EXPERIENCE IN PREPARATION OF SPENT NUCLEAR FUEL INCLUDING DAMAGED FOR SHIPMENT

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Standard operation of research or power reactors does not provide for handling damaged nuclear fuel. In this connection, preparing damaged SNF for the transport and long-term storage or reprocessing is, as a rule, a non-standard task. Analyzing the lessons learned allows solving such problems with more effectiveness.

The paper describes implemented projects in preparing the SNF with a different damage level for the transport. The Leningrad NPP, Russia, performed experiments with leaky SFAs of the RBMK reactor. The Vinca Institute, Serbia, prepared damaged SNF from RA research reactor for the transport. The Paks NPP, Hungary, dealt with VVER-440 SNF debris. Each case required development of procedures for handling damaged fuel.

Preparing leaky RBMK SFAs for transport

Now, considerable quantity of RBMK SNF is accumulated in Russia. It is stored under water in the reactor cooling pools. A program of transfer of RBMK SNF for long-term dry storage at the Mining and Chemical Combine is in progress to empty the pools. The program is developed for handling tight SNF, any damaged fuel handling procedures are not determined.

One of the possible options for the damaged SNF handling is reprocessing. A pilot transportation of fuel rod bundles from non-conforming RBMK SFAs from the Leningrad NPP Unit 2 to Mayak PA was performed in 2011 to prove practicability and feasibility of the damaged RBMK SNF reprocessing.

The non-conforming RBMK SNF includes the SFAs that cannot be stored in the long-term dry storage facilities. In most cases the non-conforming RBMK SNF is the fuel assemblies unloaded from the core ahead of schedule that did not reach their design burnup and have a big amount of uranium-235. The SFAs damaged during transport and process operations after unloading belong to the same type. However, the non-conforming SFAs of the worst type - the leaky ones - were chosen for the pilot transportation. All SFAs were unloaded from the reactor core because of the loss of tightness. Sipping test results gave the evidence that the fuel pellets were in contact with water and, accordingly, had water under the cladding of at least one fuel rod.

The selected SFAs were of a standard design, with two fuel rod bundles fixed in the grids at the SFA ends. All selected SFAs had fuel enrichment in U-235 of 2.4%, which is a typical enrichment value for the most of RBMK-1000 fuel assemblies. The fuel burnup was lower than the design value for this initial enrichment. The cooling time (13.8–16.5 years) was chosen for reasons of radiation safety. Eight SFAs were chosen for reprocessing, it makes one batch for a dissolver at the Mayak PA reprocessing plant.

When preparing the SNF for the transport, a few technical and research tasks required to be solved:

– to choose a container and to develop the components of the packaging;

– to develop a procedure and equipment for cutting and loading the SFAs into a container at the Leningrad NPP; and

– to analyze and justify safety of the proposed procedure.

A TUK-11 cask was chosen for the transport of fuel bundles, as it had acquired good reputation during its use both at the NPP and at Mayak PA. It was decided to transport the fuel bundles of the non-conforming SFAs in the ampoules, the design of which made it possible to reprocess them together with the fuel bundle. The requirements for the ampoules were governed by the selected methods of the SNF preparation, transport and reprocessing. The main requirements for the ampoule were:

- leak-tightness;
- maintaining integrity under normal and accident transport and handling conditions at the NPP and Mayak PA; and
- minimum wall thickness.

The ampoules shall be leak-tight to prevent water contamination during interim storage in the Mayak PA storage pool, as well as to allow meeting SNF humidity requirements when cutting fuel bundles. Minimum wall thickness of an ampoule facilitates SNF reprocessing.

The ampoule design, in its turn, had effect on the requirements for the fuel handling methods. The main problem faced when transporting leaky undried fuel after storage in water is to ensure fire and explosion safety of the transport package. Safe handling with leaky SNF in a leak-tight ampoule is limited to a period of time, in which a dangerous concentration of radiolytic hydrogen is generated in the ampoule posing a risk of fire and explosion. Analysis shows, that it takes at least nine months until dangerous hydrogen concentration is generated in an ampoule, air-filled under the atmospheric pressure, with one leaky, water-filled fuel rod. If an ampoule contains two leaky fuel rods, the concentration of hydrogen will be within safety limits during five months.

