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Shipment of HEU Fuel from Pamir Reactor in Belarus to the Russia and Conversion to High Density LEU Fuel

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ABSTRACT

In 2010 under the Global Threat Reduction Initiative, the Joint Institute for Power and Nuclear Research – "Sosny" of the National Academy of Sciences of Belarus repatriated HEU fresh and spent nuclear fuels to the Russian Federation. The fresh and the spent nuclear fuels were from the decommissioned reactor of Pamir-630D mobile NPP. The fuel composition was UO_2 spherical particles enriched to 45% U-235 in a nickel/chromium matrix (UO_2-Ni-Cr). Fuel rod was composed from pellets. The pellets consist of specified spherical particles with built-up cover from stainless steel. A material of clad — stainless steel. The HEU fresh fuel has been replaced with new LEU fresh fuel. New nuclear fuel will be created for research purposes at the critical facility "Giacint" on development of perspective cores for small size reactors. The fuel consists of uranium-zirconium carbon nitride $U_{0,9}Zr_{0,1}C_xN_{1-x}$ with 19,75% enrichment by U-235. Density of uranium - more than 10,5 g/sm^3. The clad material is stainless steel or niobium. This paper discusses shipment of HEU fuel and conversion to high density LEU fuel.

1. Introduction

In the fall of 2010 under the Global Threat Reduction Initiative, the Joint Institute for Power and Nuclear Research – "Sosny" (JIPNR-Sosny) of the National Academy of Sciences of Belarus repatriated highly enriched uranium (HEU) fresh and spent nuclear fuel to the Russian Federation. The fresh and the spent nuclear fuel were from the decommissioned Pamir-630D mobile reactor and IRT-M research reactor. These fuel shipments marked the complete removal of all HEU spent nuclear fuel from Belarus. The HEU fresh fuel of Pamir-630D mobile reactor has been replaced with new low enriched uranium (LEU) fresh fuel. LEU fresh fuel was design and produced for "Giacint" critical facility under Belarus-Russian –American cooperation on conversion nuclear fuel of research reactors.
This paper discusses the Pamir-630D mobile reactor, the HEU fuel, the fresh LEU fuel and the various aspects of the shipment in detail including: the planning, preparations, and coordination required for completing this international shipment successfully.

2. HEU Spent and Fresh Nuclear Fuel of Pamir-630D reactor

In 70-80 years of last century JIPNR-Sosny (early - Institute of Nuclear Power of the National Academy of Sciences of Belarus) developed the mobile nuclear power plant "Pamir-630D". Appointment of NPP Pamir was maintenance with the electric power of the mobile and stationary objects located in remote and hard-to-reach regions.
The mobile NPP had an electrical power output of 630 kW (thermal power of the reactor is 5000 kW; reactor campaign is 10000 hours) and included five basic modules: a reactor; a turbine generator set; two modules of system for control and protection; and an auxiliary module. The modules were installed on semi-trailers that could be transported by trucks. A picture (see Fig.1) of the reactor module on its semi-trailer is provided below.

