energy of 140 keV. This energy is sufficient for detection in the gamma chamber without significant overexposure of the patient. In addition, technetium lacks chemical toxicity, but exhibits good chemical and biological properties.

The radionuclide ^{99}Mo is applied in ^{99}Mo - ^{99m}Tc generators as the most suitable isotope for an optimal solution of the task regarding the supplies of short-lived nuclides to the clinics. A product of ^{99}Mo decay, ^{99m}Tc , is washed out from the generator in the clinics over a week's time.

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3. Technological equipment

3.1. Hot cells.

3.1.1. Four hot cells are required for ⁹⁹Mo production:

- a preparation hot cell (Hot Cell 1) – for sorbent loading into the sorption column and replacement of the sealing elements;
- a hot cell for preliminary purification of ⁹⁹Mo (Hot Cell 2) – for ⁹⁹Mo desorption from the sorbent and primary purification of ⁹⁹Mo from fission products;
- a hot cell for purification and dispensing of ⁹⁹Mo (Hot Cell 3) – for ⁹⁹Mo refining;
- a hot cell for dispensing and packing of the finished product (Hot Cell 4).

3.1.2. Inner dimensions of the hot cells: not less than 3m x 2m x 2m.

3.1.3. The hot cells are made of heavy concrete (specific weight ~5.0 t/m³). A biological shield of the hot cells shall be sufficient to manage radioactive substances with the activity equivalent to 10,000 g-equ of radium (~30 kCi of ¹³⁷Cs).

3.1.4. Each hot cell is equipped with a view window, at the minimum one manipulator, preferably two, an entrance repairs door, inflow and exhaust filters, waste collectors, load-lifting mechanisms, a lighting system and technological communication lines.

3.1.5. All the hot cells have under-cell space to install technological equipment and technological pipelines.

3.1.6. Hot Cells 2, 3 and 4 have a unified design.

3.1.7. Each hot cell shall be equipped with communication lines for:

- compressed air supply;
- technical vacuum supply;
- decontamination solution supply;
- a special sewerage system (or a system for liquid waste collection);
- cold water supply;
- power supply;
- a special ventilation system;
- additional tunnels.

3.1.8. The equipment installed in the hot cells shall provide for completion of all the technological stages required for the target product recovery, as well as auxiliary procedures, including decontamination of the inner surfaces and equipment in the hot cells, removal of liquid and solid radioactive wastes.

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- 3.1.9. A chain of the hot cells includes lock-type boxes for supplying non-radioactive substances, reagents, utensils, tools and sample transfer for analysis.
- 3.1.10. A horizontal transporter is used for interconnection of the hot cells and lock-type boxes.
- 3.1.11. Hot Cells 2 and 3 are connected through the pipelines for solution transfer.
- 3.1.12. The hot cells include a zone of technical maintenance, which is intended for decontamination and repairs of the standard and technological equipment of the hot cells.
- 3.1.13. A constant partial vacuum is maintained (20 mm water column) with a special ventilation system.
- 3.1.14. Contaminated air is transferred from the hot cells to fine purification filters and further to iodine-sorption filters. The filters are a design feature at the inlet and outlet of the cells and boxes. The removed air passes through the secondary fine purification filters and special absorbers. Operation filters and absorbers have a 100% reserve. Both operation and backup filters and absorbers are installed in self-contained protective canyons. Spent filters and absorbers are replaced without shutdown of the technological equipment.
- 3.1.15. Operation and backup ventilators are used for air removal. If an operation ventilator is out of work, a backup unit is switched on automatically. Ventilator power shall be sufficient to ensure 30-times air exchange in the hot cells.
- 3.1.16. The hot cells are equipped with a system of dosimetry control for sensor triggering in the cells, operator's room and control panel.
- 3.1.17. A chain of the hot cells is equipped with the following communication systems and alarms:
- a telephone;
 - operational telephone lines for communication with the most significant monitoring and engineering divisions;
 - a two-side loud-speaking system to provide communication among the most significant rooms;
 - emergency alarms of dosimetry control system;
 - an automatic fire-alarm system.
- 3.1.18. The hot cells have decontamination rooms to control personnel transfer through conditionally "clean" and "contaminated" areas.

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3.2. Technological equipment of the hot cells.

3.2.1. Hot Cell 1.

A sorption column is transferred to Hot Cell 1 from the reactor loop in the protective container. Here the container with sorbent Thermoxide-52 is removed from the column and transferred to Hot Cell 2. A container loaded with fresh sorbent is installed into the sorption column. Sealing elements of the sorption column are also replaced in Hot Cell 1. Then the column is transferred to the reactor loop to be engaged in a new production cycle.

The main technological equipment, which is installed in Hot Cell 1, is as follows:

- a device for exchange of the sealing elements on the sorption column;
- a device for opening/closing of the sorption column cover during replacement of the sorbent-loaded containers.

3.2.2. Hot Cell 2.

In Hot Cell 2 a sorbent-loaded container is washed with acidic solutions to remove fission products and with alkaline solutions for desorption of ⁹⁹Mo. Desorbate is neutralized and pumped through refining column 1 (RC1), which is loaded with sorbent Thermoxide-5M. Refining column 1(RC1) is washed with acidic solutions to remove fission products and with alkaline solutions for desorption of ⁹⁹Mo. The desorbate is neutralized and supplied to Hot Cell 3.

The main technological equipment, which is installed in Hot Cell2:

- a rig for installation and handling of the sorption column;
- a rig for installation and handling of refining column 1;
- a liquid waste collector;
- transport pipelines;
- a sampler.

3.2.3. Hot Cell 3.

In Hot Cell 3 the neutralized desorbate is pumped through refining column 2 (RC2) loaded with the sorbent Thermoxide-5M. To remove fission products, AC2 is washed with acidic solutions. Desorption of ⁹⁹Mo is achieved after RC2 washing with alkaline solutions.

The following technological equipment is installed in Hot Cell 3:

- a rig for refining column 2 installation and handling;
- transport pipes.

The finished product ⁹⁹Mo is transferred to Hot Cell 4.

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3.2.4. Hot Cell 4.

After sampling procedure is completed, the finished product is dispensed into the vials or other bottles at the Customer's request.

The following technological equipment is installed in Hot Cell 4:

- a sampler;
- a product bottle to hold the Mo-99 solution awaiting initial QA analysis and transfer to dispensing;
- a dispenser (⁹⁹Mo dispensing into sealed medical vials);
- a reloading system (for vial reloading into transport containers).

The finished product is dispensed into the standard evacuated medical vials, which are closed with a rubber septum and rolled with aluminum caps. During dispensing a rubber septum is pierced with a needle and the finished product fills an evacuated vial.

A transport container located below Hot Cell 4 is intended for further delivery of the finished product.

3.2.5. The equipment of the operator's room includes:

- peristaltic pumps (flow rate from 5 to 100 ml/min.);
- transport pipes;
- chemical utensils.

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4. Description of ⁹⁹Mo recovery and purification

A flowsheet for ⁹⁹Mo manufacture is presented in Fig. 1. A layout of the technological equipment in Hot cells 2 and 3 is shown in Fig. 2.

4.1. Preparation of reagents and materials.

4.1.1. The equipment required for preparation of reagents:

- analytical balance; measurement range: 0-1000 g;
- pH-meter; measurement range: 0-14;
- a set of densitometers: 0.7-1.9 g/ml;
- a distiller;
- an isotope microdispenser; sampling range: 10µl-10ml.
- chemical utensils.

4.1.2. Recovery and purification of ⁹⁹Mo requires the following reagents and materials:

- 0.05M H₂SO₄ 7000 ml;
- 0.5M H₂SO₄ 500 ml;
- solution of KI (20 mg/ml) 50 ml;
- C₂H₅OH (50% in 0.1n H₂SO₄) 500 ml;
- 1M NaOH 500 ml;
- 1M NaCl in 0.1n H₂SO₄ 500 ml;
- 1M HNO₃ 300 ml;
- distilled water 1000 ml;
- sorbent Thermoxide-52 280 g;
- sorbent Thermoxide-5M 35 g.

4.2. Loading of the sorption and refining columns.

4.2.1. Sorbent T-52 (280 g) is loaded into the container of the sorption column in the laboratory, which is a clean zone. Then the container is transferred to Hot Cell 1 and installed remotely into the sorption column.

4.2.2. Sealing elements are installed on the sorption column in Hot Cell 1.

4.2.3. The refining columns are loaded with sorbent T-5M:

- RC1 23 g.
- RC2 12 g.

4.2.4. The refining columns are installed into the refining systems of Hot Cells 2 and 3.

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4.3. Installation of the sorption column in the reactor loop for ^{99}Mo recovery.

4.3.1. A sorption column is transported from Hot Cell 1 to the reactor facility and installed in the loop junction system.

4.3.2. Leakage tests are made to check tight-proof junction of the sorption column with the loop.

4.4. Reactor operation at power.

4.4.1. The reactor operates at the rated power for 5 days.

4.4.2. The reactor solution is stored for 0.5-1.0 days for cooling and decay of the induced radioactivity of the short-lived nuclides.

4.5. Recovery of ^{99}Mo from the fuel solution.

4.5.1. The fuel solution is pumped through the sorption column at the flow rate of 20 l/h for 6 hours.

4.5.2. To return residual fuel solution to the reactor, the sorption column is washed with the condensate from the system of radiolysis product regeneration. The volume of condensate is 2-3 l, the rate of pumping is 4 l/h. The gas-air medium of the reactor is pumped through sorption column at the maximum rate for 15 minutes.

4.6. Transport of the sorption column to the hot cells.

4.6.1. The sorption column is connected with a cryogenic trap for removal of radioactive gases.

4.6.2. The sorption column is detached from the loop, installed into the transport container and transported to Hot Cell 1.

4.6.3. The sorption column is removed from the transport container.

4.6.4. A container with ^{99}Mo and other fission products is delivered to Hot Cell 2.

4.7. Preliminary purification of the sorbent from fission products in Hot Cell 2.

4.7.1. A sorbent-loaded container is installed into the stationary sorption column.

4.7.2. The sorbent is washed with the solutions at the flow rate of 60 ml/min.:

0.05M $\text{H}_2\text{SO}_4 + \text{KI}^*$ 3500 ml

$\text{C}_2\text{H}_5\text{OH} + 0.05\text{M H}_2\text{SO}_4 + \text{KI}^*$ 300 ml

1M $\text{NaCl} + 0.05\text{M H}_2\text{SO}_4 + \text{KI}^*$ 300 ml

distilled water 300 ml

4.7.3. Washing solutions are discharged into the liquid waste collector.

4.8. Desorption of ^{99}Mo .

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4.8.1. ^{99}Mo is washed out from the sorbent with 1M NaOH solution (volume 300 ml) at the flow rate of 30 ml/min.

4.8.2. The container with spent sorbent is transported to the temporary storage of solid radioactive wastes.

4.9. Neutralization of desorbate.

4.9.1. Desorbate is neutralized with 0.5M solution of H_2SO_4 to $\text{pH}=1$.

4.10. Sorption of ^{99}Mo on AC-1.

4.10.1. The neutralized desorbate is pumped through AC-1 at the flow rate of 5 ml/min.

4.11. Washing of AC-1.

4.11.1. AC-1 is washed with the following solutions at the flow rate of 10 ml/min:

0.1 n H_2SO_4 + KI	600 ml
$\text{C}_2\text{H}_5\text{OH}$ + 0.05M H_2SO_4 + KI	100 ml
1M NaCl + 0.05M H_2SO_4 + KI	100 ml
1M HNO_3	100 ml;
distillate	100 ml

4.11.2. The washing solutions are discharged into the liquid waste collector.

4.12. Desorption of ^{99}Mo from RC1.

4.12.1. ^{99}Mo is washed out from the sorbent with 1M NaOH solution (volume 52 ml) at the flow rate 5 ml/min.

4.12.2. RC1 is transported to the temporary storage of solid radioactive wastes.

4.13. Neutralization of desorbate

4.13.1. Desorbate is neutralized with 0.5M solution of H_2SO_4 to $\text{pH}=1$.

4.14. Sorption of ^{99}Mo on RC2.

4.14.1. The neutralized desorbate is supplied to Hot Cell 3 and pumped through AC-2 at the flow rate of 2.5 ml/min.

4.15. Washing of RC2.

4.15.1. RC2 is washed with the following solutions at the flow rate of 5 ml/min:

* The concentration of KI in all the washing solutions is 10^{-3} M.

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0.05M H ₂ SO ₄ + KI*	300 ml
C ₂ H ₅ OH + 0.05M H ₂ SO ₄ + KI	100 ml
1M NaCl + 0.1M H ₂ SO ₄ + KI	100 ml
1M HNO ₃	100 ml;
distillate	300 ml

4.15.2. The washing solutions are discharged into liquid waste collector tanks.

4.16. Desorption of ⁹⁹Mo from RC2.

4.16.1. ⁹⁹Mo is washed out from the sorbent with 1M NaOH solution (volume 26 ml) at the flow rate of 2.5 ml/min.

4.16.2. RC2 is transported to the temporary storage of solid radioactive wastes.

4.17. Dispensing and packing of the finished product Na₂MoO₄

4.17.1. The finished product ⁹⁹Mo is transferred to Hot Cell 4.

4.17.2. Specific activity and radionuclide purity are measured in the sample of the finished product ⁹⁹Mo.

4.17.3. The finished product is dispensed in portions into the penicillin vials.

4.17.4. The vials are packed into transport protection containers for further delivery to the customers.

* The concentration of KI in all the washing solutions is 10⁻³ mole/l.

