Russian Experience and Proposals on Management of Non-Conforming SNF of RBMK Reactors

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Abstract. The RBMK-1000 power reactors have been operated at Leningrad, Kursk and Smolensk NPPs in the European part of Russia. The yearly fuel discharge from the RBMK-1000 reactors makes up 3500 SFAs placed in reactor cooling pools and separate spent fuel wet storage facilities at NPPs. Since 2012 the RBMK-1000 SNF has been transited to safer dry storage in a centralized dry storage facility at the Mining and Chemical Combine in Kraskoyarsk region, Siberia. According to the approved technology leak-tight SFAs with sound grid skeletons (hereinafter, the conforming SFAs) are subject to dry storage at NPP storage facilities and transfer to the centralized storage facility. Transition of defective and leaky spent fuel (hereinafter, the non-conforming SFAs) to dry storage in NPP storage facilities and their transfer to the centralized storage facility are not provided. One of the ways to manage the non-conforming RBMK-1000 SFAs is reprocessing at Mayak PA, separation of uranium, plutonium, neptunium, and vitrification of HLW. In 2011, a pilot batch of leaky SNF was removed from the Leningrad NPP to try out and verify engineering solutions. In 2014, a batch of leak-tight non-conforming SNF was shipped from the Leningrad NPP to a reprocessing plant. The paper addresses Russian experience and proposals on management of non-conforming SNF of RBMK-1000 reactors.

Key Words: RBMK-1000, Non-Conforming SNF, management.

1. Introduction

The RBMK-1000 reactor is a one-circuit channel-type graphite-moderated power reactor designed in 1960s. The RBMK-1000 power reactors have been operated at Leningrad, Kursk and Smolensk NPPs in the European part of Russia. A fuel assembly of RBMK-1000 (FIG. 1) consists of two fuel rods bundles, each is about 3.6 m long and 79 mm in diameter. They are secured one above another on a bearing rod with a pintle. The total length of the fuel assembly is about 10 m. Each bundle contains 18 fuel rods, which are installed in a skeleton of ten spacer grids (SG) and one end grid secured on the tube. Material of the fuel rod cladding is E-110 zirconium alloy, material of the fuel pellets is sintered uranium dioxide. Fuel assemblies are installed into vertical reactor channels. The fuel is reloaded without reactor shutdown. The fuel assemblies discharged from the RBMK-1000 reactors are stored in the reactor cooling pools. After three-year cooling period they are transported to a separately located wet storage at NPP using an on-site container. Each SFA is put into a canister in the NPP storage facility to minimize the radioactive contamination of the pool water.

Transition of the RBMK-1000 SNF to dry storage in the centralized storage facility is planned to improve safety. In late 2011, a centralized storage facility in Krasnoyarsk region (Siberia) and a complex for SNF transition to dry storage were commissioned in the facility of Leningrad NPP. The similar complex at Kursk NPP was commissioned in 2014, the complex at Smolensk NPP is being constructed. The design-basis efficiency of each NPP complex is 3600 SFA per year.

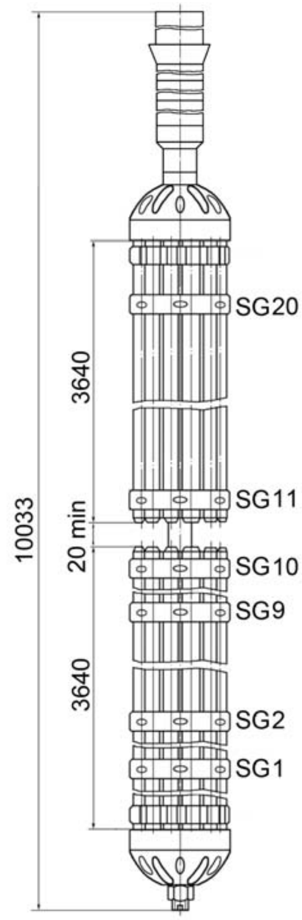


FIG.1. RBMK-1000 Fuel Assembly.

