AVAILABLE REPROCESSING AND RECYCLING SERVICES FOR RESEARCH REACTOR SPENT NUCLEAR FUEL (A NEW IAEA REPORT)

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ABSTRACT

International activities in the back end of the research reactor (RR) fuel cycle have so far been dominated by the programmes of acceptance of highly-enriched uranium (HEU) spent nuclear fuel (SNF) by the country where it was originally enriched. These programmes will soon have achieved their goals and the HEU take-back programmes will cease. However, the needs of the nuclear community dictate that the majority of the research reactors continue to operate using low enriched uranium (LEU) fuel in order to meet the varied mission objectives. As a result, inventories of LEU SNF will continue to be created and the back end solution of RR SNF remains a critical issue. In view of this fact, the IAEA, based on the experience gained during the decade of international cooperation in supporting the objectives of the HEU take-back programmes, drew up a report presenting available reprocessing and recycling services for RR SNF. This paper gives an overview of the report which will address all aspects of reprocessing and recycling services for RR SNF, including an overview of solutions, decision making support, service suppliers, conditions (prerequisites, options, etc.), services offered by the managerial and logistics support providers with a focus on available transport packages and applicable transport modes.

INTRODUCTION

IAEA, NEA and OECD continue to support the nuclear community in developing geological repositories. Therefore, a wide range of publications addressing specific safety requirements, international conferences proceedings, joint research reports, guidelines etc. on this subject is available.

The new IAEA report presented here [1] addresses the available mature options for the management of the back end RR fuel cycle (Fig. 1). Thus emphasis is made on reprocessing and recycling, including an overview of solutions, considerations of decision, regulatory requirements, fuel management service suppliers' conditions (prerequisites, options, etc.), services of the managerial and logistics support providers, and licensed transport packages and applicable transport modes.

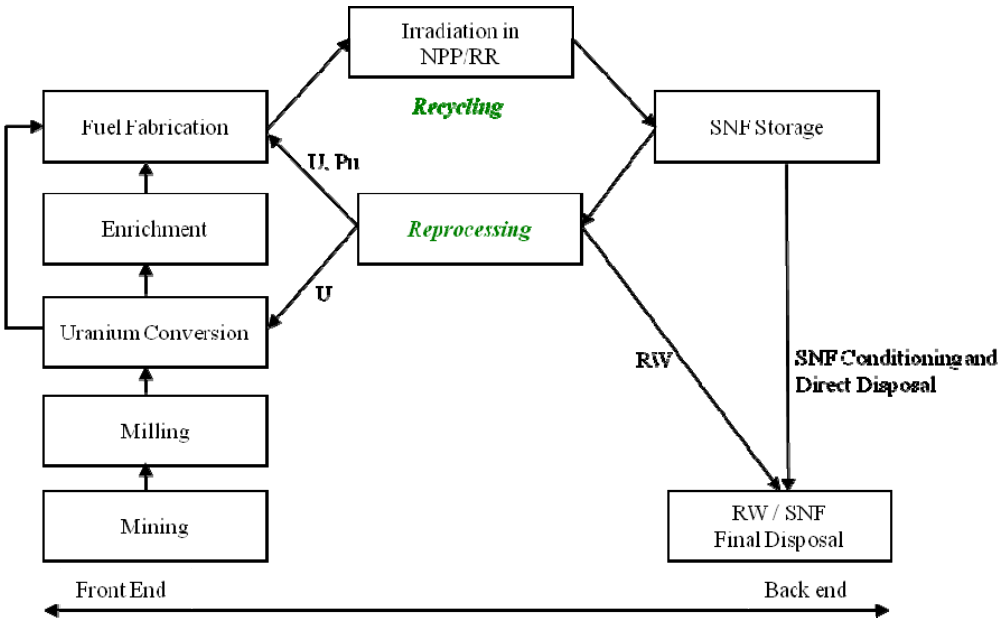

Fig 1. Nuclear fuel cycle

Industrial entities in two countries, France and Russia, offer international SNF management services on a commercial basis. These services can provide the basis for viable RR SNF management options, depending upon their scope, technical compatibility, cost and accessibility.

