Proposals for Non-conforming RBMK-1000 SFAs Handling

A. Dorofeev, B. Kanashov, S. Perepelkin, V. Smirnov (Sosny R&D Company),
N. Davidenko (Rosenergoatom Concern, OJSC),
N. Kalyazin, I. Lozhnikov (Leningrad NPP)

By now a technology on transition of the conforming RBMK SNF to dry storage has been developed and implemented, but solution of the problem of the non-conforming RBMK SNF handling has been postponed until recently. The experience gained in the process of commissioning of the SFA disassembling division at the Leningrad NPP showed that the non-conforming SNF makes up 30 % of the whole SNF batch, which demands speeding up the process of choosing a solution for the non-conforming SNF removal from the NPP. Besides, there are other problems, which remain unsolved, i.e. removal of leaky and strongly damaged SFAs from the power units and the SNF storage facility. The paper describes the current situation and problems related to the non-conforming RBMK SNF handling and demonstrates the results of work on justification of the RBMK SNF reprocessing. It also proposes a scheme of the non-conforming RBMK SNF preparation and removal from the NPP.

Introduction

The Rosatom conception [1] provides for removal of the SFAs of the RBMK-1000 reactors from the NPP facilities to the centralized SNF dry storage (KhOT-2) at the Mining Chemical Combine (hereinafter “the MCC”). By now several facilities have been commissioned, i.e. a start-up complex of the dry storage facility KhOT-2 at the MCC, a disassembling division and a complex of SNF cask storage at the Leningrad NPP. In 2012 a procedure of the SFAs disassembling and RBMK-1000 SNF removal from the Leningrad NPP to the MCC dry storage has been initiated. Assembly work at the SFAs disassembling division of the Kurskaya NPP is gradually coming to an end, the SFAs disassembling division at the Smolenskaya NPP is being constructed now. The RBMK-1000 SNF removal from the Kurskaya NPP is scheduled for 2013, from the Smolenskaya NPP – in 2016. At the NPP the RBMK-1000 SNF is stored in metal concrete UKKh-109 containers, for SNF transport to the MCC - transport packaging sets TUK-109 are used.

According to the developed technology of the RBMK-1000 SNF transition to dry storage [2], tight and conventionally tight SFAs without strong defects (hereinafter – conforming SFAs) are subject to disassembling and delivery to the MCC dry storage KhOT-2. Now there is no technology for disassembling and transition to dry storage of the untight SFAs and SFAs with mechanical defects of structural elements (hereinafter – non-conforming SFAs). According to the SFA condition control method [3], to the non-conforming SFAs we refer untight SFAs and SFAs with the following defects:

- Lack of more than two spacer grids in succession;
- Lack/destruction of spacer grid 10 of the lower fuel rod bundle or spacer grid 11 of the upper fuel rod bundle;
- Local diameter increase exceeding 87 mm;
- Gap between the fuel rods of the upper and lower fuel rod bundles less than 9 mm.

Before the start-up of the disassembling division at the Leningrad NPP it had been expected, that the amount of non-conforming SFAs would make up 3-5 %. Consequently, it was planned to use a special technology for transition of the non-conforming SFAs to dry storage. That technology should have been developed and introduced upon solution of the problem of the SNF storage pools filling (postponed solution). According to the disassembling division project, before disassembling the SFAs were sorted out in the following way: the SFAs are leak tested in the SNF storage pool, then the revealed untight SFAs are left in the pool and the tight SFAs are transferred to the disassembling division for visual inspection. If any defects are observed preventing the SFAs from disassembling and loading into the ampoules, the non-conforming SFAs are returned to the SNF storage pool.

1. Pilot Project Implementation

Since the technology for transition of the non-conforming SFAs to dry storage had not been developed, and the Mayak RT-1 plant capacities were not engaged to the full, it was proposed transporting the non-conforming SFAs to Ozersk for reprocessing. The Federal Target Nuclear and Radiation Safety program [4] allowed preparing justification of reprocessing of the non-conforming RBMK-1000 SNF, including reprocessing of the pilot batch.

1.1. Practicality of the Non-conforming SFA Reprocessing

The fuel and structural materials of the RBMK-1000 FAs are similar to those of the VVER-440 FAs, thus, no problems regarding RBMK SNF reprocessing were expected. But reprocessing of the RBMK SNF was considered unpractical due to smaller ^{235}U content in the RBMK SNF after its burn-up. However, VVER-440 SNF burn-up has increased over the last years and continues to grow. Consequently, the ^{235}U content has decreased and is expected to be decreasing gradually in the future. Since some non-conforming SFAs were unloaded from the core ahead of schedule due to loss of their integrity and did not reach their design burn-up, they are implied to have a big share of ^{235}U, which might be used for fuel fabrication after regeneration and re-enrichment.