According to the approved technology leak-tight SFAs with sound grid skeletons (conforming SFAs) are subject to transition to dry storage and transfer to the centralized storage facility. Technology for transition to dry storage includes leak tests and visual inspection of SFAs, cutting of SFA into bundles, placing of bundles into ampules, loading of ampules with bundles into a cask, drying of SNF in the cask, and preparation of the cask for shipment. SFAs are cut in a hot cell of the NPP complex. TUK-109 casks are used to transport SNF to the centralized storage facility. TUK 109 packaging contains an energy absorbing container (EAC), a metal concrete cask with two lids, a basket and 144 ampules for the fuel rod bundles. The long-term storage of SNF in the metal concrete casks (for 50 years) is possible. The cask delivered to the centralized storage facility is opened, the basket with SNF is transferred to the hot cell, where the ampules with the fuel rod bundles are reloaded into 30-seat canisters, and then the canisters are sealed with welding and put into storage cells. The transition of defective and leaky spent fuel (non-conforming SFAs) to dry storage in the NPP complexes, their transfer and receipt at the centralized storage facility are not provided.

2. Non-conforming SFA

The conforming SFAs are selected for transition to dry storage in compliance with a special procedure. The non-conforming SFAs are leaky ones and those tight ones but with the following damages:

- more than two destroyed spacer grids in succession;
- damaged or destroyed spacer grid 10 or spacer grid 11 located near the gap between the fuel rod bundles (FIG. 2a);
- local increase of the SFA diameter more than 87 mm induced by the damaged spacer grid(s) (FIG. 2b); and;
- a gap between the fuel rod bundles is less than 9 mm (FIG. 2c).

a *b* *c*

FIG. 2. Damaged RBMK-1000 SFA: a crack on the spacer grid (a), a tear on the spacer grid (b), a gap between the fuel rod bundles less than 9 mm (c).

Leaky SFAs are detected by measuring the specific activity of the water in their storage canisters. All damages to the leak-tight SFAs structure are detected visually.

About 3500 leaky SFAs are stored at three NPPs with the RBMK-1000 reactors. Total amount of damaged leak-tight SFAs is unknown because the SFAs are examined directly before cutting. The largest statistics on damaged SFAs is at the Leningrad NPP. 24% of leak-tight SFAs have been discarded because of their damaged structure during three years of operation of the Leningrad NPP complex. The shares of leak-tight non-conforming SFAs with different damages are shown in FIG. 3.

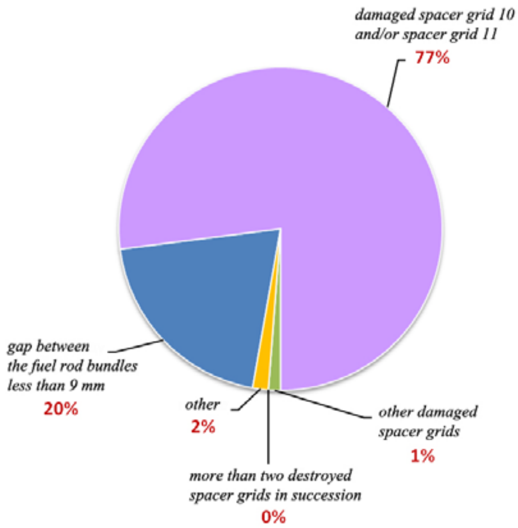


FIG. 3. Types of Damage to Non-Conforming SFAs.

Beside the SFAs with minor damages mentioned above, there are severely damaged SFAs (bent, deformed, partially destroyed) and pilot SFAs with a peculiar structure. Due to changes in their form and cross-section, the severely damaged SFAs cannot be loaded into a basket of the on-site container using a standard transfer cask and transferred to the NPP storage facility. Transition of the pilot SFAs with a peculiar structure to dry storage would require their cutting across the rods, and that cannot be done at the NPP complexes.