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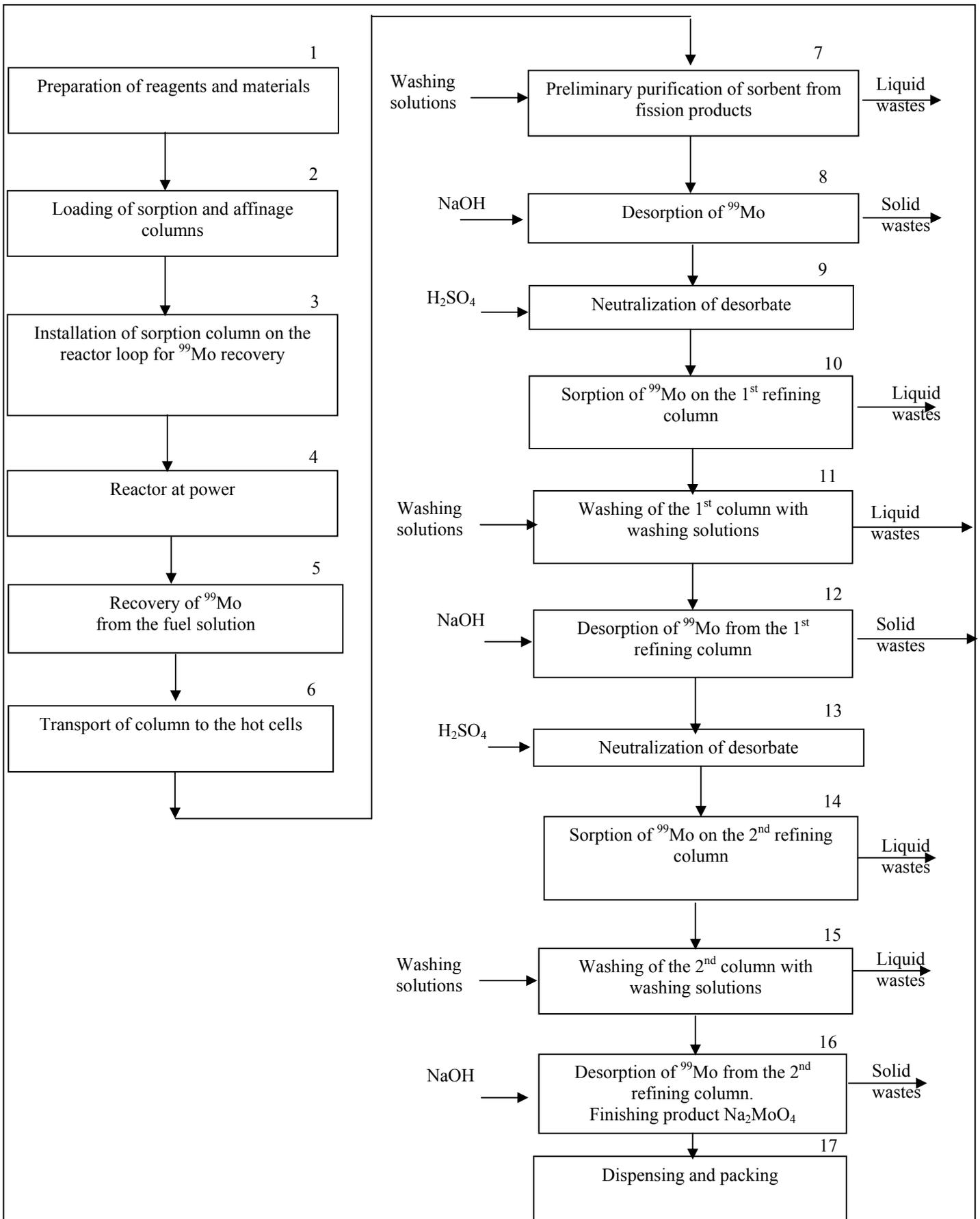


Fig. 1. Flowsheet of ⁹⁹Mo recovery

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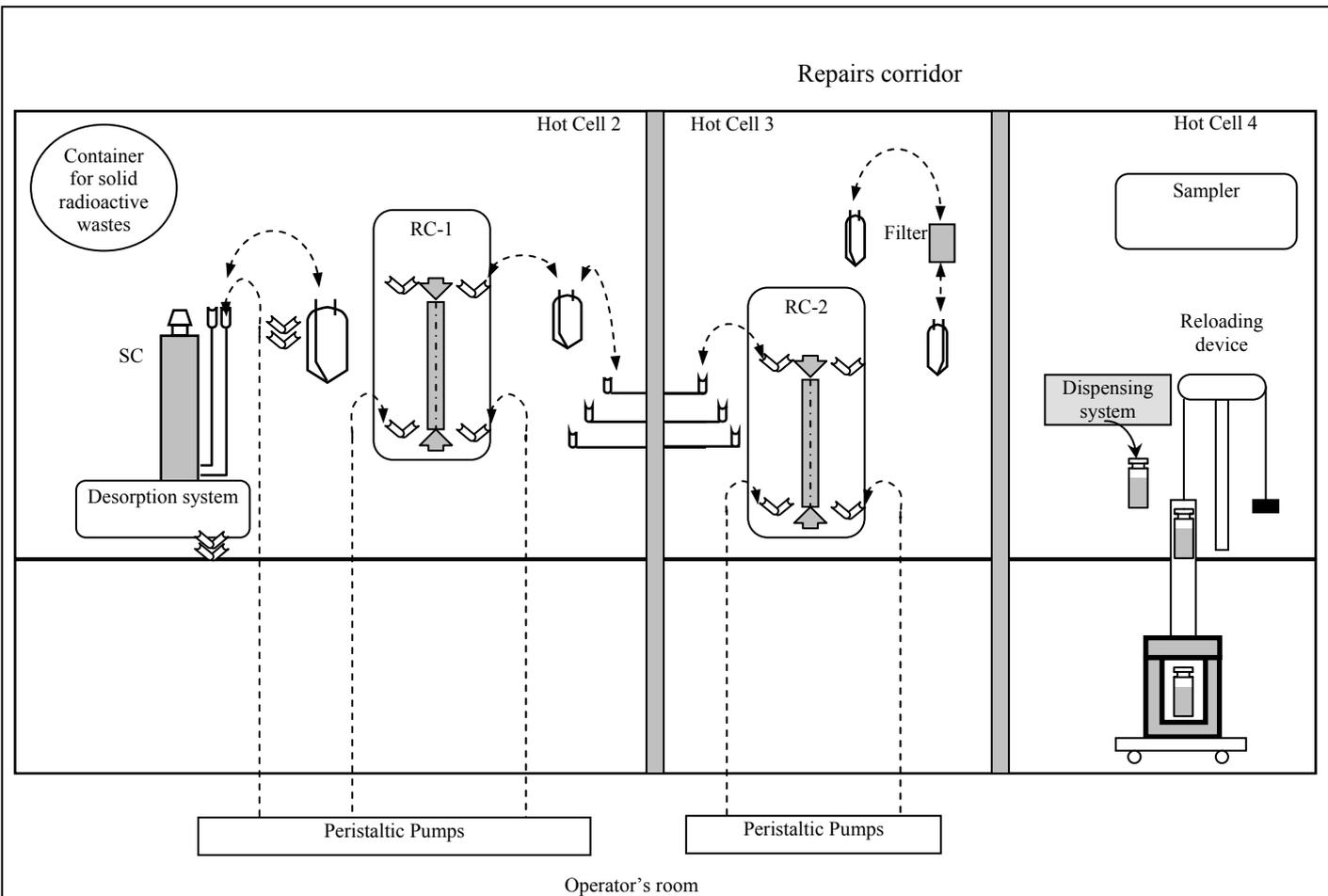


Fig. 2. Layout of technological equipment in Hot Cells 2, 3 and 4.

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5. Radioactive wastes.

5.1. Liquid and solid radioactive wastes are generated during recovery of ^{99}Mo . The data on the types and quantity of the wastes per 10 cycles of ^{99}Mo recovery are summarized in the Table below:

	Types of wastes	Quantity (per 10 cycles)
1.	Solid wastes:	
	Sorbent T-52	3000 g
	Sorbent T-5M	350 g
	Refining columns, chemical utensils, etc.	1000 g
2.	Liquid wastes	
	Washing solutions	81 l
	Decontamination solutions	100 l

5.2. Solid wastes are collected in the temporary storage containers. Glass utensils are usually broken to minimize the volume of the wastes. The wastes are utilized in accordance with the Main Sanitary Regulations for Radiation Wastes Management.

5.3. Liquid wastes are collected in the temporary storage tanks. After radioactivity decay liquid wastes are treated in accordance with the Main Sanitary Regulations for Radiation Wastes Management.

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Russian Research Center "Kurchatov Institute"

Preliminary Engineering Design

REACTOR FACILITY MIPS-100

Design Requirements Document

(item K-18a, Master Contract # DE-AC01-00NN40184
Modification "C and/or 3" to # DE-AT01-00NN40184)

Project Manager



V. Ye. Khvostionov

Technical Director

V. A. Pavshook

Coordinated
From RRC "Kurchatov Institute"



B. S. Stepennov

Moscow 2004

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LIST OF ABBREVIATIONS

ACI Access Control Instrumentation
ARS Automatic Regulation System of the Core Power
ASS Alarm Signal System signaling about SCR
C-WP Compensating Working Part
CPS Control and Protection System
CPS PL Control and Protection System of Process Loop
CPS WP Control and Protection System Working Part
CRS Catalytic Recombination System of radiolysis products
EP Emergency Protection
EP WP Emergency Protection Working Part
FLD Fuel Loading Device
HP Hydraulic Path of process loop
IGPS Information Gathering and Providing System
IID Intervention Indication Device
IRG Inert Radioactive Gases
KGP Key Gage Point
MBZ Materials Balance Zone
MIPS Medical Isotope Production System
MW Maintenance Works
NM Nuclear Material
NMCh Nuclear Measuring Channel
OGS Off-Gas System
OSPORB (PSRRS) Principal Sanitary Regulations of Radiation Safety
PB Process Box
PBYA (NSR) Nuclear Safety Rules
PL Process Loop for molybdenum-99 extraction
PUE (REIC) Rules of Electrical Installations Construction
RCS Reactor Cooling System
RD Reload Device for the column with sorbent
RMS Radiation Monitoring System
RR Research Reactor
RW Radioactive Waste
SCR Self-Sustaining Chain Reaction
SNS Start-up Neutron Source
STSF System for Temporary Storage of Spent Fuel
TPC Transport Packing Complex

1 GENERAL PROVISIONS

1.1 The basis of the Design Requirements Document of the Preliminary Engineering Design of the reactor MIPS-100 with the loop for molybdenum-99 extraction is Master Contract # DE-AC01-00NN40184 Modification "C and/or 3" # DE-AT01-00NN40184 between RRC "Kurchatov Institute" and US Department of Energy.

1.2 Design requirements documents to the following new components, devices and equipment form an essential constituent part of the present design requirements document:

- electromechanical drive for CPS C and EP working parts;
- nuclear measuring channel;
- transport packing complex for fresh fuel;
- transport packing complex for the column with sorbent;
- system for temporary storage of spent fuel.

1.3 Technical requirements and design of the reactor facility must be developed considering requirements of general industrial normative documents as well as special rules and norms in force in Russian Federation. The list of special normative documents is presented in Appendix A.

1.4 The content, order of structure, presentation and formalization of the present design requirements document meets recommendations branch standard OST 95 18-2001 "Order of research and development work. General provisions."

Techniques of reactor and its elements are patented (Appendix B). These techniques are not included in the present Design Requirements Document.

1.5 It is permissible to add modifications to the design requirements document at all the milestones and stages of development. Modifications are legalized so as the design requirements in compliance with branch standard OST 95 18-2001.

1.6 The design requirements document takes into account a high level of inherent safety of the reactor facility caused by the following physical & engineering peculiarities:

- negative coefficient of reactivity in all the power range;
- high storage capacity of water making part of fuel of the cores;
- low fuel rating of the core (the fuel maximal temperature does not exceed 100°C);
- passive means of heat removal by natural processes in case of failure of the system removing heat from the core;
- passive means of maintaining a safe (non-explosive) hydrogen concentration in the reactor facility systems in all the power range and after the reactor shutdown;

- low neutron fluence on the reactor vessel excluding radiation embitterment during all the operation period;
- selecting capacity of the fuel solution: it is only inert gases (IRG) mainly xenon and krypton fission products that go out to the environment (when IRG come to the environment, it is only external irradiation that causes radiation hazard).
- limiting resource and rate of the start reactivity input by working parts regulating the reactor in case of operation failure.

The principle point for inherent safety of the reactor facility is choice of fuel: uranyl sulfate aqueous solution with the optimal uranium-235 concentration.

2 DESIGN GOAL AND PURPOSE

2.1 The goal of work is to develop the Preliminary Engineering Design of the reactor MIPS-100 with the loop for molybdenum-99 extraction basing on the present design requirements document.

2.2. The reactor facility MIPS-100 and the process loop purpose is to operate as a part of the nuclear-technological complex for molybdenum-99 production.

2.3 A concept of a two-core reactor facility created on the basis of the “Argus” reactor with each core power no less than 50 kW is used for developing the Preliminary Engineering Design of the reactor MIPS-100 with the process loop.

2.4 Some components of the reactor facility must be developed considering the core operation at power up to 100 kW. Such components are:

- secondary coolant loop;
- gas localization system;
- fuel solution loading device;
- components mentioned in item 1.2;
- process loop.

3 DESIGN SOURCES

3.1 The design prototype is the created at RRC “Kurchatov Institute” nuclear-technological complex for molybdenum-99 production based on the “Argus” reactor with power 20 kW and the process loop.

3.2 Design-experimental studies within the framework of Master Contract # DE-AC01-00NN40184 Modification "C and/or 3" to DE-AT01-00NN40184 substantiate the present Preliminary Engineering Design.

4 TECHNICAL REQUIREMENTS

4.1 Configuration of the Design Reactor MIPS-100 and the Process Loop

4.1.1 As the reactor facility has two-core configuration, each core must contain:

- a core vessel with fuel solution in a reflector;
- a catalytic recombination system of radiolysis products;
- a control and protection system.

4.1.2 Two cores of the reactor have common systems:

- a cooling system;
- an off-gas system;
- a fuel loading device;
- a system for temporary storage of spent fuel;
- a transport packing complex for "fresh" fuel;
- a process loop;
- a transport packing complex for the column with sorbent;
- a radiation monitoring system;
- a control panel of the reactor and loop;
- a power supply system;
- a ventilation system;
- a reserve control unit.

4.2. Purpose and Technical Indices

4.2.1 The design system will make possible a safe, cheap and efficient production of the medical radionuclide molybdenum-99. The final product will completely meet international specifications.

4.2.2 The design system will increase uranium-235 utilization practically up to 100% at the reactor power ~100 times lower than in the traditional target technology.

4.2.3 Choice of the solution reactor type does not only give a principle possibility to produce molybdenum-99 directly from the core fuel but also it makes the whole technological process of the final product production nuclear and radiation safe due to inherent safety proper to solution reactors.

4.2.4 The capacity requirement of molybdenum-99 production and the economic factor make it expedient to accept a module principle of the nuclear–technological complex for final product production. The module power in fuel solution must be 100 kW; to expand molybdenum production, it will be necessary to increase quantity of modules and capability of the hot cell of the production complex.

4.2.5 The reactor facility must have two solution cores with the rated power no less than 50 kW to conserve the passive principle of safety: intrinsic properties of self-protection (inherent safety) and natural processes that prevent accidents because of possible failures of equipment or (and) personnel.

4.3 Reliability Requirements

4.3.1 The specified lifetime of the reactor MIPS-100 and the process loop must be no less than 30 years.

4.3.2 The mean-time-between-failures must be a year.

4.3.3 The mean time of repair must be 24 hours.

4.3.4 The available statistic information must be used to determine reliability indices.

4.3.5 It must be feasible to replace the reactor equipment that has a less lifetime than the specified lifetime of the reactor.

4.3.6 It is possible to prolong the specified lifetime. The possibility of such a prolongation must be substantiated according to the regulations “Requirements to substantiation of the possibility of prolonging the specified lifetime of nuclear power objects NP-024-2000”.

4.3.7 Risk of possible disturbances of the reactor operation leading to radioactive products output to the environment exceeding permissible norms must be no more than 10^{-7} reactor-year.

4.4 Ergonomic and Technical Aesthetics Requirements

4.4.1 Modern achievements in the field of industrial design must be taken into account when choosing the control panel and instrument board design, interior, decoration etc.

4.4.2 Mean anthropometrical men sizes must be accepted to determine sizes for instruments location and working places organization.

4.4.3 The working places of the shift personnel must be organized so that eye and body muscle fatigability would be minimized during the shift time.

4.4.4 Depending on functions the following points are necessary:

- control parts, instruments, signalization elements must be located on the control panel;
- alarm, warning, indicating signals must have different colors, as well as switched on and off, open and shut conditions of equipment controlled by the Alarm System and the Information Gathering and Providing System (IGPS) must differ in colors.

4.4.5 The reactor equipment must have a marking.

4.4.6 Rooms of different classes (according to the classification of Principal Sanitary Regulations of Radiation Safety) of working areas must have different colors.

