PROGRESS REPORT FOR ISTC PROJECT #2267 ½ YEAR

Construction of a Sub-critical Assembly Driven by a Proton Accelerator at Proton Energy 660 MeV for Experiments on Transmutation of Minor Actinides and Long Lived Fission Products: (*Phase I: Design, Design Documentation and Safety Substantiation*)

July 2004, JINR, Dubna, Russia

Prepared by Project #2267 manager, V. Shvetsov

Participating Institutions:

- International Intergovernmental Organization Joint Institute for Nuclear Research (JINR, Dubna, Russia) – **Leading Institution**;
- *Federal State Unitary Enterprise Research and Development Institute of Power Engineering* (**NIKIET** – Russian abbreviation);
- *Industrial Association* ***"Mayak"***;
- *Federal State Unitary Enterprise State Special Project* Institute (**GSPI** – Russian abbreviation);
- R*ussian Scientific Research Institute of Inorganic Materials* (**VNIINM** – Russian abbreviation);

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Table of contents

Introduction

The construction of large subcritical accelerator driven systems (ADS) should be preceded by experimental verifications of the theoretical predictions and of the technological features of such systems. The most important issues to be addressed are:

- Substantiation of operational safety of sub-critical systems;
- Reliable calculation and measurement of the ADS power;
- Development of methods for reliable monitoring of the subcriticality K_{eff};
- Measurement of the contribution of the high-energy part (E >10 MeV) of the neutron spectrum, being particularly important for the design of radiation protection.
- Engineering of the coupling of an accelerator with a sub-critical reactor system;

Experimental ADS with thermal power of about 15-20 kW, as proposed in the SAD project, can deliver reliable substantial answers to these problems.
Some experiments are also planned to assess the reactivity feedbacks for SAD facility.

In JINR experimental and theoretical research activities focusing on coupling of proton accelerators with fissile targets/cores have been conducted since the middle of the 50-s' under the scientific label "*electronuclear*" research. Neutron yields and spectra in lead and uranium targets have been measured, as well as neutron cross sections for a number of isotopes, important for the estimation of the efficiency of various modes of transmutation (see for example the frequently quoted experiments and results of Vassylkov and Goldanski in reference [1]). For the analysis of the *electronuclear* systems properties, mathematical models with appropriate databases and software have been developed.

JINR has the license for operation of nuclear research reactors with active cores made of metallic plutonium and plutonium dioxide. Such reactors have been operated reliably and safely for more than 40 years.

JINR also has a long-term experience with the operation of proton accelerators. This experimental background gives good prospects for setting-up and subsequently for operating a low power experimental ADS with MOX fuel at JINR in Dubna. Moreover, the JINR with its status as an international research centre allows joining the financial contributions of the JINR member countries for such projects.

This low power project will be a natural step on the way from the current experimental zero power sub-critical assemblies, driven by an external neutron source (MASURCA in Cadarache, BFS in Obninsk, YALINA in Minsk) to the proton beam driven semi-industrial installations (MYRRHA, TRADE), which are now in the conceptual design phase in Europe.

Summary

One of the advantages of the proposed project is using the existing proton accelerator at JINR with 660 MeV energy and 3.2 μA maximal current. The PHASOTRON accelerator can deliver a proton beam with up to 2 kW power, enabling to have a total power of the sub-critical core, driven with such beam, at a level of more than 100 kW. The upper limit is determined by the multiplication factor K_{eff} = 0.98, the regulatory value defining sub-critical installations in the Russian Federation. One has to note also that the multiplication factor K_{eff} should be less or equal than 0.98 in all modes of operation, including anticipated accidents, so the normal mode of operation will be established at a lower value.

Another feature of the project is the use of existing fuel elements (FE) with MOX (uranium plutonium oxide) fuel of the BN-600 type as prototype for SAD FE.

The current project is logically separated into two Phases:

- Phase I – design and technological preparation and
- Phase II – construction of the facility.

Phase I is now supported in the ISTC Project #2267 and this part of the project will be described here in more detail.

The Phase I consist of two parts: design and technology.

In the first part of Phase I, the design and the financial (budget) documentation of the construction of the installation will be developed according to the requirements of the Russian Federation and the package of documents for obtaining the licenses for the location and for the construction of the nuclear installation will be prepared.

In the technological part, the production of FE will be prepared and a pre-production batch of MOX fuel pellets will be manufactured.

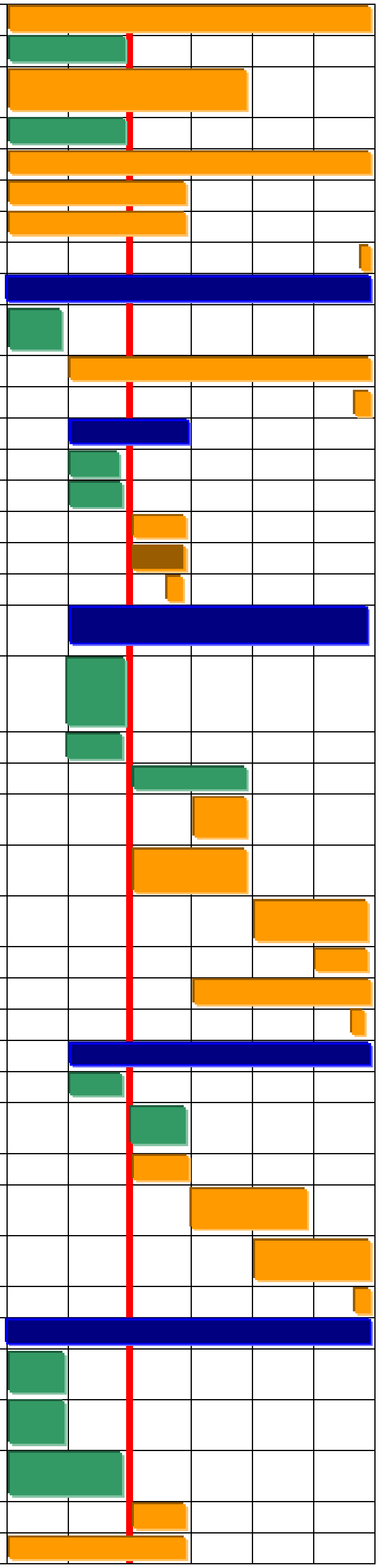
The project tasks of the Phase I with time schedules are listed in following table (the first quarter started on November 1 2003, when the JINR-ISTC contract was signed):

Table 1: SAD project time schedule (Design part).

– integral tasks; - completed tasks; - incomplete tasks; – time marker.

Tasks	Quarters					
	1	2	3	4	5	6
Task 1. Development of the concept of SAD installation. Development of the initial technical specifications						
Subtask 1.1 Basic data negotiation.						
Subtask 1.2 The protocol on design zones demarcation.						
Subtask 1.3 Basic data on MOX fuel pellet.						
Subtask 1.4 GSPI request to JINR on proton shielding calculation.						
Subtask 1.5 Development of the technical specifications (TS) on subcritical assembly.						
Subtask 1.6 Development of the TS on FE.						
Subtask 1.7 Development of the TS on beam transport line.						
Subtask 1.8 Development and approval of the project technical proposal on installation.						
Subtask 1.9 Final report preparation.						
Task 2. SAD parameters modeling						