Regenerated uranium might be re-enriched either by blending it with other ^{235}U-containing materials or by isotope separation. The quality of regenerated uranium depends on both ^{235}U content and the content of uranium even isotopes. If the presence of ^{232}U affects mainly the conditions of regenerated uranium handling, then the ^{236}U presence requires compensation by increasing the ^{235}U share in the process of re-enrichment. A quality factor to assess practicality of regenerated uranium involvement in the nuclear fuel cycle is determined by the isotope separation streams [5]. The regenerated uranium quality factor depends on the content of ^{235}U and ^{236}U, i.e. on the initial enrichment and fuel burn-up. Use of regenerated uranium may be considered practical, if the quality factor exceeds the value typical for natural uranium.

To confirm the RBMK SNF reprocessing practicality, its isotope composition was defined, the quality index was calculated and the fuel burn-up values ("marginal" burn-ups) were obtained, serving as reference values for the SNF reprocessing and further involvement of the regenerated uranium into the nuclear fuel cycle [6]. There are no statistics on non-conforming SFAs with damaged structural elements. That is why all the SFAs of the Leningrad NPP were analyzed for their reprocessing practicality, as it was assumed that burn-up distribution is the same for the non-conforming SFAs and for the whole SFA batch and that the situation is similar in other NPPs. The statistical data of the fuel burn-up and the obtained values of the RBMK SNF "marginal" burn-up allowed defining the percentage of the SFAs subject to reprocessing with further involvement of regenerated uranium in the nuclear fuel cycle. Depending on the initial enrichment, these SFAs range from 10 to 12% of the whole SFAs batch.

Moreover, the average burn-up of the non-conforming RBMK -1000 SFAs of different initial enrichment turned out to be lower than the corresponding "marginal" burn-up values. It means that uranium regenerated from the non-conforming SFAs may be involved in the nuclear fuel cycle without preliminary SFAs classification by burn-up.

1.2. Possibility of Shipment of the Untight SFAs

Normative documents regulating transportation safety do not require putting untight SNF into leak-tight canisters (ampoules) but limit release of activity from transport packaging sets into the environment. But for the storage of untight SNF in the cooling pool special canisters (ampoules), that limit release of the fuel activity, should be used. However, use of the tight ampoules for transportation and storage of untight SNF brings about the problem of accumulation and achievement of explosive concentration of radioactive hydrogen, which, in its turn, limits the permissible storage period for the ampoule with untight SNF.

The problem of accumulation of radioactive hydrogen in the tight ampoule with SNF can be solved by draining or blowing it through with the inert gas. However, now there is no technical possibility of draining and blowing separate ampoules containing SNF in the SFA disassembling division. To include the operations of draining or blowing of each ampoule into the technological process, will require deployment of additional equipment and will also lead to a more complicated design of the ampoule, as well as to increasing of the time and costs required for SNF preparation for shipment. That is why it was decided to seal the ampoules with the fuel rod bundles of the untight SFAs without draining or blowing them with the inert gas, but limiting considerably the period of SNF storage and the amount of SNF in the transport packaging sets. Taking into account the time required for SFAs disassembling, loading of SNF into the transport packaging sets, SNF transportation and storage before reprocessing, the acceptable period of storage of the ampoules with the fuel rod bundles of the untight SFAs will make up approximately six months.

Justification of the safety of the temporary storage and transportation of the untight RBMK-1000 SNF required making calculations of the hydrogen accumulation rate as a result of radiolysis of water and steam inside the tight ampoules. The calculations showed, that the presence of one untight fuel rod in the fuel rod bundle will make the period of the safe temporary storage for 30 ampoules with fuel rod bundles in the transport packaging set amount to as long as 8.6 months. In addition, calculations were made to estimate the rate of hydrogen accumulation in the tight ampoules containing the untight fuel rods of the RBMK-1000 SFAs. The calculated rate of hydrogen accumulation turned out to be considerably less than the design one.

The other complicated task concerning delivery of the untight SNF for reprocessing is the ampoule design, which should satisfy mutually exclusive requirements. On the one hand, the ampoule design must ensure its strength under normal and emergency conditions of transportation and handling at the NPP and at the RT-1 Plant of Mayak PA. On the other hand, there should be a possibility of grinding the ampoule together with the fuel rod bundle by means of a grinding machine, since there is a risk of fuel spillage in the ampoule during shipment of the fuel rod bundle of the untight SFA, as well as of fuel spillage in the shielded box during withdrawal of the fuel rod bundle from the ampoule. This problem was solved by using 2 mm-thick tubes in the ampoule design and also by placing inserts into the cells of the wrapper of the transport packaging set.