This paper summarizes the collection of information included in the IAEA report "Available reprocessing and recycling services for RR SNF" and presents the status of this publication.

1. Content of the IAEA Technical Report on Available Reprocessing and Recycling Services for RR SNF

The present document includes four chapters and three Appendixes.

Chapter 1 (the Introduction) outlines an overview of the back end nuclear fuel cycle solutions and considerations of decision. Chapter 2 presents the country specific reprocessing service description. Currently, only France and the Russian Federation offer RR SNF reprocessing services, which are addressed in this chapter. First of all the legislative background with the possible options for reprocessing are described in this chapter. Special attention is paid to the licensing procedures. The description of reprocessing facilities includes applied technology, environmental aspects, and time frame of a project realisation. Chapter 3 presents managerial and logistics support services and service providers. It considers examples of available transport packages, equipment and accessories, and transport modes. Based on experience, selection criteria, engineering, contracting and licensing support, and examples of a cost distribution for implementation projects, and of completed RR SNF shipments are also included. Chapter 4 presents conclusions, drawn during the preparation of this publication.

The Appendixes contain specific technical information about packages and equipment for RR SNF handling, as well as a service description template (SD) that outlines considerations to guide RR SNF disposition strategy based on reprocessing.

2. Overview of Included Information

2.1. RR SNF Management in France

The reprocessing process as performed at the AREVA La Hague facility [2] is summarized in Fig 2. The RR fuel reprocessing technology of the La Hague facility includes the following steps:

A – The reception and cooling step: once the fuel is received at La Hague facility, it is placed in interim storage pools for cooling. This cooling or deactivation substantially decreases the radioactivity of the fission products.

B – The reprocessing (treatment) step: after shearing the fuel is introduced into the existing dissolver through a pit specially designed for RR spent fuel. The dissolution is accomplished in a hot nitric acid solution. At this step, the process is limited by the aluminium concentration to 35-40g aluminium/L, to manage the risk of precipitation into aluminium nitrate. The resulting solution is then blended with the solution coming from the dissolution of the UOx fuel (power reactor fuel). Uranium and plutonium are extracted from the solution by a liquid-liquid extraction process. Several extraction cycles in pulsed columns, mixer-settler banks, or centrifugal extractors are necessary to meet the end-product specifications. At the end of these cycles, the following solutions are generated:

- a solution specifically containing the uranium;
- a solution specifically containing the plutonium;
- a solution containing the fission products and the minor actinides.

C – The vitrification and storage step: the fission products and the minor actinides solution is then vitrified, i.e. conditioned into a stable, homogeneous and durable glass matrix, and encased in a standard canister, "Vitrified Universal Canister" (UC-V)[1]. The UC-Vs are then stored in a specific storage facility at La Hague site for cooling.

D – Following a cooling storage period, the UC-Vs are returned to the customer country for interim storage prior to final disposal.

In order to comply with the customer country's regulations and technical constraints, the waste can also be conditioned by other means.

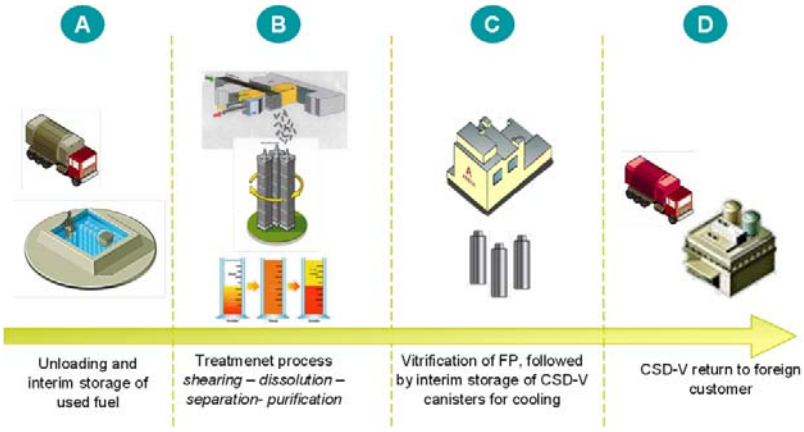

Fig 2. Schematic view of the research reactor fuel treatment process

[1] Conteneur Standard de Déchets Vitrifiés (CSD-V).

