Experience in Organization of Non-Regular Shipments of Radioactive Material

Sergey V. Komarov, Denis V. Derganov, Sergey N. Komarov (Sosny R&D Company)
Aleksander Ye. Buchelnikov (Rosatom State Corporation)

Introduction

The International Program on Russian Research Reactor Fuel Return (RRRFR) is coming to its completion giving an opportunity to summarize lessons learned and preliminary results.

The RRRFR program has involved 15 countries out of 17 having Russian-design reactors. Many Russian enterprises have participated in RRRFR projects at different stages. Among them are TENEX, FCNRS (authorized organizations), NCCP, RIAR, Luch (consignees of non-irradiated fuel), Mayak PA (the SNF consignee), Russian Railways, Volga-Dnepr Airlines, ASPOL Baltic Corporation and others (carriers), VNIIEF, VNIPIET, IPPE NSD (developers of certificates and safety assessment documents), ERTC SPb, Atomspetstrans and others (emergency response). All the projects are supervised by Rostechnadsor and controlled by Rosatom State Corporation.

Sosny R&D Company develops acceptance criteria and performs SFA inspections at research reactors, develops equipment for SFA loading into casks, upgrades vehicles for transportation of SFA packages, elaborates justification documents, participates in upgrading the equipment for foreign cask handling in the Russian Federation.

Another Sosny's important activity is the participation the Federal Targeted Program "Ensuring Nuclear and Radiological Safety in 2008 and in the Period until 2015" (hereinafter, FTP ENRS). The past three years witnessed projects on handling non-conforming SNF from the RBMK reactor, preparation for transportation and a pilot shipment of SFA from IPPE, feasibility studies of different options of preparing the Bilibino NPP SFAs for transportation and disposal.

The paper describes experience in organizing shipments of fissile materials that have been implemented in the past three years after IV International Nuclear Forum "Safe Nuclear Technologies: Safe Transport of Radioactive material" (Atomtrans-2009) and demonstrates a possibility to use this experience in organizing non-regular shipments of radioactive material in Russia.

In compliance with the resolution of Atomtrans-2009 Forum, a TUK-145/C (Type C) package has been developed and certified for air shipments of different high-activity radioactive material.

Return of RR nuclear fuel under RRRFR program

A U.S./Russia cooperation agreement was signed in 2004. By now, almost all non-irradiated fuel has been removed. In 2010, the fuel was removed from Sevastopol National University of Nuclear Energy and Industry, Ukraine. Preparation for transportation of unused non-irradiated HEU fuel from Hungary, Poland and Belarus is in progress.

Geographical locations of the countries having Russian-origin research reactors have conditioned the use of air transport as the main means of shipment of non-irradiated fissile material. This resolves several transit-related problems; in particular, logistic and customs procedures became simpler and physical protection became easier.

Return of the research reactor SFA to the Russian Federation under the RRRFR program involves much more serious tasks - economical, technical and organizational. This requires close cooperation of all organizations involved in the project.

Table 1. Completed and future RRRFR shipments of HEU fuel (since 2010)

Year	Country	FA	Cask	Transport mode
Non-irradiated nuclear fuel				
2010	Ukraine	S-36, PPU	TK-S15	road, air
Irradiated nuclear fuel				
2009-2010	Poland	MR, VVR-M2	TUk-19, SKODA VPVR/M	road, rail, sea
2010	Serbia	TVR-S	TUk-19, SKODA VPVR/M	road, rail, sea
2010	Belarus	Pamir-630, EK-10	SKODA VPVR/M	road
2011	Ukraine	VVR-M2	SKODA VPVR/M	road, rail
2012	Romania	EK-10	TUK-19	road, air
2012	Uzbekistan	IRT-3M, S-36	TUK-19	road, air
Future shipments of non-irradiated nuclear fuel				
2012	Hungary	ZR-4	TK-S15	road, air
2012	Poland	MR	TK-S15	road, air
2013	Belarus	no data	no data	road, air
Future shipments of irradiated nuclear fuel				
2012	Poland	MR, EK-10	TUk-19, SKODA VPVR/M	road, rail, sea
2013	Vietnam	VVR-M2	TUK-145/C	road, air
2013	Hungary	VVR-M, VVR-M2	SKODA VPVR/M	road, rail, sea or air
2013	Czech Republic	IRT-2M	SKODA VPVR/M	road, rail, sea