4.5 Technical Requirements to the Components of the Reactor MIPS-100 with the Process Loop

4.5.1 Technical requirements to the core vessel with the fuel solution and the reflector.

4.5.1.1 Aqueous uranyl sulfate solution must be used as nuclear fuel; enrichment by the isotope uranium-235 must be less than 20%.

Initial quantity of impurities in the fuel must not exceed the following values.

Li – 50ppm*	Co – 10ppm
C – 170ppm	Mg – 100ppm
Al – 100ppm	K – 10ppm
Fe – 300ppm	In – 100ppm
Ni – 300ppm	Ca – 100ppm
Cr – 100ppm	V – 100ppm
Ti – 100ppm	N – 30ppm
Ba – 100ppm	B – 1ppm
Be – 0.1ppm	W – 300ppm
	Cl – 1ppm

* -parts per million parts of uranium by weight.

4.5.1.2 Such uranium-235 concentration in the solution must be chosen that would provide for the minimal critical mass for the present reactor design; it helps to maintain nuclear safety in case of possible change of uranium concentration.

4.5.1.3 The solution acidity (pH) must be equal to $1 \pm 0,1$ what facilitates compatibility of the solution and the core vessel material and chemical stability of the solution.

4.5.1.4 The fuel solution must have the following parameters during the reactor facility operation:

- | | |
|---|-----------------------|
| - temperature, °C | 18...90 |
| - pressure above the solution, kg/cm ² | minus 0.6...minus 0.1 |

4.5.1.5 Quantity of fuel solution (start working load) must ensure:

- compensation of the negative temperature effect of reactivity ($5.1 \cdot 10^{-2} \beta_{\text{eff}} / ^\circ\text{C}$);
- compensation of the negative power (stationary void) effect of reactivity ($1.4 \cdot 10^{-2} \beta_{\text{eff}} / \text{kW}$);
- campaign of the reactor facility considering possible absorption of uranium with the sorbent (~0.4 grams a process cycle) without reloading work within 5-10 years).

4.5.1.6 The aqueous uranyl sulfate solution must be located in the vessel.

4.5.1.7 The core vessel must be a cylindrical container with a semispherical bottom and welded cover and it must have the following main dimensions:

- | | |
|-----------------------------|-----|
| - inner diameter, mm | 305 |
| - height, mm | 700 |
| - thickness of the wall, mm | 5 |

4.5.1.8 Strength analysis of the vessel and its units must be performed in accordance with the standard strength analysis of equipment and pipelines of atomic power plants. Results of the analysis must be proved by hydraulic tests. The tests must be conducted in compliance with regulations of the design and safe operation of equipment and pipes of atomic power plants.

4.5.1.9. There must be located inside the vessel:

- three blind vertical channels with the inner diameter 44 mm and the wall thickness 2 mm. One central channel must be located along the vessel axis. Two other channels must be located in one plane at the distance of 75 mm from the vessel axis. All the channels must be as deep as possible in the fuel solution;
- a coil heat exchanger;
- a unit of three chromel-copel thermocouples in a sealed case;
- a nipple to pour fuel solution out of the vessel.

4.5.1.10 The vessel cover must have connecting pipes (flanges) to connect:

- a catalytic recombination system of radiolysis products;
- pipelines of the cooling system and the coil;
- a pipeline connecting the vessel and the reservoirs of the off-gas system and vacuum pressure gage controlling pressure in free volume of the vessel;
- an intake-outtake unit for the solution circulating in the hydraulic path of process loop;

- a solution intake-outtake system.

The vessel and the pipelines of the cooling system must have a “ball-and-cone” connection.

4.5.1.11 The vessel must have a unified construction with the vertical channels, the coil, the nipple for pouring off solution from the vessel.

4.5.1.12 The thermocouples unit case must be situated in the central part of the core.

4.5.1.13 The solution intake-outtake unit design and intake-outtake nipples location must:

- exclude the possibility of the solution backflow in case of the process loop pump reverse;
- provide for the minimal mixing of taken in and poured off solution;
- with help of the intake nipple depth, provide for the minimal loss of the solution from the core if equipment sealing fails and the process loop pump continues operating. At the same time the nipple depth must enable the solution pumping without a stream break.

4.5.1.14 The vessel and the units contacting the fuel solution must be made of stainless steel grade 08X18H10T (0X18H10T) to make the fuel solution compatible with the vessel material.

4.5.1.15 The core vessel with a satisfactory sealing must correspond to the second seal class OST 5.0170-81.

4.5.1.16 Special requirements to the welds.

4.5.1.16.1 The welds must be butt-welded joints.

4.5.1.16.2 The butt-welded joints must have a complete fusion penetration.

4.5.1.16.3 Argon-arc welding and feed of inner cavities with argon is allowed.

Welding must be conducted with the electrode EA400/10U with the filler wire 04H19N11M3.

4.5.1.16.4 To meet control rules of welding and fusing of atomic power plants equipment PNAEG-7-010-89, quality control of welds (joints) must include:

- external examination;
- radiography;
- hydraulic tests;
- vacuum-tightness tests are conducted with helium, permissible leakage is no more than $1.3 \cdot 10^{-9} \text{ m}^3 \text{ Pa/s}$ ($1 \cdot 10^{-5} \text{ l } \mu\text{m/s}$);
- metallographic studies;
- tests of intergranular corrosion susceptibility.

4.5.1.16.5 One repair of the weld is permitted; it must be under complete control further (according to item 4.5.1.16.4).

4.5.1.16.6 The present requirements must be applied to the welds of the pipelines and the reactor equipment of stainless steel.

4.5.1.17 The vessel with the fuel solution must be located inside the graphite reflector along its central axis and be fastened vertically.

4.5.1.18 The reactor graphite made according to technical requirements TU 48-20-83-76 must be used as the reflector.

4.5.1.19 The bottom and side reflector must be no less than 450 mm thick, the reflector must be as high as the cylindrical part of the core vessel.

4.5.1.20 The reflector must consist of graphite blocks and units of typical design. The graphite blocks must have through holes for samples irradiation channels, the start-up neutron source and thermocouples. The blocks must have corresponding plugs.

4.5.1.21 The reflector blocks must have reliable joints and systems for the temperature broadening compensation.

4.5.1.22 Places of the irradiation channels, the neutron source and the thermocouples location must be chosen during the reactor development.

4.5.1.23 The reflector must be placed in a pan of stainless steel to localize the solution in case of the vessel sealing failure. The pan sizes must prevent a local critical mass appearance according to the nuclear safety rules.

4.5.1.24 The reflector design must include devices for natural convection to improve the graphite blocks cooling and limit the neutron exit out of the reflector.

4.5.1.25 There must be channels for detectors of CPS nuclear measuring channels location installed outside the reflector opposite the start-up neutron source.

4.5.1.26 There must be a room (a reactor compartment) to place there the reactor cores. The compartment must have two sections.

4.5.1.26.1 Each section must have a platform with a vessel with the catalytic recombination system equipment in the graphite reflector. The section area is up to 4 m². The total height of the facility determines the height of the section.

4.5.1.26.2 Each section must have a removable ceiling biological shielding between the section and the reactor hall.

4.5.1.26.3 The biological shielding must be designed so that the neutron irradiation and the gamma dose rate would not exceed 6.0 μ Zv/h on its outer surface (bound with the rooms where people are constantly present) when the core operates at power up to 100 kW to meet requirements of Principal Sanitary Regulations of Radiation Safety OSPORB (PSRRS).

4.5.1.26.4 The ceiling shielding must consist of blocks. The block mass must not exceed 5 tons.

4.5.1.26.5 The ceiling shielding must have holes:

- for irradiation channels and channels for ionization chambers of CPS nuclear measuring channels. The channels must be provided with protective plugs. The channels including the channels in the walls and the plugs design must minimize the direct ionizing irradiation getting to the reactor hall and adjoining rooms;

- for fuel solution intake-outtake nipples to pour solution to the core vessel and to take it out. The nipples must have releasable connections and plugs inside the shielding.

4.5.1.26.6 There must be channels in the walls to locate pipelines connecting the cores and the hydraulic path of the process loop, the primary loop cooling equipment, the off-gas system and the reservoirs of the system for temporary storage of spent fuel, and the ventilation system air pipes.

4.5.1.26.7 The sections must be separated with a biological shielding. The shielding between the sections must allow human presence in the section for a limited time when the core is shutdown. Requirements to the human stay conditions must be specified during the reactor development.

4.5.1.26.8 The floor must be covered with a sheet stainless steel and the walls, with low-absorbing and easily decontaminatable materials in compliance with sanitary rules.

4.5.2 Requirements to the reactor cooling system (RCS).

4.5.2.1 The cooling system must remove heat from the cores when the reactor continuously operates at the rated power for a long period and maintain the solution temperature in each core no higher than 90°C.

4.5.2.2 The cooling system of the reactor MIPS-100 must have two coolant loops.

4.5.2.3 The coolant of the cooling system must be distilled water according to the State standard GOST 6709-72.

4.5.2.4 The pipelines and the equipment material contacting the coolant must be stainless steel grade 12X18H10T (except the coils located in the cores vessels).

4.5.2.5 The primary loop purpose must be to cool the fuel solution of the reactor's cores.

4.5.2.6 The primary loop must be closed. It must contain:

- cooling coils;
- a heat exchanger;
- a pump;
- a compensation tank.

4.5.2.7 The coils must be parallel in the primary loop to provide for independent cooling of the solution of each core. Technical measures must be provided to maintain the cooling parameters of one core if cooling of the other core stops.

4.5.2.8 The direction of the coolant movement must coincide with the direction of the gravitation force to meet requirements of nuclear safety rules.

4.5.2.9 It must be a tube-type heat exchanger. The coolant of the primary loop must run in tubes; water of the secondary loop must run in the tube space. The water flow must run in opposite directions to make the cooling process more effective.

4.5.2.10 The heat-exchange surface of the heat-exchanger must remove heat corresponding to the reactor power no less than 100 kW.

4.5.2.11 The pump must provide for the coolant flow rate $6 \text{ m}^3/\text{h}$. A reserve pump must be available.

4.5.2.12 The reactor control panel must be used to control the pumps. There must be provided signaling about the pumps operation (on/off).

4.5.2.13 The pumps must be equipped with necessary measuring instruments to monitor their operation.

4.5.2.14 The compensation tank must provide for necessary reserve of the coolant and compensation of the coolant thermal broadening. The necessary reserve of the coolant considering periodical addition of water to the loop must be determined during the design development.

4.5.2.15 The compensation tank must have two level-signaling devices indicating the rated and the minimal levels to control water presence in the loop including leakages and unexpected drainage of the coolant. If water is on the minimal level the pumps must be disconnected.

4.5.2.16 The water pipelines connection with the tank must provide that air and gaseous products of water radiolysis get to the free volume of the tank.

4.5.2.17 The tank must have connecting pipes to pour water out of the tank and add water to the primary loop as well as to connect the free volume of the tank and atmosphere.

4.5.2.18 The loop must have connecting pipes for bleeding air when it is filled with water.

4.5.2.19 To monitor operation, the primary loop must be equipped with instruments for measuring:

- coolant flow rate;
- temperature of the coolant at the entrance and exit of the coils;
- the minimal and rated levels of the coolant in the compensation tanks.

4.5.2.20 Information about the coolant flow rates, temperatures and levels must be given to the reactor control panel (IGPS).

4.5.2.21 The cooling system must enable that the coolant would be periodically replaced and the loop would be completely emptied removing water.

4.5.2.22 The coolant must be poured off and if necessary kept in a container (reservoir) with a sufficient volume for complete evacuation of water out of the primary loop of the reactor.

4.5.2.23 The coolant must be poured out of RCS to the container due to pressure difference.

4.5.2.24 The free volume of the reservoir must be connected to the off-gas system to make a preliminary underpressure. A vacuum pressure gage with the measuring range minus 1...1.5 kg/cm² and accuracy 1.5 must be provided to monitor underpressure in the free volume. Manually controlled stop valves must be installed in the supply pipelines.

4.5.2.25 There must be a filter in the unloading pipeline out of the RCS to the reservoir to accumulate possible mechanical products of corrosion. The reservoir must have a manifold and manually controlled stop valves to drain water.

4.5.2.26 It must be possible to decontaminate the inner surface of the reservoir with acid and alkaline solutions.

4.5.2.27 The secondary loop purpose must be to cool the coolant of the primary loop, to cool the gas-vapor mixture in CRS as well as to cool RCS pumps that need a forced cooling.

4.5.2.28 The secondary loop must be closed and it must include:

- A heat exchanger of the RCS primary loop;
- A CRS heat exchanger;
- A pump;
- A compensation tank;
- A cooling unit.

4.5.2.29 The pump must provide for the coolant flow rate no less than 12 m³/h. A reserve pump must be available.

4.5.2.30 The secondary loop must meet requirements analogous to ones mentioned in items 4.5.2.11...4.5.2.21.

4.5.2.31 The cooling unit must cool water of the secondary loop with air and decrease the water temperature down to 20°C.

4.5.2.32 It is from the control panel that they put on and control the cooling unit, give signals about its operation. The unit must be quipped with necessary for its operation monitoring and measuring instruments.

4.5.2.33 Air must be taken for cooling and get to the atmosphere. The taken air must be purified from mechanical impurities.

4.5.2.34 Refrigerating mediums used in the cooling unit should be environmentally benign.

4.5.2.35 They must meet the condition that the pressure from the secondary loop side would be higher than from the primary loop side in the heat exchanger.

4.5.2.36 RCS equipment that requires periodical maintenance and operations for preparing and turning on must be located in the service area.

4.5.2.37 Stop valves must be provided for RCS operation including measures of maintenance. The spectrum of the stop valves must be chosen during the design development.

4.5.2.38 Equipment of the primary and the secondary cooling loops must be placed in one room.

4.5.2.39 The room building structures must divide location areas of the primary and the secondary cooling loops equipment to decrease the personnel exposure to radiation.

4.5.2.40 There must be pans of stainless steel provided to localize possible leakages of the coolant.

4.5.2.41 The RCS room must be classified as a room of temporary presence of personnel in compliance with OSPORB (PSRRS) classification of the room purposes.

4.5.2.42 According to the sanitary rules requirements, the floor and the walls must be covered with low-absorbing and easily decontaminatable materials. The room floor must be moistureproof.

4.5.3 Catalytic regeneration system of radiolysis products (CRS)

4.5.3.1 Each core of the reactor must have its own CRS.

4.5.3.2 CRS must recombine radiolytic gases oxygen and hydrogen that appear in the fuel solution when the core operates at power. It must provide for a not above 3% volumetric concentration of hydrogen in the core vessel and in CRS itself before the entrance to the recombiner.

4.5.3.3 Gaseous products of water radiolysis together with water vapor, air and radioactive inert gases must be continuously pumped through the catalyst by natural circulation.

4.5.3.4 CRS must include:

- a recombiner;
- an electric heating unit;
- a heat exchanger with a water accumulator;
- pipelines.

4.5.3.5 CRS together with the reactor vessel must form a sealed closed loop. The sealing must correspond to the second seal class OST 5.0170-81.

4.5.3.6 CRS loop parts must have hydraulic loss factors as minimal as possible.

4.5.3.7 The structural elements and the pipelines must be made of the stainless steel 08X18H10T (12X18H10T).

4.5.3.8 The recombiner must contain three cassettes with catalyst installed one over another.

4.5.3.9 The catalyst must be ceramic pins covered with platinum black. The pin diameter is 0.54 mm, its length is 62 mm.

4.5.3.10 The pins must be located as equilateral triangle along the gas-vapor mixture flow in the cassettes. One cassette contains ~ 1000 pins.