Subtask 2.1 Numerical analysis of the SAD parameters.
Subtask 2.2 Energy release in SAD elements calculations.
Subtask 2.3 Calculations of the neutron spectra and angular distributions inside the SAD installation and behind biological shielding.
Subtask 2.4 Calculations of the neutron fields in experimental channels.
Subtask 2.5 Calculations of the SAD kinetic properties.
Subtask 2.6 Calculations of the SAD biological shielding.
Subtask 2.7 Calculations of the induced activity in SAD elements.
Subtask 2.8 Final report preparation.
Task 3. Design and development of the beam transport line
Subtask 3.1 Design and development of the beam transport line elements.
Subtask 3.2 Technical project (TP) of the beam transport line.
Subtask 3.3 Final report preparation.
Task 4. Design and development of the SAD fuel elements
Subtask 4.1 Documentation preparation.
Subtask 4.2 Documentation negotiation.
Subtask 4.3 Documentation correction.
Subtask 4.4 Documentation release and approval.
Subtask 4.5 Final report preparation.
Task 5. Production preparation, preproduction batch of fuel pellets manufacturing
Subtask 5.1 Production and certification of the plutonium dioxide, coordination of the isotopic content with precision not worse than 10-4 for basic isotopes.
Subtask 5.2 Delivery of the depleted uranium dioxide.
Subtask 5.3 Verification of the ceramic properties of the materials.
Subtask 5.4 Preparation of working design documentation on fuel pellets and FE.
Subtask 5.5 Preparation of production: development of the technology of pellets manufacturing, manufacture of tools.
Subtask 5.6 Preparation of the technology of FE assembly and capsulation.
Subtask 5.7 Preproduction batch of fuel pellets release.
Subtask 5.8 Obtaining certificate – license for FE transport package.
Subtask 5.9 Final report preparation.
Task 6. Design and development of the subcritical assembly (SA)
Subtask 6.1 Calculation works.
Subtask 6.2 Initial data for GSPI (layout drawings, requirements to external systems).
Subtask 6.3 Systems classification.
Subtask 6.4 Development of the requirements on automatic control and monitoring system (ACMS), its composition and structure.
Subtask 6.5 Developments of SA design, including substantiation of safety.
Subtask 6.6 Final report preparation.
Task 7. Civil engineering solutions on installation creation and allocation
Subtask 7.1 Investigations of the radiation conditions at installation position.
Subtask 7.2 Development of preliminary technological arrangement of an annex to the building.
Subtask 7.3 Coordination of the arrangement between JINR and NIKIET.
Subtask 7.4 Development of a preliminary general layout.
Subtask 7.5 Development of the technological tasks on sections.



Subtask 7.6 Coordination by the developers of contiguous parts of the project of technological arrangement.						
Subtask 7.7 Development of an intermediate architectural - construction plans.						
Subtask 7.8 Technical specifications on connection of sources of energy, water and water drain.						
Subtask 7.9 Development of budget documentation.						
Subtask 7.10 Coordination of design solutions.						
Subtask 7.11 Sending the design materials to the state supervision authorities.						
Subtask 7.12 Final report preparation.						

The deliverables of the Phase I are a set of documents in an order as determined by Russian Federation laws and normative documents:

- Design assignment document: the official request from JINR as customer organization to GSPI as general designer to start design work;
- Protocol on separation of responsibilities;
- Protocol on project basic data coordination;
- General Requirements Specification;
- As a result of the task on SAD parameters modelling, a technical report will be issued according to the project time schedule;
- The technical project for the beam transport line, including working drawings will be issued by JINR in the beginning of 2005;
- The technical project for the FE, including working drawings will be issued by VNIINM in the beginning of 2005;
- The technology for the fuel pellets manufacturing will be prepared at Mayak and a pre-production batch (3-5 kg) of pellets will be manufactured in April 2005;
- The technical project for the SA, including safety operation assessment will be issued by NIKIET in the beginning of 2005;
- The technical project for the new building and for the technological systems will be issued by GSPI in August 2004;
- The general engineering project will be issued by GSPI in December 2004;
- The general engineering solutions for the substantiation of safe operation will be issued by GSPI in March 2005;
- The latter two documents will be sent to the Federal Service on Atomic Supervision (former Gosatomnadzor agency) for getting the licenses for the allocation and for the construction of the SAD installation (necessary expertises and coordination will be done during the project implementation).

Details of the Phase II of the project are not yet specified precisely now. Nevertheless, the time schedules for the final project realization may be estimated from the preliminary investigations during the ISTC proposal preparation: 1.5 – 2 years for the Phase II of the project in case of sufficient funding. The financial valuation in its turn may be done after issuing the general engineering project (one of the parts of this project will be the cost assessment) by GSPI at the end of 2004.

Project Description

SAD basic data

The SAD project basic features are determined by the characteristics of the "PHASOTRON" proton accelerator at JINR and by the choice of the regular Russian MOX fuel elements of the BN-600 reactor type. The proton current (maximum value is 3.2 μA) and the corresponding power dumped in the spallation target determine together with the value of the multiplicity K_{eff} of the core, the total thermal power of the installation.

The basic data of the SAD-facility, the parameters of the accelerator and the MOX fuel characteristics are listed in the following tables:

Table 2: SAD installation basic data

Thermal power	up to 30 kW
Proton energy	660 MeV
Beam power	up to 1 kW
Proton beam / target orientation	Vertical
Fuel elements orientation	Vertical
Criticality coefficient	$K_{eff} \approx 0.95$
Fuel - see table below for details on composition	MOX, $UO_2 + PuO_2$
Cladding tubes maximum temperature	400° C
Spallation target	Replaceable: Pb, W
Reflector	Pb
Coolant	Air

Table 3: Beam parameters

Intensity of the extracted proton beam:	3.2 μA ($1.997 \cdot 10^{13}$ protons/s)
Beam emittance:	$\Sigma_x = \pi(5.1 \pm 2.3) cm \cdot mrad$ $\Sigma_y = \pi(3.4 \pm 1.4) cm \cdot mrad$
Time structure	
Fast extraction	
Frequency	250 Hz
FWHM	20 μs
Number of protons in pulse	$0.8 \cdot 10^{11}$
Slow extraction	
Frequency	250 Hz
Pulse width	3500 μs
Beam microstructure	
Micropulse FWHM	10 ns
Micropulse period	70 ns

Table 4: Basic features of the SAD core fuel

Parameter	Value
Fuel composition	$(UO_2 + PuO_2)$
Plutonium dioxide content in the fuel, %(mass)	up to 30*
^{239}Pu content in Pu %(mass), not less than (with accuracy not worse than 10^{-4} for basic isotopes)	95
Fuel density, g/cm^3	From 10,0 to 10,7
Fuel pellet diameter, mm	5,95*

*– parameters become defined more accurately during FE design

The installation will be equipped with experimental channels, which will allow to place detectors and isotopic samples in different parts of the installation and to extract them after irradiation.

Work Completed

Task1: Development of the concept of SAD installation. Development of the initial technical specifications

Design assignment document was issued by JINR in January 2004. Russian project participants in 2003 signed protocol on separation of responsibilities. Russian project participants in 2003 signed protocol on project basic data coordination. Russian project participants in April 2004 signed specification of general requirements. NIKIET, VNIINM and JINR in June 2004 signed requirements specifications on SAD FE. Technical specifications on the fuel pellet were issued by VNIINM and sent to “Mayak “.

All subtasks of the Task 1 of the project now are completed.

Task 2 SAD parameters modeling

Geometry and materials

Table 5: Lead target (Figure 1)

Number of prisms	13
Hexagonal prisms:	
Number	12
Pitch, mm	36
Gap between prisms, mm	1.5
Height, cm	60.6
Cladding	SS
Central prism:	
Number	1
Height, cm	60
Cladding	SS
Proton input channel:	
Diameter, cm	3
Depth, cm	10

Table 6: Core

Number of cells for FA	141
Number of loaded FA	134
Number of loaded lead prisms	7
Fuel load, kg	396.9
Fuel density, g/cm^3	10.2
Content of PuO_2 in fuel, weight %	29.5
Content of ^{235}U in fuel, weight %	0.7
Height of fuel, cm	58

