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AVAILABLE REPROCESSING AND RECYCLING SERVICES FOR RESEARCH REACTOR SPENT NUCLEAR FUEL

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
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fax: +43 1 2600 29302
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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

In addition to safety, security and environmental protection assurance, responsible use of nuclear technology requires that credible solutions be developed to manage the full cycle of research reactor fuel, including its disposal after removal from the reactor core. The end point of research reactor spent nuclear fuel (SNF) management is the development of a geological repository, which will be used for the disposal of spent fuel assemblies, directly or after conditioning, or the shipping of SNF to a reprocessing facility and the closing of the fuel cycle with the disposal of the waste after reprocessing. Since the existing experience in SNF disposal (directly or after conditioning) is very limited and available to just a few States, this publication discusses the key aspects of research reactor SNF reprocessing and recycling as the only currently available solution based on mature technologies for the management of the back end of the fuel cycle.

The international experience accumulated from research reactor fuel take back programmes for high enriched uranium has been collected and presented in this publication to provide information to research reactor managers, research reactor SNF storage facility managers and decision making bodies with regard to the reprocessing and recycling options for back end management of SNF.

The IAEA wishes to thank all of those who participated in the consultants meetings and helped in the drafting and preparation of this publication. The IAEA is particularly grateful to M. Budu (Russian Federation) and M. Chiguer (France) for their contribution. The IAEA officers responsible for this publication were P. Adelfang, F. Marshall and S. Tozser of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. INTRODUCTION

1.1. BACKGROUND[1]

During the initial years of research reactor operation history, the back end management of the nuclear fuel cycle was not at the centre of attention of the nuclear community. Thus, research reactor spent nuclear fuel (SNF), including high enriched uranium (HEU), remained at research reactor sites. This was undesirable for several reasons, especially those concerning security and non-proliferation issues. International activities addressing the back end management of the nuclear fuel cycle of research reactors have been dominated by SNF acceptance programmes in the countries in which the fuel was originally enriched. Two programmes were created under the Global Threat Reduction Initiative (GTRI):

— The Russian Research Reactor Fuel Return (RRRFR) Programme, for fuel originating in the Russian Federation;
— The US Foreign Research Reactor Spent Nuclear Fuel (FRR SNF) Acceptance Program, for fuel originating in the United States of America.

The major goal of the programmes was to eliminate the inventories of fresh and spent nuclear fuel (HEU) at research reactor sites worldwide. The repatriated HEU material, if reprocessed, is then downblended to low enriched uranium (LEU), and the recovered plutonium and uranium may only be reused for peaceful purposes. The HEU take back programmes support reactor conversion. Formerly called the Reduced Enrichment for Research and Test Reactors Programme, this element of the GTRI programme facilitates the conversion of research reactors and radioisotope production facilities from the use of HEU to LEU fuel and isotope targets. However, the take back programmes will soon have achieved their goals. When there are no more HEU inventories at research reactors and no commerce in HEU for them, the primary driver for the take back programmes will cease, and they will be phased out.

The majority of research reactors continue to operate to meet their various mission objectives, including research, education and radioisotope production. As a result, inventories of LEU SNF will continue to be created during the lifetime of a research reactor. It is expected that SNF will continue to accumulate and be stored at research reactor sites for several years. States operating research reactors have to develop a national final disposition route, even for relatively small amounts of LEU SNF, which is difficult, especially for States without a nuclear power programme. Finding appropriate, sustainable and cost effective solutions for the back end management of the nuclear fuel cycle is critical to the continued use of research reactors.

A State needs to consider many factors when developing a back end strategy for its research reactor SNF. Currently, the choice is limited to three strategies [4]:

(a) Direct disposal (or once through fuel cycle);
(b) Storage and postponed decision (or wait and see option);
(c) Reprocessing and recycling (or closed fuel cycle).

These options might not yet be available to every State due to public opinion and the financial, technical and political situation.

Strategy (a), direct disposal, has not yet been implemented in any country. Developing a geological repository for SNF is not an easy task. Progress towards its implementation has only been made in Finland, France, Sweden and the United States of America. The policy, technological and financial challenges involved in the development and maintenance of a geological repository for hundreds of years can make it prohibitive for most States, especially for those without a nuclear power programme.