The AREVA reprocessing plant of La Hague has reception and reprocessing authorization for a wide range of known RR SNF. An extension of this authorization shall be obtained if the plant plans to receive new types of RR SNF.

Based on the past activities and experience in reprocessing various type of research and fast reactor spent fuel, AREVA has decided to launch the project of a new Polyvalent Fuel Treatment Facility (TCP[2]) at La Hague site. TCP will address various fuel specificities at the shearing and dissolution steps in order to answer varied customers' needs without hampering current La Hague reprocessing plant capacity. The new facility will substantially expand the reprocessing spectrum services of the La Hague plant.

AREVA is also conducting reprocessing qualification at La Hague plant for silicide RR SNF (U_3Si_2), with a similar process as for U-Al fuel adapted to the specific characteristics of silicide. The R&D program has already showed positive results and the solution is currently being qualified at an industrial-scale.

2.2. French International Agreements and Licensing Summary

Along with the usual customer-supplier commercial and industrial relationship, the inter-governmental discussions for Intergovernmental Agreements (IGA) between the Governments of France and the corresponding country are to be very well considered in the whole project time frame. Fig. 3 below shows the typical schedule and main steps to be followed from first discussions and exchanges about a RR SNF management solution up to the effective contract signature.

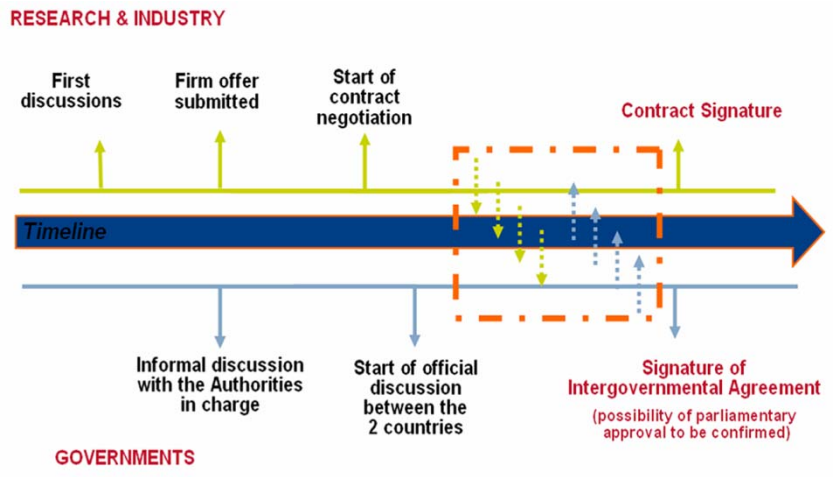

Fig 3. Typical schedule for a new RR spent fuel reprocessing contract

The IGA application requires three groups of information. Each of these is to be clearly developed in the final agreement:

- Project description: information on the material owner or related contractor (if different from the material owner), introduction of the main stakes for the owner or related contractor, location of the nuclear material, legal status and origin of the material, , the planned contractual structure for material treatment and recycling, the planned scope of collaboration between the parties;
- Acceptability of reprocessing: type and characteristics of material to be reprocessed (design, total mass, mass of oxide and heavy metals, burn-up rate, cooling, initial enrichment, etc.), the material transportation (cask and transportation procedures to be realized);
- Schedule: quantities to be reprocessed and timing, period of delivery of SNF from the customer to AREVA La Hague facility, periods of treatment, period of waste return, use/reuse of the recycled material, deadline for last return of waste, destination of waste.

The French approval certificates of AREVA transportation casks are regularly renewed in order for this equipment to be available for all RR SNF removal projects. Agreement extensions have to be obtained for each type of RR SNF to be transported in these casks. When needed, specific baskets can be designed and manufactured for RR SNF transportation.