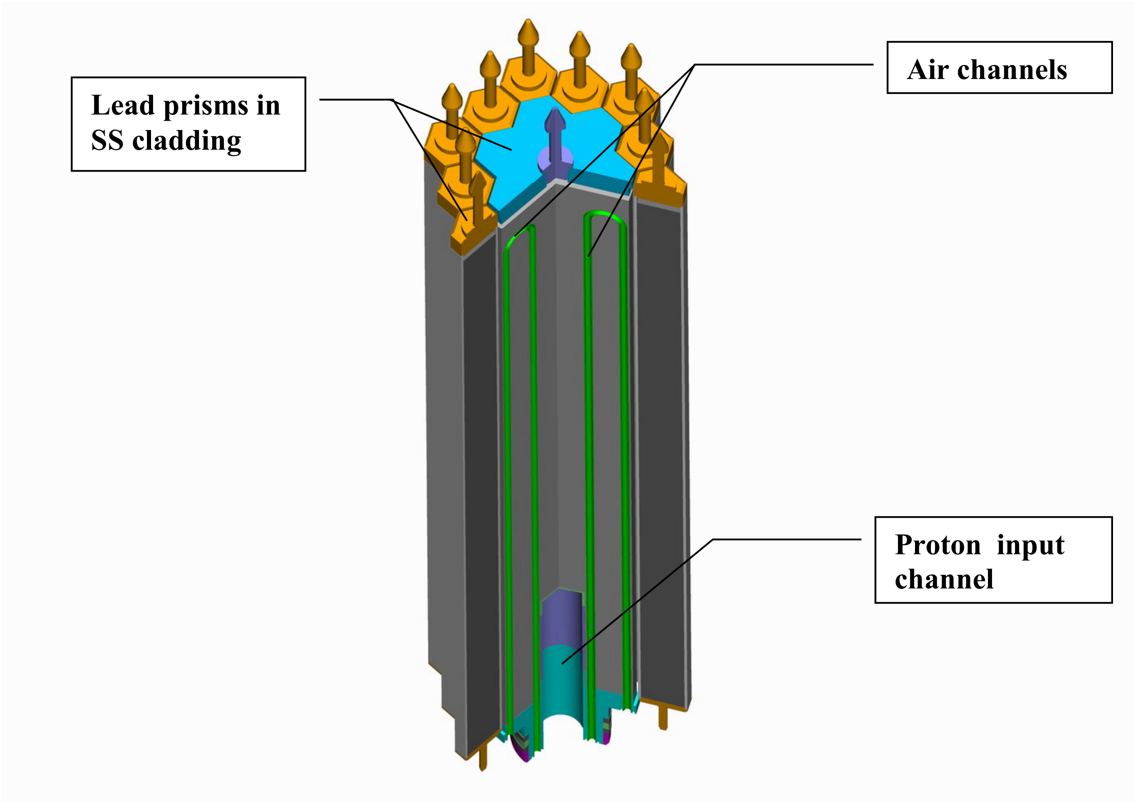


Figure 1. Lead target section

Target parameters

Table 7: Target parameters, calculated with LAHET

Proton energy, MeV	660
Beam power, kW	1
Neutron generation, n/p	12.95
Total neutron leakage from target, n/p	12.73
Side neutron leakage, n/p	12.22
Total energy of leakage, MeV/p	103.2
Total heat generation, W	840
Neutron source for blanket, n/s	$1.143 \cdot 10^{14}$

Core parameters

Table 8: Core parameters, calculated with MCNP

K_{eff}	0.9515
Neutron lifetime, μs	24
Fission power, kW	27.6
Peak factor of heat generation (height)	1.21
Heat generation in SAD parts:	
Fuel, kW	25.96
Target (neutron and photon from fissions)	97.3
Core cladding	204.3
Side Pb reflector	565.4
B_4C	204.6
Shielding concrete	771.1
Fuel Elements irradiation parameters:	

Max power density, W/cm^3	18
Max flux density of the fast neutrons (E> 0,1 MeV), cm^{-2}s^{-1}	2.2·10^{12}
Integral fluence of the fast neutrons (E> 0,1 MeV) at the end of campaign, cm^{-2}	8.0·10^{19}

Neutron spectra in experimental channels

SAD core and lead reflector simplified section is shown in Figure 2.

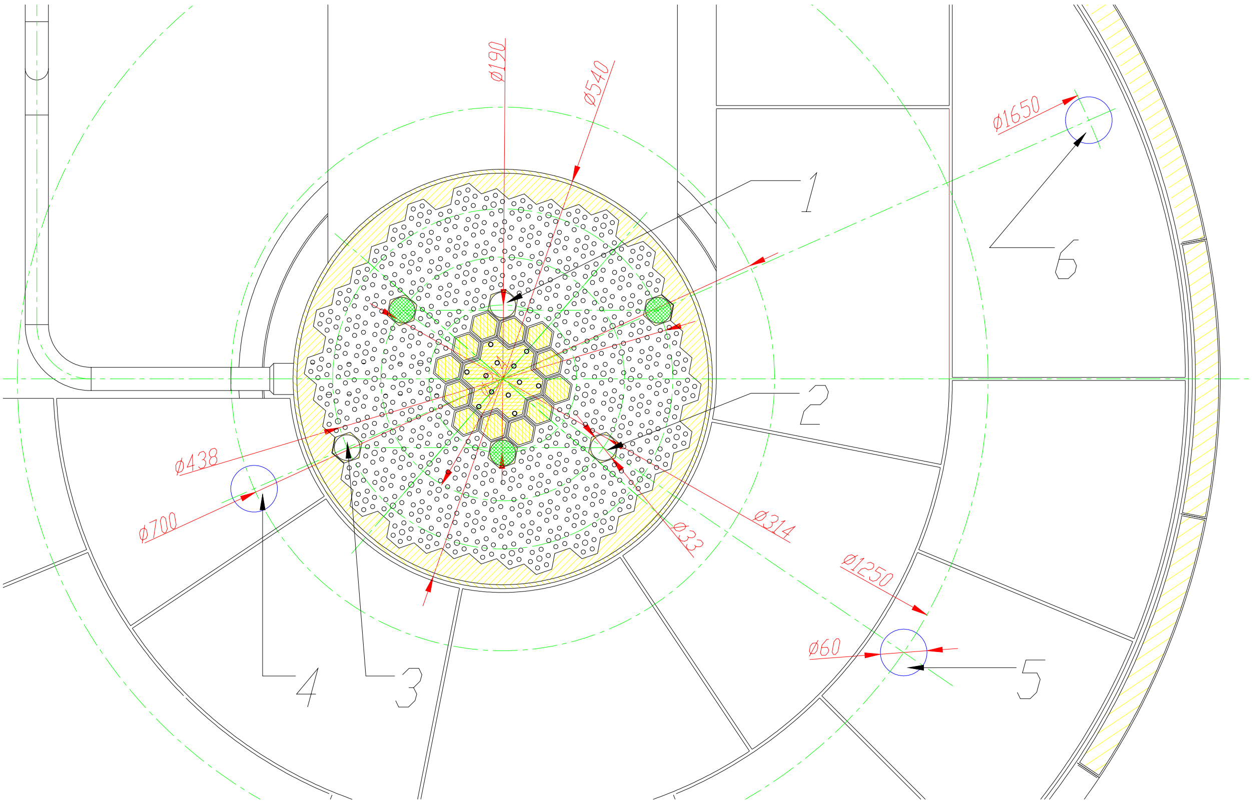


Figure 2. SAD core and reflector section through the central plane (construction elevation number 9800); lead blocks not hatched. 1-6 – vertical experimental channels

Results of the neutron spectra calculations are shown in Figure 3. Spectra were calculated in the centers of experimental channels and represent averaged over 5 cm height values.

Subtasks 2.1; 2.2; 2.4 are completed.

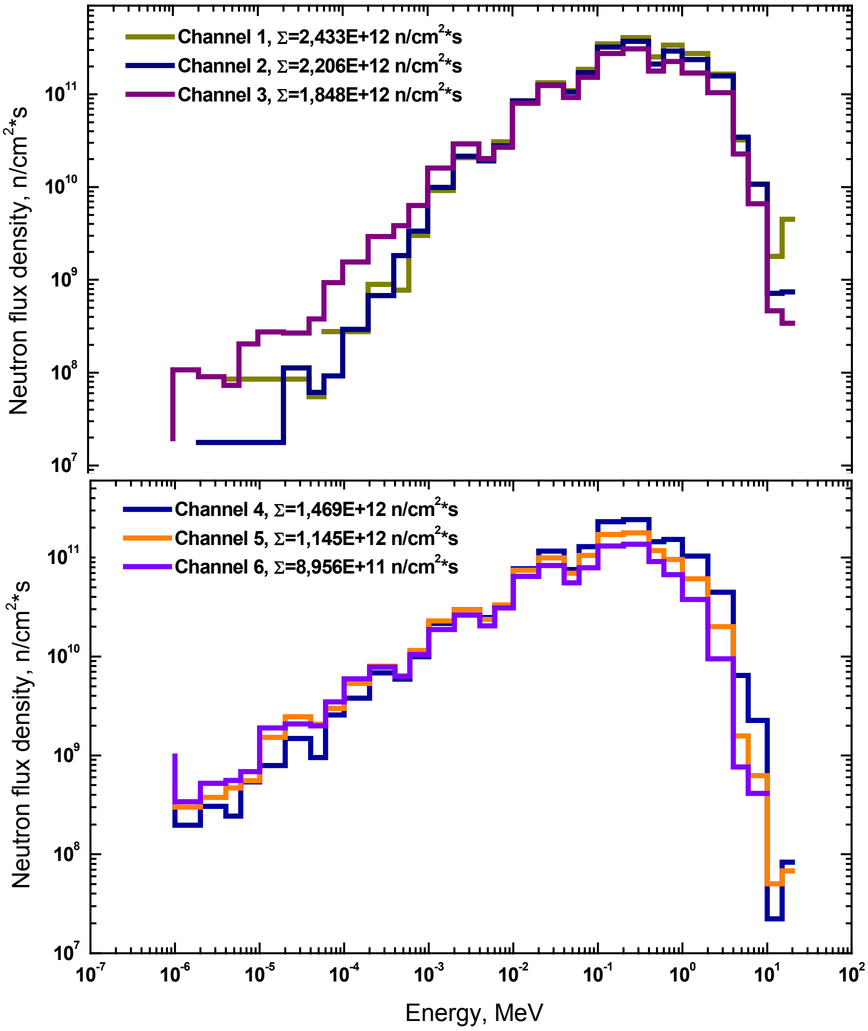


Figure 3: neutron spectra in the centers of vertical experimental channels: 1 – integral flux density 2,433E+12 n/cm^{2}s at 26 kW power; 2 – 2,206E+12; 3 – 1,848E+12; 4 – 1,469E+12; 5 – 1,145E+12; 6 – 8,956E+11.