Fig. 1 demonstrates the ampoule designed and used for the transport of the fuel rod bundles from non-conforming RBMK SFAs as a part of the TUK-11 cask, and for interim technological storage in the Mayak PA storage pool.

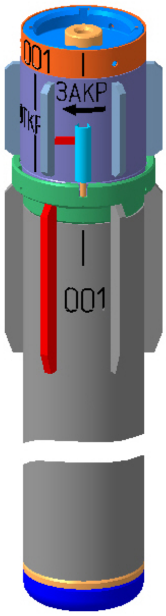

Fig. 1. Transport ampoule for the fuel rod bundles from non-conforming RBMK SFAs

The SFAs were cut into fuel rod bundles in a hot cell of the Leningrad NPP Unit 2. In the same cell the fuel rod bundles were loaded into ampoules and the ampoules were sealed with a special lid. The ampoules with SNF were loaded into a TUK-11 cask using a transfer cask. When transferring and loading an ampoule with fuel rod bundles into the cask, the radiation safety was provided by installing a shielding plug and a pintle on the ampoule lid. The top of the pintle was compatible with the existing grapples of the reactor hall.

The trial shipment and reprocessing of the SFA batch took place in late 2011.

Preparing damaged RA SNF for transport

For 25 years of operation the RA reactor (Vinča Nuclear Research Institute, Serbia) had accumulated a stock of more than 8000 TVR-S SFAs. The TVR-S type fuel assemblies are small cylindrical blocks in aluminum claddings (Fig. 2).

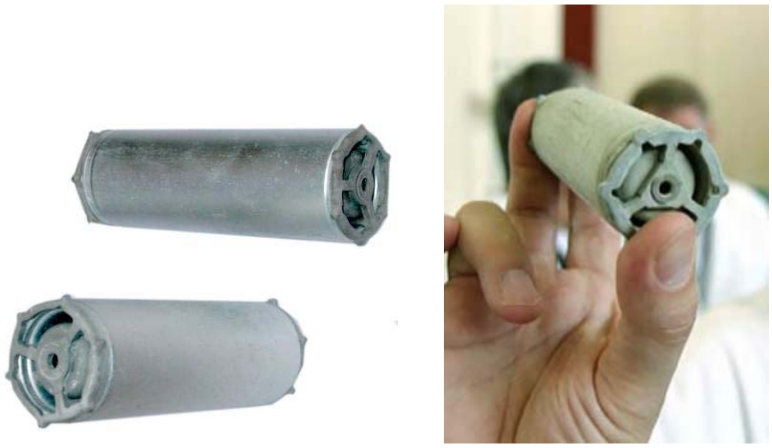

Fig. 2. TVR-S type fuel assemblies

The fuel storage is an annex to the reactor building containing four pools of water. A transport channel connects the pools with the reactor reloading chamber. The fuel was stored in the standard way loaded in stainless steel channels in the cooling pool of the RA reactor. The channels were suspended on special metal frames.

By the end of the reactor operation nearly all standard storage locations had been fully occupied by the reactor channels containing the spent fuel. To provide a more compact arrangement of the fuel in the storage pool, unique aluminum barrels to accommodate the major part of the oldest fuel were developed and fabricated. The barrels were stored in a few vacant places at the bottom of the storage pool. No SFA shipments had ever been made. Long storage of the SNF in water with high percentage of chloride and sulfate ions and a high conductivity caused corrosion of the spent fuel and radioactive release into the storage pool water. The inspection of the spent fuel stored in the pool revealed that all the fuel was leaky that required the utmost carefulness in handling and repackaging the fuel. In this connection, SNF removal was an urgent, high-priority task.