1.3. Implementation of the Pilot Project

To check the technical solutions and demonstrate the possibility of the non-conforming RBMK -1000 SNF shipment and reprocessing, a trial batch of the non-conforming SFAs was delivered to Mayak PA (pilot project). Since there is no equipment for handling TUK-109 transport packaging sets at the RT-1 Plant of Mayak PA and the SFA disassembling division had not been commissioned at the Leningrad NPP by that time, the trial batch of the RBMK -1000 SNF was shipped from the second Unit of the Leningrad NPP in the TK-11 railway container cars. The SFAs were disassembled and loaded into the ampoules in a shielded box at the second Unit of the Leningrad NPP.

Eight non-conforming SFAs were chosen for trial reprocessing, taking into account mass of SNF, which might be loaded at a time into the dissolution apparatus of the RT-1 Plant of Mayak PA.

For shipment of the trial batch of the non-conforming RBMK-1000 SFAs the following equipment was designed and fabricated: expendable tight ampoules (Figure 1), TUK-11R-2 cask (Figure 2) based on the TUK-11 cask and wrapper 12, equipment for handling the ampoules in a shielded box, for loading the ampoules with the fuel rod bundles into the casks and for handling the cask components and the ampoules at the RT-1 Plant of Mayak PA. Safety of each stage of SNF handling was justified. The SFAs trial batch was delivered and reprocessed at the end of 2011.

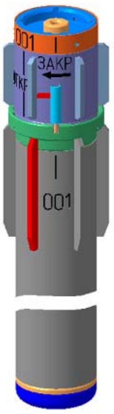


Fig. 1. Ampoule for shipment of fuel rod bundles of the non-conforming RBMK SFAs

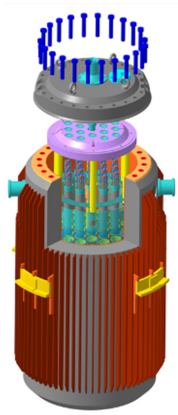


Fig. 2. TUK-11R-2 cask for shipment of fuel rod bundles of the non-conforming RBMK SFAs

It should be noted that dose obtained by the personnel in the process of the RBMK SNF loading into the TUK-11R-2 casks turned out to be considerably lower than the dose obtained while loading fuel rod bundles into the TUK-11R-1 casks to be shipped to the SSC RIAR for research. That is why the Leningrad NPP specialists proposed using the scheme and equipment developed for the RBMK SNF delivery to Mayak PA for shipment of SFA fuel rod bundles to the SSC RIAR.

Regarding the positive experience of the pilot RBMK SNF shipment and reprocessing, the Rosatom Program [7] provides for reprocessing of up to 50 ton/year of the non-conforming RBMK-1000 SNF starting from 2013. This reprocessing rate includes removal of both non-conforming and conforming SFA from the NPP. The required amount of SNF to be reprocessed might be delivered in the TUK-109 casks, provided that Mayak PA is supplied with the TUK-109 cask handling equipment and the Leningrad NPP SFA disassembling division – with the auxiliary equipment for handling of the non-conforming SFAs.

2. New Tasks and Prospects

Operation of the Leningrad NPP SFA disassembling division in 2012 showed that the share of non-conforming SFAs considerably exceeds 3-5% as it was expected. For instance, non-conforming SFAs with minor mechanical defects, which however prevent the SFAs from being disassembled and loaded into the TUK-109 casks, made up about 30 %. In case of the full engagement of the disassembling divisions at three NPPs with the RBMK-1000 reactors, the stream of the non-conforming SNF subject to reprocessing will exceed the capacity of the RT-1 Plant of Mayak PA.

The program approved by the Rosatom Corporation [7] provides for termination of the SNF reprocessing, including the non-conforming RBMK SFAs, at Mayak PA by 2030. However, taking into account the decision on extension of the reactor lifetime up to 45 years, the last RBMK-1000 reactor would be shutdown in 2035. For the whole period of the RBMK-1000 reactors operation about 20 tons of SNF will be accumulated. At the rate of SNF reprocessing equal to 50 ton/year, it would take about 120 years to remove all the non-conforming SNF (about 6 thousand tons) from the NPPs. Thus, shipment of 50 tons of the non-conforming SNF a year to Mayak PA for reprocessing will not solve the problem of SNF removal from NPPs. To solve this task, new technological solutions should be found.