Year	Country	FA	Cask	Transport mode
2015	Poland	EK-10	SKODA VPVR/M	road, rail, sea
2015	Kazakhstan	VVR-Ts	TUK-19	road, rail

The RRRFR program has become a catalyst for enhancement of the fleet of containers, development of the SFA loading equipment, development and use of new transport equipment and routes. Below is a description of the latest several projects. The equipment and technologies developed for these projects has already been used for domestic shipments.

Preparation and removal of damaged SFA from Serbia

The project on removal of damaged Russian-origin SNF from Serbia was completed in late 2010.

One of the peculiarities of the Serbian project was a big quantity of severely damaged fuel. The fact that the fuel at the Serbian facility was damaged caused no doubts, since the activity of the water had been constantly increasing; however, it was almost impossible to experimentally check the health of the fuel, the degree of its damage and the state of aluminum tubes containing the fuel. So, in selecting a fuel handling technology and making safety analysis, we had to develop conservative theoretical models and follow the predictions.

The big quantity of the spent fuel and its fast-worsening state required that the fuel be removed as a single run and in the shortest possible time. A long route, several transit countries and transport modes, two types of casks, new European regulations and many other nuances made the Serbian campaign one of the most complicated in terms of getting licenses.

Non-tight canisters were used to transport the Serbian fuel. It was quite a trick, since the damaged fuel is usually transported in a tight packaging. Sosny and VNIIEF experts analyzed and justified all safety aspects of handling the new canisters. The major issue was fire and explosion safety. The oxidized surface has a big quantity of associated water, and its removal was unfeasible in the infrastructure of the Vinca Institute. Once confined, the damaged SNF may generate an explosive hydrogen-oxygen concentration within several months. To avoid this, a non-tight design of the canister was selected allowing for regular blowing of the spent fuel inside the cask and preventing a hazardous hydrogen-oxygen concentration. Thus, it was demonstrated that a tight canister for the damaged fuel is not always a sound option and each particular situation requires a thorough analysis to come out with the best decision.

An important thing that had a positive effect on the Serbian project was a centralized coordination of the RRRFR shipments. This facilitates advantageous interactions between the projects and allows using experience, ideas, equipment and engineering solutions developed under other projects. So, the SNF was loaded with a transfer cask and transported in ISO containers for TUK-19 casks developed for the removal of the spent fuel from Romania, as well as SKODA casks fabricated for the removal of the spent fuel from the Czech Republic. Proven routes were used to deliver empty casks (by road and air); a sea route used for the removal of the spent fuel from Hungary for the first time was selected. In their turn, some Serbian solutions will be used in other projects. For instance, the Vietnamese project has adopted the “Serbian” idea and design of the equipment to transfer the casks by forklift.

Thus, the projects benefit from a unified program in terms of safety, schedule and cost.

The spent fuel started from Vinca Institute on the night of the 18th/19th November, 2010. It was a very important event for Serbia that had been waiting for it for almost 26 years. Serbian president Boris Tadic who had come in person to see off the vehicle convoy emphasized this fact in his address to the organizers of the shipment. The removal of the spent fuel from Vinca Institute got a wide response and appraisal of the international community and became a good example of international cooperation in enhancing safety of the nuclear industry.

Fig.1. President of Serbia (in the center) is expressing appreciation to the organizers of the Vinca SNF removal for their excellent job

Fig.2. The international team of the Vinca project at the port of Koper, Slovenia

Development of a route with ferrying across the Black sea

In 2012, a new transport plan was developed to deliver empty TUK-19 casks for the removal of the spent fuel from Romania. The plan included:

– Delivery of ISO containers with TUK-19 casks and ancillary equipment from Mayak PA to the port of Caucasus by rail,

– Transportation by the *Slavyanin* ferry (Fig.3) across the Black sea to the ferry terminal in Varna, Bulgaria,

– Reloading of the ISO containers from the railcars onto trucks at the ferry terminal in Varna,

– Shipment by trucks from the ferry terminal in Varna to IFIN-HH, Romania across the Bulgarian-Romanian border.