With regard to strategy (b), Adelfang et al. [5] report that after discharge from the research reactor core, SNF is stored underwater to allow for cooling, usually in at-reactor storage facilities. This wet storage can be extended, in at-reactor or away-from-reactor storage facilities, in some cases over long periods (~50 years), or the SNF might

[1] This section is based on Refs [1–3].

be transferred to dry storage (at-reactor or away-from-reactor) sites and stored for even longer periods. None of these strategies for SNF management can be considered as the end point of the research reactor nuclear fuel cycle.

Regardless of how long this extended interim storage is drawn out, the resolution of the back end problem will remain, while proliferation, safety and physical protection concerns continue. There is also the risk of spent fuel element cladding corrosion in long duration wet storage, potentially resulting in fission product release to the water. During dry storage, there is a risk of losing the mechanical integrity of the spent fuel assemblies (SFAs). Management of leaky or defective SFAs increases costs.

Adelfang et al. [5] report that perpetual postponement of a final decision on the end point for the SNF produced is not sustainable. Thus, every State with a research reactor will find it necessary to develop a national strategy for SNF management, and for States with small nuclear power programmes (with one or two research reactors and without any nuclear power plants), the expensive construction of geological repositories for the relatively small amounts of accumulated SNF might not be practicable.

Currently, for the generating country, one of the end points of the research reactor nuclear fuel cycle is attained when the SNF is sent for reprocessing and further utilization to one of the countries where commercial back end fuel cycle services are offered. Industrial entities in France and the Russian Federation offer international research reactor SNF reprocessing and recycling services on a commercial basis.[2] These services can provide the basis for viable SNF management options depending on their scope, technical compatibility, cost and accessibility.

The management of radioactive waste separated during reprocessing research reactor SNF will need to be further addressed, but it might offer advantages compared to managing it. Each country possessing SNF should take a decision on its management strategy based on whether the strategy is:

— Technically sound;
— Safe and secure;
— Environmentally responsible;
— Economically feasible;
— Good value for money;
— Publicly acceptable;
— Not burdensome for future generations.

The possibility of using a particular management strategy or process will depend on political considerations, cost, geography and geology, the availability of domestic technology and resources, and the availability of another State to share technology or to offer commercial services. Political considerations include government policy and public support — in particular when the use of a reprocessing facility is under consideration. It will also be necessary to fully consider the environmental consequences of the fuel management strategy and carefully weigh the associated advantages and disadvantages.

All available, technically feasible options should be investigated as far as possible, without excluding or failing to evaluate any option that might be currently impossible because of laws or policy at the time of the assessment. This allows a full analysis of the available options to be made and ensures that options are not rejected that might later be possible due to changes in policy. The areas that have to be addressed by customers of commercial back end services, include the following:

(a) Suppliers of SNF reprocessing services:
    — Contact information;
    — Services offered;
    — Accepted types of fuel.
(b) Legal requirements:
    — Agreements on fuel origin;
    — Government–to–government agreements between sender and recipient countries;

[2] The H-Canyon facility at the Savannah River Site, United States of America, has the capability and intent to reprocess a limited quantity of aluminium cladded SNF from foreign and domestic research reactors to recover HEU and downblend it to LEU. However, this capability is limited to fuels that have already been received under the FRR SNF Acceptance Program and is further described in Ref. [6]. Currently, the United Kingdom does not provide reprocessing services for SNF from foreign research reactors.

— Management of processed products and radioactive waste;
— Contractual obligations, government guarantees and liability insurance;
— Transfer of ownership of SNF, processed products and radioactive waste.

(c) Transport:
— Regulatory and recipient requirements;
— Possible routes;
— Available transport packages;
— SNF and site preparation at the sender facility.

(d) Reprocessing and conditioning:
— Interim storage (duration and conditions);
— SNF reprocessing;
— Processed products (e.g. plutonium and uranium);
— Options for radioactive waste forms and management (e.g. storage duration and returning procedures);
— End user statements.

(e) Milestones and time frame:
— Milestones and time frame of the project realization (e.g. government–to–government agreement development, technical preparation, licensing, shipment, reprocessing and waste return);
— The development work required.

(f) Input information required from both sides:
— Specific procedures at the sender and recipient sites;
— SNF information required from the sender by the recipient for making the acceptance decision;
— Transport package information from the recipient (cask owner) for ensuring handling equipment at the site of the sender.