Besides the problem of handling non-conforming SFAs in SNF storage facilities, there is also a problem of removing untight and strongly damaged SFAs from NPP units and SNF storage facilities. Untight SFAs of the Kursk and Smolensk NPPs are not transferred to the NPP SNF storage facilities, but are accumulated in the reactor cooling pools, thus, leaving less space for the SFAs discharged from the reactors. The cooling pools of the NPP units also accommodate heavily deformed SFAs which might not be loaded into TK-8 casks and transferred to the SNF storage facility. To start preparation of the NPP units for decommissioning, it would be necessary to discharge these SFAs from the cooling pools. Justified period of untight SFAs storage in water makes up 60 years [8]. For the first untight SFAs this time runs out in 2035. That is why by that time it is highly important to introduce a technology of SFAs transition from water to dry storage and a technology of SFAs shipment for reprocessing.

To develop appropriate technologies for RBMK-1000 SFAs handling, it is necessary to make the following essential decisions:

1) The disassembling division efficiency should be increased.

2) Defects of some tight non-conforming SFAs must be compensated to allow SFAs shipment to the KhOT-2 in the standard ampoules of the TUK-109 (TUK-109T) casks.

3) Tight non-conforming SFAs beyond repair should be disassembled and transferred to the KhOT-2 in the ampoules of enlarged diameter.

4) Non-conforming SFAs, feasible for reprocessing with regard to their uranium quality factor, should be disassembled; the fuel rod bundles should be placed into special ampoules and sent to Mayak PA for reprocessing.

5) Untight SFAs, which are already located in the SNF storage facility and might be delivered to the SNF storage facility, should be disassembled in the Leningrad NPP disassembling division. Besides, there is also an additional possibility to disassemble the untight SFAs in the shielded box of the second NPP unit.

6) Strongly damaged and pilot SFAs should be disassembled in the cooling pool according to a special technology.

7) To ensure maximal engagement of the existing NPP infrastructure, it is necessary to use TK-8 casks for the on-site SNF transfer and the TUK-109 (TUK-109T) casks for removal of the SNF from the NPPs.

To remove the non-conforming RBMK-1000 SFAs from the NPPs, it is necessary to develop and implement the following technologies:

1) For compensation of the SFA defects and disassembling of the tight non-conforming SFAs to provide a possibility for loading the fuel rod bundles into the standard ampoules of the TUK-109 (TUK-109T) casks for their further shipment to the KhOT-2;

2) For preparation and transfer of the tight non-conforming SFAs from the SNF storage facility to the KhOT-2 in the ampoules of the enlarged diameter;

3) For preparation and shipment of the tight non-conforming SFAs from the SNF storage facility to the RT-1 Plant of Mayak PA in the ampoules of the enlarged diameter;

4) For preparation and shipment of the untight SFAs from the SNF storage facility to the RT-1 Plant of Mayak PA;

5) For preparation and transfer of the untight SFAs from the SNF storage facility to the KhOT-2 (after 2030);

6) For transfer of the untight SFAs from the NPP units to the NPP SNF storage facilities;

7) For preparation and shipment of the damaged and pilot SFAs from the NPP units to the RT-1 Plant of Mayak PA;

8) For preparation and shipment of the damaged and pilot SFAs from the NPP units to the KhOT-2 (after 2030).

2.1. Repair and Shipment of the Tight Non-conforming SFAs in the Standard Ampoules of the TUK-109 transport packaging sets

Defects in the SFA structural elements create a number of problems for the process of SFA transition to dry storage. Large tearing of the spacer grid leads to increase of the cross-sectional dimension of the fuel rod bundle and makes it impossible to load the fuel rod bundle into the ampoule. Destruction of more than two spacer grids in succession, as well as destruction of spacer grids DR10 and DR11 result in instability and again lead to increase of the cross-sectional dimension of the fuel rod bundle, thus, preventing it from being loaded into the ampoule. Damaged spacer grid DR10 does no allow securing the SFA while disassembling it into fuel rod bundles. It is impossible either to disassemble the SFA with a gap between the fuel rods of the upper and lower bundles less than 9 mm without damaging the fuel rods.

Thus, for loading of the fuel rod bundles into the ampoules of the TUK-109 (TUK-109T) casks and for transfer of the casks to the KhOT-2, it is necessary to develop and implement a technology for smoothing the spacer grid tearing and for compensation of the spacer grid deformations. Besides, it is also important to develop and introduce a technology for disassembling SFAs with a gap between the fuel rods of the upper and lower bundles less than 9 mm.