Fig.3. The *Slavyanin* ferry used for the shipment of empty TUK-19 casks

The new route can be useful for further shipments of radioactive material (not only RRRFR shipments) between the Russian Federation and European countries, since the port of Murmansk usually used for such shipments is located far away from European (mostly, Mediterranean) ports and the period of transportation can exceed one month (like in the Serbian project). The route through the port of Caucasus significantly decreases the period of transportation, which is a positive factor from the viewpoint of physical protection.

Development of TUK-145/C packaging (Type C)

In September, 2009, Sosny started development of the first Type C packaging by order of the U.S. Department of Energy under the RRRFR program. At the initial stage, a concept decision was taken to develop a dismountable

energy absorption container accommodating a SKODA VPVR/M cask (Fig.4).

In June 2010, after the feasibility to develop a Type C packaging for air shipments was validated, Sosny got a Technical Assignment for development of the Type C packaging approved by the Department of Nuclear and Radiation Safety of Rosatom State Corporation and concurred by all concerned entities. The packaging was assigned identification number TUK-145/C.

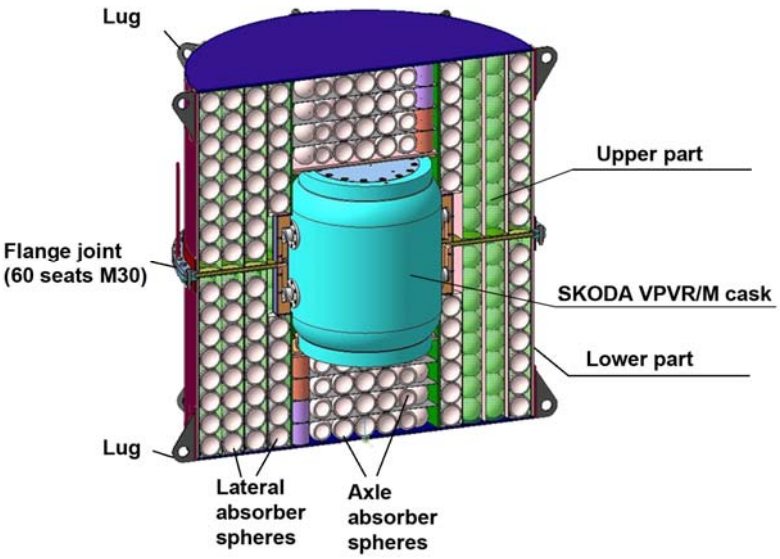

Fig. 4. Concept design of the TUK-145/C package

Since field tests for impact onto a solid target at a velocity of 90 m/s is a mandatory requirement, Sosny experts designed a mockup packaging TUK-145/C, which was a scaled-down replica. The 1:2.5 scale mockup was fabricated in April, 2011. By that time, a program of tests had been developed and approved by Rostatom State Corporation.

By order of Rosatom No.1-1/38-p dated 30 March, 2011, a Test Commission was assigned to include representatives of different Russian enterprises.

The mockup packaging TUK-145/C was tested in May, 2011 on a rocket sled at VNIIEF. After the tests it was visually examined and analyzed (Fig.5).

Fig. 5. Successful completion of the tests on the rocket sled

A certificate of approval of the package design was obtained in April, 2012. The energy absorption container (EAC) was fabricated in June, 2012.

To try out the procedure for reloading the TUK-145/C package from the truck in the aircraft (Volga-Dnepr aircraft AN-124-100), a dry run was carried out at Ulyanovsk-Vostochny airport in June 2012 (Fig.6).