(g) Environmental aspects:
— Environmental impact of the entire process;
— Best practices;
— Waste management procedures.

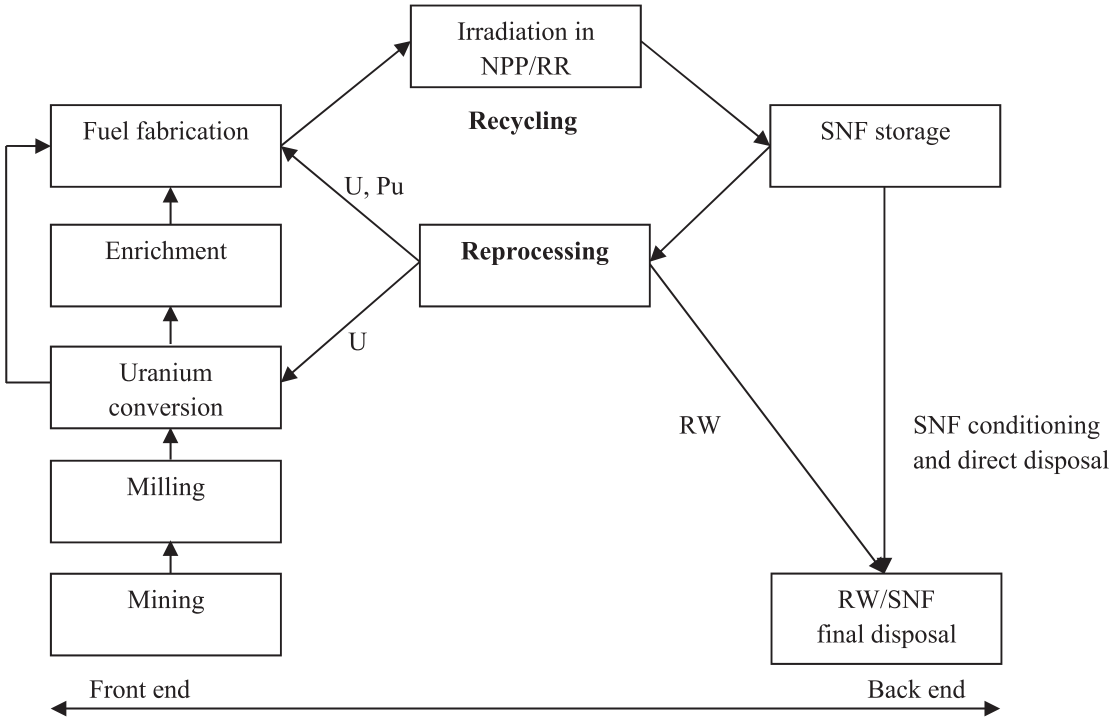
(h) Contracts:
— Consideration of a lease or loan of nuclear fuel instead of buying;
— Costs of SNF handling;
— Option to use or dispose processed products in the nuclear fuel cycle.

1.2. OBJECTIVE

The main objectives of this publication are to present the available reprocessing and recycling services based on mature technologies as an option for back end management of research reactor SNF and to describe the available facilities, regulatory frameworks, equipment, services and service providers. It also discusses potential research reactor coalitions for project optimization. Disseminating this information supports the research reactor operating community and helps stakeholders resolve the back end management of LEU SNF.

1.3. SCOPE

Figure 1 shows the main stages of the nuclear fuel cycle. The front end comprises all stages of nuclear fuel manufacture, from mining of raw material to fabrication of fuel assemblies. The back end comprises SNF management after its removal from the reactor core. This publication explores SNF storage and disposal stages and presents back end management stages of the fuel cycle to research reactor operators. It focuses on the available options for research reactor SNF reprocessing and recycling services based on mature technologies, and it provides an overview of considerations and solutions, regulatory requirements, fuel management service suppliers' conditions, management and logistical support provider services, and licensed transport packages and applicable transport modes.



Note: NPP — nuclear power plant; Pu — plutonium; RR — research reactor; RW — radioactive waste; SNF — spent nuclear fuel; U– uranium.

FIG. 1. The nuclear fuel cycle.