Two main authorizations issued by the French Nuclear Safety Authority (ASN) [3] are necessary in order to implement a reprocessing solution in France: transportation authorization and reception-reprocessing authorization at La Hague plant.

[2] Traitement des Combustibles Particuliers.

2.3. RR SNF Management in Russia

At present, in Russia functions one reprocessing facility – FSUE Mayak PA reprocessing plant RT-1, situated in Ozersk of the Chelyabinsk Region [4]. The main distinctive feature of the plant RT-1 is a wide range of reprocessed fuel. SNF of power reactors (VVER-440 and BN-600), naval propulsion reactors, commercial-scale reactors and research reactors is reprocessed here [5]. The distinctive features of the plant RT-1 technology are:

- Three multipurpose process lines allow not only reprocessing different fuel types on each of them, but also implementing joint reprocessing of different SFAs.
- Extraction of neptunium during SNF reprocessing is aimed at its separated storage and fabrication of radioisotopic products.
- Commercial output of regenerated uranium with targeted ^{235}U enrichment by means of mixing the uranium resulted from reprocessing different SNF.
- Separation of different elements from residual SNF solutions for fabrication of radioisotopic products (caesium, strontium, promethium, krypton, etc.).

The SNF delivered to the plant is placed into a cooling pool (Fig.4), where more than three meters of water above the fuel make a reliable biological shielding. The duration of RR fuel interim storage is up to 2 years before reprocessing. Safety of the SNF interim storage is ensured by highly efficient pool water purification system and radiation monitoring systems. The first stage of SNF reprocessing is to cut the SFAs and load the fragments into a batch-type dissolver, where the fuel is dissolved in nitric acid solution. Then the nitric-acid solution of fuel composition is clarified by filtering and after that is reprocessed by the PUREX process. The PUREX process allows to extract and separate the valuable elements (uranium, plutonium, neptunium). The targeted products of SNF reprocessing are:

- Uranyl nitrate melt, obtained from evaporation of nitric-acid solution of uranium;
- Triuranium octoxide, obtained from precipitation by ammonia and subsequent roasting of the precipitate;
- Plutonium dioxide, obtained from precipitation by oxalate and subsequent roasting of the precipitate.

Beside the mentioned targeted products, krypton (^{85}Kr), strontium (^{90}Sr), caesium (^{137}Cs), americium (^{241}Am), promethium (^{147}Pr) and other radionuclides are separated from the spent fuel [6].

Fig 4. General view of the SNF pool at FSUE Mayak PA

The FSUE Mayak PA directions of further development include extension of the reprocessed SNF domain from 2017 by U-Be, U-Zr, uranium metal, plutonium fuels and materials, SNF from molten salt RR and other spent nuclear fuels.

Development and implementation of optimizing process design solutions is aimed at minimizing the operating costs and volumes of liquid radioactive waste during SNF reprocessing. This includes a number of new processes making part of the SNF reprocessing cycle, the implementation of which is anticipated to result in a three-fold decrease of operational medium-level (ILW) radioactive waste (RW). New RW processing facilities (a cementation complex, a high-level waste (HLW) vitrification complex, a solid RW management complex) are planned for construction and commissioning between 2015 and 2020. Simultaneous upgrades to the existing equipment and asset replacement are in the plan, too. The developed concept of the new multi-functional vitrification complex will allow the solidification of all types of liquid HLW in borosilicate or aluminophosphate glass using detachable single-use fusion crucibles. Thus, the solidification of operational HLW resulted from reprocessing Russian and foreign SNF, return of the RW to foreign SNF suppliers, and clearing the storage tanks from the accumulated waste will be ensured [7].

2.4. Russian International Agreements and Licensing Summary

The main provisions of the Federal Law No. 7-FL "On Environmental Protection" dated 10 January 2002 are as follows:

- The SNF import is permitted for interim storage and/or reprocessing.
- The project shall undergo a state ecological expertise[3] during which a general decrease of the radiation effects and enhancement of environmental safety, resulted from implementation of the project shall be justified.
- The basis for the import are international contracts of the Russian Federation.
- The Law gives preference to the option of returning the radioactive waste resulting from reprocessing to the country of origin of the RR SNF.
- The RR SNF imports are subject to the yearly limits approved by the Government of the Russian Federation.