Fig. 6. TUK-145/C and its developers

At present, an application for a certificate of approval for the shipment of SFAs from DNRR research reactor of Dalat Nuclear Research Institute, Vietnam in TUK-145/C is pending approval. The Russian certificate for the TUK-145/C package design has been submitted to the Vietnamese and Hungarian regulatory bodies for endorsement; international projects involving the TUK-145 packaging for air shipments of high-activity radioactive material are being discussed.

It is worth mentioning that organization of air shipments was started in 2005 after Russian regulations NP-053-04 were put into effect. Over the past years, considerable progress has been made in this field, i.e. equipment has been prepared and several SNF shipments by air have been certified and completed. In the authors' opinion, in view of development of international cooperation the transport of the spent fuel by air is relevant for discussion at the Atomtrans-2012 Forum regarding the experience gained, new proposals and the legal framework.

In the course of the RRRFR program, considerable experience in organizing various shipments of radioactive material has been gained. Despite the fact that the international regulatory method based on TS-R-1 has been widely used in all countries, administrative procedures for licensing transportation of radioactive material differ. This is due to a different scope of procedures to go through at competent authorities in each particular country. For the purpose of strengthening the international cooperation in safety and security of radioactive material, it is necessary to focus on harmonization of national regulations and development of emergency response regulation procedures during international shipments of radioactive material.

Pilot shipment of non-conforming RBMK-1000 SFAs

In 2011, a pilot project was completed to ship a trial batch of non-conforming SFAs of the RBMK-1000 reactor from the Leningrad NPP and reprocess it Mayak PA. The project was aimed at validating the feasibility of the safe transport of non-conforming (in the first place, leaky) SFAs and practicality of their reprocessing, as well as at searching for the consignor's and the consignee's well-coordinated procedures for SNF handling.

It had been an established opinion for a long time that the RBMK SNF reprocessing was impractical. This had sound reasons: the initial enrichment in uranium-235 was low (2% maximum), the cost of uranium was not high, and other sources of uranium completely satisfied the demand for it. Things have changed since then: fuel with the initial enrichment of up to 2.8% is used, and the cost of uranium has increased several times. To provide all necessary data for resolving a dispute on the practicality of the RBMK SNF reprocessing and to validate the feasibility of shipment and reprocessing, Rosenergoatom Concern took a decision on January 14, 2011 to carry out a pilot project on transportation of fuel rod bundles of non-conforming spent fuel assemblies from Power Unit 2 of the Leningrad NPP to Mayak PA.

Moreover, there was another important reason behind the project. Unlike the conforming RBMK SNF to be placed for a long-term dry storage in accordance with Rosatom's concept, no decision on the non-conforming RBMK SNF has been made yet within a legal framework. Strong reasons are required to make a decision on transportation and reprocessing of the non-conforming RBMK SNF on a regular basis.

From the practical viewpoint, some technical issues had to be resolved to implement the project:

- select spent fuel assemblies for the trial batch;
- select a cask and develop packaging components for transportation of the trial batch of the non-conforming SFAs (primarily, leaky ones);
- develop a procedure and equipment for cutting the SFAs and loading the bundles into the cask at the Leningrad NPP;

– develop a procedure and equipment for handling the fuel rod bundles at Mayak PA.

Moreover, research tasks related to safety analysis of the non-conforming SNF handling had to be tackled. It was also necessary to obtain appropriate approvals. In 2011, these tasks were successfully completed and in November 2011 the trial batch of the non-conforming RBMK spent fuel assemblies was transported from the Leningrad NPP and reprocessed at Mayak PA.

The project involved the well-proven cask TUK-11 with basket 12. It also provided for SFA cutting in the hot cell of Power Unit 2 at the Leningrad NPP. However, the major challenge with regard to transportation of the non-conforming SNF is fire and explosion safety of the package with leaky non-dried fuel that had been stored underwater for a long time. So, a decision was taken to transport the fuel rod bundles of the non-conforming SFAs in air-tight thin-wall canisters that could be reprocessed together with the bundles at the radiochemical plant. The canisters had to satisfy strength requirements under normal and accident transport conditions and during handling at the NPP and Mayak PA.