The experience gained from decades of international cooperation in supporting and implementing HEU take back programme objectives, with hundreds of successful shipments, is also included. Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.4. STRUCTURE

Section 2 presents research reactor SNF reprocessing services, which currently only France and the Russian Federation offer. The legislative background, with the possible options for reprocessing, is described, as well as corresponding transport packages and transport modes, with a particular focus on licensing procedures. The description of reprocessing facilities includes applied technology, environmental aspects and the time frame of project realization. Section 3 presents management and logistics support services and providers. It provides examples of available technical resources, equipment, shipment modes, and international conventions and agreements. Section 4 concludes. Appendices I and II contain specific technical information about packages and equipment for SNF handling, and a service description template is provided in Appendix III.

2. RESEARCH REACTOR SNF REPROCESSING SERVICES

2.1. FRANCE: AREVA

The reprocessing of research reactor SNF separates the content into recyclable material and radioactive waste. It offers many advantages compared to direct disposal, such as a reduction in radiotoxicity and in the volume of waste. The conditioning of the waste is also very important and is usually done by vitrification. It is brought into a form specifically designed to ensure safe interim storage for extended periods of time as well as final disposal (99% of the activity is encapsulated in a stable matrix). A crucial aspect in the safety of SNF management is bringing the unusable radioactive nuclides into a form that ensures safe handling, storage and disposal plays.

Reprocessing and recycling SNF from nuclear power plants is already a proven solution for nuclear utilities and Member States. Currently, uranium–aluminium SNF from research reactors is reprocessed at AREVA facilities on an industrial scale, and more than 23 t have already been reprocessed. To provide research reactor operators safe and sustainable solutions for SNF management, AREVA is conducting R&D on SNF reprocessing at its facilities and steady R&D efforts, including new types of fuel, such as uranium–silicon and uranium–molybdenum.

2.1.1. Legislation in France

Radioactive waste generated from the operation of nuclear facilities is regulated by Act No. 2002-276 of 27 February 2002 on the Environmental Code [7] and Programme Act No. 2006-739 of 28 June 2006 on the Sustainable Management of Radioactive Materials and Wastes [8]. At the international level, radioactive waste management falls under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9] and Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste [10].

Article L542-2-1 of the Environmental Code [7] authorizes the reprocessing of foreign spent fuel and radioactive waste in French facilities under certain conditions. Every year, nuclear facility operators submit a report with an inventory of these materials to the minister of energy.

The Ministry for the Ecological and Inclusive Transition defines the legal and regulatory frameworks, roles and responsibilities in civilian nuclear activities on French territory, supervising both independent and State controlled parts of the nuclear sector. The ministry supports any State in their civilian nuclear development, provided it is 4S compliant (safety, security, safeguards and sustainability) and provides particular guidelines for foreign nuclear material and radioactive waste.

The Nuclear Safety Authority (Autorité de sûreté nucléaire, ASN) is an independent administrative authority established by Act No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field [11]. The ASN regulates nuclear safety and radiation protection in order to protect workers, patients, the public and the environment from risks that could be incurred due to nuclear activities. It authorizes and controls the activities of nuclear facility operators.

2.1.1.1. Regulatory requirements

Decree No. 2008-209 of 3 March 2008 concerning the procedures applicable to foreign spent nuclear fuel and radioactive waste reprocessing [12] specifies certain conditions, including:

- The import of SNF into French territory for reprocessing has to be controlled by an intergovernmental agreement between France and the material country of origin. This agreement settles a forecasted schedule for receipt and processing of the material and, if any, the later planned use of the material separated during reprocessing.
- Along with its radioactivity, the mass of SNF is to be taken into consideration when calculating the waste to be returned after reprocessing, matching the material imported into French territory.
- Advanced annual reporting is required at the reprocessing facility (AREVA La Hague, Cherbourg, France) featuring material accountability, receipt and return dates, and reprocessing periods.

2.1.1.2. Options for SNF and radioactive waste handling from the viewpoint of legislative possibilities

In accordance with the Programme Act No. 2006-739 of 28 June 2006 [8]:

(a) Article 5 defines the following [8]:
   - "A radioactive material is a radioactive substance for which a subsequent use is planned or envisaged, where applicable after treatment."
   - "Radioactive wastes are radioactive substances for which no subsequent use is planned or envisaged."

(b) The framework for reprocessing foreign SNF is in Article 8 [8]:
- Import for "treatment can be authorised only as part of intergovernmental agreements and provided the radioactive wastes resulting after the treatment of these substances are not stored in France beyond a date set by said agreements. The agreement states the estimated periods for the reception and treatment of these substances and, where applicable, the prospects for the subsequent use of radioactive materials separated during treatment."