In compliance with the Government Decree no. 418, dated 11 July 2003 the following project preparation procedure has been formed:

(1) Conclusion of a government-to-government agreement with the foreign country on cooperation in SNF import (both of Russian and foreign origin) into the Russian Federation. In a number of cases, Russia already has an acting agreement. The international contract should contain provisions for the destiny of radioactive waste resulted after SNF reprocessing. Two options are possible: RW re-turn to the export country, or permanent disposition in the Russian Federation.

(2) Elaboration of the documentation for an SNF import Unified Project in compliance with the established requirements, including:

- Draft Foreign Trade Contract (FTC);
- Special ecological programme (programmes) (SEP);
- Materials to justify general decrease of the risks of radiation impact and enhancement of environmental safety as result of the Unified Project implementation, as well as the timeframe of interim technological storage of spent fuel assemblies and reprocessing products, stipulated by the FTC;
- Other materials to be submitted to the state ecological expertise, including the conclusion of the Russian Federal Service for Environmental, Technological and Nuclear Supervision (Rostechnadzor) and the Ministry of Public Health of the Russian Federation.

An import/export license is required for nuclear commodities and technologies, including RR SNF or RW resulted from reprocessing. Federal Centre for Nuclear and Radiation Safety (FCNRS) is authorized by the Government of the Russian Federation to sign FTCs for SNF imports, and also prepares applications, and obtains import licenses for SNF.

The Russian regulations for the safe transport of radioactive material (RM) establish the following approvals:

- Package design approval;
- Shipment approval.

The Special Transports Unit of Rosatom's Nuclear and Radiation Safety and Organization of Licensing and Approval Activities Department coordinates the preparation of all commercial RM package design and shipment certificates.

2.5. Managerial and Logistics Support

During the preparation of this technical report and by the time of its publication the IAEA made sustained efforts to encourage all potential suppliers to send relevant contributions. The entire Chapter 3 contains information received from various French, Russian, Czech and German suppliers who provided services for RR SNF shipments to France and Russia, and who could offer their contribution to this technical report by the time of its publication, as well as by the courtesy of Savannah River National Laboratory. Packages, equipment, and services from any other suppliers may be accepted in France and Russia provided that the relevant certificates and licenses are obtained.

A brief description of required support equipment, as well as examples of engineering support for project preparation and implementation are addressed in the IAEA technical report. A summary of available RR SNF packages presented in the IAEA technical report is included in Table 1.

The principal characteristics of available transport modes (Table 2) are described in detail, along with a summary of transport selection and shipment coalitions considerations, and applicable international conventions and agreements.

[3] Measure in the field of ecological expertise organized and implemented by the federal or regional executive body in conformity to the procedure established by the Federal Law "On ecological expertise" No. 174-FZ from 23.11.1995 and other regulatory acts of the Russian Federation. The ecological expertise means establishing the conformity of the documentation justifying the economic or other activity envisioned by the object of the ecological expertise to the ecological requirements established by technical procedures and regulations in the field of environmental protection, with the purpose to prevent the negative impact of such activities to the environment.

Table 1. Summary of Available RR SNF Packages

Package	Mode of Transport	Appendix I Ref.
TUK-19	Road, Railway, Water, Air	I.1
TUK-145/C	Road, Railway, Water, Air	I.6
ŠKODA VPVR/M	Road, Railway, Water	I.2
Castor MTR2	Road, Railway, Water	I.3
TUK-128 (TUK-135)	Road, Railway	I.4
TUK-32	Railway	I.5
TN™MTR-68, 44, RHF	Road, Railway, Water	I.7
TN™MTR-52, 52S, 52SV2	Road, Railway, Water	I.7
TN-LC	Road, Railway, Water	I.8
TN®17/2	Road, Railway, Water	I.9
NAC-LWT	Road, Railway, Water	I.10