4.5.3.11 Gas-vapor mixture temperature must not exceed 400°C at the exit from the recombiner. There must be a fitting with three Chromel-Copel thermocouples in a sealed case to monitor the temperature. The readings of the thermocouples (one working and two reserve thermocouples) must be given to the reactor control panel (IGPS).

4.5.3.12 Connecting pipes must be provided to connect supply pipelines of the gas analyzer to calibrate the thermocouples depending on hydrogen concentration. It is necessary to enable gas sampling from the areas before and after the recombiner and samples' returning to the part after the heat exchanger.

4.5.3.13 The electric heating unit is intended for preliminary heating of gas-vapor mixture during CRS preparation for operation. It must be installed before the recombiner.

4.5.3.14 The electric heating unit must have two electric heating cells (one working and the other reserve); each cell of 1 kW power.

4.5.3.15 The electric heating cells must be separated with a thermal cell of aluminum from the gas-vapor medium. Heat will be transferred from the electric heater through aluminum to gas.

4.5.3.16 The electric heating unit must make the temperature 120...150°C on the surface of the thermal cell. The maximal temperature does not exceed 300°C. The electric heater power (voltage) change must cause temperature change. The working voltage must be chosen at the stage of CRS tests.

4.5.3.17 The electric heaters operation must be controlled and their condition (on/off) must be signaled at the reactor control panel.

4.5.3.18 Water of the secondary loop must cool air-vapor mixture in the heat exchanger after the recombiner.

4.5.3.19 There must be a 2 l condensed water accumulator after the heat exchanger. The rest of water must flow by gravity to the core. The accumulator must have a connecting pipe to connect with help of a supply pipeline to the hydraulic path of the process loop.

4.5.3.20 The recombiner body and the pipeline lifting part must have heat insulation in order to maintain a preset temperature difference.

4.5.3.21 CRS equipment and pipelines must be well fastened and have temperature movements self-compensation devices.

4.5.4 Control and protection system (CPS)

4.5.4.1 To meet requirements to RR control and protection system purpose and configuration of “PBYA IR (NSR RR) Nuclear Safety Rules of Research Reactors”, CPS of each core must:

- control the core power (intensity of the nuclear chain reaction);
- control power with CPS working parts;
- realize planned and emergency shutdown of the core;
- control the core process equipment and its operational parameters.

4.5.4.2 CPS must have:

- CPS working parts and a start-up neutron source with electromechanical drives;
- Nuclear measuring channels for monitoring, protection and regulation;
- Automatic regulation system of the reactor power;
- Emergency protection subsystem;
- Control and monitoring subsystem;
- Signaling subsystem;
- Information gathering and providing system;
- Power supply subsystem.

4.5.4.3 CPS working parts (CPS WP) and start-up neutron source (SNS)

4.5.4.3.1 CPS working parts (EP and C-WP) must be placed in the channels of the core vessel.

4.5.4.3.2 EP WP physically must be boron carbide bushes in steel claddings, boron carbide density not lower than 1.3 g/cm^3 .

4.5.4.3.3 To meet PBYA IR (NSR RR) requirements, EP working part efficiency must not exceed $1 \beta_{\text{ef}}$ when C-WP placed in the integrated channel is loaded to the core. As C-WP is being removed, EP WP efficiency grows and reaches its maximum when C-WP is out of the core. The total efficiency of EP WP must be not less than $10 \beta_{\text{ef}}$ in order to bring the core to the subcritical condition when alarm signals require emergency shutdown.

4.5.4.3.4 Compensating working parts must be made of boron carbide with density not less than 1.3 g/cm^3 in the steel cladding. C-WP must be placed in the inner cavity of EP WP. To

meet requirements of normative documents on RR nuclear safety, C-WP efficiency must compensate the core reactivity margin and maintain the core in the safe subcritical condition (the effective neutron multiplication factor must not exceed 0.99 after EP WP lifting). C-WP as well as EP WP must be introduced into the core when shutdown signals appear.

4.5.4.3.5 CPS WP must be as long (high) as the core vessel.

4.5.4.3.6 EP and C-WP design must make their movement independent and minimize the jamming probability.

4.5.4.3.7 In compliance with requirements of “Rules of Structure and Safe Operation of Executive Mechanisms of Devices Effecting Reactivity PNAEG-7-013-89”, CPS WP must have end switches of the lower position, which must operate directly from the working parts (control over rope gear operation).

4.5.4.3.8 CPS WP must be moved with help of an electromechanical drive of CPS working parts of the reactor MIPS-100 (see “Electromechanical Drive for Control and Protection System Working Part of MIPS-100 Reactor. Design Requirements Document”).

4.5.4.3.9 Each working part must have its own drive to meet PBYA IR (NSR RR) requirements of minimizing independent quantity of CPS executive mechanisms.

4.5.4.3.10 The start-up neutron source (SNS) intensity must be enough to control the core in the subcritical state.

4.5.4.3.11 SNS must be installed in the reflector channel. The lower (effective) position of the start-up neutron source must be on the border between the cylindrical and semispherical parts of the vessel.

4.5.4.3.12 SNS must be placed in a container of aluminum alloy.

4.5.4.3.13 An electric drive analogous to the CPS WP drive must move SNS (as high as the core vessel). SNS free fall must be excluded in case of the electric drive de-energization.

4.5.4.3.14 A rope gear must connect CPS WP and SNS and their drives.

4.5.4.3.15 The drives must be controlled at the control panel of the core.

4.5.4.3.16 The following electrical engineering equipment of each drive must be connected to the electric circuits of the control panel:

- end switches corresponding to the WP and SNS upper and lower positions;
- magnetic solid coupling
- electric motor;
- potentiometric position pickup (only for C-WP);
- end switches working directly from CPS WP.

4.5.4.3.17 CPS WP drives location must enable their maintenance.

4.5.4.4 Nuclear measuring channels of monitoring and protection (NMCh)

4.5.4.4.1 NMCh must provide for power monitoring (neutron flux density) and its change rate and the core protection by power level and power increase rate. According to PBYA IR (NSR RR) recommendations, monitoring and protection functions are combined in one channel.

4.5.4.4.2 Three NMCh must be used for monitoring and protection. Though not less than two channels are necessary three channels are used to enable the core operation at power when one of the channels is under maintenance.

4.5.4.4.3 A nuclear measuring channel of the MIPS-100 reactor must be used as NMCh (see “Nuclear Measuring Channel of MIPS-100 Reactor. Design Requirements Document.”).

4.5.4.4.4 To measure neutron flux density in all the range of power change from the rated value to 120%, NMCh neutron flux detectors must be installed in a position that would enable neutron flux density measuring in the range from the subcritical level to the level corresponding to 120 kW power of the core. The detectors must be placed opposite the start-up neutron source.

4.5.4.4.5 There must be devices to fix the detectors in an established position and to conduct detectors’ replacement and maintenance from the service area.

4.5.4.4.6 Each NMCh must have indicators to measure the reduced neutron flux density and its change rate. Signals proportional to the neutron flux density and its change rate must also be given to IGPS.

4.5.4.4.7 The following signals must come from NMCh to CPS electric circuits:

- amount to the power setting 120% from the preset value;
- amount to the power setting 110% from the preset value;
- amount to the power increase rate setting (acceleration period) 10 s;
- amount to the power increase rate setting (acceleration period) 20 s;
- inactive or faulty condition of NMCh.

4.5.4.4.8 To meet requirements of nuclear safety rules permitting combination of monitor and protection functions in one channel, connection of external devices and electric circuits to NMCh must not effect NMCh operation and violate conditions of NMCh protective functioning.

4.5.4.5 Automatic regulation system of the core power (ARS)

4.5.4.5.1 Nuclear safety rules of RR require that the core must be equipped with an automatic regulation system of the core power. The core ARS must automatically bring the core out of the subcritical state to the rated power level with a preset acceleration period and then maintain this level.

4.5.4.5.2 ARS must provide for the following parameters of the core automatic start-up:

- acceleration period, s not less than 20;
- power level, kW up to 100.

4.5.4.5.3 ARS must include:

- NMCh of MIPS-100 reactor;
- Power amplifier;
- One of C-WP with a drive.

4.5.4.5.4 Technical requirements to the power amplifier are presented in “Nuclear Measuring Channel of MIPS-100 Reactor. Design Requirements Document.”

4.5.4.5.5 Requirements to the detector location conditions are analogous to requirements mentioned for the detectors of NMCh of monitoring and protection.

4.5.4.5.6 ARS must be switched on with help of switching equipment at the control panel meeting at least the following conditions:

- NMCh is in active state;
- EP WP are up in active state.

If these conditions are violated the core control must automatically be turned to the manual mode.

4.5.4.5.7 A “waiting” mode (temporary disconnection of ARS) must be available considering self-regulation properties of the core operating at the rated power. If the power changes by $\pm 5\%$ from the preset value ARS must automatically switch on the power regulation mode. The operator must initiate switching ARS to the “waiting” mode.

4.5.4.5.8 To increase the automation level, when C-WP equipped in ARS gets to the upper (lower) position the other C-WP must automatically lift (sink) by one step and stop. By this, compensating introduced reactivity ARS returns the equipped in the automatic regulation system C-WP to the core. SNS must be automatically removed from its effective position at the power level corresponding to ARS NMCh current 10^{-9} A.

4.5.4.5.9 The electric drive must be disconnected from ARS when C-WP gets to the end switcher of the lower or upper position.

4.5.4.6 Emergency protection subsystem

4.5.4.6.1 EP subsystem must enable that the core is automatically shutdown and brought to the subcritical state by way of de-energizing magnetic solid couplings (MSC) of CPS WP drives (when magnetic solid couplings are de-energized CPS WP fall by their own gravity from any intermediate position to the core) when any alarm signal is received.

4.5.4.6.2 EP subsystem must have EP WP as executive parts.

4.5.4.6.3 In compliance with the list of signals of RR emergency protection subsystem necessary automatic response and settings of EP operation (response), the core EP subsystem must automatically operate in the following cases:

- The emergency setting of power level (120% from the preset value) is simultaneously reached in two of three NMCh of monitoring and protection;

- The emergency setting of reactor acceleration period (10 s) is simultaneously reached in two of three NMCh of monitoring and protection;
- two of three NMCh of monitoring and protection are simultaneously in a failed state;
- voltage in CPS power supply line fails.

It must be possible to switch on the EP subsystem by pushing the buttons. The buttons must be placed on the core control panel and in the room of the reserve control post as well as close to the fuel loading device during the core physical start-up.

4.5.4.6.4 According to Nuclear Safety Rules of RR, EP subsystem must produce a “blocking” signal inhibiting CPS WP removal from the core in the following cases:

- the warning setting of power level (110%) is simultaneously reached in two of three NMCh of monitoring and protection;
- the warning setting of acceleration period (20 s) is simultaneously reached in two of three NMCh of monitoring and protection;
- the pressure in the core vessel is higher than normal one (more than 10%);
- the pressure in the off-gas system reservoirs is higher than normal one;
- the experimental loop is operating.

It is allowed to block protection signals by power level and acceleration period at power levels lower than 1% and 10^{-3} % from the rated power correspondingly.

4.5.4.6.5 To meet PBYA IR (NSR RR) requirements to RR EP system, the core EP subsystem must have:

- tests of alarm signals production;
- continuous diagnostics of EP subsystem’s circuits operability and control over their operable condition;
- it must be only after normalizing the parameter causing EP subsystem response and further effecting the controller that EP subsystem must be brought to the operating state after response.

4.5.4.7 Control and monitoring subsystem

4.5.4.7.1 The control and monitoring subsystem must:

- indicate current values of the core power and acceleration period;
- control SNS and CPS working parts and monitor their position;
- control the core process equipment and monitor its operation;
- monitor process parameters of the core.

4.5.4.7.2 Four NMCh with help of indicating instruments must indicate current values of power and acceleration period of the core.

4.5.4.7.3 The power monitoring instruments must have a scale calibrated in units of the detector's current in logarithmic scale. The instrument class must be not lower than 0.2 (reduced error must be not more than 0.2%). The measuring range must correspond to the NMCh output signal change range of the present parameter.

4.5.4.7.4 The power monitoring instruments must have threshold elements, which can be regulated in the measuring range.

4.5.4.7.5 The acceleration period monitoring instruments must have a scale calibrated in acceleration period units (seconds). The instrument class must be not lower than 0.2 (reduced error must be not more than 0.2%). The measuring range must correspond to the NMCh output signal change range of the present parameter.

4.5.4.7.6 To meet requirements of nuclear safety rules of RR to RR CPS WP monitoring, control conditions and algorithms, the control and monitoring subsystem must provide for the following algorithm of CPS WP movement:

- WP must be only removed from the core one after another and step by step (consecutive sequence): increase reactivity, automatically stop increasing reactivity and make a pause. The operator must initiate each step. Each step must introduce not more than $0.3 \beta_{ef}$. The positive reactivity introduction rate must not exceed $0.07 \beta_{ef}/s$;
- WP removal from the core must be fulfilled meeting necessary conditions;
- Magnetic solid couplings de-energization must introduce EP WP into the core; Whether the motor or MSC de-energization must introduce C-WP.

4.5.4.7.7 Conditions for lifting EP WP to the working position must be at least as follows:

- there are no alarm or warning signals;
- C-WP are in the extreme lower positions in the core;
- SNS is in the effective position.

4.5.4.7.8 Conditions for lifting C-WP must be at least as follows:

- there are no alarm or warning signals;
- EP WP are up in the working position;
- C-WP positions indicators are in operable state.

4.5.4.7.9 Monitoring of the following positions of CPS WP must be provided:

- extreme positions of CPS WP;
- intermediate positions of C-WP.

4.5.4.7.10 Monitoring of the extreme positions must be provided in case of voltage failure of the external sources of power supply. The extreme positions sensors must be end switches in the drives and end switches responding directly the working part.

4.5.4.7.11 The position indicators (position pickups) must have a scale calibrated in mm. The reduced error of the device must not exceed 1%. The position indicators must include threshold elements, which can be regulated in the measuring range. The intermediate position sensors must be potentiometric sensors in the drives.

4.5.4.7.12 SNS must be controlled by way of one click on the buttons and also automatically when the signal comes from ARS to lift the neutron source.

4.5.4.7.13 SNS extreme positions must be monitored when the end switches in the drive operate.

4.5.4.7.14 SNS and CPS WP control, their position monitoring must be at the control panel. SNS and CPS WP position monitoring and control of their introduction to the core must be in the reserve control post room too.

4.5.4.7.15 The control and monitoring subsystem must control the following process equipment and monitor its operation:

- Pumps (main and reserve ones) and RCS heat exchanger;
- CRS electric heaters;
- Stop valves with electromechanical drives connecting the core with the common systems of the reactor facility.

4.5.4.7.16 Each pump must be switched on (off) with help of buttons.

4.5.4.7.17 It must be provided that each pump would be automatically switched off if the corresponding compensation tank has the minimal level.

4.5.4.7.18 The equipment control circuit must have necessary blockings to provide for safe operation of this equipment in compliance with normative-engineering and operational documents.