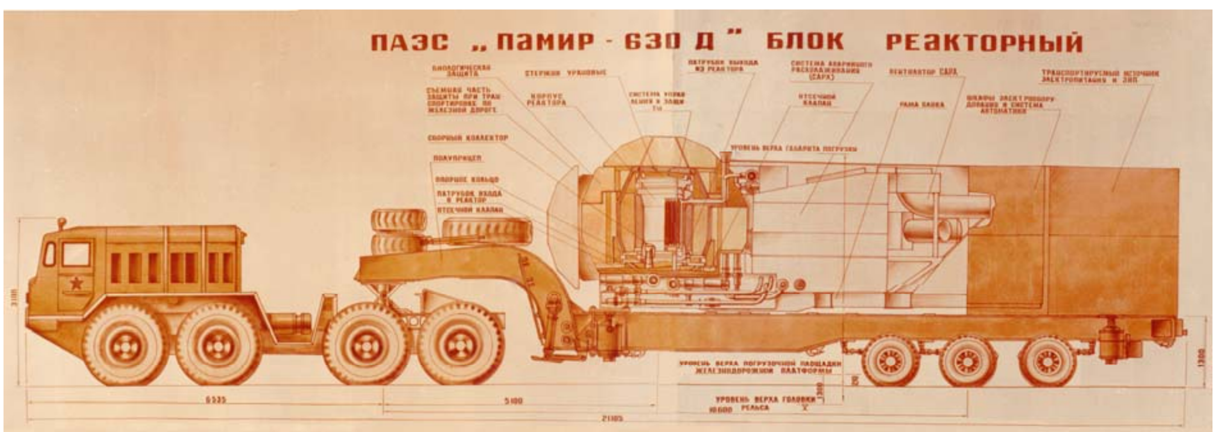


Figure 1. Reactor module of NPP "Pamir-630D".

The coolant of reactor was nitrogen dioxide with nitric oxide additives ($N_2O_4 \leftrightarrow 2NO_2 \leftrightarrow 2NO + O_2$). The moderator and reflector neutrons of core was the zirconium hydride $ZrH_{1,9}$.
The reactor core consisted of 106 fuel assemblies, surrounded with 45 reflector assemblies (see Fig 2).
Flattering of power distribution as to the radius and the height of the core was reached with decreasing of moderator's content in a central region of the core as well as by placing of burning

out absorber (boron enriched to 85% boron-10) into a part of FA which simultaneously served for compensation of excess reactivity of the reactor for a campaign. Three types of fuel assemblies were used in the active core placed with the pinch of 45 mm. 12 sealed ampoules of rod's drive of the control system are founded into the bottom of the reactor. The material of neutron absorber was europium dioxide Eu_2O_3.

Each fuel assembly (see Fig 3.) included seven fuel rods. The fuel elements (see Fig.4) were made from UO_2 particles enriched to 45% ^{235}U in a nickel / chromium matrix (UO_2-Ni-Cr) and clad in stainless steel. Diameter of fuel rod - 6, 2 mm, length - 650 mm. Thickness of clad - 0, 4 mm. Volume content of UO_2 in the fuel composition was near 60%. Fuel rod was composed from 5.2 mm diameter pellets. The pellets consist of specified spherical particles with build-up cover from stainless steel. The height of fuel core was 500mm.

