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First Experience in Developing the Technology for Liquid Spent Fuel Transport and Reprocessing

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Abstract

Notwithstanding the fact that solution reactors with liquid nuclear fuel are operated both in Russia and abroad, no handling procedures concerning the preparation of liquid spent fuel for transport and reprocessing have been developed previously.

This paper presents the peculiarities of the Foton JSC IIN-3M reactor's (Tashkent, Uzbekistan) liquid spent fuel preparation for removal to the Russian Federation.

Particular attention was paid to the safety of liquid spent fuel handling and shipment.

Introduction

The HEU IIN-3M liquid spent fuel removal was a part of the Russian Research Reactor Fuel Return (RRRFR) program initiated by the U.S. Department of Energy, the IAEA and the Russian Federation. The RRRFR program successfully completed several dozens of shipments of fresh and spent fuel from different countries using Russian origin research reactors to the country of origin for reprocessing and further use in nuclear industry.

The preparation of IIN-3M liquid spent fuel for shipment to the Russian Federation for reprocessing included the following activities:

- Design, manufacture and test the equipment to discharge liquid spent fuel from the reactor into temporary storage canisters;
- Discharge the liquid spent fuel from the reactor into temporary storage canisters and inspect the spent fuel;
- Design, manufacture and test the equipment to load liquid spent fuel into transport canisters;
- Design, manufacture at Sosny R&D Company's Pilot Production Facility and perform a dry run of the equipment to load the transport canisters into the SKODA VPVR/M cask at UJV Rez,

Czech Republic and at the IIN-3M reactor site;

- Design, manufacture and test the equipment for liquid spent fuel receipt at Mayak PA;
- Perform research activities to determine and improve the reprocessing processes; prepare and issue the safety analysis report and obtain the license authorizing the liquid spent fuel receipt and reprocessing at Mayak PA.

Russian-origin homogeneous reactors using uranyl sulphate solution (UO_2SO_4) enriched to 90% in ^{235}U are listed in Table 1. At present the conversion of the ARGUS reactor in Kurchatov Institute to use the low-enriched uranium is in progress.

Table 1 Russian-origin solution reactors

RR Owner	Facility Name	Quantity, l	Status
Kurchatov Institute	GIDRA (HYDRA)	22.8	operational
Kurchatov Institute	ARGUS	22	operational
JSC Foton	IIN-3M	23	in decommissioning
NIIP	IIN-3M	22.4	decommissioned
VNIITF	IGRIC	54	operational
VNIIEF	VIR-2M	104.6	operational

In addition, there are reactors that use other solutions:

- VNIITF has a YAGUAR reactor facility that uses $UO_2SO_4 + H_2O + CdSO_4$ solution;
- The ROMASHKA reactor in the Kurchatov Institute that used the $UC_2 + H_2O$ solution was decommissioned; all fuel was discharged and loaded into capsules.

No technologies to prepare liquid spent fuel for transport and reprocessing have been developed previously, nor such a fuel have been included in the fuel inventory that can be reprocessed at Mayak PA.

Equipment

The equipment developed for the IIN-3M liquid spent fuel removal can be divided into three main groups: equipment for handling operations at JSC Foton site, transport equipment and equipment for liquid spent fuel handling at Mayak PA.

Equipment for Handling Operations at JSC Foton Site

This equipment (Fig. 1) was used to discharge the liquid spent fuel from the reactor vessel and to load it into 6 temporary storage canisters ensuring the simultaneous measurement of the liquid volume. It ensured the nuclear safety of operations, the radiation protection of the personnel and also prevented any unauthorized access to the uranyl sulphate solution arranged for temporary storage. The equipment design process included several safety analyses, such as nuclear, radiation, fire and explosion (hydrogen accumulation) safety analyses, and an analysis of possible accidents. The equipment was tested at the production site of Sosny R&D Company, delivered to JSC Foton in October 2013, mounted and commissioned in January 2014.

Figure 1 Partly-mounted equipment for liquid spent fuel discharge and temporary storage in the reactor hall

Transport Equipment

A special canister was designed to ensure the liquid spent fuel safe transportation in the TUK-145/C package (Fig. 2) previously used to transport RR SNF from Vietnam and Hungary by air.