The spacer grid tearing might be eliminated in several ways: polishing, leveling or by means of nippers (Fig. 3). Each way has its advantages and drawbacks, that is why testing them on mock-ups might help to choose the optimal one. Before using the nippers, it is necessary to determine the extent of the spacer grid tearing to be smoothed and the extent of tearing which will remain. For polishing, it might be useful to consider a possibility of equipping the available cutoff machine with an abrasive disk or using a pneumatic polishing machine. The spacer grid might be leveled by means of a pneumatic “hammer”, but in this case it is necessary to assess the load applied to other parts of the spacer grid and the fuel rods.

a b c

Fig.3. Pneumatic instruments for smoothing the spacer grid tearing:
nippers (a), polishing machine (b), “hammer” (c)

Damaged spacer grids might be fixed by applying clamps on them or near them. As clamps spring elements, such as a spliced ring (Fig.4), might be used. As an option, steel strap clamps might be applied by means of a special pneumatic instrument, which strains the steel strap, fixes its both ends with a brace and cuts the ends (Fig.5, 6). Before taking a final decision on the types of the clamps and the instruments for their application, it is necessary to test them first and measure the cross sectional dimensions of the fuel rod bundle after the clamps have been applied.

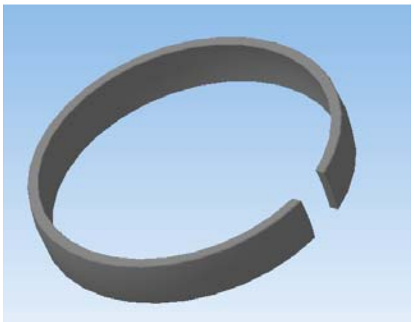


Fig. 4. Spring sliced ring to be applied on the SFA

Fig. 5. Pneumatic instrument for applying the clamps on the SFA

Fig. 6. Brace used for fixing the clamp ends

The SFAs having a gap between the fuel rods of the lower and upper fuel rod bundles less than 9 mm might be disassembled according to a special technology, when the following sequence of operations is performed (Fig.7):

- Cutting off of the suspension above the SFA upper tailpiece;
- Removing of the SFA upper tailpiece;
- Cutting off of the central rod above the end-capping spacer grid of the upper fuel rod bundle;
- Removing of the upper fuel rod bundle from the central rod;
- Cutting off of the central rod above the lower fuel rod bundle;
- If needed, tilting of the lower fuel rod bundle.

Similar technology was used for disassembling of the SFAs with central fastening of the fuel rods in the shielded box of the second unit of the Leningrad NPP for further shipment of the fuel rod bundles to the SSC RIAR for research. This scheme will require application of a grapple for the central rod and a solid radwaste tank for collection and removal of fragments of the central rods from the shielded box of the disassembling division.

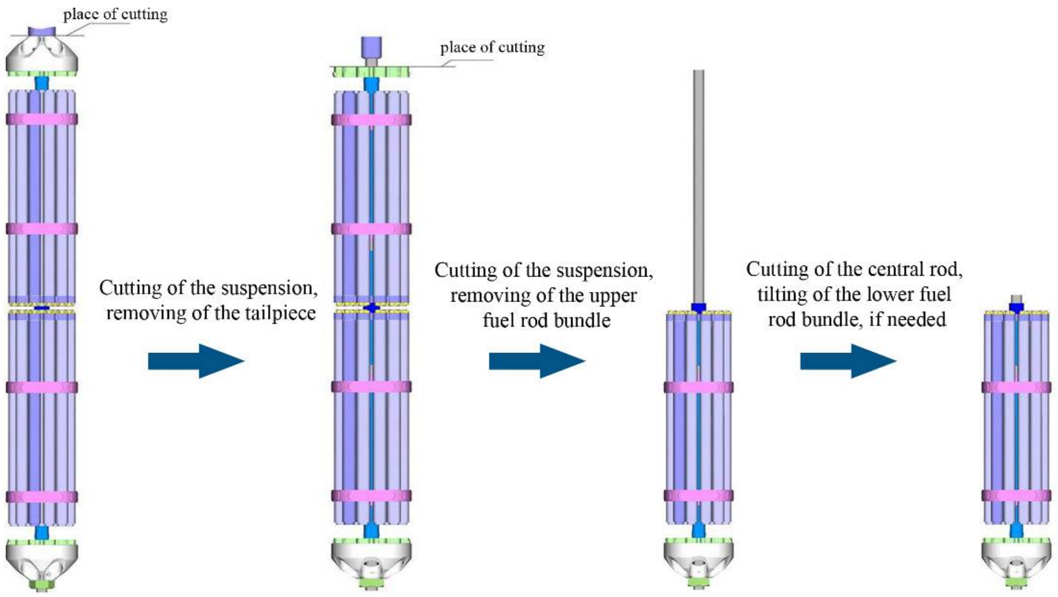


Fig. 7. Scheme of disassembling of the SFAs with a gap between the fuel rods of the upper and lower fuel rod bundles less than 9 mm

2.2. Preparation and Shipment of Tight Non-conforming SFAs from the NPP SNF storage facilities using the enlarged diameter ampoules

For removal from the NPP SNF storage facilities of tight non-conforming SFAs with damaged spacer grids beyond repair or failed to have been repaired, it is necessary to develop and implement a technology of preparation and transportation of the SFAs to the KhOT-2 and the RT-1 Plant of Mayak PA in the ampoules with the enlarged diameter.