In 2007, SNF removal concept was developed. In 2008, after signing a contract with the IAEA within the framework of the RRRFR program, a procedure for SNF preparation for the transport was developed.

The project activities included the following:

– development of the procedure and equipment for repackaging the SNF into canisters;

– safety analysis;

– fabrication and mounting of the equipment in the reactor facility;

– SNF repackaging into canisters;

– development of the procedure and equipment for loading the canisters with SNF into casks;

– interim storage;

- loading the canisters into casks.

All operations of preparing and loading the SNF into canisters were performed remotely by specially developed equipment (Fig. 3) and tools on the working frame (Fig. 4) installed above the SNF storage pool.

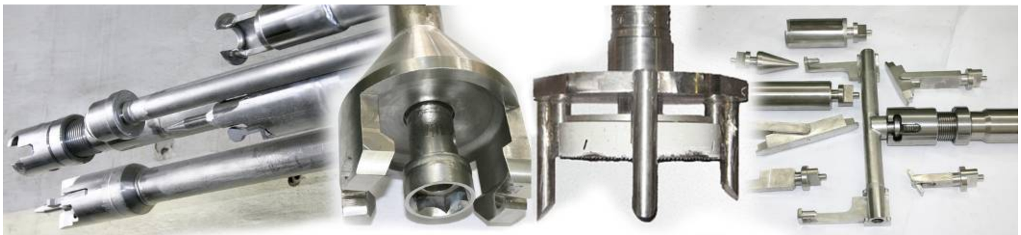

Fig. 3. SNF repackaging tools

Fig. 4. Working frame and operator's room

The water in the pool ensured protection of the personnel. The working frame tower had three levels. The underwater level accommodated different tools and equipment: a level for aluminum barrels, canister seats, seats for solid waste vessels. The second level was the main working ground for the operators. Here, there were seats for long-length tools and video monitors. The third level was designed for handling operations with the long-length tools.

The reactor channels were too long to be removed from the baskets in the cooling pool; so this operation, as well as cutting of their upper parts, which did not contain the fuel, were performed in a shielded room in the reactor vessel. The operations performed in the shielded room were completely automated; the operator controlled and operated the equipment remotely. The lower fragments of the reactor channels were cut off with a tube cutter and a winch driven by a stepper motor ensuring precise positioning of the channels. Then, the reactor channels were cut on the working frame tower with a tube cutter of a different design.

The aluminum barrels were opened on the working frame tower with a driller and a tilter. The principle of the procedure was sequential concentric drilling of the bottom to remove the fuel-containing tubes.

A set of long-length tools was designed to transfer the tubes and separate spent fuel assemblies and to handle the canisters, i.e. to transfer them in the pool and to install their covers. The fuel-containing canisters were put into special racks under water in the pools.

The process could be observed from a specially established operators' room with video surveillance and communication systems, a control panel for the water chemistry control system and control units for the radiation monitoring system. It also was a place of making accounting records of the radioactive material.

The safety analysis of the proposed handling procedure determined fire and explosion safety assurance being the main problem. The oxidized surface of the spent fuel contains a plentiful of bound water. When enclosed, the spent fuel can generate an explosive concentration of hydrogen and oxygen within several months. To avoid this, an untight design was selected for the canisters. Special requirements for drying, periodical blowing the casks and their gas contents were justified.

The canisters to be transported in TUK-19 casks or SKODA VPVR/M casks have a unified design and vary only in height and mass. The spent fuel is dried inside the cask.

Handling the casks on the grounds at the reactor facility required special engineering solutions. A rail system was mounted in front of the reactor building to transfer the casks between the reactor hall, the storage room and the outside ground. The crane in the storage room has low capacity so it was decided to use a forklift to transfer the casks there. Since it was necessary to simultaneously install a big number of casks in the reactor hall, the load on the floor was calculated to ensure their safe arrangement.

Over 2008-2009, more than 120 items (more than 580 pieces of equipment) were developed and fabricated. All the equipment was fabricated at Russian plants. In November 2010, the preparation of the spent fuel from the RA research reactor for the safe transport to Russia was successfully completed.