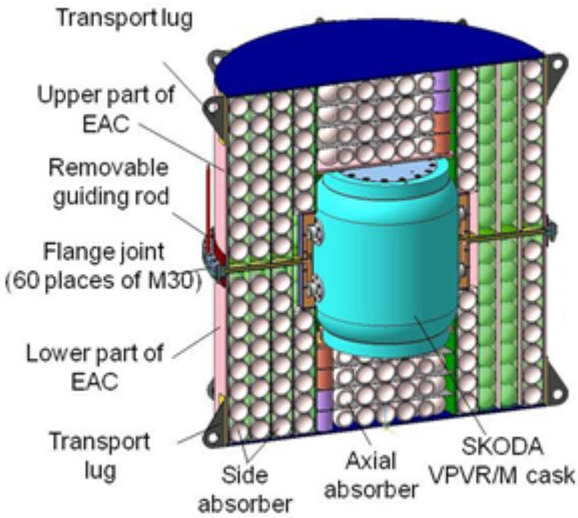
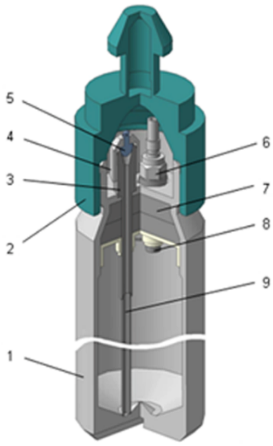


Figure 2 TUK-145/C

The canister consists of a body and a lid (Fig. 3). The canister body is a welded cylindrical assembly. A lead shield plug seals the internal space of the canister from the top to ensure the personnel radiation protection while installing and removing the lid, connecting the canister to the systems for pouring the liquid spent fuel in/out of the canister and during the leak testing. There are two connectors in the canister neck: one for fuel and one for gas. The gas connector is used to vacuum the canister during its filling with the liquid spent fuel, to replace the gas medium and to leak test the welds.

A system of special polyethylene energy absorbers of four types (Fig. 4) was added in the free cells of the SKODA VPVR/M cask as well as on the top and bottom of each canister providing additional dynamic protection for the dangerous radioactive content of the package.



1 - body
2 - lid
3 - fuel connector
4 - coupling nut
5 - plug
6 - gas connecter
7 - lead plug
8 - gas branch pipe
9 - fuel pipe

Figure 3 Transport canister

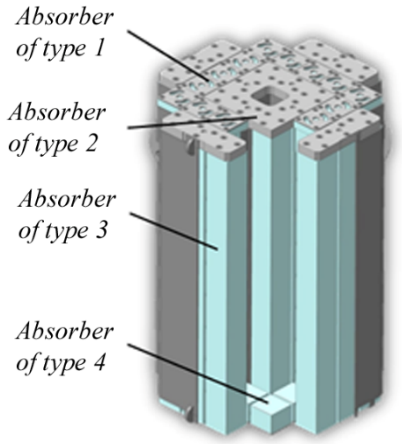


Figure 4 SKODA VPVR/M basket with energy absorbers

The same equipment used to discharge the liquid spent fuel from the reactor vessel in temporary storage canisters was adapted and also used prior to shipment to reload the liquid spent fuel in the 16 transport canisters, to leak-test the loaded transport canisters and to check their mass.
To load the transport canisters in the SKODA VPVR/M cask some equipment previously used for loading spent fuel assemblies at Dalat Research Reactor Institute in Vietnam was also used in Uzbekistan (the handling platform, support plate with an adapter and guide pins), together with new specially designed equipment for this shipment (Fig. 5) that included the transport canisters, transfer cask, grapples and shock absorbers.

Figure 5 Equipment dry run to verify compatibility with SKODA VPVR/M cask

<u>Equipment for Liquid Spent Fuel Handling at Mayak PA</u>

Special equipment was designed for the acceptance, temporary storage and reprocessing liquid spent fuel at Mayak PA. This equipment included a grapple, fixing device and the process line to discharge the liquid spent fuel from the transport canisters and feed it into the reprocessing equipment. Also the

U extraction parameters were optimized, measures to compensate the effect of the corrosive solution on the process equipment were developed and the parameters of the radioactive waste resulted from liquid spent fuel reprocessing and handling were specified. After performing the full safety assessment and developing the work procedures and instructions for Mayak PA personnel, Rostechnadzor issued to Mayak PA the License for the acceptance, temporary storage and reprocessing the IIN-3M RRSF.

Shipment

The handling operations at the IIN-3M site consisted in loading the liquid spent fuel transport canisters into the SKODA VPVR/M cask, loading the SKODA VPVR/M package into the ISO container and installing the ISO container on a truck. Then the cargo was shipped by road to the Tashkent airport, were a special truck and trailer and the energy absorbing container were delivered beforehand by air. Using a crane, the SKODA VPVR/M was installed on the special trailer in the energy absorbing container forming the TUK-145/C package, the truck was boarded in an An-124-100 aircraft (Fig. 6) and shipped to the Russian Federation. The truck then shipped by road the TUK-145/C package from the airport to the Mayak PA site.

Figure 6 Special truck with TUK-145/C boarding the An-124-100 aircraft

Safety Assessment

Particular attention was paid to the safe liquid spent fuel handling at all stages of this project.