Task 3 Design and development of the beam transport line

The proton accelerator PHASOTRON at JINR has 10 beam channels, used in various experiments. The normal beam losses at transition through the longest beam lines do not exceed 5%.

In the beam transportation system deflecting OM-1 type magnets and quadruple doublet ML-3 type lenses will be used. These standard magnetic elements have being designed and manufactured in many copies during the PHASOTRON exploitation.

The beam transfer from horizontal into a vertical plane will be realised using two strong bending magnets which have to be designed and constructed.

The total number of magnetic elements in the beam line is about 20. Total weight of the set of magnetic elements is estimated at 80 tons.

Requirements specifications for vacuum pipe, support stands, large bending magnets, vacuum shutter, diagnostic elements were developed.

Technical projects of the small bending magnets (OM-1) and doublets of the focusing quadruple lenses (ML-3) are completed.

Proton beam route was tracked inside the Phasotron building.

Beam dynamic was calculated for several versions of the magnetic elements allocation. Final version with 37.6 m length was chosen resulting beam transportation with losses less than 5% (less than 3% on the large bending magnets outside accelerator hall) and beam diameter on the target 30 mm (86.5 % beam intensity).

Sketch projects of the beam line power supply system and beam diagnostics were developed.

Sketch project of the beam line was developed.

Subtask 3.1 was completed.

Task 4 Design and development of the SAD fuel elements

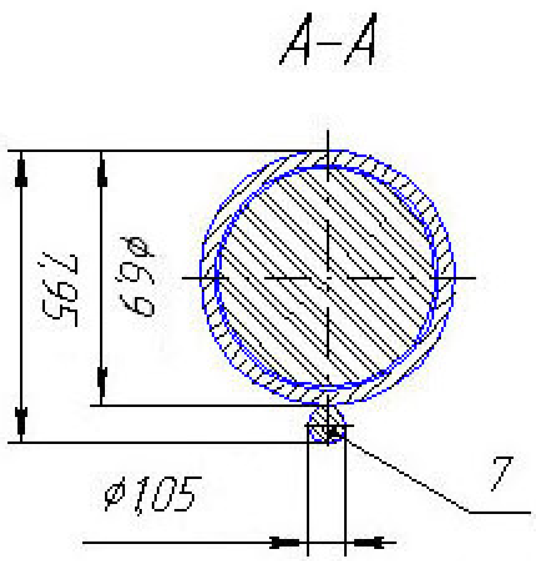
FE design is based on BN-600 FE. It is shown in Figure 4.

Operating conditions

- Maximum dose for constructional materials of fuel element – 0.25 dpa.
- Fuel maximum burn up – 0.1 % h.a.
- Maximum linear power of fuel element – 0.275 kW/cm.
- Maximum temperature of fuel element cladding – 150°C.
- Core coolant - dry, dust-free air.
- Maximum coolant temperature at core output - 125°C.
- Fixed resource of fuel element for operation of installation at nominal power (27 kW) – 10000 h.
- Fixed core lifetime of fuel element - 10 years.

Processing requirements for fuel element

- Uranium and plutonium feed powders, which are used for BN-600 MOX fuel fabrication.
- Constructional materials of standard BN-600 fuel elements.
- MOX fuel pellets fabrication at “Mayak”.
- Fuel element fabrication at “Mayak”.
- Fuel element quality control by “Mayak” control procedures and equipment.
- Components fabrication at MSZ JSC.



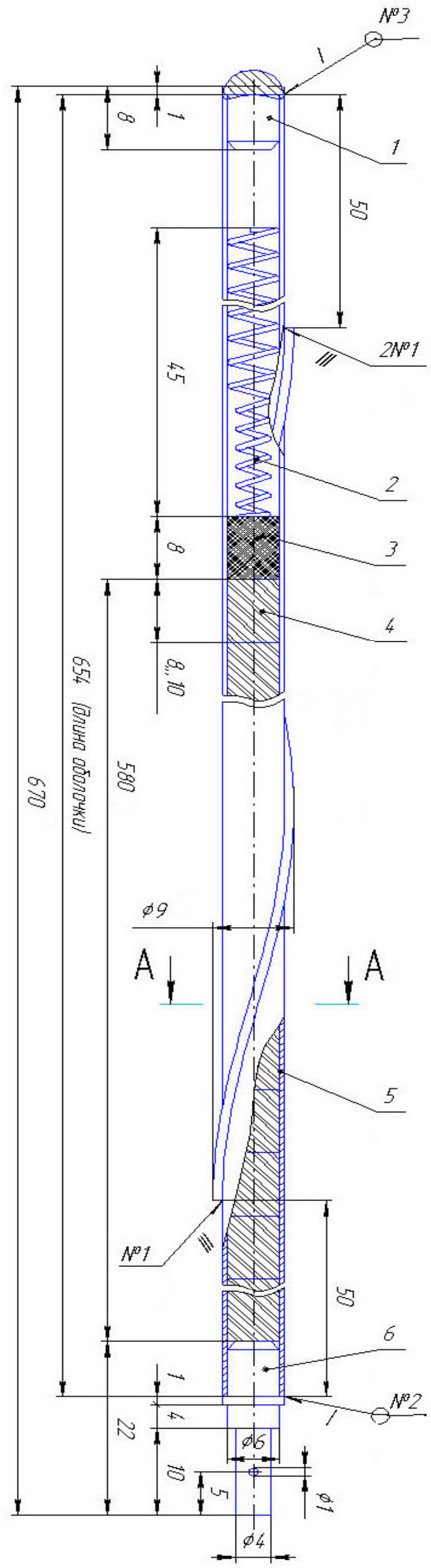


Figure 4. SAD FE: 1 – cap; 2 – lock; 3 – porous plug; 4 – fuel pellet; 5 – cladding; 6 – bottom end; 7 – positioning wire.

SAD fuel pellet

Table 9: SAD fuel properties

Mass share of U and Pu sum, %, not less	87,6
^{239}Pu conditional mass in Pu dioxide, %, not less	95,0
^{235}U conditional mass in U dioxide, % not more	0,7
Pu conditional mass share to U and Pu sum, %	30,0±0,3
Oxygen ratio	1,98
Density, g/cm^3	10,4±0,2
Impurities mass share, %, not more	
Aluminum	0,02
Calcium	0,02
Magnesium	0,02
Iron	0,03
Silicon	0,02
Nickel	0,02
Chromium	0,02
Nitrogen	0,01
Carbon	0,01
Fluorine + Chlorine	0,005
Grain size, μm, not more	70