Preparing damaged VVER-440 SNF for transport

In April 2003, during cleanup operations with the VVER-440 fuel assemblies in the cleanup tank in Pool 1 at Unit 2 of the Paks NPP, Hungary, the cleaning solution began uncontrollable heating. That resulted in damage of 30 fuel assemblies. The investigations showed that almost all SFAs were damaged to one extent or another. Fragments of the fuel elements and the pellets that had spilt out of the claddings piled up in the middle of the tank. The lower parts of the spent fuel assemblies did not suffer visible damage.

The aim of the incident consequences elimination was to remove the SNF from the tank, bring it to a safe form and prepare it for safe storage and transport. Hindered access to the spent fuel, great variety of forms and conditions of failed fuel assemblies and fuel rods, necessity to perform the work without interfering with normal operation of the NPP were the main problems.

Russian companies performed a big scope of research and development work including development and validation of the restoration technology, design and fabrication of necessary equipment and tools. The proposed procedure implied to remove the SNF manually using remotely-controlled tools, to decrease water level in the well and to lower the working frame into the well.

The working frame (Fig. 5) was the most complicated piece of equipment. It was intended to carry the tools, canisters, personnel, control and supporting systems. During the operations the frame was lowered into the well of the cleanup tank using a crane. Controlled air flow in the gap between the working frame bottom and the water surface prevented aerosols from the personnel workplaces. The water layer over the damaged fuel was determined for reasons of radiation safety of the personnel on the working frame. This approach allowed decreasing the distance from the working frame to the object of the work as SNF was removed from the cleanup tank. A video surveillance system with its monitors on the working frame barriers helped the operators to control their remote manipulations.

To ensure safe work performance, nonstop-operation monitoring systems were created: for subcriticality, boron concentration, dose rate, water temperature, water level, aerosol activity and air flowrate.

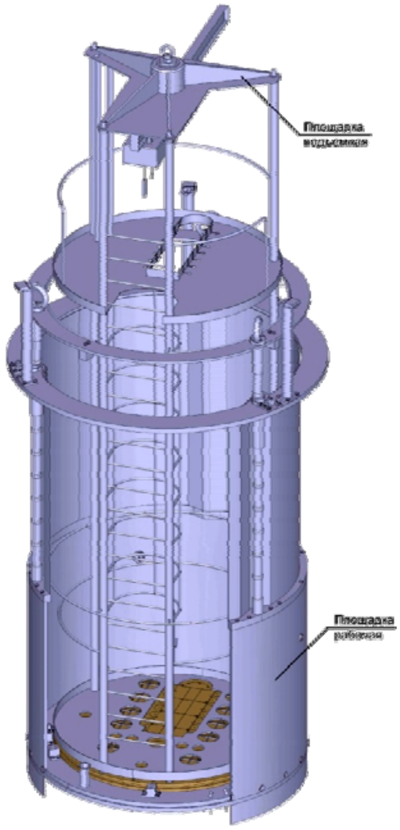

Fig. 5. Working frame for operations in the cleanup tank of Unit 2, Paks NPP.

Untight water-filled canisters were developed to repackage the SNF. The internal space of the canisters contacted the water of the cooling pool through a pressurizer. The pressurizer ensured removal of gaseous products that were generated during water radiolysis from the canisters and prevented the radionuclides dissolved in the water of the canister from releasing into the cooling pool.

More than a hundred types of SNF handling tools were created. These were long-length manipulators, saws of various types to cut SFAs and the tank structures, SRW canisters and many other tools. Grapples of various types were designed to transfer large SFA fragments to the canisters. Large SFA fragments were picked up and put into the canisters with long-length manipulators retoolable for different SNF types with filling knives, brushes, grippers. A suction system was developed to remove small SNF fragments from the tank.