Table 2. Available Transport Modes

Shipment by air	Most suitable in case of SNF small amounts; in case of long distances from the RR's site; if there are transit countries to cross; if maximal physical protection must be provided; implies highest cost-per-unit; demands more labour- and time-consuming safety analysis.
Shipment by water	Most suitable in case of SNF large amounts; in case of long distances from the RR's site; if there are any sea ports in the export country; special regulations apply for inland waterways.
Shipment by railway	Most suitable for states that share common borders with the reprocessing country; implies lowest cost-per-unit.
Shipment by road	Often the only possible mode for SNF shipment over short distances (from the RR's site to the railway station, the airport, the seaport, from the railway terminal to the sea terminal, from the airport to the reprocessing plant); for safety reasons not applicable for SNF shipment over long distances.

Experience shown that engineering support is required during SNF preparation and shipment different stages:

(1) Decision preparatory phase: preparation of feasibility studies, selection of route, transport modes and packages, support in forming RR coalitions for cost and schedule optimization, development and licensing of new packages and transport means etc.

(2) Contracting support: allows implementation of turnkey solutions providing project management of subcontractors, interface with authorities, schedule control, work implementation coordination etc.

(3) Licensing support: according to [8] RR SNF is transported in Type B(U)F or C packages (for fissile materials) that require multilateral approval of certificates for package design and shipment, therefore engineering support is provided during licensing in the country of the RR, reprocessing plant as well as in transit countries.

(4) Support for the RR facility preparation: during SNF inspection and acceptance by the reprocessing facility, development of spent fuel assemblies' loading technology in transport packages, RR facility modifications for allowing the transport package handling, failed fuel repackaging etc.

(5) Shipment support: carriers licensing, contracting and coordination, SNF loading in transport packages, preparation of shipment documents, technical escort of the shipment, interface between the RR, reprocessing plant, carriers and different authorities during shipment etc.

(6) Post shipment activities support: support during preparation, licensing and shipment of the RW resulted from reprocessing back to the SNF originator country.

During many years of international cooperation lead by IAEA [9], US and Russian Governments for the implementation of the HEU take-back programmes, as well as of RR SNF commercial reprocessing and recycling services provided by France and Russia, worldwide service providers have worked together and developed experience in all above mentioned stages of SNF preparation and shipment.

AREVA TN has several decades of experience in the international transport of spent fuel by road, rail and sea, can rely on the collaboration of companies in the AREVA group and can offer efficient, reliable and safe solutions. AREVA TN's main activity is to design, manufacture and deploy package systems for nuclear material for both nuclear power plants and research reactors. AREVA TN has extensive experience under the U.S. Foreign Research Reactor Fuel Return Program with the transport of irradiated research reactor fuel elements (TRIGA, MTR, DIDO, etc.) to Idaho National Laboratory and Savannah River Site in the USA from Japan, Denmark, Austria, Netherlands, Portugal, Taiwan, and Indonesia, shipments of LEU and HEU from the DOE/NNSA Y-12 site in Oak Ridge to France, and of

fresh MTR and TRIGA fuel elements and radioisotope production targets from France to numerous countries, including the USA, Australia, Indonesia, The Netherlands, Sweden, Norway, Japan and South Africa. AREVA TN also transported nuclear fuel to AREVA's La Hague reprocessing plant from Australia, France, and Belgium. AREVA TN also has significant experience transporting irradiated targets, irradiated fuel pins, and irradiated hardware to hot cells and other research facilitates using the smaller TN-106 cask.

Beside its reprocessing and recycling activities, AREVA also provides comprehensive solutions for SNF management such as engineering work in developing waste storage and disposal equipment and facilities.