3. Removal and reprocessing of the pilot batch of leaky SNF

Before commencing the work on transition of the RBMK-1000 SNF to dry storage (2012) it was expected that the amount of non-conforming SFAs would make up 3-5% and the most SFAs would be leaky. One of the safe ways to manage the non-conforming RBMK-1000 SFAs was reprocessing with separation of uranium, plutonium, neptunium, and vitrification of HLW. In 2010-2011, the feasibility of delivery and reprocessing of leaky RBMK-1000

SNF was analyzed and a pilot batch of SNF was delivered and reprocessed at Mayak PA to confirm practicability. The pilot batch consisted of eight leaky SFAs.

Reprocessing of the RBMK-1000 SNF and the use of obtained regenerated uranium are considered unpractical due to the small content of uranium-235. But the most of leaky SFAs were discharged from the reactor ahead of schedule and had little burn-up. The fuel and structural materials of the RBMK-1000 fuel assemblies are similar to those of VVER-440 which are routine reprocessed at the RT-1 plant, thus, no technical problems regarding the RBMK-1000 SNF radiochemical reprocessing were expected. So, the main task was to develop a technology for safe handling of leaky SNF that could be used both at the NPP and the RT-1 plant.

In 2010-2011, the RT-1 plant had no equipment for handling of TUK-109 casks; the complexes for SNF transition to dry storage at the NPPs were not commissioned and were not intended to cut leaky SFAs. Thus, its was planned to ship SNF in a TUK-11 cask with a modified Type 12 basket (FIG. 4) and to cut SFAs from the pilot batch in a hot cell of Unit 2 of the Leningrad NPP. Earlier this hot cell and the cask had been used to ship the fuel rod bundles to the Research Institute of Atomic Reactors, Dimitrovgrad, Russia for examinations. Some modifications to the procedure for SNF loading in a cask and some new equipment were required to deliver the leaky SNF to the RT-1 plant.

The concept of leaky SNF handling was to use the leak-tight ampoules to transport the fuel rod bundles in a cask, to perform transport operations and temporary store the SNF at the NPP and at the RT-1 plant. The design of the leak-tight ampoule is shown in FIG. 4 e.

a *b* *c* *d* *e*

FIG. 4. Transport Packaging (a) for shipment of fuel rod bundles of leaky RBMK-1000 SFAs and its components: inner plate (b), basket (c), insert (d), ampoule (d).

The use of tight ampoule is induced by the regulations restricting the release of activity and the fuel into the cooling pool water during the temporary storage of leaky SNF. However, use of air-tight ampoules for leaky SNF removed from the wet storage brings about the problem of accumulation of radioactive hydrogen which limits the permissible storage period. SNF drying can solve this problem, but it can not be used because of the technical difficulties related to the deployment of additional equipment in the hot cell, a new complicated design of ampoule and increased cost for the SNF preparation for shipment. Conservative calculations demonstrated that the concentration of radiolytic hydrogen in tight ampoules with leaky SNF during their storage for six months would not reach the explosive value. Experimental study of the hydrogen accumulation in a tight ampoule with leaky RBMK-1000 SNF demonstrated the significantly less rate of the hydrogen accumulation compared with the calculations. Thus, it was decided to seal the SNF-containing ampoules without drying or blowing with the inert gas.

In process of SNF handling at the RT-1 plant it was planned not to withdraw the fuel rod bundles from the ampoules for further chopping and radiochemical reprocessing in order to prevent any spillage of the fuel in the hot cell and the removal of the spilled fuel from the ampoules. Consequently, the ampoule design shall allow chopping the fuel rod bundle and the ampoule together. On the other hand, the ampoule shall be strong enough to ensure the leak tightness under normal and accident conditions of shipment in a cask and during handling at the Leningrad NPP and RT-1 plant. This problem was solved by using 2 mm-thick tubes in the ampoule design and also by placing the tube-like inserts into the transport basket cells.