Predictions and the tests carried out at SSC RIAR demonstrated that the fire hazardous and explosive hydrogen-oxygen concentration cannot be produced inside the air-tight canisters (if filled up with air under atmospheric pressure without inert gas flushing) for 9 months or longer provided that the capsules would accommodate only one leaky fuel rod filled with water and for 5 months if the canister would contain two leaky fuel rods. As for the TUK-11 cask, the fire hazardous and explosive hydrogen-oxygen concentration is not produced inside it no matter how long the SNF is kept in it.

The canisters with the fuel rod bundles were inserted in upgraded baskets 12 that had special inserts to ensure extra strength of the packaging and to reduce a risk of damage during transportation. To ensure proper radiation safety during installation of the lid on the cask at the NPP and its removal at Mayak PA, an inner support plate was used. This plate makes part of the packaging. A limited space in the cask was a major challenge in developing the packaging. That is why the pintle of the inner support plate was put inward when the cask lid was put on and moved outward when the lid was removed.

Fig.7. Canister for transportation of fuel rod bundles of non-conforming RBMK SFAs

Fig.8. Testing of equipment for handling the casks and canisters at Mayak PA.

In view of successful completion of the pilot shipment and reprocessing of the RBMK SNF, Rosatom State Corporation has planned reprocessing of 50 tons/year beginning from 2013 under the *Program for Development of Infrastructure and SNF Handling for 2011-2010 and up to 2030*.

Pilot SNF shipment from IPPE

In 2008, the Federal Targeted Program for Ensuring Nuclear and Radiation Safety started preparation of the spent fuel for shipment from IPPE. The Institute has accumulated significant stocks of the fuel from research reactors and critical assemblies tested in hot cells. So, the major part of the fuel is leaky / damaged.

To prepare the SFAs for the shipment, several types of equipment and systems were developed and commissioned including:

– air-tight canisters for loading deformed and non-deformed VM SFAs in TUK-19 casks and fuel rods from VM SFAs in TUK-108/1 casks;

– a set of equipment for the hot cell for handling standard baskets, unloading the SNF from the baskets, cutting the upper end parts of the VM SFAs, loading the VM SFAs in the canisters, and air-tightening the canisters with

the lid.

Preparation of the spent fuel for transportation from IPPE was started in 2009. First, the SNF inventory was defined to be accepted and reprocessed at Mayak PA with no changes to the standard technology. The TUK-19 cask handling procedure was modified.

Out of all the spent fuel stored in the storage facility, the VM SFAs and all EK-10 SFAs were selected for the first shipment. The end parts of the VM SFAs were cut off to fit in the air-tight canisters. All necessary shipping and licensing documents were prepared, and a procedure for TUK-19 leak tests was developed.

After all the preparation operations were completed, the EK-10 SFAs and canisters with the VM SFAs were loaded into 16 TUK-9 casks, which in their turn were put into special freight large-capacity containers. The containers were delivered to the reloading ground by trucks and reloaded on rail flatcars. Then, a special train was made up and sent to Mayak PA.

We can conclude that the pilot removal of the RR SNF from IPPE was a transfer of the RRRFR experience on Russian sites.

The major problem affecting big-scope shipments of the spent fuel from IPPE is the bad rail road connecting Obninskoye station with the Institute site. The rail road has not been operated for many years and got almost destructed. At present, reconstruction of the rail road is being prepared.

Fig.9. Reloading the containers with SNF from trucks onto rail flatcars

It is noteworthy that Russia has more than a dozen of organizations with significant stocks of the spent fuel from research reactors and critical assemblies (117 facilities in total). Organization of the fuel removal and reprocessing requires coordination of the operators' activities, since it is desirable to use a unified system of project management, unified equipment and transport plans and unified licensing documents to optimize the budget and the overall schedule of the Russian RR SNF consolidation and reprocessing.

The *Program for Development of Infrastructure and SNF Handling for 2011-2010 and up to 2030* states that the RR SFAs should be removed from Russian facilities before 2020.