Since in the SNF storage pools the SFAs are kept in canisters with the inner diameter of 98 mm, it is not expected that the enlarged SFA diameter will exceed this value. The inner diameter of the tilter canister, which is used to accommodate the lower fuel rod bundle during the SFA disassembling, is also equal to 98 mm. That is why the tight non-conforming SFAs with defects of the spacer grids might be disassembled in the same way as the conforming SFAs. In case of damage of the spacer grids, special clamps must be applied onto the SFAs. If the SFA diameter exceeds the diameter of the tilter canister, then the technology of the SFA disassembling without tilting of the lower fuel rod bundle should be applied.

It is expedient to use untight ampoules for removal of the fuel rod bundles of the tight non-conforming SFAs. It will enable to perform SNF drying in metal concrete containers using the available test bench, to avoid problems of accumulation of radiolytic hydrogen and to organize SNF accumulation and buffer storage at the NPP before shipment. In its turn, the possibility of buffer storage of the metal concrete containers with SNF will allow installing a wrapper with ampoules of enlarged diameter inside the shielded box of the disassembling division instead of using a tank for solid radioactive waste, and to perform disassembling of the tight non-conforming SFAs as they are received. The non-conforming SNF might be shipped in the same way as the conforming SNF: empty casks are delivered and left at the NPP, and the filled casks are taken away. Temporary SNF storage will require supplying each NPP with non-expendable metal concrete containers with the wrappers and enlarged diameter ampoules.

The fuel rod bundles of the tight non-conforming SFAs beyond repair should be shipped in the enlarged diameter ampoules to the KhOT-2 due to the fact that delivery of the non-conforming SNF to the RT-1 Plant of Mayak PA in the amount of 50 ton/year will allow removing only 13 % of the revealed non-confirming SFAs from the NPP.

2.3. Preparation and Shipment of the Untight SFAs from the SNF Storage Facility

The main problem related to disassembling and shipment of untight SFAs is probability of fuel spillage in the shielded box during disassembling and in the metal concrete cask during shipment. That is why expendable tight ampoules of enlarged diameter should be used for shipment and temporary storage of the fuel rod bundles. To reduce the risk of fuel spillage, the untight SFA should be disassembled in such a way so as to avoid tilting of the lower fuel rod bundle, so to say “from the bottom up”. Probable fuel spillage in the ampoules might be contained in the following way: by inserting a special funnel into the ampoule neck for the lower fuel rod bundle (Fig. 8) and by placing a can under the fuel rods of the upper fuel rod bundle (Fig. 9). Fig. 10 demonstrates accommodation of the equipment for containment of the fuel spillage in the SFA disassembling division.

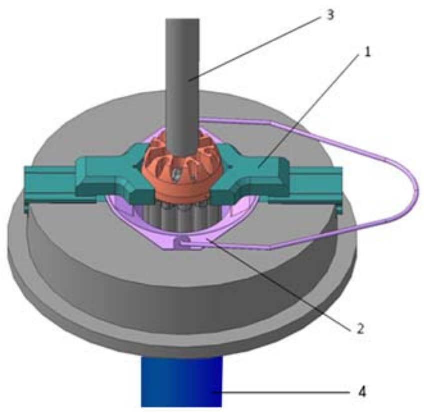


Fig. 8. Funnel in the clamping device: 1 – jaw; 2 – funnel; 3 – SFA suspension; 4 – ampoule