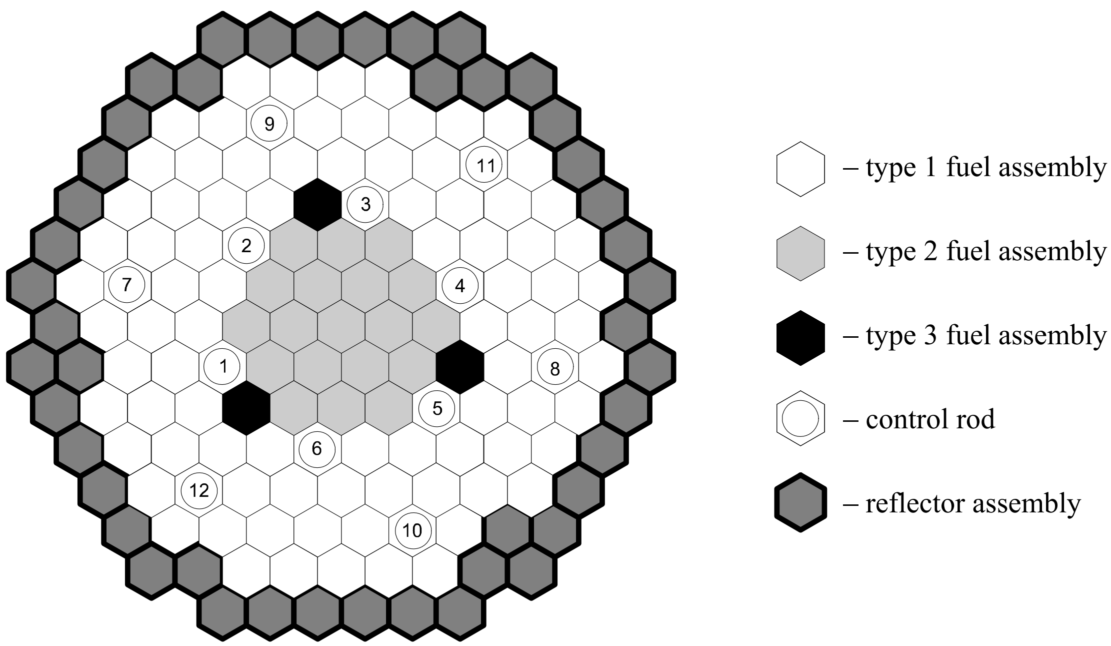


Figure 2. Cartogram of the"Pamir-630D" reactor loading

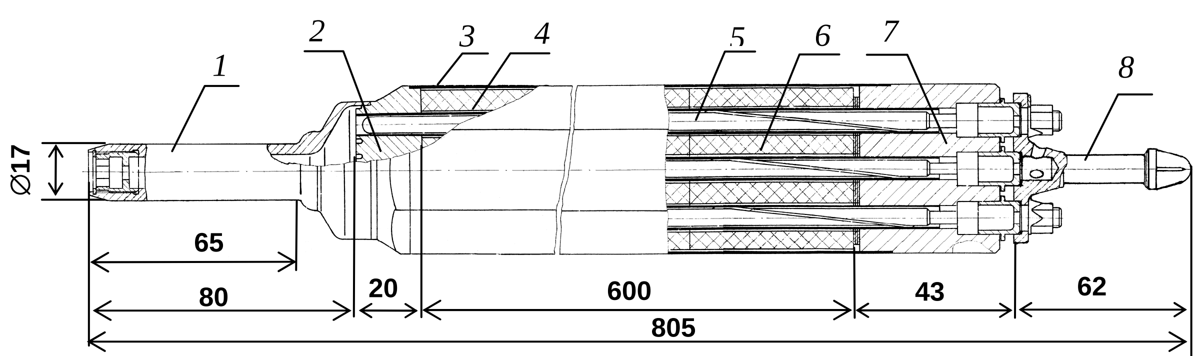


Figure3. Fuel assembly of NPP "Pamir-630D":
1 – bottom nozzle; 2 – bottom tube plate; 3 – clad; 4 – casing tube; 5 – fuel rod;
6 – zirconium hydride block; 7 – top tube plate; 8 – top nozzle

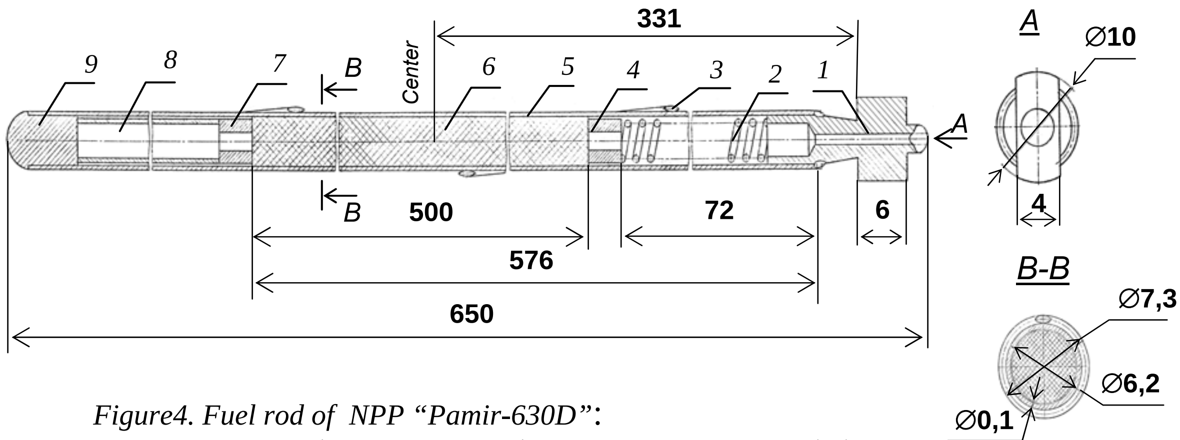


Figure4. Fuel rod of NPP "Pamir-630D":
1 – top cap; 2 – spring; 3 – spacer wire; 4 – top stopper; 5 – clad;
6 – fuel core; 7 - bottom stopper; 8 – plug; 9 – bottom cap