4.5.4.7.19 Signals about condition of each pump must belong to the indicating signalization of CPS as well as IGPS.

4.5.4.7.20 CRS heaters control circuits must enable switching on each heater with help of switching equipment.

4.5.4.7.21 Signals about condition of each heater must belong to the indicating signalization of CPS and IGPS.

4.5.4.7.22 Control over stop valves with electromechanical drives connecting the free volume of the present core vessel to the off-gas system reservoirs must be provided at the control panel of each core.

4.5.4.7.23 Signals about stop valves condition must belong to the indicating signals of CPS and IGPS.

4.5.4.7.24 The control and monitoring subsystem must monitor the following process parameters of the core (required ranges of measuring instruments are indicated in brackets):

- solution temperature (0...150°C);
- water temperature at the entrance and exit of RCS coil (0...100°C);
- water temperature at the entrance and exit of RCS heat exchanger and CRS heat exchanger (0...100°C);
- water temperature at the entrance and exit of the air-cooling system (0...100°C);
- gas temperature at the exit from CRS recombiner (0...400°C);
- reflector temperature (0...150°C);
- water flow rate through each coil (0...3 m³/h), RCS heat exchanger (0...16 m³/h) and CRS heat exchanger (0...2 m³/h);
- pressure in the free volume of the core vessel (minus 1...+1.5 kg/cm²);
- pressure in the off-gas system reservoirs (minus 1...1.5 kg/cm²);
- rated (corresponding to 2/3 of volume) and minimal (corresponding to 1/3 of volume) levels in RCS compensation tanks;
- hydrogen concentration (0...5%).

The monitoring measuring instruments must have the class not lower than 1.5 (reduced error not more than 1.5%); measuring ranges are chosen so that the limit value of the measured parameter would be in the second third part of the scale.

4.5.4.7.25 The monitoring measuring instruments must produce unified output signals. The signals must get to IGPS.

4.5.4.8 Signaling subsystem

4.5.4.8.1 In compliance with PBYA IR (NSR RR), the signaling subsystem must produce:

- alarm signals (light and sound);
- warning signals (light and sound);
- indicating signals (light);
- emergency signal siren.

4.5.4.8.2 The alarm signals must duplicate any alarm signal appearance (see item 4.5.4.6.3);

4.5.4.8.3 The warning signals must duplicate the “blocking” signals appearance (see item 4.5.4.6.4) and signals about faulty state of any of three channels of monitoring and protection.

4.5.4.8.4 The indicating signals must give information about voltage in electric circuits, connection and condition of the core equipment and devices. The concrete quantity of indicating signals must be determined at the designing stage.

4.5.4.8.5 When the alarm signal appears the corresponding indicator must light and be memorized. The light signal can only be removed by way of pushing a button after normalizing the parameter.

4.5.4.8.6 When the warning signal appears the corresponding indicator must light. The light signal must be removed automatically after normalizing the parameter.

4.5.4.8.7 The indicating signals light indicators must light at normal operation of the equipment.

4.5.4.8.8 A sound indicator must duplicate the alarm and warning signals. The alarm and warning sound signals must have different tonality; it must be possible to stop the sound.

4.5.4.8.9 It must be possible to prove sound and light signalization.

4.5.4.8.10 The emergency signal siren must announce emergency situations to the personnel.

4.5.4.8.11 The emergency signal siren must have a different tone quality in comparison with other sound signals, according to general provisions of research nuclear facilities safety.

4.5.4.8.12 The emergency signal siren must be switched on in the reactor control panel and the reserve control post rooms.

4.5.4.9 Device of logical processing of signals

4.5.4.9.1 The device must realize CPS logical schemes.

4.5.4.9.2 The device must:

- transform the input signals to a proper form for logical processing using elements of transistor-transistor logic and microprocessor technology;
- process the signals according to preset algorithms and produce control signals for executive devices;
- coordinate parameters of the control signals and parameters of the executive devices.

4.5.4.9.3 The device must have a standard embodiment.

4.5.4.9.4 There must be indicators signaling about the device operation on the faceplate of the device.

4.5.4.10 Information gathering and providing system (IGPS)

4.5.4.10.1 CPS of the core must have IGPS to meet recommendations of general provisions of research nuclear facilities safety to increase informational support of the operator. IGPS must receive analog and discrete signals from the CPS logical units and measuring

channels, monitoring measuring instruments of the process parameters and equipment and transform them to proper signals for information provision.

4.5.4.10.2 Information must be displayed.

4.5.4.10.3 The provided information must be divided in several information windows according to functional purpose.

4.5.4.10.4 Information windows must contain:

- symbolic circuit (process flowsheet diagrammatic representation) of the core;
- graphical view of power change in time from four NMCh;
- graphical view of the core process parameters change in time (temperatures, pressure, flow rates);
- graphical view of C-WP position change in time;
- alarm, warning and indicating signalization.

4.5.4.10.5 Each information window must contain:

- analog and digital view of indicators of acceleration period and power control from three NMCh of monitoring and protection;
- analog and digital view of indicators of C-WP position;
- SNS and CPS WP end indicators;
- analog and digital view of monitoring indicators of pressure in the free volume of the core vessel and solution temperature.

4.5.4.10.6 IGPS must accumulate and store information during necessary time.

4.5.4.10.7 IGPS must make possible formation of data bank to process information with standard software.

4.5.4.10.8 IGPS must have a printer.

4.5.4.10.9 IGPS must provide for placing monitors at the main and reserve control panels.

4.5.4.11 CPS power supply subsystem

To meet nuclear safety rules of research reactors requirements to RR CPS power supply:

- Two independent mutually backing power sources must supply electric power to the CPS core.
- There must be reserve sources with autonomous electric power supply for NMCh of monitoring and protection in addition to two independent mutually backing power sources. These sources must also be used as reserve ones for CPS WP end indicators.

4.5.5 Requirements to off-gas system (OGS)

4.5.5.1 OGS must service each core and the process loop of the reactor MIPS-100.

4.5.5.2 OGS must include:

- reservoirs for gases storage;
- pipelines with stop valves;
- a pump;
- filters;
- a vacuum pressure gage.

4.5.5.3 There must be not less than three reservoirs for gases storage to provide for evacuating periodically gases out of the cores vessels in connection with the core operation, keeping gases for necessary delay time and diluting them with atmospheric air to decrease gases activity to acceptable norms before their emission to the environment. The total volume of the reservoirs must be not less than ten times total free volume of the cores.

4.5.5.4 To meet OSPORB requirements of necessity of using remote control methods during work with radioactive materials, applying corrosion and radiation resistant materials, the main constructive material of OGS must be stainless steel and the stop valves must have remote control with help of electromechanical drives.

The electric mechanism must have end switches:

- a retract switch signaling about open state of the valve;
- a torque switch directly operating when the valve is shut.

4.5.5.5 The pump must make the minimal underpressure 0.1 kg/cm^2 in the reservoirs. The pump must have a safety valve.

4.5.5.6 The filters with material catching aerosols and radioiodines must be installed in the input pipeline to OGS and in the output one to the ventilation.

4.5.5.7 The filters design must make possible replacing the material.

4.5.5.8 The vacuum pressure gage must monitor pressure in any reservoir. The vacuum pressure gage must produce a unified signal proportional to the pressure value. The measuring range must be from minus 1 up to 1.5 kg/cm^2 . The gage class must be not lower than 1.5 (reduced error not more than 1.5%). The indicator of the vacuum pressure gage must be in the control panel room of the reactor MIPS-100. A signal of pressure excess in comparison with the preset value must get to CPS of each core.

4.5.5.9 OGS equipment must have flange connection. OGS equipment must be sealed according to the second seal class OST 5.0170-81.

4.5.5.10 OGS equipment control and its condition signalization must be in the control panel room of the reactor MIPS-100. Technical measures must exclude possibility of simultaneous evacuation of the cores vessels.

4.5.5.11 The OGS room must be classified as a room of temporary presence of personnel in compliance with OSPORB (PSRRS) classification of the room purposes.

4.5.5.12 The floor and the walls of the room must be covered with low-absorbing and easily decontaminatable materials in compliance with sanitary rules.

4.5.6 Requirements to fuel loading device (FLD)

4.5.6.1 FLD must perform initial loading of each core of the MIPS-100 reactor and adding fuel solution to the core because of the process loop operation. FLD must enable pouring the solution out of the reactor vessel to the system for temporary storage of spent fuel. So it must be possible to put the batcher in the biological shielding of lead 5 mm thick.

4.5.6.2 FLD must be installed in the service area and it must be connected to the branch pipe pouring solution into the core vessel and to the reservoir of the transport packing complex of “fresh” fuel during reloading operations.

4.5.6.3 It must be impossible to fill simultaneously two cores with help of one FLD.

4.5.6.4 FLD must realize a dosed supply of fuel solution from the reservoir with “fresh” solution to the core vessels.

4.5.6.5 FLD must have a batcher. The minimal portion of the loaded solution is 100 cm^3 and the maximum portion is $2,000 \text{ cm}^3$. The batcher must have volume not more than five liters and the inner diameter 80...100 mm (to have a satisfactory accuracy of measuring the solution quantity in the batcher).

4.5.6.6 Technical measures must block that solution would be poured from the reservoir to the vessel by-passing the batcher. It must be either impossible that the solution from the reservoir would fill the batcher and the solution from the batcher would fill the vessel simultaneously.

4.5.6.7 Pressure difference must cause that the solution would get from the reservoir to the batcher. It must be possible to pour the solution back by gravity from the batcher to the reservoir.

4.5.6.8 Solution must flow by gravity from the batcher to the reactor vessel.

4.5.6.9 It must be possible to connect free volume of the batcher with OGS reservoirs and atmosphere through the stop valves to enable operations of items 4.5.6.7 and 4.5.6.8. The stop valves must have electromechanical drives.

4.5.6.10 FLD must have a vacuum pressure gage with measuring limits from minus 1 to 1.5 kg/cm^2 , the device must have a class not lower than 1.5 to monitor pressure in the batcher.

4.5.6.11 FLD batcher must be equipped with a regulated level signaler. After the signaler operates the batcher filling must automatically stop. The signaler response error must not exceed $\pm 1 \text{ mm}$.

4.5.6.12 FLD pipelines must have such a diameter that the rate of positive reactivity introduction would not exceed $0.07 \beta_{\text{eff}}/\text{s}$ when solution is poured to the vessel.

4.5.6.13 The pipelines for filling the batcher and the vessel with solution must be equipped with valves with electromechanical drives and electric valves for emergency stop of solution loading. Time of the electric valves response must be not more than 1 s. There must be backup valves with manual control.

4.5.6.14 The solution loading to the vessel of the present core must be impossible or must automatically stop in the following cases:

- EP WP are not installed in the working position;
- Any C-WP is removed;
- EP subsystem operates;
- Any CPS WP escape button placed on the control panel and near FLD is pushed.

4.5.6.15 Dead-end or stagnations areas quantity must be minimized.

4.5.6.16 FLD must have a pan to localize solution if it is spilled.

4.5.6.17 FLD pipelines and equipment material must be stainless steel grade 08X18H10T.

4.5.6.18 It must be possible to decontaminate FLD equipment and pipelines.

4.5.6.19 Two people must be able to manually transfer FLD.

4.5.7 Requirements to the system for temporary storage of spent fuel (STSF)

4.5.7.1 Requirements to STSF are presented in the document "System for temporary storage of spent fuel of MIPS-100 reactor. Design requirements document".

4.5.7.2 The room for temporary storage of fuel of MIPS-100 reactor must have not higher than 2nd class (submergence must be impossible) according to classification of nuclear fuel storages presented in "Safety Rules of Nuclear Fuel Storage and Transportation at Nuclear Power Objects" PNAEG-14-029-91.

4.5.7.3 The following measures must be taken to prevent submergence:

- STSF reservoirs must be placed above ground level of the room;
- It is not acceptable to lay water supply pipelines through the STSF room. Water heating must be replaced with another alternative kind of heating;
- A drainage system must be available. The drainage system must remove water if it gets to STSF room. Passive drainage must be preferred when the drainage system will be developed.

4.5.7.4 To meet PNAEG-14-029-91 and OSPORB (PSRRS) requirements, STSF room must have:

- a ventilation;

- a radiation monitoring;
- hydrogen concentration monitoring instruments;
- an alarm signal system signaling about SCR.

4.5.7.4.1 The ventilation system must:

- remove and dilute gas mixture of the free volume of STSF reservoirs. Pressure must be automatically maintained in the range from minus 0.5 kg/cm² to minus 0.9 kg/cm² in the free volume;
- provide for air exchange in the room (combined extract and input ventilation).

4.5.7.4.2 Exhaust ventilation must have:

- a filter to clean the removed air from aerosols;
- sensors for monitoring hydrogen concentration in the free volume and STSF room;
- stop valves with remote control.

4.5.7.4.3 There must be radiation monitoring of the following parameters in STSF room:

- dose rate of gamma irradiation;
- volumetric gas activity.

4.5.7.4.4 Standard instruments with concentration measuring limits from 0 to 5% must be used to monitor hydrogen concentration.

4.5.7.5 Alarm signal system signaling about self-sustaining chain reaction (ASS SCR)

4.5.7.5.1 ASS SCR must contain two detectors of SCR prompt radiation, a communication line and a light and sound signaling system.

4.5.7.5.2 Standard apparatuses intended for SCR discovery and alarm must be used as ASS SCR.

4.5.7.5.3 ASS SCR apparatuses parameters must meet requirements of "Rules of Design and Operation of Alarm Systems Signaling about a Self-Sustaining Chain Reaction and Measures Limiting its Consequences" (PBYA-06-10-99).

4.5.7.5.4 ASS SCR detectors must be located in STSF room.

4.5.7.5.5 The light and sound signal system must be located in the control panel room of the reactor MIPS-100.

4.5.7.5.6 Light and sound signals must be given in the control panel room and at the entrance to STSF room. The SCR signal sound must differ from other signals sounds.

4.5.7.6 For fire safety:

- STSF room must be equipped with automatic fire alarm or basic fire-fighting means. Sand or carbonic acid of the fire extinguishers must be used as the basic fire-fighting means.

- It is prohibited to extinguish fire with water;
- It is not allowed to lay power supply cables that are not necessary for STSF operation;
- It is prohibited to store combustible materials in the room.

4.5.7.7 The STSF room must be classified as a room of temporary presence of personnel in compliance with OSPORB (PSRRS) classification of the room purposes.

4.5.7.8 The floor and the walls must be covered with low-absorbing and easily decontaminatable materials in compliance with sanitary rules.

4.5.8 Requirements to transport packing complex of fresh fuel

4.5.8.1 Requirements to the transport packing complex of “fresh” fuel are presented in the design requirements document “Transport packing complex of “fresh” fuel solution of MIPS-100 reactor.”

4.5.8.2 Quantity of the complexes must be sufficient for the full working load of the reactor MIPS-100.

4.5.8.3 The room for storing TPC with “fresh” fuel must meet requirements analogous to requirements to STSF room except hydrogen concentration monitoring.

4.5.9 Process loop for molybdenum-99 extraction from the fuel of the reactor MIPS-100 (PL)

4.5.9.1 PL must provide for molybdenum-99 extraction from the fuel solution of each core.

4.5.9.2 PL must:

- pump the fuel solution through a removable column with sorbent and purify the column from the remaining solution;
- install the column with sorbent in the working position for the final product extraction and remove the column for further transportation;
- remove gaseous fission products from the column with sorbent.