Process flow sheet for SAD fuel pellets

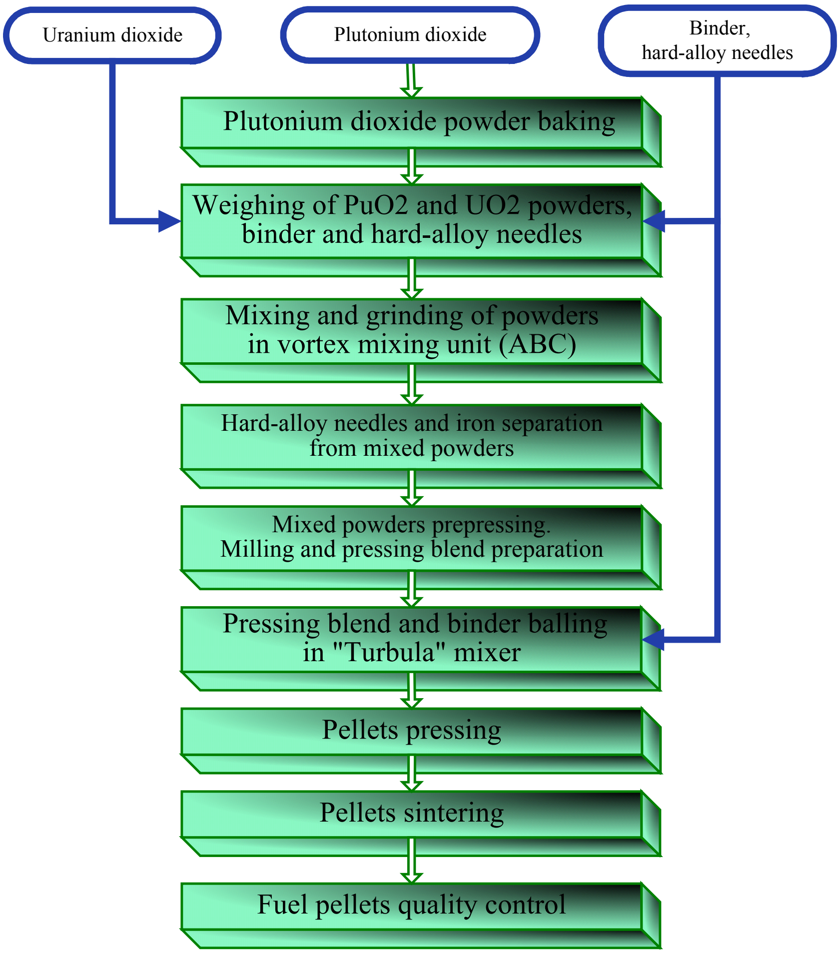


Figure 5. SAD fuel pellets manufacturing technology

Process flow sheet for SAD fuel pellets

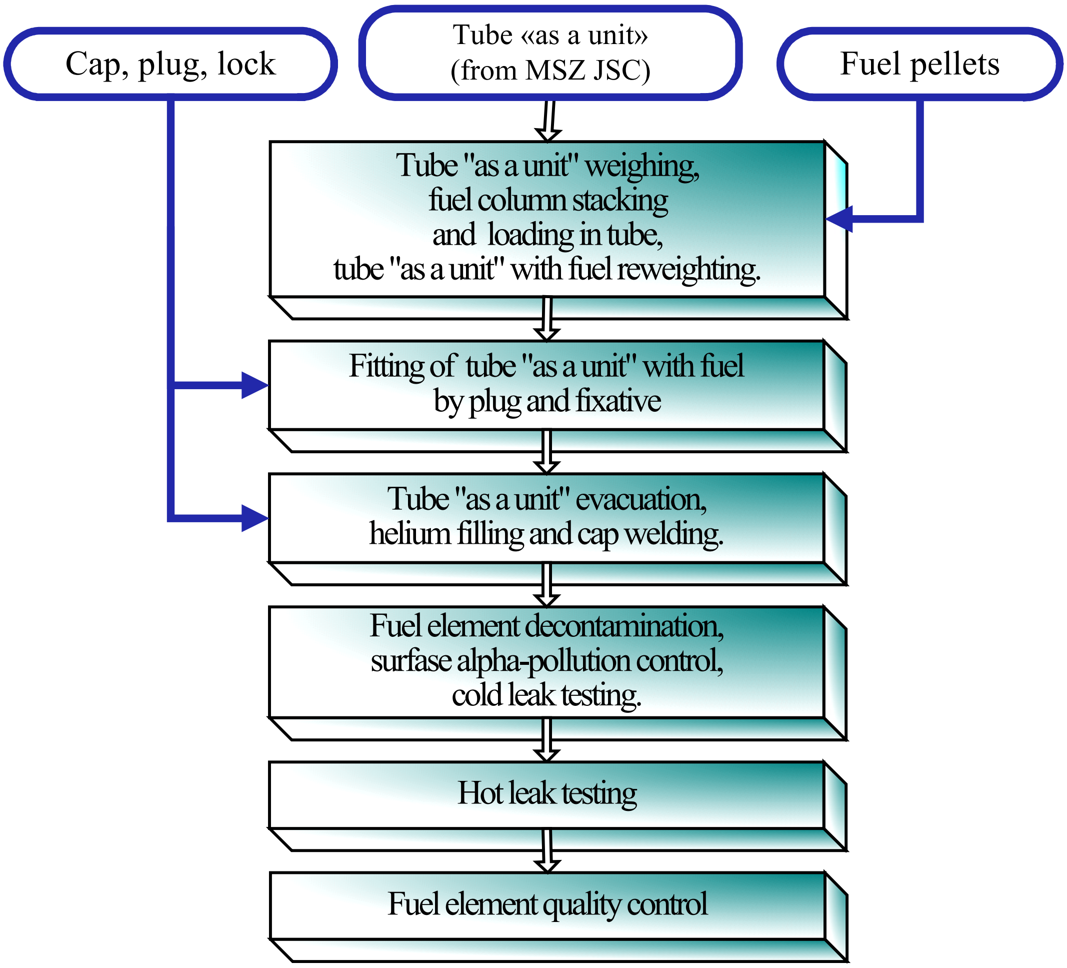


Figure 6. SAD fuel elements manufacturing technology

Subtasks 4.1 and 4.2 are completed.

Task 5 Production preparation, preproduction batch of fuel pellets manufacturing

Development of production technology of plutonium dioxide powders of ceramic quality

In accordance with Agreement # 2267 (Project SAD), the FGUP "PO Mayak" carried out works to obtain the powder PuO_2 of ceramic quality [1], including development out the filtering, drying and heating modes of plutonium oxalate. Plutonium oxalate was heated in a layer of 40-50 mm thick with air blow at the temperature of 600-750 °C during 6-8 hours.

Basing on the experimental operations done, the following heating mode of plutonium oxalate was proposed:

- heating temperature -750°C;
- heating time –6 hours;
- air volume discharge – 150 l/h.

To implement the whole SAD-program on the production of MOKS-fuel, about 250 kg of plutonium dioxide was produced.

Data, featuring the physical and chemical properties of the obtained PuO_2 powders were sent to the VNIINM and JINR. As a result of properties consideration at the VNIINM, the lots were singled out that fit, according to their composition, for the production of MOKS-fuel (Agreement Protocol of IA "Mayak" No.20-256 of April 1, 2004).

Investigation of physical and chemical properties of depleted uranium dioxide

Investigations on the possibility of usage of depleted uranium dioxide with exceeded storage period were carried out under laboratory conditions and at the installation "Paket".

Physical-chemical properties of the UO_2 powder were determined:

- specific surface – 4,0± 0,5 m^2/g;
- oxygen index – 2,10 ± 0,02;
- bulk density - 2,25 g/cm^3.

The powder humidity varies, depending on the season and, probably, on the package quality, in the range from 0,45 to 1,1 mass/ % .

Sintering ability test of depleted uranium powder was carried out, which showed a possibility of its use in the production technology of the MOKS-fuel.

Recommendations were given on recovery heating of depleted uranium dioxide available at the IA "Mayak" [2].

Laboratory examination of sinterability of the obtained plutonium dioxide powders with depleted uranium dioxide

The ability of obtained PuO_2 powders to be sintered with depleted uranium dioxide was checked under laboratory conditions. The density of the MOKS-fuel (UO_2 +30% PuO_2) pellets after sintering was equal to 10.3 g/cm^3 (Figure 7).