Two reactors of NPP Pamir-630D have been produced for carrying out of tests. The first one reactor of NPP Pamir-630D was put into operation in 1985 and testing was halted in 1986. During tests the reactor was deduced on various levels of power. Average energy-producing for the period of tests is estimated by $6{,}9 \cdot 10^6$ kW·hour. The fuel was discharged in 1991 with an average burn up of 0.78% uranium atoms. All 106 spent fuel assemblies were stored in the spent fuel pool (one no hermetic Pamir assembly was failed and was placed in a sealed canister). Except for Pamir fuel the spent nuclear fuel which was tested in IRT-M reactor were stored in pool. It was five sealed canister with experimental ball fuel rods and fuel rods type EK-10. The burn up of this fuel is estimated from 7 to 20 %.

The spent fuel pools of the Spent Fuel Storage Facility are located in the same building where the pilot reactor was tested. The critical parameters of the water in the pool are checked out once a week. The water in the pool is checked for specific activity of fission-produced isotopes of Cs-134 and Cs-137 and corrosion-produced Co-60 isotopes.
The second reactor of Pamir-630D NPP was not tested. The 114 fresh fuel assemblies and 53 specimen fuel Pamir rods were stored in the Fresh Fuel Storage Facility. Before the beginning of shipment the fuel assemblies have been disassembled and from them fuel rods are taken. Summary there was prepared 851 fresh fuel Pamir rods for shipment on exchange program of HEU/LEU uranium fuel.

3. LEU Fresh Nuclear Fuel for "Giacint" Critical Facility

LEU fresh fuel was design and produced for "Giacint" critical facility under Belarus-Russian – American cooperation on conversion nuclear fuel of research reactors.
The low enriched fuel consists of uranium-zirconium carbon nitride $U_{0,9}Zr_{0,1}C_xN_{1-x}$ with 19.75% enrichment by U-235. Density of a fuel composition is not less than 12 g/sm^3, porosity - less than 12 %, density of uranium - more than 10,5 g/sm^3, diameter of a tablet - 10,7 mm. Length of the uranium fuel part of rod - 500 mm, diameter of the fuel rod 12 mm, common length of the fuel rod - 620 mm (see Fig.5). Thickness of clad is 0,6 mm. The clad material is stainless steel or niobium.