4.5.9.3 For operation, PL must include:

- a hydraulic path;
- a process box;
- a reload device;
- a trap for radioactive gases from the column with sorbent;
- a monitoring and control system.

4.5.9.4 A transport packing complex (TPC) must be used for transporting the column with sorbent (see “Transport packing complex for the column with sorbent of MIPS-100 reactor”. Design requirements document.)

4.5.9.5 The PL hydraulic path (HP) must be connected with help of supply pipelines to the intake and outtake units of solution of the cores vessels, the CRS water accumulators, and the cryogenic trap. There must be a valve at the end of the supply pipelines of two cores before their connection to PL. The valve must mechanically connect one of the cores and at the same time firmly close the pipeline of the other core. The valve must have a remotely controlled drive and equipment for signalization at the control panel.

4.5.9.5.1 PL HP must enable the following modes of the technological process:

- move the fuel solution from the core vessel through the column with sorbent and return the solution to the vessel;
- purge the column with sorbent with the reactor gas and blow gas to the core vessel;
- wash the column with sorbent with water from the CRS water accumulator and move water to the core vessel.

4.5.9.5.2 Technical measures must make impossible during the technological process that:

- the fuel solution gets to the CRS water accumulator;
- the fuel solution is pumped from the core vessel in the washing mode;
- the stop valves connecting the core with HP are open and the pump is on if the column is not placed in HP and the connecting joint is not sealed.

4.5.9.5.3 All the solution and water must be removed from the column after conducting the technological process.

4.5.9.5.4 Inner cavities and dead stagnation areas of the pipelines must be minimized. Local critical masses formation must be impossible.

4.5.9.5.5 For the final product extraction, PL HP must have:

- a column with sorbent;
- a pump;
- stop valves;
- supply pipelines.

4.5.9.5.6 The sorption column must:

- have the volume for sorbent not more than 500 cm^3 ;
- elastically fix the column of poured sorbent;
- preserve PL and the core from sorbent particles getting to them during solution pumping;
- automatically shut the intake and outtake connecting pipes when the transportation supply pipelines are disconnected;

- be remotely removed from PL and installed to the transport container;
- supply solution from below.

4.5.9.5.7 The pump must:

- pump liquid and gaseous mediums;
- be sealed (2nd class by OST 5.0170-81);
- deliver solution at flow rate from 3 to 25 dm³/h (by way of voltage variation in the motor);
- provide for pressure difference 4 kg/cm²;
- rotate the motor in the reverse mode with help of voltage polarity reversal;
- provide for time of continuous operation not less than 24 hours.

There must be a reserve pump. The pump must be made of a radiation resistant material.

4.5.9.5.8 The stop fittings (bellows stop valves) must have:

- seal class according to State standard GOST 9544-75;
- remote control with help of electric mechanisms.

The electric mechanisms must have retract end switches (open state) and torque end switches (closed state). There must be backup valves with manual control to connect PL HP to the solution intake and outtake units, CRS water accumulating units and the cryogenic trap. Control over the valves must be located in the service area.

4.5.9.5.9 Transport pipelines of fuel solution must have:

- a pitch to the pouring-out side (core vessel) not less than 5 degrees of arc to make fuel run by gravity;
- the second barrier (casing) to prevent radioactive product outlet to the environment in case of the pipeline sealing failure.

The fuel solution supply pipelines must have the inner diameter 6 mm and the wall thickness 2 mm. The water supply pipelines must have the inner diameter 4 mm and the wall thickness 2 mm.

4.5.9.5.10 The material of the column, the supply pipelines, settings of the valves and the pumps must be stainless steel grade 08X18H10T.

4.5.9.5.11 The place of HP and the column connection (connecting joint) must have a pipe to connect a vacuum pressure gage to monitor the connecting joint sealing.

4.5.9.5.12 The vacuum pressure gage must have: a contact unit, the signal from which must come to the PL control system; the measuring limits from minus 1 to +1.5 kg/cm²; the class not lower than 1.5; it must be located in the service area.

4.5.9.6 The main equipment of PL HP (the pumps, the valves, the unit of the column with the sorbent installation) must be placed in a process box (PB). PB must also be a shielding

barrier preventing that radioactive products would get out of it when the column is replaced or when other technological operations are performed including when some solution of limited volume is spilled.

4.5.9.6.1 PB must be made of stainless steel.

4.5.9.6.2 PB must have a pan. The pan inclination must be not less than 3 degrees of arc. The pan must have a spherical hollow to accumulate spilled solution there. The spherical hollow must have a screen filter to clean the solution from mechanical impurities before returning it to the core vessel. The filter mesh size must be 0,2 mm. The pan form must exclude conditions for SCR.

4.5.9.6.3 PB design must make possible access to the equipment located inside it to replace this equipment. It must have devices for installing the local shielding from ionizing irradiation. PB must make possible visual observation of operation of the reload device located inside PB.

4.5.9.6.4 It must be possible to connect PB through the flange joint to the exhaust ventilation system through the filter with material catching aerosols and radioiodines. The underpressure 20 mm of mercury column must be maintained in PB during the exhaust ventilation operation.

4.5.9.7 Reload device of the column with sorbent (RD)

4.5.9.7.1 RD must remotely perform the following operations:

- unseal the transport packing complex (TPC): remove the protective plug;
- remove the column with sorbent from TPC;
- install the column with sorbent to HP and seal the hydraulic loop;
- disconnect the column from HP;
- move the column to TPC;
- close TPC with the protective plug.

4.5.9.7.2 It must be possible to manually duplicate RD operation from the service area.

4.5.9.7.3 The electromechanical drives used in RD must have retract and torque end switches.

4.5.9.7.4 The following hoisting mechanisms must be available to transfer TPC with the column and install it to the motor transport.

- a transport platform with the electromechanical drive and the carrying capacity not less than 5 tons;
- a bridge crane controlled from the floor with the lifting capacity not more than 10 tons. It must be possible to move the load in two directions in the horizontal plane.

4.5.9.8 A system for radioactive gases removal from the column with sorbent

4.5.9.8.1 The system purpose must be to evacuate radioactive gases from the column with sorbent after the final product extraction before the column disconnection from PL HP.

4.5.9.8.2. 99% of gases must be localized in the cryogenic trap.

4.5.9.8.3 Gas should be taken from the column to the trap due to vacuum appearing in the trap cooled with liquid nitrogen.

4.5.9.8.4 The trap must contain a cavity for gases location and a cavity with liquid nitrogen in one container. The cavity with liquid nitrogen must have heat insulation from the environment.

4.5.9.8.5 The cavity for gases must have a pipe for connection with: PL HP near the connecting joint (unit); OGS and vacuum pressure gage. The cavity must be connected to HP and OGS with help of stop valves with remote and manual (backup) control. The stop valves must have end switches. The cavity must be connected to the vacuum pressure gage with help of stop valves with remote control. The vacuum pressure gage must be placed in the service area. It must have the measuring limit from minus 1 to $+1.5 \text{ kg/cm}^2$, the device class 1.5.

4.5.9.8.6 The cooling cavity must have a connecting pipe to connect to the supply pipeline for filling it with liquid nitrogen. The cavity must be filled with nitrogen from the service area under visual observation of the filling process.

4.5.9.8.7 Technical measures must make impossible that solution would get from PL HP to the trap and that gas would leak from the free volume of the core vessel to the trap.

4.5.9.8.8 The trap must be equipped with a biological shielding decreasing the personnel irradiation level to the acceptable norms.

4.5.9.8.9 There must be measures providing for an efficient disconnection and installation of the trap.

4.5.9.8.10 The material of the system for radioactive gases removal must be stainless steel.

4.5.9.8.11 The cavity for gases and connected to it pipelines, joints and equipment must have the 2nd seal class according to OST 5.0170-81.

4.5.9.8.12 Radiation monitoring in the PL room must include measurement of gamma irradiation dose rate, air volumetric activity and iodine radionuclides content in the air.

4.5.9.9 PL monitoring and control system (MCS PL)

4.5.9.9.1 MCS PL must control equipment of the hydraulic path, the reload device and the system catching radioactive gases from the column with sorbent. It must also monitor operational state of this equipment.

4.5.9.9.2 MCS PL must enable the following modes of PL HP operation:

- mode “sorption”: pump the solution from the core vessel through the column with sorbent;
- mode “purging”: pump the reactor gas through the column with sorbent;
- mode “washing”: pump water from the CRS water accumulator through the column with sorbent.

4.5.9.9.3 Any of HP modes of operation (open the valves and switch on the pump) must only be possible in the following cases:

- the column with sorbent is installed in the working position and pipelines connecting HP, the trap and PB pan are shutdown;
- the reload device is in the initial position;
- CPS WP are in the lower position; their control circuits are de-energized.

4.5.9.9.4 When the pump is operating the MCS PL must produce an electric signal prohibiting operation of the reload device, effect on CPS WP and HP stop valves.

4.5.9.9.5 There must be a mutual blocking to prevent simultaneous opening of the valves for pumping water and solution.

4.5.9.9.6 The mode “purging” must be provided by way of reverse operation of the pump (by the pump voltage polarity reversal).

4.5.9.9.7 There must be automatic and manual control over HP operation modes.

4.5.9.9.8 When PL HP is automatically controlled beginning from the initial state (all the valves are shut and the pump is de-energized), the valves with electromechanical drives must be opened one by one according to the preset HP operation mode, after that the pump must be switched on. Each following operation must only start when the preceding operation is finished. The mode of operation must finish when the mode preset time passes or when the button “stop” is pushed. The HP must be brought to the initial condition in the reverse sequence after finishing the mode. Initial data for the automatic control must be:

- HP operation mode;
- HP operation mode time;
- Pump number.

4.5.9.9.9 When PL HP is manually controlled it must be possible to choose any electric equipment and operate with it meeting conditions (see items 4.5.9.9.3...4.5.9.9.5).

4.5.9.9.10 MCS must block simultaneous operation of HP from two cores.

4.5.9.9.11 MCS must enable operations of the reload device under automatic and manual control.

4.5.9.9.12 RD automatic control must follow a preset algorithm. The consequence of reload operations must be determined at the designing stage.

4.5.9.9.13 Manual control must provide for RD step-by-step operation.

4.5.9.9.14 The operation must end after a preset operation time passes or the “stop” button is pushed (within tens of milliseconds period).

4.5.9.9.15 MCS must control the stop valves of the system for catching gases. Such measures must be taken that the column would be only disconnected from HP after evacuating gases from the column to the trap.

4.5.9.9.16 MCS must have a device for accumulating data and representing PL state and operation.

4.5.9.9.17 The device must have three switchable information windows. There must be symbolic circuits of the hydraulic path and the reload device displayed in two windows. There must be a graphical view of the pump current change in time represented in the third window.

4.5.9.9.18 PL equipment must be represented as graphical symbols in the symbolic circuits. Change of the equipment state must be showed as change of its color on the screen.

4.5.9.9.19 A timer must be provided to indicate the operation time.

4.5.9.9.20 Each information window must contain at least the following information:

- with which core is PL operating;
- sealing of HP connecting joint;
- gases evacuation from the column;
- PL electric power supply voltage.

4.5.9.9.21 The device must accumulate and store information about PL equipment operation for necessary time.

4.5.9.9.22 The device must be equipped with a printer.

4.5.9.9.23 MCS must have access control instrumentation (whether a removable device breaking the circuit of MCS electric power supply or a password) to exclude a unauthorized access to PL control.

4.5.9.9.24 MCS must be located in the room of the MIPS-100 reactor control panel. It must be possible to bring PL to the initial state from the room of the reserve control post.

4.5.9.10 Two independent mutually backing power sources must supply electric power to the PL equipment. There must be reserve sources with autonomous electric power supply.

4.5.9.10.1 The reserve electric power sources must have parameters permitting to bring HP and RD to the initial state.

4.5.9.10.2 Conversion to the autonomous electric power supply must not cause losing the information about HP and RD equipment condition or changing this condition.

4.5.9.10.3 Disappearance of HP or RD external electric power supply must switch off the controllers, which switch on these circuits.

4.5.9.11 In compliance with OSPORB classification, PL (PB and RD) room must belong to unattended rooms during HP operation. It must belong to the rooms of personnel temporary presence when there is no column with final product in the room.

4.5.9.12 PL room must have a biological shielding to decrease radiation exposure to permissible values during HP operation for people constant presence beyond this room.

4.5.10 Requirements to the radiation monitoring system (RMS)

4.5.10.1 In compliance with “Radiation Safety Norms” NRB-99 (RSN-99) on radiation monitoring amount of the radiation object, RMS of the reactor MIPS-100 must monitor the following parameters:

- dose and dose rate of the external gamma and neutron irradiation;
- radioactive contamination of skin, cloths, shoes, working surfaces of the rooms and equipment;
- volumetric activity of radioactive gases in the air of the working rooms and during their emission to the environment;
- radioiodines quantity in the air of PL room and during emission to the environment;
- individual doses of gamma and neutron exposure of the personnel.

4.5.10.2 RMS must have stationary equipment and portable devices as well as instruments for individual radiation monitoring of the personnel including emergency dosimeters.

4.5.10.3 The RMS stationary equipment with corresponding detection units must measure parameters in the following ranges:

- | | |
|---|------------------------|
| - dose rate of gamma irradiation, $\mu\text{Sv/s}$ | $10^{-3}\dots 10$; |
| - dose rate of neutron irradiation
(with neutrons energy $0.025\dots 10^7$ eV), $\mu\text{Sv/s}$ | $3\cdot 10^3\dots 3$; |
| - volumetric activity of beta active gases, Bq/m^3 | $0.1\dots 10^6$; |
| - volumetric activity of iodine radionuclides, Bq/m^3 | $0.1\dots 10^6$; |
| - surface contamination with beta particles, part./min cm^2 | $1\dots 10^5$; |
| - surface contamination with alpha particles, part./min cm^2 | $0.1\dots 10^5$. |

4.5.10.4 The stationary equipment must have threshold devices, which should operate on a preset level. When the threshold devices operate light and sound signalization must be switched on.

4.5.10.5 There must be sound and light indicators installed at the entrances to the radiation hazardous rooms. The indicators must be on if the threshold level is reached in the device monitoring radiation in the present room.

4.5.10.6 The portable devices must backup the stationary equipment in case of its failure of electric power supply disappearance.

4.5.10.7 The minimal radiation monitoring must include:

- Measuring gamma irradiation dose rate and air volumetric radioactivity in the rooms of the MIPS-100 reactor control panel and the reserve control panel.
- Measuring gamma and neutron irradiation dose rate and air volumetric radioactivity in the reactor hall;
- Measuring gamma irradiation dose rate, air volumetric radioactivity, radioiodines content in the air in the process loop room;
- Measuring gamma irradiation dose rate and air volumetric radioactivity in STSF room;
- Measuring gamma irradiation dose rate and air volumetric radioactivity in RCS process equipment room;
- Measuring air volumetric radioactivity and radioiodines content in the air before air emission to the ventilation stack.

Stationary posts must be organized to measure surface contaminations with radioactive substances. The concrete places of their location must be determined in the design.

4.5.10.8 The stationary equipment must be placed in instruments stands in the control panel room of the reactor MIPS-100. It is permitted to place the instruments stands with equipment in the reserve control post room, in this case information from radiation monitoring devices must be given to the reactor control panel room.

4.5.10.9 The stationary equipment must permit continuous round-the-clock operation. It must include self-diagnostics means and electric power supply of the detection units. The industrial network must supply electric power to the equipment.