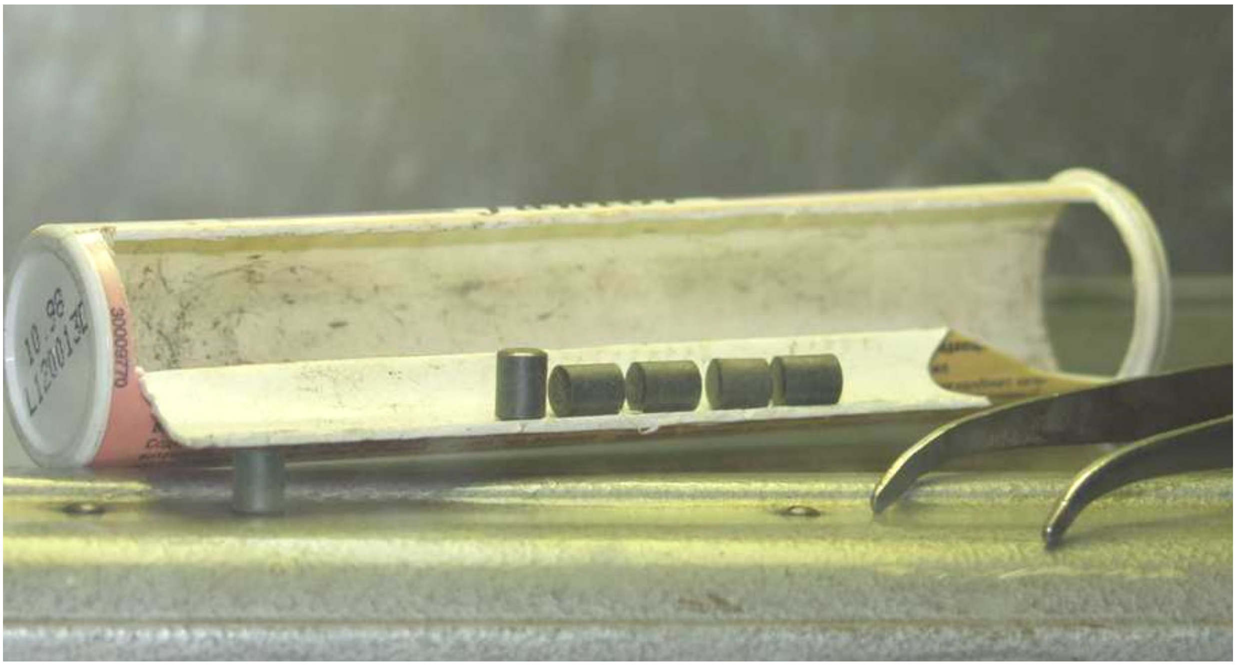


Figure 7. Control tests of the MOX fuel pellets.

The program [3] of carrying out experimental works on the production of MOKS-fuel pellets at the “Paket” installation for nuclear installation “SAD” was drawn up.

Factory preparation for the manufacture of an adjusting lot of MOKS-fuel pellets

To prepare the production facilities to the manufacture of MOKS-fuel, measures were arranged, where top-priority tasks on the preparation of installation “Paket” for MOKS-fuel manufacture were reflected.

Inasmuch as MOKS-fuel with plutonium enrichment of 30 mass % is supposed to be used in the nuclear installation “SAD” (earlier fuel with 25 mass % enrichment was manufactured), it became necessary to license the factory for a corresponding kind of activity. IA ”Mayak” has prepared and submitted to GAN RF (Nuclear Supervision Agency) a request to obtain permission on MOKS-fuel production at the installation “Paket”.

After presented documents have been considered by GAN, amendment No.1 of January 16, 2004 to the current license No. ГН-03-115-0890 was obtained.

Data on plans of works at the installation “Paket” were submitted to the department of Urals regional inspection and to Ozersk inspection of GAN (outgoing No. 20-855 of April 8, 2004, No.20-976 of April 4, 2004).

After consideration of submitted documents, permission was obtained to carry out experimental works (research works) on working through the production technology of MOKS-fuel at the installation “Paket”.

A number of documents, submitted by the JINR, were considered and agreed upon:

a) Sub-agreement on the Project No.2267 between JINR and FGUP “IA Mayak”;
b) Protocol on distribution of responsibility zones between organizations participating in the SAD project;
c) Requirements specification.

Remarks were issued on specification design for MOKS-fuel pellet and technical assignment design (fuel element for installation SAD).

Depleted plutonium dioxide with the exceeded storage period was retested for compliance with Technical Conditions 95.213-80.

Design documentation for press-tools and technological rigging was developed, pre-production models were manufactured.

Primary tests of press-tools and experimental operations on manufacture of MOKS-fuel pellets were carried out.

Subtasks 5.1, 5.2 and 5.3 are completed.

Task 6 Design and development of the subcritical assembly (SA)

SAD design

Preliminary SAD active core design was developed. Results are presented in the document "Initial technical data for General Designer", issued by NIKIET in May 2004 in accordance with project time-schedule. SAD core and auxiliary components are shown in Figure 8.

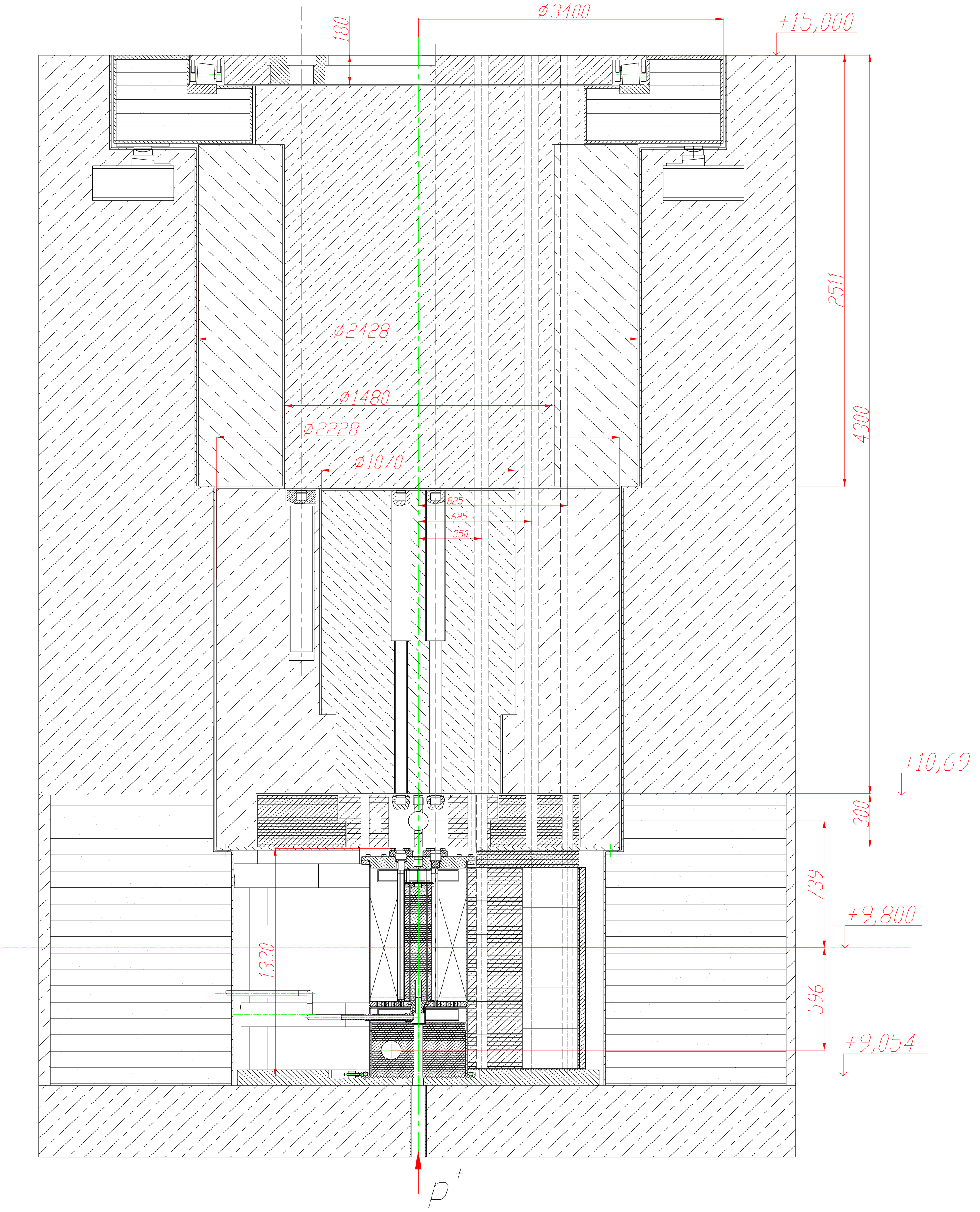


Figure 8. Preliminary design drawing of the active core and main units.

SAD technical specification

Target

Material – lead.

Height – 60 cm.

Weight – 150 kg.

Core

The sub-critical blanket of SAD (Figure 9) is placed within a biological shielding, which is made of heavy concrete and placed in radial and top directions from the active core (AC). Pipes are foreseen in the shielding blocks to provide the allocation of the cooling loops for the target, the core, the experimental channels (vertical and horizontal), the power control channels, the proton guide etc. The upper part of the biological shielding will provide access to the blanket and to the experimental channels during fuel loading/reloading operations and to experiments with detectors and samples.

The SAD core consists of 141 fuel assemblies; each assembly by itself combines 18 fuel pins, separated by wire spacers, and welded onto the cladding tube in helical manner. The fuel assembly does not have sidewalls, but only lower and top frames where the FE are fixed. A central supporting rod made of stainless steel achieves the integrity.

The low specific energy release in the system allows the usage of air-cooling, both for the target and for the active core.

The core design parameters are listed in Table 10.