(c) Article L542-2 of the Environmental Code [7] states that:
- "The disposal in France of radioactive wastes from abroad…is forbidden."

In order to comply with this, AREVA updated its material accountancy system, which enables the calculation of the amount and type of waste to be sent out of France (usually back to customers). This new system, called EXPER, was implemented in October 2008.

The mass of the waste to be sent out of France is calculated on the basis of the non-soluble metallic structural components of the SNF: an equivalent mass calculated through EXPER system is sent in the form of a universal canister of compacted waste (UC-C). The activity of the waste to be sent out of France is calculated on the basis of the SNF neodymium content: an equivalent activity calculated through EXPER system is sent in the form of a universal canister of vitrified waste (UC-V or UC-U):

(i) The non-reusable materials include fission products and structural pieces and are conditioned into a stable and compact form licensed by all involved authorities for transport, storage and final disposal:
- Fission products are encapsulated in a stable, homogeneous and durable glass matrix with very long term predictable behaviour.
- Structural pieces (hulls and end-pieces) are compacted (see Fig. 2).

(ii) Both the vitrified and compacted waste are encased in a standard universal canister. No safeguards are required for this waste because the fissile material has been removed.

(iii) This final waste conditioning applies for SNF reprocessing from research reactors and nuclear power plants, which means the management of SNF post-reprocessing final waste from both sources can be combined, reducing waste management costs.

The management of SNF post-reprocessing waste from research reactors can present the following:

- For materials testing reactor (MTR) type (plate) of fuel, only vitrified waste remains after treatment, and no structural pieces are left, as the entire fuel assemblies are dissolved during the process.
- In the case of small SNF inventory leading to small amounts of final waste to be managed for the customer, a UC-U can be more suitable for the return of the activity calculated with the EXPER system.

FIG. 2. Mock-up sheared fuel hull canisters (UC-C) (courtesy of AREVA).

2.1.1.3. The main steps and time frame of licensing procedures and intergovernmental arrangements

Authorization for shipment to receive and reprocess SNF at the AREVA La Hague plant is necessary. Authorization is issued by the ASN after the application process. The considered transport cask has to be licensed in France, and French approval certificates for AREVA transport casks are regularly renewed. Agreement extensions have be obtained for each type of research reactor SNF to be transported in these casks. When needed, specific baskets can be designed and manufactured for the transport. However, the basket designs have to be included in the ASN application for review. Based on similar principles, shipment certificates have be obtained in the country of origin of the SNF and for countries through which the transport cask will travel. During the preparation of the application file, the following studies ensure transport safety for installations, equipment, operators, the environment and the general public, and, in particular, in accident transport conditions:

- Detailed design description of the basket and content;
- Thermal studies, depending on the content to be transported (e.g. design of the research reactor fuel, burnup rate and cooling time), to determine the maximum temperature during transport;
- Studies on the mechanical behaviour and performance of the transport cask, its inner components and the transported SNF;
- Criticality analysis to determine the SNF quantities that can be transported;
- Containment analysis on radiation protection, and thermal and radioactive release calculations.

The main steps for obtaining an agreement extension of a shipment certificate are:

- Exchange of research reactor SNF basic information between AREVA and the customer;
- Preparation of the application file, including the main studies listed above;
- File application to the ASN and possible follow-up questions.

The general time required to obtain an agreement depends on the complexity of the research reactor SNF to be transported, the types of SNF already known to the ASN and the specific measures that need to be implemented for such transport. The AREVA La Hague reprocessing plant has receipt and reprocessing authorization for a wide range of known types of SNF. An extension of this authorization is to be obtained if the plant plans to receive new types. In such cases, the following are examples of areas that need to be addressed to assess the safety of new research reactor SNF reprocessing:

(i) Technical issues:
  - Receipt and unloading procedures in the pool of the AREVA La Hague plant;
  - Use of interim storage equipment;
  - Handling tool use, transfer from pools to the reprocessing facility, loading in the dissolution facilities.

(ii) Chemical analysis:
  - Compliance with a qualified range of dissolution conditions (e.g. temperature, acidity and kinetics);
  - Management of possible specific material not referenced in the basic process;
  - Characterization of dissolution solutions to be injected into downstream flow at the facility.