At present, the *Program for Handling Research Reactor SNF for a Period of 2011-2020 and up to 2030* developed under the *Program for Development of Infrastructure and SNF Handling for 2011-2010 and up to 2030* is pending approval. The Program states that IPPE site should become completely free from the SNF due to the fastest possible removal of the fuel, extending the inventory list of the SNF to be reprocessed at Mayak PA due to special funds, and taking decisions on storage of non-reprocessable spent fuels.

The successful completion of the fuel removal from IPPE has proved appropriateness of the measures provided by the subprogram. The reconstruction of the rail road will provide an opportunity to remove all the SNF within 2013-2012 (Mayak PA is ready to receive the fuel) and then to completely relieve the IPPE storage facility from the SNF within 2016-2020.

The use of large-capacity TUK-108/1 casks will speed up the process increasing the rate of removal up to 1-2tU/year. Bearing in mind that the low-enriched fuel make up ~ 90% of the total mass of all the SNF at IPPE, the major part of the fuel can be removed under the FTP ENRS 2008-2015 with relevant modifications. The rate of preparation and removal of the spent fuel with high initial enrichments depends on extra out-of-budget funds, mainly. The complete removal of the RR SNF from IPPE will allow decommissioning of the research reactors and the spent fuel storage facility on the site.

SNF management at Bilibino NPP

The forthcoming shutdown of the Bilibino NPP has urged relieving the reactor storage pools from the spent fuel assemblies. The feasibility study offered the following options of handling the SNF at the Bilibino NPP:

1) further storage of the SFAs in the storage pools;
2) disposal nearby the NPP (in wells and mines);
3) removal (for reprocessing or disposal).

The options are addressed in detail in the paper “Intermediate Results and Prospects for Handling the Bilibino NPP Spent Fuel”, which concludes that the safest option is to remove the SNF from the Bilibino NPP to Mayak PA for reprocessing or interim storage. The first option does not resolve the problem, the second one cannot guarantee reliability of safety barriers against propagation of radionuclides because of seismic instability of the region, possible climate warming and peculiarities of the EPG-6 fuel composition.

The feasibility study completed by Sosny in 2010-2011 demonstrates that there are two ways of the fuel removal from the Bilibino NPP: the north sea route with interim storage at an interim storage base or by large-capacity aircrafts (Fig.10).

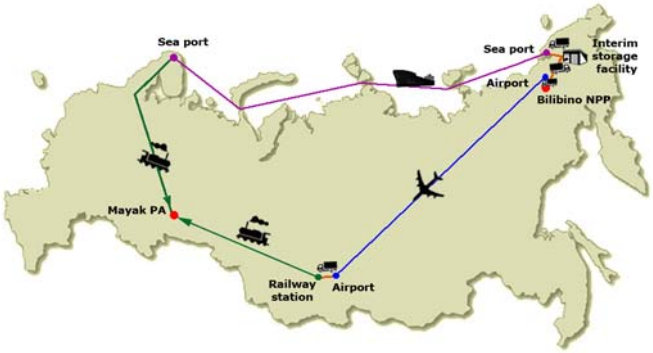

Fig.10. Possible routes of transportation of the SFAs from the Bilibino NPP

The feasibility study identified principle routes and assessed the cost of the work including the removal. The way of transportation can be selected in late 2012 basing on transportation risk assessments.

Conclusions

Following the resolutions of the previous Forum, the following work has been done in the past three years:

- modernization of procedures and logistics of RM transportation has been actively implemented;
- the design of the Type C package has been developed to provide transportation of RR SNF by air.

In our opinion, the relevant topics to be discussed at Atomtrns-2012 are as follows:

- organization of regular shipments of the RBMK SNF for storage and/or reprocessing (including those associated with the forthcoming decommissioning of the power units);
- development of a transport and technological plan for removal of the spent fuel from the Bilibino NPP;
- necessity to prepare a set of equipment for a force majeure removal of the SNF (war, natural disasters, terrorist threats) based on the Type C package.