Sosny R&D Company took part in the implementation of the RRRFR Programme in the framework of which re-search reactor fresh and spent fuel of Russian origin was returned to the Russian Federation from Belarus, Bulgaria, Czech Republic, Germany, Hungary, Kazakhstan, Latvia, Libya, Poland, Romania, Serbia, Ukraine, Uzbekistan and Vietnam. The role of the Sosny R&D Company in the programme is to develop technologies and equipment for SNF loading in packages, provide training services for the RR operators on handling Russian packages and equipment, prepare regulatory documents including safety assessments. In support for SNF shipments organization projects Sosny R&D Company provided many technical solutions:

- Foreign package certification in the Russian Federation (Czech ŠKODA VPVR/M in 2005, German CASTOR MTR2 in 2010) and FSUE Mayak PA technology adaptation for handling new packages;
- Development of an overpack for the Russian TUK-19 package shipment by any conveyance, including air;
- Vessel modernization for RR SNF shipments;
- Development of transfer casks for SFA loading in TUK-19 and ŠKODA VPVR/M packages;
- Development and delivery of equipment, safety assessment and licensing for new fuel reprocessing technologies at FSUE Mayak PA;
- Creation of the type C package TUK-145/C for shipments by any conveyances including air of radioactive materials with no restrictions on the radioactivity content.

Different other contractors have proven international experience in different stages of RR SNF preparation and shipment:

- Czech Republic: ÚJV Řež, a.s. (SKODA VPVR/M package services), SKODA a.s. (package development) and DMS s.r.o. (Class 7 dangerous goods shipment on public road);
- Germany: DAHER – NCS (package and shipment services);
- Russia: J/S ASPOL-Baltic Corporation (SNF sea shipments) and Volga-Dnepr Airlines (fresh and spent nuclear fuel air shipments);
- USA: Edlow International (radioactive materials transport), Holtec International (spent fuel management); NAC International (spent fuel transport packages and services).

The IAEA technical report also contains a summary of US- and Russian-origin HEU RR SNF take-back programmes, IAEA involvement in these programmes, and examples of LEU RR SNF shipments for reprocessing.

3. Preparation Status and Conclusions

The preparation and editorial phase of the IAEA Technical Report "Available Reprocessing and Recycling Options for Research Reactor Spent Nuclear Fuel" ended, and is now following the publication procedure within the IAEA.

The upcoming IAEA Technical Report "Available Reprocessing and Recycling Options for Research Reactor Spent Nuclear Fuel" offers a comprehensive description of services available, at the time of writing, for reprocessing and recycling RR SNF. The presented existing experience, service providers available to develop feasibility studies and available technologies that can serve as models form a complete knowledge basis for the assessment of the potential project technical specificities, risks, time frame, and budget estimations at the initial phase of planning and decision-making.

References

1 Available Reprocessing and Recycling Options for Research Reactor Spent Nuclear Fuel. DRAFT Technical Report, IAEA, 2015.

2 B. Stepnik, M. Grasse, D. Geslin, C. Jarousse, A. Tribout-Maurizi, F. Lefort-Mary, AREVA involvement in UMo fuel manufacturing and research test reactor fuel treatment, RRFM-2012, Prague, 2012.

3 http://www.french-nuclear-safety.fr/ASN/About-ASN (French Nuclear Safety Authority, About ASN, 2014).

4 http://www.po-mayak.ru/wps/wcm/connect/mayak/site/About/ (FSUE Mayak PA, About the facility, 2014).

5 V. Savkin, Reprocessing of research reactor spent nuclear fuel at the PA "Mayak", Workshop on "Technical and Administrative Preparations for Shipment of Russian-Origin Research Reactor Spent Fuel to the Russian Federation", Rez, 2008.

6 D. Kolupaev, Handling SNF at FSUE “Mayak” PA, paper presented at the meeting on SNF removal from Germany to Russia, Berlin, 2009.

7 K. Ivanov, Plans of SNF reprocessing until 2030 at FSUE Mayak PA, IAEA Contact Expert Group Workshop: Economic Aspects of Spent Fuel Management: Reprocessing and Direct Disposal, Stockholm, 2011.

8 IAEA Regulations for Safe Transport of Radioactive Materials, SSR-6, Vienna, 2012.

9 S. Tozser, P. Adelfang, E Bradley, A Decade of IAEA Cooperation with the RRRFR Programme, PATRAM-2013, 18–23 August 2013, San Francisco, USA.