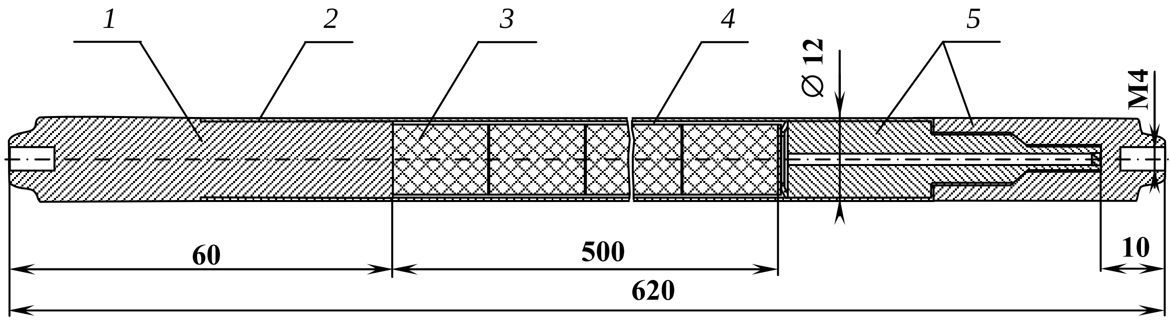
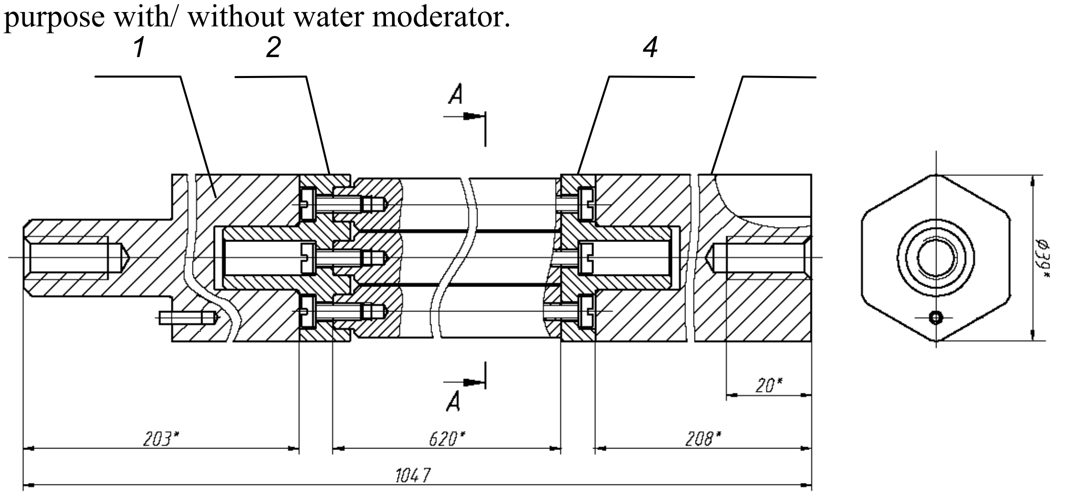


Figure 5. LEU fuel rod:
1 – top cap; 2 – clad; 3 – fuel core; 4 – space; 5 – bottom cap

In frame of uranium-235 equivalent exchange of HEU/LEU nuclear fuel, FSUE "SRI SIA "LUCH" produced 218 LEU fuel rods , including 168 in stainless steel clad and 50 in niobium clad. Features of the fuel rod technology:

- divergence of U-235 content from nominal value < 3%;
- unevenness of uranium content on height of the fuel core ± 5% of average value;
- fuel rod deflection density < 0,3 mm;
- fission product yield < 10-3;
- uranium pollution surface clad < 10-8 g/cm2;
- gas between fuel core and clad – He (pressure 0.11MPa).

The fuel assembly for "Giacint" critical facility consists from seven LEU fuel rods (see Fig.6). The fuel assembly does not have the clad.
These fuel assemblies will be used for developing new low power nuclear reactor configurations cooled by gas or water. In particular, this nuclear fuel can be used at conversion HEU on LEU nuclear fuel in research reactors. Critical assemblies have been developed for performance of this purpose with/ without water moderator.



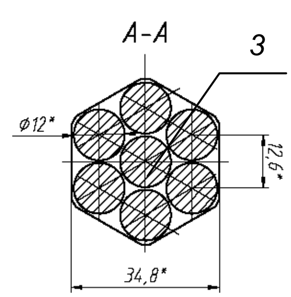


Figure 6. Fuel assembly "Giacint" critical facility :
1 – bottom nozzle; 2 – bottom tube plate; 3 – fuel rod;
4 – top tube plate; 5 – top nozzle