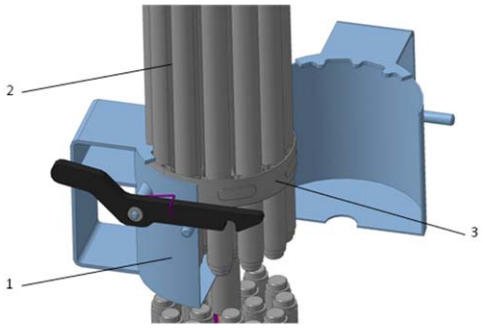
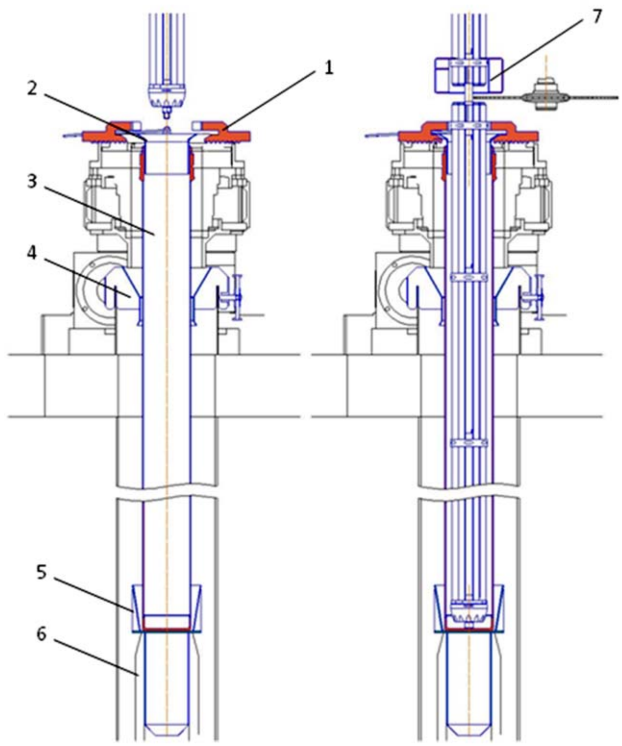


Fig. 9. Installation of the can on the spacer grid of the upper fuel rod bundle: 1 – can; 2 – upper fuel rod bundle; 3 – spacer grid 11



Before loading of the lower fuel rod bundle

Cutting off of the lower fuel rod bundle

Fig. 10. Location of the equipment for containment of the fuel spillage in the SFA disassembling unit: 1 – jaw; 2 – funnel; 3 – ampoule; 4 – upper centralizer; 5 – lower centralizer; 6 – tilter canister; 7 – can

Safe handling of the untight SFAs might be ensured only in case of considerable upgrading of the systems supporting the disassembling division. That is why disassembling and shipment of the untight SFAs should be postponed until completion of disassembling and shipment of the tight SFAs, i.e. for the period after 2030. Since Mayak PA does not plan SNF reprocessing after 2030, it will be necessary to prepare the untight SFAs for long-term dry storage and remove them to the KhOT-2 at the MCC. Thus, along with implementation of the technology for containment and collection of the SNF fuel spillage, the disassembling division upgrades should also include introduction of a technology for drying the ampoules with the fuel rod bundles of the untight SFAs.

Provided that the labour capacity is increased, modernization of the disassembling divisions to provide a possibility for disassembling of the untight SFAs might be completed by mid 2020 after filling of the NPP cask storage facilities. While removing the SNF from the NPP cask storage facilities, it is possible to complete the disassembling division upgrades and to remove a portion of the untight SFA to the RT-1 Plant for reprocessing by 2030.

2.4. Shipment of the Untight SFAs from the NPP Units to the SNF Storage Facility

At the Leningrad NPP the untight SFAs are transferred to the SNF storage facility in the TK-8 casks, which contain a special wrapper and canisters. In the SNF storage facility the canisters with the untight SFAs are filled with water and are placed into the cooling pool for storage. The technology for shipment of the untight SFAs from the NPP units to the NPP SNF storage facilities used at the Leningrad NPP might be improved for its application at the Kursk and Smolensk NPPs. It should contain technological and design solutions for the following problems:

1) Containment of probable fuel spillage in a special canister while loading the SFAs into the TK-8 casks, SFAs shipment, SFAs unloading from the TK-8 casks and storage in the cooling pool of the SNF storage facility;
2) Prevention of “contaminated” water leakage from the untight SFA into the TK-8 cask and from the TK-8 cask into the environment during shipment;
3) Prevention of “contaminated” water leakage from the canister with the untight SFA into the water of the SNF cooling pool during storage.

The indicated problems might be solved by using a tight canister for SFAs shipment and a funnel, which is inserted into the canister neck under the “trail” of the transport unit, for containment of probable SNF spillage in the canister during SFAs loading.

2.5. Preparation and Shipment of the Damaged and Pilot SFAs from the NPP Units

The problem of removing the damaged SFAs from the cooling pools of the NPP units is associated with the fact that the damaged SFAs may not be loaded into the wrapper of the TK-8 cask by means of the transport unit, transferred to the SNF storage facility and disassembled in the disassembling division. The pilot SFAs containing 7-meter fuel rods might be disassembled if cut off “on fuel”, which is not stipulated in the disassembling division project.