Handling Equipment Safety Assessment

Nuclear, radiation, fire and explosion (hydrogen accumulation) safety analyses, and analysis of possible design and beyond design basis accidents (e.g. earthquake) were performed for the technologies to handle the liquid spent fuel at JSC Foton and Mayak PA site during the design phase. The Institute for Physics and Power Engineering (Obninsk), Scientific and Engineering Center for Nuclear and Radiation Safety (Rostechnadzor, Moscow) and State Inspectorate Sanoatgeokontechnazorat (Uzbekistan) confirmed these analyses.

Transport Equipment Safety Assessment

The activity of the liquid spent fuel was app. $1 \cdot A_2$, much below the SSR-6 limit of $3000 \cdot A_2$ for air shipments of radioactive materials in Type B(U) packages.

The design of the package satisfied the applicable IAEA SSR-6 specific requirements[1] stated in paras 639, 644, 649 and 650 b) (ii) for liquid radioactive materials.

Rosatom's expert organization VNIIEF played a critical role in the safety assessment of the TUK-145/C design and transport canisters, which lead to the issuance of the two Russian Certificates of Approval for Package Design and Shipment for this project: RUS/3205/B(U)F-96T authorizing the liquid spent fuel transportation in SKODA VPVR/M package by road within the territory of Uzbekistan and RUS/3197/B(U)F-96T(Rev.1) authorizing the liquid spent fuel transportation in TUK-145/C by air and road within the territory of the Russian Federation.

The TUK-145/C package strength safety assessment and tests performed on a mock-up for impact against an unyielding target at a speed of 90 m/s showed that in all studied impact scenarios the energy absorbing container limits the impact load on the SKODA VPVR/M cask down to levels at which the SKODA VPVR/M cask maintains its integrity and remains leak-tight (Fig. 7).

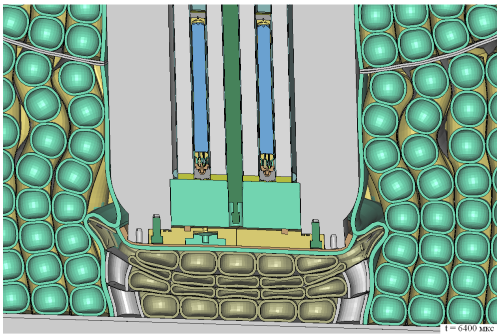


Figure 7 Deformed TUK-145/C package after impact

The state of the liquid spent fuel canisters in the TUK-145/C package after impact against an unyielding target at a speed of 90 m/s was analysed for the following accident cases:

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[1] 639. The design of the package shall take into account temperatures ranging from –40°C to +70°C for the components of the packaging. Attention shall be given to freezing temperatures for liquids and to the potential degradation of packaging materials within the given temperature range.

644. The design of any component of the containment system shall take into account, where applicable, the radiolytic decomposition of liquids and other vulnerable materials and the generation of gas by chemical reaction and radiolysis.

649. The design of a package intended for liquid radioactive material shall make provision for ullage to accommodate variations in the temperature of the contents, dynamic effects and filling dynamics.

650. A Type A package designed to contain liquid radioactive material shall, in addition (…)

b) (ii) Be provided with a containment system composed of primary inner and secondary outer containment components designed to enclose the liquid contents completely and to ensure their retention within the secondary outer containment components, even if the primary inner components leak.

1. Axial impact in upright position (impact on the bottom of the transport canisters);
2. Angle impact on the bottom of the transport canisters;
3. Axial impact in upside-down position (impact on the lids of the transport canisters);
4. Angle impact on the lids of the transport canisters;
5. Side impact (horizontal position impact).

The calculation results (Fig. 8) showed that in all studied cases the SKODA VPVR/M cask ("secondary outer containment") and the transport canisters ("primary inner containment") - due to special design features assuring a three-step deformation process during impact, maintain their integrity and tightness forming "a containment system that enclose the liquid contents completely and ensure their retention within the secondary outer containment components, even if the primary inner components leak" (para. 650 b) (ii) SSR-6).