4. Legal Frameworks

The legal frameworks of shipments were:
Government-to-Government Agreement (GTGA): Unites States and the Russian Federation – *'Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning Cooperation for the Transfer of Russian-Produced Research Reactor Nuclear Fuel to the Russian Federation'*, dated May 2004. The GTGA provided the rules for participant eligibility, funding responsibilities, and program approval.
Diplomatic Note: United States and the Republic of Belarus – *'Agreement between the Government of the United States of America and the Government of the Republic of Belarus regarding assurances concerning the provision of technical assistance that may be provided by the Government of the United States of America, through the United States Department of Energy and its contractors, to support the transfer of spent research reactor nuclear fuel from the Joint Institute for Power and Nuclear Research "Sosny" of the National Academy of Sciences of Belarus to the Russian Federation',* dated October 1, 2010. This Agreement provided liability protection and tax exemption for this nuclear nonproliferation project.
GTGA: Republic of Belarus and the Russian Federation – *'Agreement between the Government of the Republic of Belarus and the Government of the Russian Federation on cooperation for import to the Russian Federation of irradiated and fresh high-enriched nuclear fuel of the research reactor and delivery to the Republic of Belarus of fresh low-enriched nuclear fuel'*, dated October 8, 2010. This GTGA provided the pathway and guidelines for returning the spent and fresh HEU nuclear fuel to Russian Federation, the final disposition of the Radioactive Waste (RAW) in Russia, and also delivery to the Republic of Belarus of fresh LEU nuclear fuel.

5. Cask Specifications

For several reasons such as fuel specifications, cask availability, and facility configuration, the SKODA VPVR/M cask (see Fig.7) was selected for the spent nuclear fuel shipment. The cask was specially designed for use by the RRRFR program and, with top and bottom loading capabilities, can be easily accommodated in most facilities. The cask is made of steel and aluminum and has a diameter of 1.2 m, height of 1.5 m, and weighs 12.4 mt fully loaded. Two basket configurations were used for the JIPNR spent fuel, the standard 36 SFA basket and the TS-3 basket which holds six canisters. Four casks were used to transport the 111 items (105 intact assemblies and 6 sealed canisters). The casks were transported in ISO containers, one cask per ISO container.

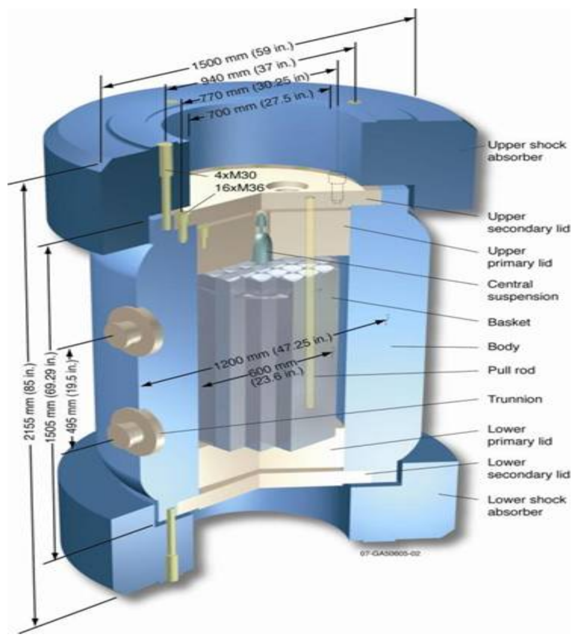


Figure 7. SKODA VPVR/M cask

In Russia, the SKODA VPVR/M cask certificate for design and transportation was issued by the Rosatom State Nuclear Energy Corporation on June 11, 2010. In Belarus, the certificate validation was issued by Gosatomnadzor on September 3, 2010.
For the fresh nuclear shipment TK-S16 casks (see Fig.8) was selected. This cask has the certificate for design and air transportation the fresh nuclear fuel both Russia and Belarus.