Table 10: SAD core design parameters

System	Parameter	Value
Target *	Number of elements	19 hexagonal prisms
	Material	Lead
	Pitch, mm	36
	Spacing between prisms, mm	1.5
	Height, cm	60
Active Core	Number of fuel assemblies	141
	Number of fuel elements per one assembly	18
	Fuel density, g/cm^3	10.2
	Plutonium dioxide content in the fuel composition, %(mass)	29.5
	^{235}U content in U, %(mass)	0.4
Fuel element	Pitch, mm	7.95
	Clad tube diameter, mm	6.9
	Clad tube thickness, mm	0.4
	Fuel pellet diameter, mm	5.95
	Fuel height, cm	58

* Specification of the first target. It will be exchangeable for investigations of different dimensions and materials

The first target assembly consists of a set of hexagonal lead prisms with air-cooling of the central 7 prisms. Other materials than lead and other dimensions will be used for the target in the course of the SAD experimental program.

K_{eff} = 0.95 is achieved at loading 133 FA. 8 FA cells are filled with lead prisms.

On the basis of the data, listed above, preliminary neutron spectra in experimental channels were calculated with MCNP. Neutron flux density is on the level of $10^{11} \div 10^{12}$ n/cm^{2}s with maximum at 0.6 – 1.0 MeV.

Reflector

The active core is surrounded by a lead reflector of 60 cm thickness in radial direction and of 20 cm in axial direction at the top and at the bottom. The lead density is 11.15 g/cm^3. A B_4C layer of 3 cm thickness to reduce the number of low energy neutrons in the concrete is located between the lead reflector and the concrete shielding in radial direction.

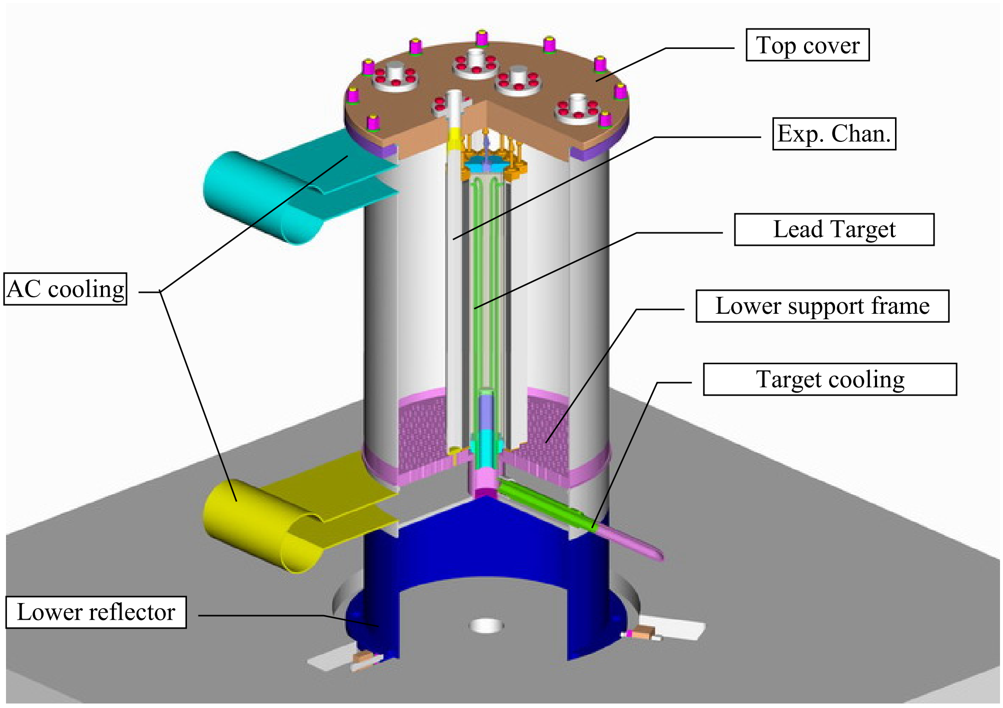


Figure 9. SAD core section (fuel cassettes and reflectors not shown)

Lead chemical composition is given in Table 11.

Table 11. C1 lead chemical composition

Element	%
Pb	99.985
Ag	0.001
Cu	0.001
Zn	0.001
Bi	0.006
As	0.0005
Sn	0.0005
Sb	0.001
Fe	0.001
Mg+Ca+Na	0.002
Total admixtures	0.015

Cooling system

Core cooling system parameters are listed in Table 12

Table 12. Core cooling system technical requirements.

Parameter	Value
Thermal power, kW	27.4
Coolant	Dry air
Coolant flow direction	Top-down
Coolant inlet temperature, °C	50
Coolant outlet temperature, °C	96
Coolant consumption, kg/s	0.6
Coolant average velocity, m/s	10
Coolant pressure, MPa	0.12 (absolute)
Pressure loss, kPa	
Inlet	1.6

Core	2.1
Outlet	0.9

Lead target cooling system parameters are listed in Table 13

Table 13. Lead target cooling system technical requirements.

Parameter	Value
Material	Pb
Thermal power, kW	0.5
Coolant	Dry air
Coolant inlet temperature, °C	50
Coolant outlet temperature, °C	125
Coolant consumption, kg/s	0.0067
Coolant velocity, m/s	50
Pressure loss, kPa	20

Two versions of the cooling system were developed: unified and separate for core and target. Final choice will be done by General Designer (GSPI) after equipment selection.

General safety assessment

SAD Installation is intended for carrying out of the experimental researches. It contains fissile materials, the structure and geometry of the installation provides attenuation of chain fission reaction in absence of external sources of neutrons.

Main safety principles

- In all design modes of operation, including works on service of an active core and a target and emergency operations, nuclear accident should be excluded;
- In all conditions and design modes of operation, including service of an active core and a target and emergency operations doses for personal, population and environment should not exceed established by norms and rules of Russian Federation and to be at reasonably achievable low level.

Main safety criteria

- Established by the installation project subcriticality level in all design modes should be more than 4 %, and at any design accidents more than 2 %;
- Absence of the untight FE in active core in the operation of the installation.

The first criterion is provided with sequential initial loading of the core, established subcriticality level makes ~ 5 % is ensured by permanent control of the level of average power of the core, and also design and circuitry of the installation.

The second criterion is provided with FE design (FE designer – VNIINM), FA and core design (FA & core designer – NIKIET); permanent control of tightness of the FE and cooling system parameters.

Subtasks 6.1 and 6.2 are completed.

Task 7 Civil engineering solutions on installation creation and allocation

General Solutions for the Facility Allocation

Preliminary technical and economical estimations, made during the ISTC proposal preparation, showed that the SAD facility should be located in a new building that has to be constructed in the free area between the existing accelerator building and existing outhouses (Figure 10).