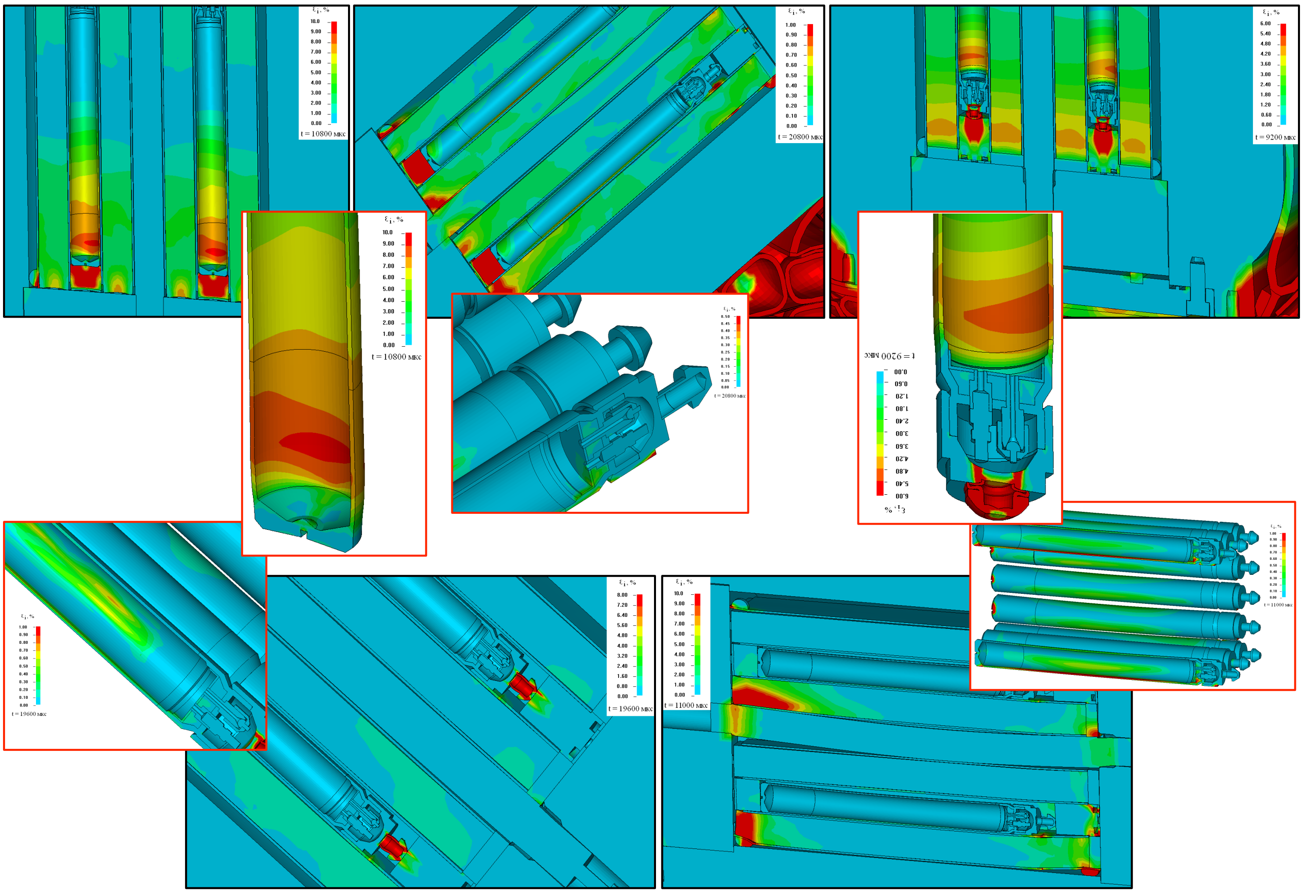

Figure 8 Total Strain Intensity Distribution Field

The nuclear safety of a single package was assessed for normal and design basis accident conditions of transport taking into consideration the results of the strength and thermal safety assessment, with as well as without account taken for the absorbing properties of the SKODA VPVR/M's boron steel basket. Beyond design basis accident conditions of transport considered two scenarios: water leaking inside the SKODA VPVR/M cask due to losing its tightness and liquid spent fuel leaking inside the

SKODA VPVR/M cask due to losing the tightness of all transport canisters.

The maximum k_{eff} for a single package in all these cases didn't exceed 0.738 granting a consistent safety margin. The CSI equalled 0 since an infinite array of packages remains subcritical in normal and accident conditions of transport.

Conclusions

In September 2015, for the first time liquid spent fuel was transported by air to the Mayak PA radiochemical plant for reprocessing.

The technologies developed for the preparation for shipment and reprocessing the liquid spent fuel from Uzbekistan can be applied for handling liquid spent fuel of Russian solution reactors, and also for shipments of other highly radioactive uranium liquids for reprocessing at Mayak PA.

References

1. First Experience in Developing the Procedure for Liquid Spent Fuel Transport and Reprocessing. D. Derganov, A. Ivashchenko, S. Komarov, A. Samsonov (Sosny R&D Company), U. Salikhbaev, N. Maksumov (INP AS RU), T. Kirilova (Foton JSC), M. Tyacke (INL). X International Nuclear Forum "Safety of Nuclear Technologies: Transport of Radioactive Materials – ATOMTRANS-2015", St. Petersburg, Russian Federation, 5-9 October, 2015.