SNF-containing ampoules were loaded into a transport packaging using a transfer cask and two steel plates with holes and plugs (see FIG. 5). The external plate was installed on the transport cask to protect the personnel from the radiation during loading of the SNF-containing ampoules. The internal plate was installed in the cask before to protect the personnel from the radiation during the removal of the external plate from the cask after the SNF loading and during the lid installation. The internal plate was transported in a cask and remotely unloaded at the RT-1 plant before withdrawal of the SNF-containing basket.

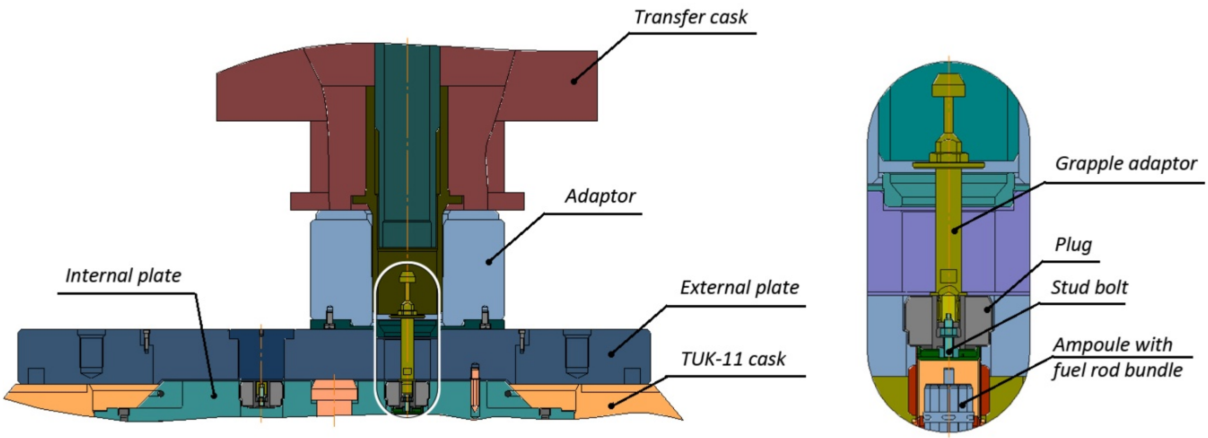


FIG. 5. Loading of Ampoules with Fuel Rod Bundles in a Cask.

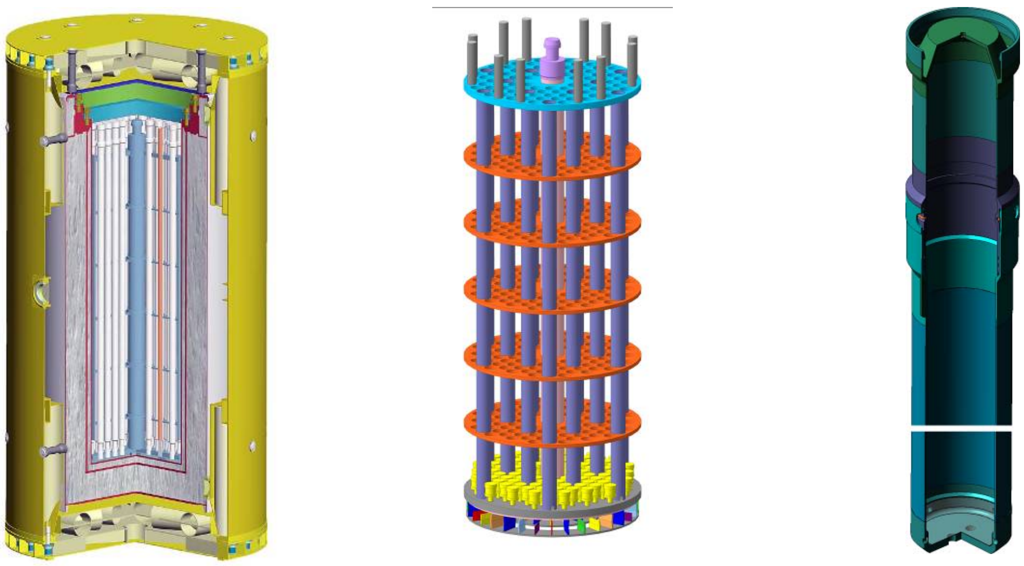
Also the additional equipment was designed and fabricated. It included adaptors, grapples, tools and other equipment for loading the fuel rod bundles in the ampoules in the hot cell at the NPP, for loading the ampoules with the fuel rod bundles in a cask, for handling the casks and the ampoules at the RT-1 plant. Safety at all stages of SNF handling was justified, the safety assessment reports were prepared, the combined trials of the equipment were held, the certificate of approval for packaging design and shipment was obtained as well as the licenses authorizing the work.