4.5.10.10 The portable devices must have autonomous electric power sources.

4.5.10.11 The equipment for measuring gases and radioiodines volumetric activity must contain:

- detection units;
- own pump units;
- an indicator of the pumped air flow rate;
- a sound and light signalization of reaching the preset thresholds;
- indication of the volumetric activity;
- devices producing signals to the external circuits of signalization.

4.5.10.12 Air lines for sampling air from the rooms must have electric valves. The valves control elements and their state signaling systems must be placed in the reactor control panel room and in the reserve control post room.

4.5.10.13 The dosimeters for personnel individual monitoring (of neutron and gamma irradiation) must have the following ranges:

- for on-line monitoring, Sv 3·10⁻⁴ ... 1;
- emergency dosimeters, Sv 5 ... 5·10³.

4.5.11 Requirements to the control panel of the reactor and the process loop

4.5.11.1 The reactor MIPS-100 and the process loop control must be located in one room: the control panel room.

4.5.11.2 The control panel room must contain:

- the control panels of each core;
- the control panel of the technological loop;
- the control panel of the common systems of the reactor.

It is permitted to combine the control panels in one control panel; in this case the control panels must be functionally separated.

4.5.11.3 The control panel must include the operator's panel and the operator's board.

4.5.11.4 There must be the present core process equipment, SNS and CPS WP control and signalization and IGPS monitors on the operator's panel. The control panel must have an access control instrumentation to prevent non-sanctioned (unauthorized) effect on CPS WP control.

4.5.11.5 There must be a device representing information about state and operation of PL equipment including control working parts on the PL operator's control panel.

4.5.11.6 Each core operator's board must contain:

- the main units of ARS and CPS nuclear measuring channels and their indicators;
- device of logical processing of CPS signals;
- CPS signaling subsystem;
- SNS and CPS WP position indicators;
- CPS electric power supply sources.

4.5.11.7 There must be PL equipment electric power supply units, PL MCS elements on the PL control board.

4.5.11.8 The secondary transformers of the monitoring measuring instruments, control and signaling working parts of the reactor common systems process equipment must be placed on the operator's board.

4.5.11.9 It must be possible to supply electric power from the control panel room to the reactor equipment.

4.5.11.10 The control panel room must have television observation of the reactor process rooms and reload operations of the column with sorbent. The TV camera for observation of the reload operations must be able to vertically move. It must have a biological shielding. The quantity of the cameras and the monitors must be determined in the design.

4.5.12 Requirements to the reserve control post

4.5.12.1 The MIPS-100 reactor must have a reserve control panel post to meet requirements of “Principal Safety Rules of Nuclear Power Facilities” about necessity of bringing the reactor to the safe condition from the reserve control panel room. In compliance with this document, the reserve control panel of the reactor MIPS-100 must:

- introduce SNS and CPS WP of each core into the core and signal their extreme positions;
- bring PL equipment to the initial state;
- control OGS equipment and signal about its state;
- switch on the emergency signal siren;
- control the ventilation system;
- disconnect the electric power supply of the main control panel.

4.5.12.2 Radiation situation in the reactor rooms must be monitored with help of the reactor radiation monitoring system (RMS) from the reserve control panel room.

4.5.12.3. There must be a reserve set of the portable radiation monitoring devices (dosimeters), a store of individual protection means and overalls, equipment for measuring individuals doses of the personnel exposure located in the reserve control panel room.

4.5.12.4 The TV apparatus must enable supervision over the reactor process rooms.

4.5.12.5 The reserve control post must have speakerphone, interphone and phone communication systems analogous to the main control panel of the reactor.

4.5.12.6 It must be technically impossible to control the reactor simultaneously from the main control panel and from the reserve control panel.

4.5.12.7 Connection lines of the monitoring and control circuits of the main control panel and the reserve control post must be laid in different cable routings to connect to the main and the reserve control posts in order to prevent that both circuits would fail for a common reason.

4.5.12.8 The reserve control post must be situated beyond the reactor process rooms.

4.5.13 Requirements to the electric power supply system

4.5.13.1 The electric power supply system must supply electric power to the MIPS-100 reactor systems and equipment including electric light.

4.5.13.2 The electric power supply system must be equipped with consumed electricity meters.

4.5.13.3 Two independent mutually backing power sources (transformer stations) must supply electric power to the reactor MIPS-100. The backing source must automatically be switched on. The electric power voltage quality must correspond to GOST 13109-67.

4.5.13.4 The electric power supply system must provide the reactor electric receivers with four-wire circuit of three-phase current with a dead-earthed neutral. The line voltage value must be 380 V; the phase voltage must be 220 V; the alternating current frequency must be 50 Hz.

4.5.13.5 The electric network must have necessary automatic and protective means to meet requirements of rules of electrical installations construction (PUE).

4.5.13.6 It must be possible to disconnect the electric receivers of each core from the power network without disturbing electric power supply of the other core.

4.5.13.7 There must be individual switching on and protecting commutation means to supply power to the reactor systems and power equipment.

4.5.13.8 Power cables housings must be made of incombustible materials. They must have anticorrosion coat.

4.5.13.9 The power cable routings must be separately laid from the control cable routings. The cables of electric power supply of the reserve control panel must be laid in a separate routing.

4.5.13.10 The terminal clamps must have a marking to meet PUE (REIC) requirements.

4.5.14 Requirements to radioactive waste handling (RWH)

In compliance with requirements of “Sanitary rules of radioactive waste handling SPORO-2002 (SRRWH-2002)” and guidance of safety during handling radioactive waste of research nuclear facilities RB -008-99 (RS-008-99):

4.5.14.1 The reactor complex must have a room (a specially chosen section) for temporary storage of RW produced during the reactor operation and decommissioning. Unauthorized access to RW must be impossible.

4.5.14.2 RW quantity and classification must be determined in the design.

4.5.14.3 RW must be collected separately from usual waste in RW formation places.

4.5.14.4 Certified tanks for RW must be used for RW accumulation. The tanks must have a radiation hazard sign. The waste closed radionuclide sources must be collected in the tanks of the source manufacturing plant.

4.5.14.5 RW of different groups and categories must be separated during temporary storage.

4.5.14.6 Places of operation with RW must be equipped with RMS apparatuses.

4.5.14.7 The gamma irradiation dose rate must be not more than 0.1 mGy/h at the distance 1 m from the tank with RW. It must not exceed 0.005 mGy/h on the boundary with RW temporary storage section.

4.5.14.8 Special transport containers must be provided to transport RW to its utilization centers. Middle and highly-active RW loading and unloading must be mechanized.

4.5.14.9 According to the sanitary rules requirements, the floor and the walls must be covered with low-absorbing and easily decontaminatable materials.

4.5.15 Requirements to the ventilation system

4.5.15.1 In compliance with RR sanitary rules, the ventilation system of the MIPS-100 reactor rooms must be combined extract and input ventilation with a mechanical impulse.

4.5.15.2 The local (exhaust) ventilations must be available for the following rooms:

- the reactor cores;
- the process loop including the process box;
- the system for temporary storage of spent fuel.

4.5.15.3 The design speed of air movement in the working apertures of the rooms with local ventilation must be accepted equal to 1.5 m/s.

4.5.15.4 The local ventilation must have a reserve air exhauster.

4.5.15.5 The separate systems must realize the input, extract and local ventilation.

4.5.15.6 The ventilation must be organized in such a way that air would move from less contaminated rooms to more contaminated rooms.

4.5.15.7 The local ventilation must have filters. Material of the filters must purify the removed air from aerosols and iodine radionuclides. A periodical replacement of the filters must be possible. The working part of the filter must be protected from surface mechanical impurities.

4.5.15.8 The air exhausters must be placed beyond the radiation hazardous area.

4.5.15.9 It must be possible to control the ventilation system equipment from the reactor control panel and the reserve control post.

4.5.15.10 The place where the input ventilation takes air must be equipped in a conventionally pure area. The input chambers must have equipment to condition air moved to the attended rooms of the reactor. Air must come from the attended rooms to the rooms with local exhaust ventilation.

4.5.15.11 Air emission must be realized through a vent stack. The height of the vent stack must be calculated. Calculating permissible ventilation emission, it is necessary to meet the

requirement that the efficient dose would not be exceeded during normal operation and design accidents in compliance with methodical recommendations # MU 2.2.8/2.6.16.7-02 of ventilation organization at the radiation objects.

4.5.15.12 Before emitting air to the environment it must be possible to sample air to prove its activity.

4.5.15.13 The air lines for air removal must be made of non-absorbing and corrosion resistant materials.

4.5.15.14 The ventilation system must maintain normal climatic parameters in accordance with GOST 12.1.005-88.

4.5.16 Requirements to raw material, materials and components

4.5.16.1 The materials, raw materials, semi-finished products, components, instruments must have a certification and documents (certificates, specifications, technical descriptions, operating guides etc) to meet requirements of documents on certification of atomic power objects.

4.5.16.2 The technical parameters, life times, operation modes of applied materials, components, instruments must provide for stability of operation characteristics of the reactor and the process loop during a preset life time and storage.

4.5.16.3 Materials applied for manufacturing the reactor and the process loop equipment must be corrosion, radiation and decontaminating solutions resistant.

4.5.16.4 The equipment manufacturing enterprise must conduct acceptance tests of the received main materials as established in the specifications of the article (nomenclature and amount of acceptance tests). The materials quality is assessed in accordance with standards and specifications for the concrete semi-finished products and raw materials.

4.6. Service Conditions, Maintenance and Repair Requirements

4.6.1 The reactor MIPS-100 must be designed for a continuous round-the-clock operation. It must remain operable under the following climatic conditions:

- | | |
|---------------------------------|---------|
| - environmental temperature, C° | 10...35 |
| - relative humidity, % | 30...80 |

4.6.2 The reactor must have earthquake-proof equipment designed for 10 points maximum earthquake.

4.6.3 Maintenance and repair measures must be taken to maintain the reactor operability during all its life time.

4.6.3.1 The reactor equipment must belong to maintainable and repairable objects according to GOST 27.002-89 classification.

4.6.3.2 Maintenance work (MW) or equipment replacement must be conducted at the shutdown reactor (core).

4.6.3.3 Methods of maintenance or equipment replacement must not violate conditions and (or) limits of safe operation of the reactor (core).

4.6.3.4 It must be possible to replace disabled equipment from the service area.

4.6.3.5 MW or replacement of equipment located in the ionizing irradiation area and (or) having induced activity must be conducted under radiation monitoring with help of RMS. The personnel must be equipped with individual radiation monitoring instruments.

4.6.3.6 There must be two kinds of MW:

- constant (before the reactor start-up);

- periodical.

4.6.3.7 The constant MW must include equipment preparation and tests of its operation according to requirements of normative-technical and operational documents for this equipment.

4.6.3.8 The periodical MW must include:

- examination of the equipment condition;
- elimination of defects discovered during examination;
- tests of the equipment operation parameters correlation with the design parameters;
- metrological certification of measuring instruments.

4.6.3.9 Methods, time and amount of MW of the standard equipment must be established in normative-technical and operational documents for this equipment. A set of necessary instruments, tools and gages must be provided.

4.6.3.10 In compliance with recommendations of the main provisions of equipment maintenance and repair, non-standard equipment MW technical-organizational actions must include:

- verify availability of normative-technical, operational, repair and design documents;
- analyze operation and observations during run;
- equip with MW instruments;
- provide with MW executors;
- conduct MW operations;
- test design parameters of the equipment.

Requirements to materials and repair parts nomenclature must be specified during the reactor development and manufacture.

4.6.3.11 If there is a need of using non-standard instruments or tools, such instruments or tools must be developed.

4.7 Safety and Environmental Protection Requirements

Besides safety considering technical requirements to the reactor, other measures must be taken to maintain safety conditions. The main of these measures must be as follows.

4.7.1 The reactor equipment and systems must have necessary normative-technical and operational documents.

4.7.2 The reactor must operate according to its operation regulations (schedule) to meet requirements of the principal provisions of nuclear safety. Content of the regulations must be presented during the reactor development.

4.7.3 Maintenance and repair instruments and decontaminants must be provided for mounting, starting-up, as well as MW and repairing.

4.7.4 Overalls, individual protection means must be provided for the attending personnel labor. The concrete nomenclature must be specified during the reactor development.

4.7.5 To meet industrial sanitation requirements, the reactor rooms must have artificial lighting, heating and water-supply to make work environment meet current standards.

4.7.6 Hydrogen explosion protection at the reactor facility

4.7.6.1 It is necessary to determine possible processes and sources of hydrogen formation in the reactor systems during normal operation and malfunction.

4.7.6.2 The design must provide technical measures to exclude conditions for explosive hydrogen concentration appearance in the reactor facility systems (hydrogen concentration must not exceed 3% by volume).

4.7.6.3 Sources initiating hydrogen-containing mixtures explosion must be excluded from the reactor facility design. The reactor units' temperature must not exceed the temperature of detonating mixture combustion initiation during normal operation and malfunction (the

detonating mixture is a hydrogenous gaseous medium, in which hydrogen concentration exceeds explosive concentration).

4.7.6.4 The hydrogen-gas mixture must not be able to get from the reactor systems to the adjoining rooms. If necessary a hydrogen explosion protection system must be provided: a system of hydrogenous mixture removal and emission to the environment. In this case there must be hydrogenous mixture thermodynamic parameters measuring instruments in the rooms. The quantity of hydrogenous mixtures parameters control posts in the rooms with a volume limited with a sealed barrier must be chosen and substantiated in the design taking into account possible places of their accumulation.

4.7.6.5 The reactor design must determine and substantiate conditions of technological blocks response to hydrogenous mixture parameters values in the rooms.

4.7.6.6 The reactor facility equipment where hydrogen and oxygen can accumulate in stoichiometric relationships during operation must have a strength margin to resist the shock wave during hydrogenous mixture detonation.

4.7.7 In compliance with fire safety rules (PPB-01-93 (FSR-01-93))

4.7.7.1 The fire safety of the reactor, its equipment and systems, the rooms decoration must be based on application of incombustible and nonflammable materials.

4.7.7.2 It must be prohibited to use such combustible and volatile flammable liquids during MW, joint application of which can provoke a fire or a denotation.

4.7.7.3 It is necessary to determine the rooms categories by methods "Determination of the rooms categories" edition on fire and explosion-fire safety (NPB 105-96) and the area class (according to the rules of electrical installations construction). The protection grade of applied electrical equipment must correspond to the area class.

4.7.7.4 The reactor rooms must be equipped with:

- Automatic alarm signal system (light and sound) for discovering ignition or fire. It must be feasible to manually switch on the alarm signal system.
- Basic fire-fighting means according to established standards.

4.7.8 A plan must be elaborated in case of emergency situations according to nuclear safety rules. The plan must contain regulations of the personnel action and a signaling scheme. The personnel must be trained for emergency situations. There must be emergency (evacuation) light in the reactor rooms, passes and stairs for people evacuation in case of the emergency situation. The emergency light must have autonomous power supply independent of the electric power supply of the main light. There must be also an autonomous light with the inner power supply sources. A set of protective and decontaminating means, dosimeters, overalls must be available in case of radiation accident to meet requirements of the main rules of radiation safety. The concrete nomenclature and quantity of these means must be determined during the reactor development. The set must be stored beyond radiation hazardous rooms of the reactor complex.

4.7.9 Places for accumulation of manufacturing waste and household rubbish must be provided and equipped with waste accumulators. Organizations, which will collect waste including RW, must be determined during the reactor operation.