However, it is not expedient to construct a special area outside the NPPs for receipt and preparation for shipment of the damaged and pilot SFAs, as well as to design a new long-length cask for their shipment, due to their small number. That is why the SFAs should be disassembled into the fuel rod bundles/fragments and prepared for shipment at the NPP units. Since the only possible way of the pilot SFAs disassembling is cutting them off “on fuel”, it is necessary to take measures for containment and collection of the fuel spillage during disassembling. The infrastructure and equipment available at the NPPs should be engaged to the full in the process of the damaged and pilot SFAs removal from the NPP units. The rate of disassembling and preparation for shipment of the damaged SFAs is not expected to be high, that is why it will be necessary to ensure their buffer storage and, consequently, SNF drying.

The following transport and technological scheme may be proposed for removal of the damaged and pilot SFAs from the NPPs:

- Withdrawal of the SFAs from the canister (canister should be disassembled, if needed) and their accommodation in the cooling pool of the NPP unit;
- Disassembling/fragmentation of the SFA on a tray in the cooling pool of the NNP unit with a help of long-length instrument. This operation should provide for containment and collection of probable SNF spillage;
- Packaging of the fuel rod bundles/fragments into tight dried ampoules up to 200mm in diameter on the tray in the cooling pool of the NNP unit;
- Drainage and drying of the ampoules with SNF at the NPP unit;
- Temporary technological (buffer) storage of the ampoules with SNF in the reactor cooling pool;
- Loading of the ampoules with SNF into the wrapper of the TK-8 cask by means of a transfer cask and a charging feeder with a turnplate;
- Transfer of the ampoules with SNF to the SNF storage facility;
- Arrangement and temporary technological (buffer) storage of the ampoules with SNF in the cooling pool of the SNF storage facility;
- Transfer of the ampoules with SNF to the SFA disassembling division and their loading into the metal concrete container of the TUK-109 transport packaging set with a special wrapper;
- Temporary technological (buffer) storage of the ampoules with SNF in the metal concrete container of the TUK-109 cask;
- Shipment of the package with SNF from the NPP.

The technology for disassembling of the damaged and pilot SFAs on the tray in the cooling pool of the NPP unit was developed by the NUKEM Technologies for the Ignalina NPP. For implementation of this technology canisters with round and rectangular cross sections were designed to accommodate the fuel rod bundles and fragments of the Ignalina NPP SFAs having different kinds of damage and different degree of bending. For reprocessing at Mayak PA, it will be necessary to ship the fuel rod bundles and fragments of the damaged and pilot RBMK SFAs of the Russian NPPs into the ampoules with a diameter not exceeding 200 mm.

The proposed scheme may be used at all the NPP units with the RBMK-1000 reactors. Taking into account the complicated character of work associated with the underwater SFAs disassembling and the need to allocate enough space for the equipment deployment, operations related to preparation of the damaged and pilot SFAs for shipment and their removal from the NPP units could be started only as soon as the unit has been finally shutdown and all the undamaged SFAs have been removed from the cooling pool. While designing the equipment for disassembling of the damaged and pilot SFAs should be designed in such a way so it could be transferred from unit to unit. The damaged and pilot SFAs, prepared for shipment by 2030, should be sent for reprocessing to the RT-1 Plant of Mayak PA. After 2030 the damaged and pilot SFAs should be sent to the KhOT-2 of the MCC.

Conclusion

The Federal Target Program allowed justifying the practicality of the non-conforming RBMK SNF reprocessing, as well as finding technological solutions for shipment of the fuel rod bundles of the non-conforming SFAs for reprocessing, such as application of tight expendable ampoules, avoiding of SNF drying, since the storage period of the ampoules with SNF is limited and the number of the ampoules in the cask is limited too. Implementation of the pilot project confirmed the possibility of the non-conforming RBMK SNF shipment and reprocessing.

Large amount of the non-conforming SFAs in the SNF storage of the Leningrad NPP makes it urgent to develop and introduce special technologies for the SFAs preparation for shipment and removal for dry storage and reprocessing, including the technology for eliminating damages of the SFA structural elements.

Since Mayak PA plans to stop receiving and reprocessing SNF in 2030, it will be necessary to develop a technology for transition of SNF to dry storage and removal to the KhOT-2 of the MCC for all types of non-conforming SFAs by that time.

To ensure operation of the Kursk and Smolensk NPP units, it is necessary to develop and implement a technology for safe transfer of the untight SFAs to the NPP SNF storage facilities.

While preparing the NPP units for decommissioning, it is expedient to initiate development of a technology for underwater disassembling and shipment for reprocessing and dry storage of the damaged and pilot SFAs.

Implementation of the proposed scheme will enable removing all the non-conforming RBMK-1000 SFAs for dry storage at the KhOT-2 of the MCC and for reprocessing at Mayak PA.

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