Eight leaky SFAs formed a pilot batch. The cut, shipment and reprocessing of the SFA pilot batch took place in late 2011.

The analysis of capabilities of the NPP and the RT-1 plant, performed in 2010-2011, demonstrated that the developed procedure can be used to deliver for reprocessing only a small amount of leaky SFAs from Unit 2 of the Leningrad NPP. The procedure for transport and handling at of RT-1 plant and the equipment of NPP complexes shall be modified to remove the SNF for reprocessing on a regular basis.

4. Removal and reprocessing of the leak-tight damaged SNF batch

The concept was to use nontight ampoules with the extended diameter and a TUK-109 cask to ship the fuel rod bundles of damaged SFAs (FIG. 6). TUK-109 cask was used for SNF standard loading at the Leningrad NPP but a lot of additional equipment had to be purchased by the RT-1 plant.



a *b* *c*

FIG. 6. Transport Packaging (a) for shipment of fuel rod bundles of leak-tight non-conforming RBMK-1000 SFAs and its components: basket (b), ampoule (c).

A special ampoule for the fuel rod bundles from the leak-tight damaged SFAs was designed. Ampoule design allows:

- performance of transport and handling operations in the hot cell of the SNF storage at the Leningrad NPP;
- SNF drying in TUK-109 cask following the existing procedure;
- penetration of water into the ampoules when they are stored in the pool at the RT-1 plant;
- draining the ampoules when they are removed from the pool for further cutting at the RT-1 plant;

- performance of transport and handling operations in the hot cell for SNF preparation for cutting at the RT-1 plant;
- chopping the ampoules together with a fuel rod bundle in process of their reprocessing at the RT-1 plant.

Special baskets were designed and fabricated to arrange the ampoules in the TUK-109 cask. Due to the extended diameter of the ampoules, the basket capacity was reduced up to 102 ampoules comparing with a standard one. The safety was analyzed and the certificate of approval for the packaging design and shipment was obtained.

Since the procedure for SNF unloading from the cask and for SNF transfer for chopping to the RT-1 plant (FIG. 7) was complicated in comparison to the standard one, the existing equipment had to be modified and the additional equipment had to be procured.