4.8 Metrological Requirements

4.8.1 Design studies of the reactor and the process loop characteristics must be conducted using software approved with experimental results.

4.8.2 The strength analysis of the reactor equipment must meet rules of strength analysis of nuclear power facilities equipment and pipelines PNAEG 002-86.

4.8.3 Standard measuring instruments must be used to measure parameters during the reactor operation. The measuring instruments must have necessary documents and verifiers necessary for metrological certification.

4.8.4 If any non-standard measuring instruments are used, they must be certified according to the standards requirements. Methods and metrological certification means must be developed and certified for the non-standard measuring instruments.

4.9 Marking and Package Requirements

4.9.1 A package must be provided to transport and store the reactor components, to protect them from precipitates and mechanical damages.

4.9.2 The package must have:

- Devices for its moving whether with mechanisms (if the package with equipment weights 50 kg or more) or manually by two people (if it weighs less than 50 kg).
- Mechanical locks (bolts) as well as damping devices and marking (top, bottom, no turn over) to exclude the equipment damages during transportation.

4.9.3 The transport packing complexes must have a radiation hazard sign.

4.9.4 The package must have the following marking:

- “top”;
- “bottom”
- “do not turn over”
- “net weight”
- “gross weight”.

4.9.5 The reactor components must have the marking:

- name;
- production year;
- works number;
- producer factory.

4.10 Transportability and Storage Requirements

4.10.1 It must be possible to transport the reactor equipment components by any land-based vehicles.

4.10.2 The warranty storage time must be not less than three years. The reactor components must be stored in storage conditions.

4.10.3 Proposals of the reactor components conservation considering their transportation and storage conditions must be presented during the reactor development.

4.10.4 The standard equipment transportation and storage must meet requirements of normative-technical documents for this equipment.

4.11 Non-Disclosure Requirements

4.11.1 The following commercial classified information (trade secrets) must be not disclosed during research and development:

- price of products delivered to different customers;
- technology of the final product production and purification;
- quantity of produced product; ways of expanding production.

4.11.2 Participants in developing the technology, the main equipment and the operation must not disclose the trade secrets to any other organization or private person.

4.11.3 Original constructions and new technological processes, operational modes and other solutions related to know-how must be protected with patents or certificates.

4.11.4 Conventional terms and a list of technical information, which are commercial classified information, must be developed in a separate document with the stamp “for administrative use only”.

4.12 Decommissioning Requirements

4.12.1 The design must contain proposals of organizational and technical measures for decommissioning the reactor and the loop to meet requirements of safety rules during the research nuclear facilities decommissioning.

4.12.2 The decommissioning process must meet the following requirements:

- Provide for nuclear and radiation safety of the personnel and population during radioactive equipment and materials dismantling, decontamination, conservation, transportation and disposal.
- Minimize the doses of the personnel exposure during decommissioning work;
- Minimize financial and material expenses for decommissioning operations.

4.12.3 The decommissioning project must present recommendations of work conduction and decommissioning process, work performance conditions, weight and sizes characteristics of moved weight, especially designed instruments for conducting the whole complex of work, supposed radiation situation etc.

4.12.4 The following decommissioning operations must be provided:

- unload the cores; if necessary keep nuclear fuel for delay time and take out for processing;
- dismantle the equipment and the systems; conduct decontamination and conservation;
- decontaminate free rooms to use them for other purposes further.

4.12.5 The decommissioning project must contain a list and an analysis of possible accidents and organizational and technical measures of preventing these accidents or decreasing their consequences to an acceptable level.

4.12.6 Before decommissioning start, an integrated engineering and radiation examination of the systems, equipment, constructions and buildings must be conducted to estimate their strength, and to make detailed cartograms of irradiation doses rates and radioactive contaminations. The decommissioning project must be corrected according to the examination results, if necessary.

4.13 Special Requirements

The present item contains requirements to nuclear materials protection from unauthorized access, movement and use during the reactor operation.

4.13.1 Requirements to nuclear materials control and account (registration)

The requirements are developed in compliance with “Principal Rules of Registration and Control of Nuclear Materials” NP-030-01”.

4.13.1.1 The used in the reactor nuclear material (NM) forming a part of fuel solution of the cores must be subject to control and account.

4.13.1.2 For NM control and account, there must be a materials balance zone (MBZ), for which NM inventory quantity should be established and NM balance should be conducted for a preset time interval. NM available amount should be measured in key gage points (KGP).

4.13.1.3 The reactor and the process loop must have a common MBZ considering the technological process of the final product production.

4.13.1.4 It must be possible to establish MBZ boundary by physical boundary of the reactor facility formed with the reactor complex rooms constructions.

4.13.1.5 KGP must be determined in such a way that they would measure actual quantity of NM.

4.13.1.6 An access control instrumentation (ACI) must be provided to discover NM unauthorized removal, use and movement and penetration to the limited access area.

4.13.1.7 ACI as observation devices (television or photo apparatuses) must monitor access to the reactor complex building and room.

4.13.1.8 ACI as intervention indication devices (IID) must be installed:

- at the entrances to the reactor complex rooms;
- in the TPC for “fresh” fuel and STSF (if they contain NM)
- in the connecting pipes for pouring the solution in and out of the core vessel;
- on the PB removable walls.

Access to IID must be provided to prove their condition.

4.13.1.9 It must be accepted that masses of nuclear material forming a part of the cores fuel solution are constant from the moment of loading it to the core to the moment of unloading it out of the core for NM account during the reactor operation.

4.13.1.10 NM control must be provided for each core during the reactor operation. NM control methods must be developed during the reactor development. The method of critical measurements must be preferred during the methods development.

4.13.1.11 NM absorption connected with PL operation must be considered and specified during the reactor development. The maximal loss of NM must be coordinated with the corresponding authorized body.

4.13.1.12 The criterion of anomalies discovery in the core NM control and account must be a nonmetering failure corresponding to that the absolute value would exceed 3% inventory difference from the NM total registered quantity.

4.13.2 Requirements to engineering and technical means of physical protection

The requirements to engineering and technical means of physical protection of the reactor MIPS-100 are developed in compliance with “Rules of physical protection of nuclear materials, nuclear facilities and nuclear materials’ storage stations”.

4.13.2.1 The reactor MIPS-100 must be equipped with engineering and technical means of physical protection including engineering means and physical barriers for its physical protection.

4.13.2.2 The engineering means must include:

- an intruder alarm system placed along the perimeter of guarded areas: the reactor site, the reactor building, the reactor complex rooms (guarded areas);
- access means installed in the check-points and guarded areas (the reactor building, the reactor complex rooms);
- an optic-electronic observation system to control the periphery of the guarded area of the reactor site, entrances to the reactor complex building and room;
- a special communication system;
- means of discovering unauthorized carrying (transporting) of nuclear materials, explosives to the guarded areas;
- supply systems (light, power supply etc).

4.13.2.3 The peripheries of the guarded areas and check-points must be equipped with:

- engineering means, which operation should be based on two different physical principles at least;
- optic-electronic observation (control) means;
- wire communications;
- supply systems.

4.13.2.4 The physical protection engineering means must have reserve electric power supply.

4.13.2.5 IID and locks must be installed on all the doors of the reactor complex building and room. The escape ways must be locked. The keys must be kept at the check-point and inside the rooms near the escape doors in a container with IID to enable people free escape in emergency situations.

4.13.2.6 The reactor physical barriers must be structural units of the reactor complex building and room. The windows must have bars and IID. The bars' keys must be kept at the check-point and in the room in a container with IDD.

5. STAGES AND MILESTONES OF DEVELOPMENT

5.1 The present item is developed according to GOST 2.103-68 (re-edition date is 1995). It also meets requirements of PBYA IR (NSR RR). The development of the reactor MIPS-100 must have the following milestones and stages.

5.1.1 A preliminary (draft) design must be developed. At this stage, design documents must be developed and calculation and experimental studies must be conducted to substantiate the design documents including:

- A design sheet;
- A layout drawing;
- A process flowsheet of the reactor with the loop for molybdenum-99 extraction;
- A block diagram of the reactor CPS;
- An estimation of water removal from the core fuel solution influence on reactivity;
- CRS mock-up tests.

5.1.2 A detail design must be developed. All the design documents containing final technical solutions of the reactor and the loop construction and initial data for developing the working papers must be developed at the stage of the detailed design.

5.1.3 The working design papers must be developed. Necessary design documents must be developed for manufacturing and testing a prototype (pilot model).

5.1.4 The prototype must be manufactured. At the stage of the prototype manufacture, the following actions must be performed:

- manufacture non-standard equipment of the reactor with the loop for molybdenum-99 extraction including non-standard maintenance and repair instruments;
- conduct preliminary tests of equipment after its manufacture and if necessary to correct documents according to the tests results.

5.1.5 Putting the prototype into operation must have the following milestones:

- conduct mounting and start-up and adjustment work in the place of the reactor and the loop construction;
- conduct physical and power start-up of the reactor;
- correct documents of the reactor and the loop according to the results of the physical and power start-ups if necessary;
- put the reactor and the loop for molybdenum-99 extraction into trial operation.

**List of Special Normative Documents With Requirements
to be Met during MIPS-100 Reactor Development**

##	Title of Document
1	General Provisions of Research Nuclear Facilities Safety. NP-033-01
2	Nuclear Safety Rules of Research Reactors. NP-009-98
3	Rules of Structure and Safe Operation of Executive Mechanisms of Devices Effecting Reactivity. PNAEG-7-013-89
4	Safety Rules of Nuclear Fuel Storage and Transportation at Nuclear Power Objects. PNAEG-14-029-91
5	Radiation Safety Norms. NRB-99
6	Principal Sanitary Regulations of Radiation Safety. OSPORB-99
7	Sanitary Regulations of Research Reactors Design and Operation. SP 1128-73
8	Sanitary Rules of Radioactive Waste Handling. SPORO-2002
9	Requirements to Substantiation of the Possibility of Prolonging the Specified Lifetime of Nuclear Power Objects. NP-024—2000
10	Safety Rules during the Research Nuclear Facilities Decommissioning. NP-028-01
11	Principal Rules of Registration and Control of Nuclear Materials. NP-030-01
12	Guidance of Safety during Handling Radioactive Waste. RB-008-99
13	Rules of Physical Protection of Nuclear Materials, Nuclear Facilities and Nuclear Materials' Storage Stations # 264 approved by RF Government regulation from March 07. 1997
14	Safety Rules during Radioactive Substances Transportation. PBTRV-73
15	Principal Rules of Safety and Physical Protection during Nuclear Materials Transportation. OPBZ-83
16	Rules of Electrical Installations Construction and Operation. PUE, editions.5, 6, 7 (items 6,7)
17	Safety Rules during Electrical Installations Operation. POTRM-016-2001
18	Rules of Construction and Safe Operation of Erecting Cranes. PB-10-382-00
19	Fire Safety Rules of Russian Federation. PPB-01-93 with modifications ## 282, 814, 817
20	Standards of Strength Analysis of Nuclear Power Facilities Equipment and Pipelines. PNAEG-7-002-87

21	Nuclear Power Facilities Equipment and Pipelines. Welding and Fusing. General Provisions. PNAEG-7-009-89
22	Nuclear Power Facilities Equipment and Pipelines. Welding and Fusing Joints. Control Rules. PNAEG-7-010-89
23	Norms of Designing Earthquake-Proof Atomic Plants. NP-031-01
24	Requirements to the Quality Provision Program for Research Nuclear Facilities. NP-042-02

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List of Patents

1. RF patent №2132730
«Solid polymeric sorbent for extraction of fission Mo-99 from neutron irradiated uranyl sulfate solution and its production method».
Assignee: Russian Research Center “Kurchatov Institute”
Priority: February, 26, 1998
Authors: Nikolay N. Ponomarev-Stepnoy, Vladimir A. Pavshook,
Grigory F. Bebikh, Vladimir E. Khvostionov, Petr S. Trukhliaev,
Ivan K. Shvetsov, Elena L. Vandysh.

2. RF patent №2145127
«A method of production and extraction of fission Mo-99 from liquid homogeneous uranous phase ».
Assignee: Russian Research Center “Kurchatov Institute”
Priority: February, 26, 1998
Authors: Nikolay N. Ponomarev-Stepnoy, Vladimir A. Pavshook,
Grigory F. Bebikh, Vladimir E. Khvostionov, Petr S. Trukhliaev,
Ivan K. Shvetsov,

3. USA patent № 5,910,971 June, 8, 1999
«Method and apparatus for the production and extraction of molybdenum-99».
Assignee: TCInternational Incorporated. Albuquerque N.M.
Authors: Nikolay N. Ponomarev-Stepnoy, Vladimir A. Pavshook,
Grigory F. Bebikh, Vladimir E. Khvostionov, Petr S. Trukhliaev,
Ivan K. Shvetsov.

4. USA patent № 00950418.4-2208-US0019574 July, 14, 2000.
«Method of strontium-89 radioisotope production».
Assignee: TCInternational Incorporated. Albuquerque N.M.
Authors: Sergey S. Abalin, Yury I. Vereshchagin, Vladimir A. Pavshook,
Nikolay N. Ponomarev-Stepnoy, Dmitry Yu. Chuvilin,
Vladimir E. Khvostionov

Specific Requirements for Sr-89 Extraction and Purification Process

1. Introduction

1.1 The present Specific Requirements utilize technical solutions for the following processes: gas flow filtering, Sr-89 sorption, radiochemical removal of accompanying fission fragments from the final product. These solutions were developed and implemented earlier in the course of work under ISTC Project #1664 and Master Contract DE-AC01-00NN40184, Modification "C/3" to DE-AT01-00NN40184.

1.2 A design requirements document for the gas loop for Sr-89 production in solution reactor will be finalized upon completion of the research and experimental work dedicated to specification and justification of the parameters of the gas loop for MIPS -100 (planned for 2004-2005).

1.3 The Design Requirements Document for the preliminary technical design provided under K-18(a) task, Master Contract DE-AC01-00NN40184 ensures a possibility for attaching the Sr-90 gas loop to the MIPS-100 unit.

2. Technical Requirements.

2.1 A system for gas flow filtering must be provided. The system must be mechanically strong and corrosion resistive to gases flowing out of the reactor vessel; it must be able to operate at temperatures of the out-flowing gases (up to 100°C) , and be radiation hard under β - and γ - exposure (absorbed dose rate no less than $5 \cdot 10^6$ Gy).

The degree of purification from aerosols in the gas flow must be not lower than 99.99999%.

Multilayered regenerable metal-ceramic filters (MKF) consisting of fine-porous metal layers deposited on rough-porous supporting plates are a part of the filtering system.

2.2 A Sr-89 deposition system must be provided. The system must be radiation hard under β - and γ - exposure (absorbed dose rate no less than $5 \cdot 10^6$ Gy).

The system must have effective surface to allow deposition of 90% of Sr-89 present in the gas flow. The structural material of the system must be subject to decontamination when treated by a weak solution of hydrochloric acid (3M HCl).

Glass tips 3x5mm pre-treated with hydrofluoric acid can be used as a part of the deposition system.

2.3 The radiochemical purification procedure must rest on the principle of extraction chromatography.

A Sr-specific resin (Sr-Resin of Bio-Nucleonics, Inc., USA) , which is a crown-ether of di-tert-butyl-decyclohexane-18crown-6, immobilized on a polyacrylate matrix. The reagent's particle size is 100-150 μ m.