The main operations were as follows:

- First, the top plate of the tank was cleared from the SFA and fuel rod fragments, which were then loaded into canisters. Smaller bulk SNF fragments were shoveled into the canisters, too. SFA heads were separated from the fuel column and loaded into solid RW vessels.

- The center of the tank was a heap of fuel rod fragments and had to be cleared with grabs and manipulators.
- The upper plate and the fuel assemblies under it were successively cut into fragments and taken out. Thus, the operators gained access to the SFA lower parts and using a force grapple installed them in a cutter to separate the tails from the fuel column.
- The bulk SNF and the SFA fragments were removed from the lower plate of the cleanup tank in the same way as from the upper one.
- Once free space was cleared out, the central part of the bottom plate was drilled through and taken out.
- Picking up the bulk SNF from under the lower plate followed by removal of remaining SFA fragments and the bulk SNF again. As a result, there remained an insignificant amount of SNF on the bottom of the tank that later was removed by the suction system.

Practical operations on elimination of the incident consequences in Well 1 of Unit 2 at the Paks NPP were completed in 2007. The maximum individual dose accumulated over the entire period of operations did not exceed 10% of the annual dose limit, and the average one made up less than 5%. More than 5 tons of damaged nuclear fuel were brought to safe controllable conditions and consigned for interim storage in the Paks cooling pool.

The next phase of the SNF preparation for the transport was its drying, which included draining, filling with inert gas and sealing the canisters. To choose an optimal procedure, different procedures for draining the water were tried out; the experiments were conducted on short mockup canisters containing irradiated VVER-440 fuel and full-size canisters containing SNF dummies.

The experiments and evaluations of the time, dose rates and accumulated radwaste, the thermal vacuum drying without pre-draining of the boric acid solution was accepted as the optimum method. The experiments validated the safety of handling the canisters prepared by this technology, as well as the safety of accumulating the SNF on the filtering elements. It was found out that the process of drying the canisters does not require special measures to protect the personnel and the environment due to a low release of fission products. A drying mode and a procedure for air diluting of the non-condensed gases evacuated from the canister were developed to prevent formation of an explosive mixture.

The SNF was dried in the canisters in 2013. The fuel is ready for the transport.

Conclusions

Experience shows that complexity of the tasks related to damaged SNF handling depends on the fuel conditions, technical capabilities and limitations of the fuel user.

To develop a procedure of SNF preparation for the transport, the information on the fuel conditions shall be available. This background information shall be comprehensive and reliable, for it has direct influence on the effectiveness of the procedure to be developed. In this connection, a significant phase of the work is to collect and analyze the information. Direct examination of the fuel is the most reliable source of information. The lacking data can be obtained by experiments, calculations and modeling of the processes which caused damage to the fuel.

Damaged SNF handling procedures require development of unique long-length tools adapted to the peculiarities of each case. The procedure effectiveness is enhanced through a combination of a multi-purpose and specialized, but simpler, tool. The multi-purpose tool benefits due to less time spent for changing and readjustment. The specialized tool, as a rule, is more reliable and effective.

Backup tools with different principles of operation proved to be useful taking into account absence of practical experience in performing challenging process operations.

The maximum use of available standard equipment allows sparing resources for development of new devices and makes it easier for personnel to master a new methods and procedures, which is significant to safety.

Nuclear and radiation safety is the utmost priority, like in all operations with nuclear fuel.

Fire and explosion safety is one of the complicated issues when assuring safe handling of leaky SNF. This issue is especially acute when choosing and developing a packaging for storage and transport of SNF. The main methods that prevent dangerous concentrations of hydrogen and oxygen are dilution or removal of the gases with radiolysis products, and limited time of sealed SNF storage.

Personnel training from basic process operations and up to accident response is a prerequisite for success in performing non-standard work. Practical training is the most effective using the existing equipment and fuel or mockups as close to the real equipment as possible.

The experience gained by Russian experts in development and application of the procedures for preparing damaged nuclear fuel for the transport allows creating SNF handling procedures that meet statre-of-the-art safety, reliability and efficiency requirements.