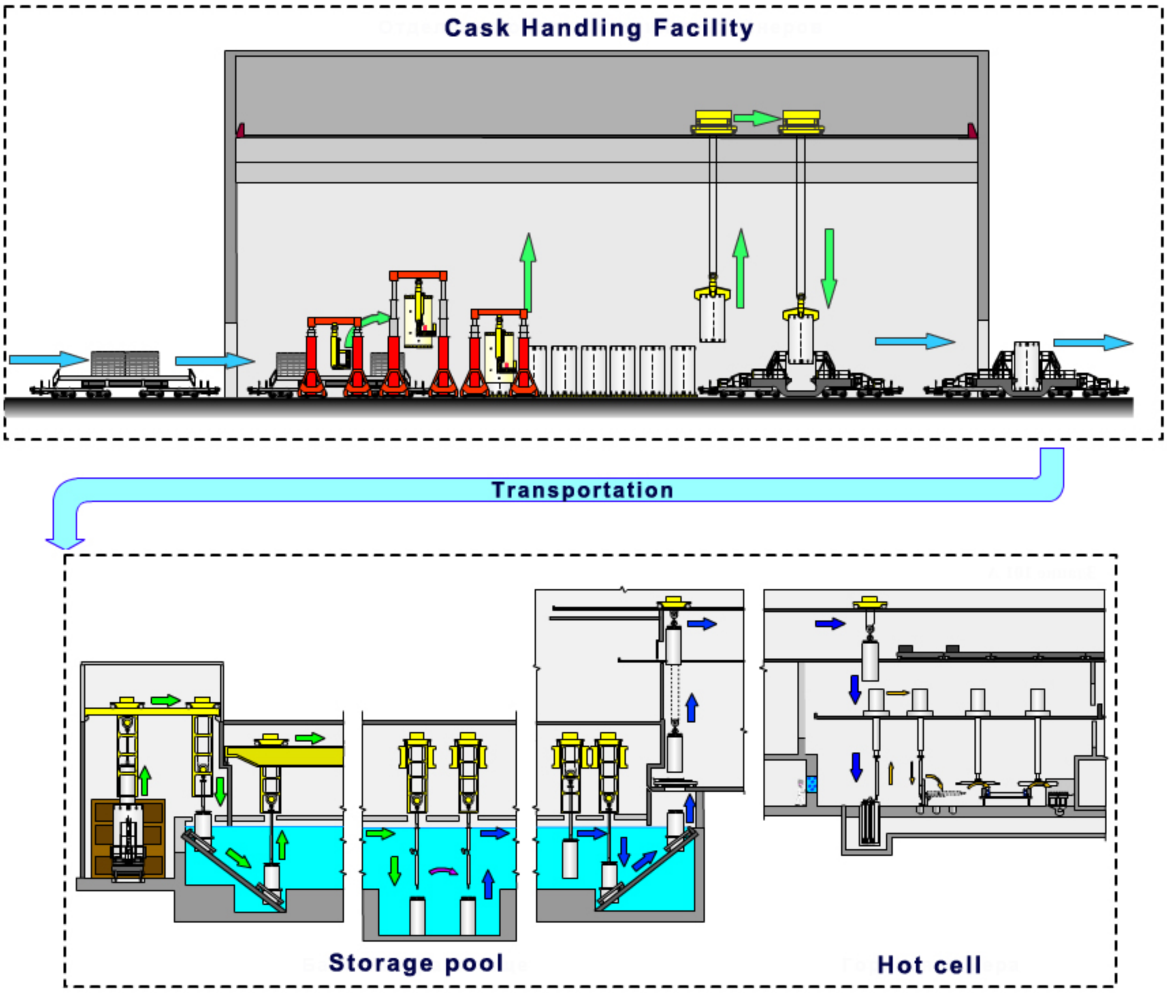


FIG. 7. Transport and Process Scheme of RBMK-1000 SNF Handling at RT-1 Plant.

The hydraulic 1100 t crane and special yokes were procured to unload the cask with the EAC out of the railcar, to put it upright and to remove the EAC in a cask handling facility. A special Type TP9-1 railcar was procured to transport the cask upright without the EAC from the cask handling facility to the SNF storage facility and back.

The load capacity of cranes used to withdraw the SNF-containing basket out of the cask and place it in a pool was increased. The hoist trolleys used to transport the SNF-containing basket in and out of the pool were modified in order to increase the height of the basket transport way. The load capacity of the hoist trolley used to transfer the SNF-containing basket in a pool was increased. An area for reloading of some ampoules from one basket to another was arranged in the pool in order to reduce the mass of the SNF-containing basket and to exclude any modifications of other hoisting equipment for transfer of SNF-containing basket to the hot cell for SNF preparation for chopping.

Also, the various auxiliary equipment for handling the cask, the basket and the ampoules at the RT-1 plant (adaptors, grapples, tools, etc.) was designed and fabricated.

The equipment for handling the ampoules of a new type was designed, fabricated and installed in the hot cell of the SNF storage facility at the Leningrad NPP.