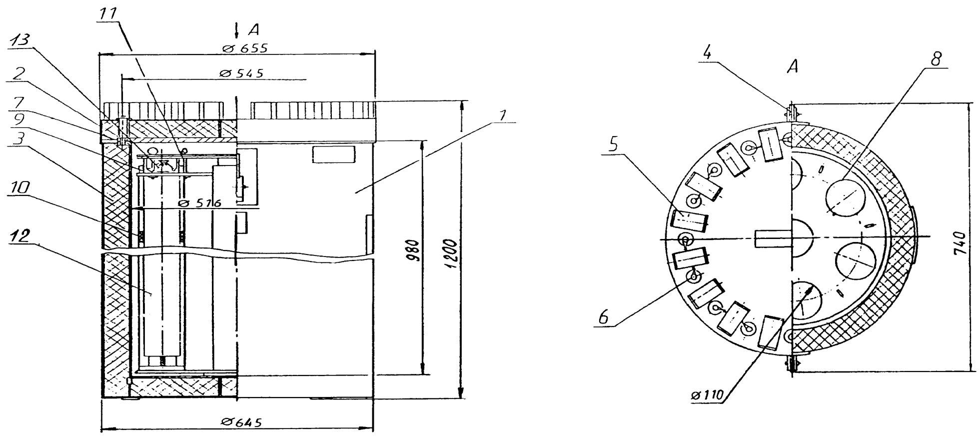


Figure 8. TK-S16 casks:
1 – body; 2 – cover; 3 – lagging; 4 – lifting element; 5 – damper;
6 – bolt M12; 7 – innerseal; 8 – fettling; 9, 10 – cellular polystyrene plug;
11 – fettling lid; 12 – polyethylene and calico casings; 13 – silica gel

Both for shipment of spent nuclear fuel in SKODA VPVR/M cask and for shipment of fresh nuclear fuel in TK-S16 cask calculations on nuclear and radiating safety have been lead in Russia (VNIEF, Russia) and Belarus (JIPNR-Sosny, NAS Belarus). Loading of casks by nuclear fuel completely corresponded to national requirements on nuclear and radiating safety.

6. Shipment Logistics Summary

Part I. Shipment of Spent Nuclear Fuel
Once the Government of Belarus declared its commitment to return the spent fuel, a project kick-off meeting was held in January 2009. From the beginning, the project had two major challenges. The first challenge was to determine where and how the Pamir spent fuel would be dispositioned. The Ni-Cr fuel matrix and stainless steel cladding of the Pamir SFA could not be reprocessed at Mayak using the standard processing line (used for UO_2 / UAl fuel matrix and aluminum clad fuel). A technology research project was conducted in parallel to the shipment preparations to determine how the Mayak processing line could be modified and the flow chart updated to accommodate the Pamir SFAs. The second challenge was the project completion deadline of September 2010, which was accelerated to support commitments made by the National Nuclear Security Administration (NNSA). The average project schedule for shipping spent fuel to Russia had been over 2 years; this shipment was to be conducted in 18 months.

Authorization to import the spent nuclear fuel into Russia was received using the procedure mandated by Russian decree. A Unified Project (UP) was developed and approved after a positive conclusion by the State Ecological Expertise Review Board. The UP is a collection of analyses and documents that look at: justifying the safety and assessing the environmental

impact of import; implementation of special ecological programs; anti-terrorist measures; cask licenses; emergency response; and the Foreign Trade Contract (FTC). The FTC was the main contract between FCNRS and JIPNR-Sosny to import the spent nuclear fuel. The FTC includes transportation, reprocessing, storage and disposal. Once the UP was approved, a governmental decree was issued along with the import license.
In Belarus, transportation permission was supported by documents looking at: physical protection; emergency response; cask licensing; facility license; and environmental and health concerns. The transportation permission was issued by the State Industrial Supervisory Authority, Gospromnadzor. The export license was issued by State Military-industrial Committee of Belarus.

By the beginning of September 2010, the last of the four casks had arrived, the final equipment setup and testing and personnel training had been completed and the facility was ready for loading. A truck was used to back each ISO container into the room that was located below the main hall where operations were conducted. The SKODA cask was lifted from its ISO container and positioned in the main hall in its designated storage location. Prior to the loading of each cask, the specified number of SFAs were verified and transferred (via a transfer cask) from pool #1 to pool #2 in preparation for loading. In period of this transfer the residual activity measurement of separate SFAs by means of special created installation were spent. A cask was then lowered onto the working platform surrounding the spent fuel pools where the impact limiters and secondary lids were removed. The SKODA cask was placed over pool #2 and the basket was connected to the hoist and handling rods. The basket was lowered into the pool and the fuel assemblies were loaded into the basket according to the loading schemes. An IAEA inspector performed a measurement on each SFA to record the cesium peak to verify the presence of spent fuel. After the last SFA was loaded into the basket, the basket was raised and secured into the cask. The loaded cask was then placed in the cradle where the secondary lids were installed and the vacuum drying and leak testing were performed. IAEA inspectors placed two seals on the top secondary lid per safeguard requirements. Once the cask passed the leak test, the impact limiters were installed and the cask was placed in its designated storage position on the main level of the main hall. An IAEA safeguard seal was also installed on the impact limiter. The cycle was repeated for all four casks. 35 SFAs of "Pamir-630D" reactor were loaded into standard baskets in the first three casks. The fourth cask contained the TS-3 basket which was used for the 6 sealed canisters (5 canisters with SFAs of IRT-M reactor and 1canister with SFA of "Pamir-630D" reactor). The loaded casks were lowered from the main hall to their ISO containers and stored outside until the day of transportation to the rail station.