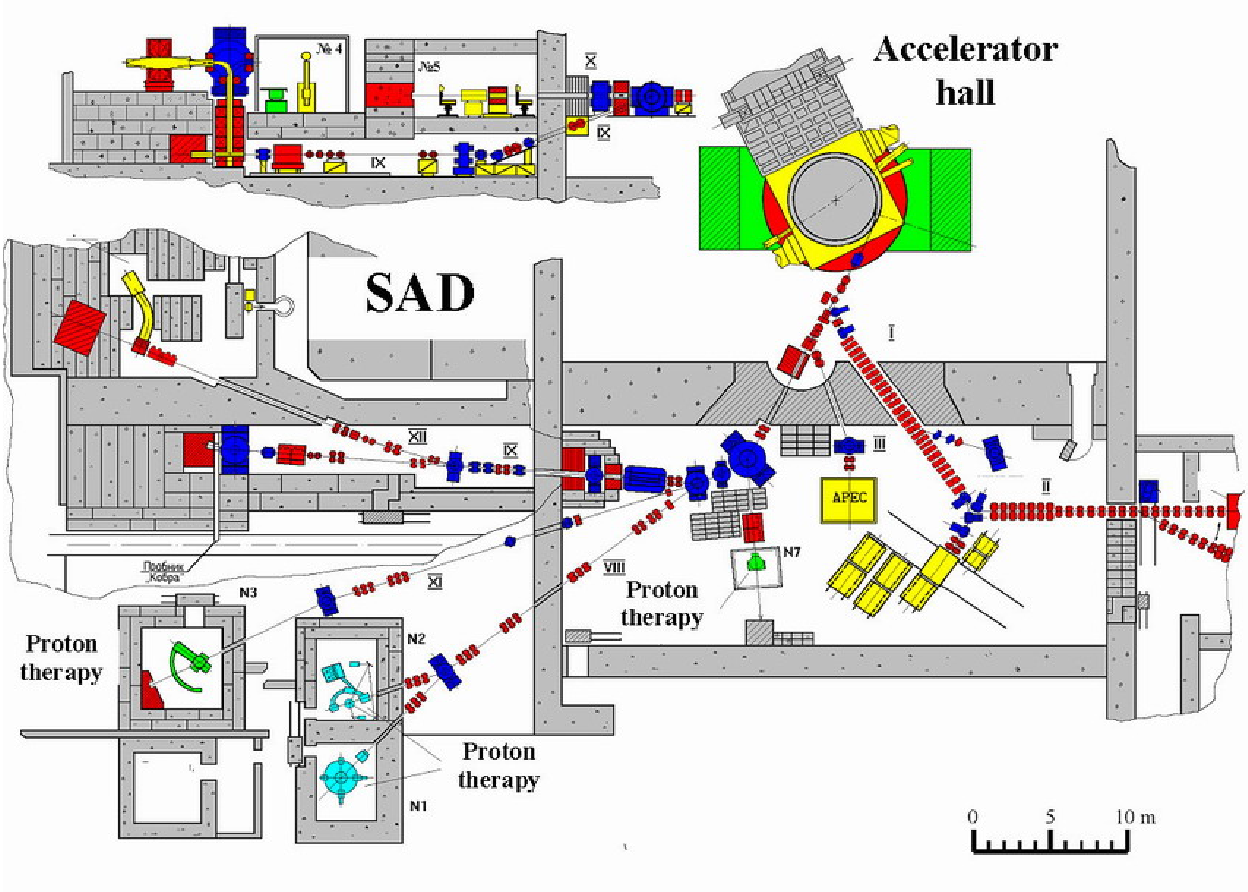


Figure 10. General plan view of the JINR "Phasotron" accelerator complex (in the left upper corner side view of the neutron/meson therapy complex).

The general layout of the installation guides the proton beam injection from the bottom of the installation after a 110 degrees turn with strong bending magnets. So the proton beam heats the target from below and it is necessary to have a rather thick beam stop in the forward i.e. top direction. The biological shielding properties will be determined by the highest neutron energy.

The horizontal beam coming from the PHASOTRON is first deflected 20 degrees downwards inside the accelerator hall, then turns 110° in the SAD building and hits the spallation target, located inside the fuel blanket from below. This construction allows avoiding safety problems with possible water ingress accidents, which would exist in the case of beam injection from the upper side and with the cooling water of the bending magnets above the sub-critical core (Figure 11).

Main parameters of the SAD building are listed in the Table 14

Table 14. SAD building qualitative characteristics.

Parameter	Value
Site area, m^2	350
Total area, m^2	950
Building volume, m^3	8300
Bulk concrete volume, m^3 (biological shielding)	1900
Steel shielding, ton	290
Bulk heavy concrete volume, m^3 (ρ = 3.6 and 4.5)	25
Soil shielding volume, m^3	2000
Excavated soil volume, m^3	4000
Concrete retaining wall necessary to dismount, m^3	350

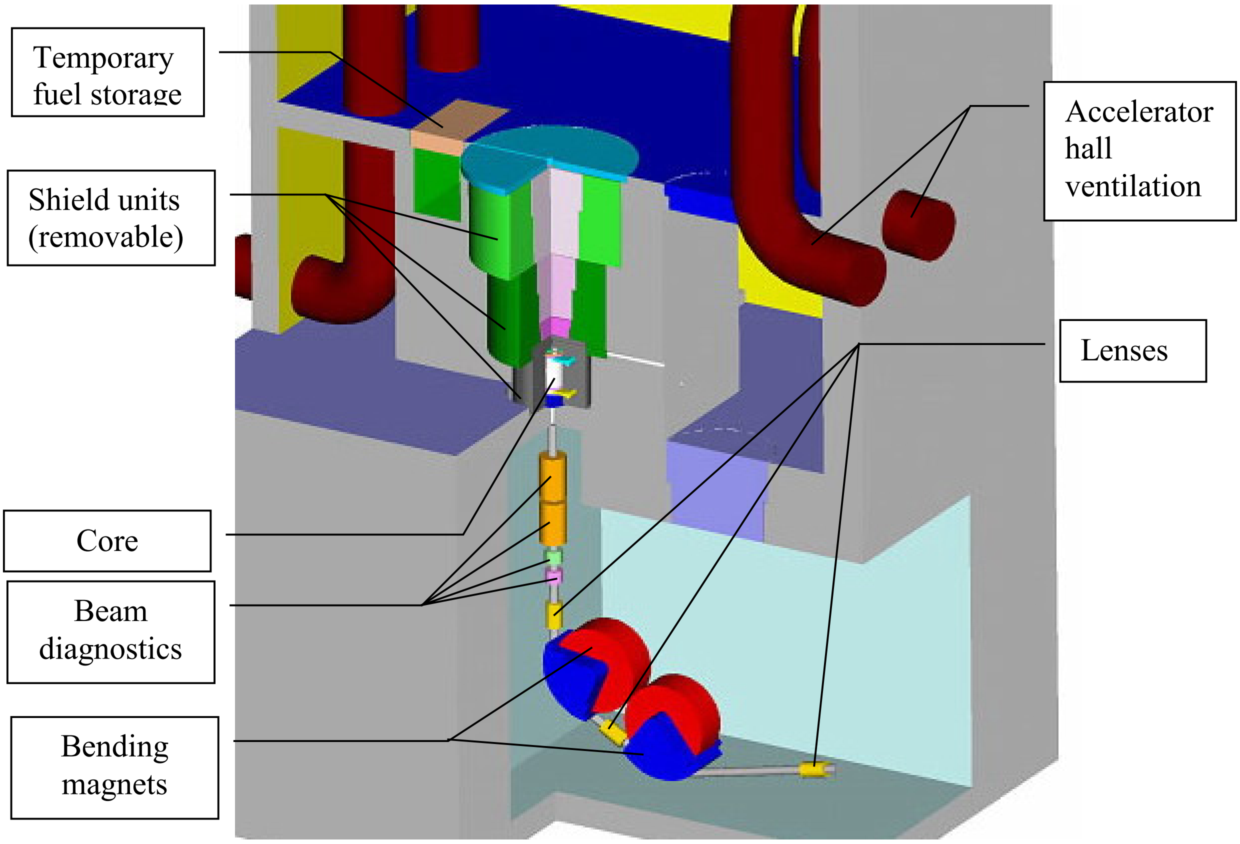


Figure 11. SAD building general layouts: total volume of concrete shielding is about 3000 m^3, weight of the steel shielding about 1000 tons

Current work

Task 2 SAD parameters modeling

First priority subtasks **2.3**; **2.6** and **2.7** on numerical simulation of the neutron spectra in SAD building and induced activity calculation now are in progress.

Task 3 Design and development of the beam transport line

Technical project of the SAD beam line is underway (subtask **3.2**). All activity goes according to the schedule.

Task 4 Design and development of the SAD fuel elements

Technical project of the SAD FE (subtask **4.3**) and working documentation on FE (subtask **4.4**) development is in progress. All activity goes according to the schedule.

Task 5 Production preparation, preproduction batch of fuel pellets manufacturing

Factory preparation for the manufacture of the preproduction batch of MOKS-fuel pellets (subtask **5.5**) goes ahead of schedule.

Task 6 Design and development of the subcritical assembly (SA)

Subtask **6.3** is underway; work goes according to the schedule.

Task 7 Civil engineering solutions on installation creation and allocation

Development of a preliminary general layout of the SAD building (subtask 7.4) is underway. Work goes according to the schedule.

Conclusion

During the first two quarters of the ISTC project #2267 realization significant progress was achieved in all tasks of the project.

All activities went according to the schedule or ahead of. Five organizations – project participants have demonstrated good cooperation and effective management.

All necessary paperwork was completed according to the time schedule.

References:

[1] Works program on PuO_2 powder production at the plant RT: FGUP"PO Mayak"; A.I. Bobylev, I.V. Minakov. – No.ЦЛ/3904 of October 7, 2002;

[2] Recommendations on uranium preparation for MOKS-fuel production: Recommendations/ FGUP " IA Mayak"; A.I. Bobylev, I.V. Minakov. – .ЦЛ/1732. – Ozersk, 2004;

[3] Experimental works program on manufacture of fuel kernels from the MOKS-fuel for JINR, Dubna (Project SAD): FGUP " IA Mayak"; A.I. Bobylev, I.V. Minakov. – No.ЦЛ/295 of February 9, 2004;