The safety of non-conforming SFA handling at the Leningrad NPP and the RT-1 plant was justified, the safety assessment reports were prepared, the combined trials of the equipment of the hot cell of the SNF storage facility at the Leningrad NPP and the RT-1 plant equipment were performed, and the licenses for work were obtained.

204 leak tight SFAs with damaged spacer grids were selected for cutting and shipment to the RT-1 plant, and none of them should have destroyed spacer grid 11 or any damage of the spacer grid 10. In October and November 2014 all selected non-conforming SFAs were cut and loaded into casks. In late November 2014 four casks loaded with non-conforming SNF were shipped to the RT-1 plant for reprocessing.

5. Prospects

The share of non-conforming SFAs located in the storage facility at the Leningrad NPP was significantly larger than it was previously assumed. And the most of them were leak tight SFAs with damaged structures. One of the ways for handling leak tight non-conforming SFAs is to repair their skeletons in order to perform further SFA cutting, loading of the fuel rod bundles into standard ampoules, transit SNF to dry storage and arrange it in the centralized storage facility. The repair is to be performed in a hot cell of the NPP complex. In process of the SFA skeleton repair any tear on the spacer grid should be removed through the polishing, for instance, and the clamps should be installed on the SFAs to compensate the damage of the spacer grid. In process of developing the procedure for SFA repair the final cross-sectional dimensions of the fuel rod bundles shall be defined, the mechanical impact on the SFA grid skeleton and the fuel rods shall be assessed, the safe SFA cutting and the long-term storage of the fuel rod bundles fastened with the clamps shall be analyzed. Each SFA that has a gap between the fuel rod bundles less than 9 mm is to be disassembled through the removal of the fuel rod bundles from the bearing rod one by one.

In case the repair of the SFA grid skeleton is too complicated or failed, the ampoules with the extended diameter are to be used for loading with the fuel rod bundles, further transit to dry storage and transfer to the centralized storage facility or to the RT-1 plant for reprocessing. The use of ampoules with the extended diameter in the centralized storage will result in reduced amount of the fuel rod bundles in the canister and in increased amount of the cells necessary for their long-term storage. But the centralized storage facility has a spare capacity.

The leaky, severely damaged and pilot SFAs are to be reprocessed at the RT-1 plant. Leaky SFAs found in the NPP storage facilities and transferred to the storage facilities from the reactor units are to be prepared in the hot cells of NPP complexes. The technology shall include the use of tight ampoules and the collection of all fuel spillages as routine operation. In case the whole process cycle from the SNF sealing in the ampoules to its chopping will be too long, it is necessary to include the SNF drying in the ampoules in order to ensure the safe shipment and temporary storage. The activities on handling leaky SFAs will require the significant modification of the hot cells at the NPP complexes. This modification can be performed only after the removal of the most leak tight SFAs.

Special technology for handling severely damaged and pilot SFAs at the reactor units is to be developed to prepare these SFAs for the removal. It will include the SFA cutting in the reactor pool under the water layer. Since it is almost impossible to ensure the quick cutting and preparation of the severely damaged SFAs for the removal due to a variety of SFA damages, the handling procedure shall include the SNF drying and temporary storage. All activities on handling the severely damaged and pilot SFAs are to be started only after shutdown of the reactors for the decommissioning and after the removal of other SFAs from the reactor pools.

6. Conclusions

In 2011 and 2014, the non-conforming RBMK-1000 SFAs were shipped to Mayak PA and reprocessed at the RT-1 plant. The significant results are: concept of non-conforming RBMK-1000 SNF shipment and reprocessing in the expendable ampoules was verified; safe shipment of non-dried leaky SNF in the air-tight ampoules was proved; and procedure for SNF transport and handling at the Leningrad NPP and the RT-1 plant have become mutually acceptable. In future the technologies for delivery of leaky, severely damaged and pilot SFAs for reprocessing and a technology for SFA grid skeleton repair in order to remove all non-conforming SNF from the NPPs are to be developed and introduced.