The loaded ISO containers with the SKODA casks were transported one at a time by truck to the area where the rail station was located. Special Forces guards were located approximately every 200 meters along the route from the Sosny Institute to the entrance of the rail station, including extra guards at overpasses and bridges. All traffic was diverted or stopped while the material was on the roadway. Each round trip took about 2 hours to complete. Under heavy guard by Belarusian Special Forces, the train departed for the Belarus / Russian Federation border. All details of roadway/railway transportation from territory of JIPNR-Sosny up to the Belarus / Russian Federation border have been thought carefully over and prepared. As result of these activities there were no incidences or issues during the transport. At the border, the responsibility for guarding the spent fuel was transferred to the Russian guards. The travel time from the border to Mayak was approximately 3 days.

Part II. Shipment and Delivery of Fresh Nuclear Fuel

In accordance with GTGA between Republic of Belarus and the Russian Federation from October 8, 2010 the shipment of HEU nuclear fuel to Russian Federation realize under the condition of the delivery of LEU nuclear fuel to Belarus with uranium-235 equivalent amount. For performance of this condition FSUE "SRI SIA "LUCH" produced LEU nuclear fuel in advance according to the order of ROSATOM Corporation. Uranium fuel has been taken for this purpose from the State reserve of the Russian Federation. IAEA and DOE of USA through their subcontractors provided financing producing of LEU fuel and an HEU/LEU fuel exchange.

Uniqueness of operation on exchange of fuel consist that on a platform of the airport in current of several hours simultaneously there was a unloading LEU nuclear fuel and loading HEU nuclear fuel aboard the plane. The plane of the Volga-Dnepr company has delivered casks with LEU fuel in the national airport Minsk (Belarus) in precisely appointed time. The plane has been placed on specially allocated zone which has been taken on protection by Special Forces guards. Casks with HEU fuel in ISO-container have been delivered to this time from JIPNR-Sosny to place of airport by truck also under armed escort. According to the developed technological scheme the operation on an unloading LEU nuclear fuel and loading HEU nuclear fuel aboard the plane have been executed. Owing to precisely planned actions of all executors this complex operation has been fulfilled for 3 hours without any incidents.

For conformity to national requirements of Belarus under the treatment of nuclear materials JIPNR-Sosny developed and received approval under following programs and documents:

- 'Conditions of Safe Transport' document
- TK-S16 Cask validation
- Transportation Program
- Physical Protection Program
- Emergency Response Program
- Transportation Permission
- Export License of HEU nuclear fuel
- Import License of LEU nuclear fuel

A picture (see Fig.9) of the train and air shipment provided below.

Figure 9. Shipment of Spent and Fresh Nuclear Fuel, Belarus 2010

7. Conclusion

The shipment of highly enriched uranium nuclear fuel from the Joint Institute for Power and Nuclear Research – "Sosny" marked the end of a successful project that removed all of the spent HEU from Belarus. LEU fresh fuel was design and produced for "Giacint" critical facility under Belarus-Russian –American cooperation on conversion nuclear fuel of research reactors. Exchange of HEU/LEU nuclear fuel was realized with uranium-235 equivalent amount in frame of international project. This project was an excellent example of international cooperation between the various organizations of Belarus, Russian Federation, United States of America, and IAEA.