(iii) Safety and criticality analysis for all operations at the AREVA La Hague facility, from receipt to the end of the reprocessing process.

(iv) Instrumentation and control issues:
  - Equipment coding and programming;
  - Real time measurements of all the process parameters.

These analyses are conducted at the preliminary project studies stage. Once this is finalized, the detailed project studies stage begins, including the preparation of the preliminary safety report. This report is submitted to the ASN as the basis for the assessment and exchanges between AREVA and the ASN. After these exchanges, the ASN approves the material for receipt and reprocessing at the AREVA La Hague plant. The duration of this authorization process varies considerably depending on the complexity of the research reactor SNF to be reprocessed.

As described in Refs [1, 2], in addition to the usual customer–supplier commercial and industrial relationship, intergovernmental exchanges are also considered in the licensing time frame. Except for the shipment certificate and reprocessing authorization to be obtained after application to the safety authorities, discussions on intergovernmental agreements between the Government of France and the corresponding State are initiated while the contract is negotiated. Figure 3 shows the typical schedule and the main steps that are followed from the first discussions and exchanges on research reactor SNF management.

This standard schedule is to be followed according to the provisions of the Programme Act No. 2006-739 of 28 June 2006 [8]. As of the end of 2016, three intergovernmental agreements on SNF reprocessing in French facilities had been signed with Belgium, Italy and the Netherlands. The application for an intergovernmental agreement requires the following information:

(a) Project description:
- — Identification of the material owner or related contractor (if different from the material owner);
- — Introduction of the main stakes for the owner or related contractor;
- — Location, legal status and origin of the material;
- — Material owner country information (e.g. energy policy, economics and nuclear power plants);
- — Planned contractual structure for the material reprocessing and recycling;
- — Planned scope of collaboration between the parties.

(b) Acceptability of reprocessing:
- — Type and characteristics of the material to be reprocessed (e.g. design, total mass, mass of oxide and heavy metals, rate of combustion, cooling and initial enrichment);
- — The material transport (cask and transport procedures to be prepared).

(c) Schedule:
- — Quantities to be reprocessed and timing;
- — Period of delivery of SNF from the customer to the AREVA La Hague facility;
- — Periods of reprocessing;
- — Period of waste return;
- — Use/reuse of recycled material;
- — Deadline for last return of waste;
- — Destination of waste.

From AREVA's experience on the intergovernmental agreement process, two years are necessary for final agreement to be reached by all parties, starting from the official discussion between the States. The time required for this process has to be planned when scheduling SNF management operations.

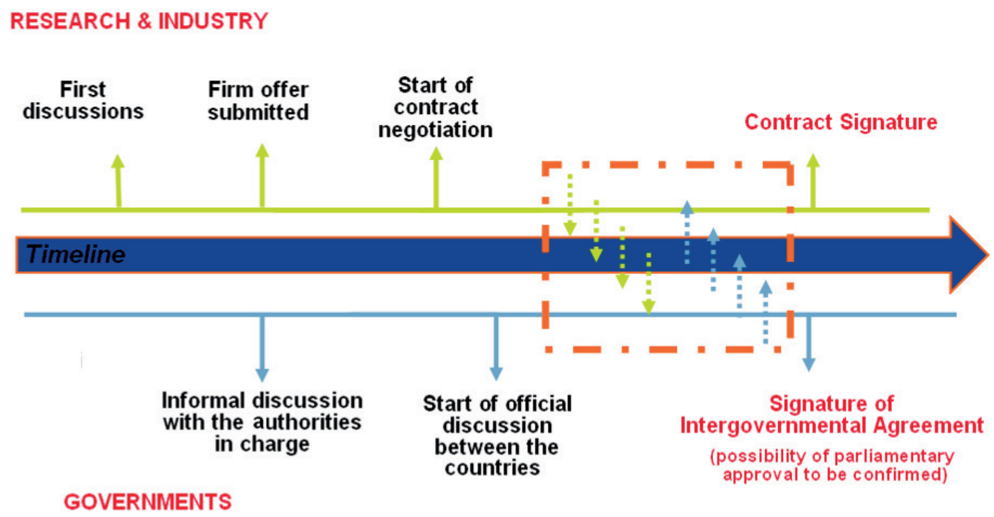
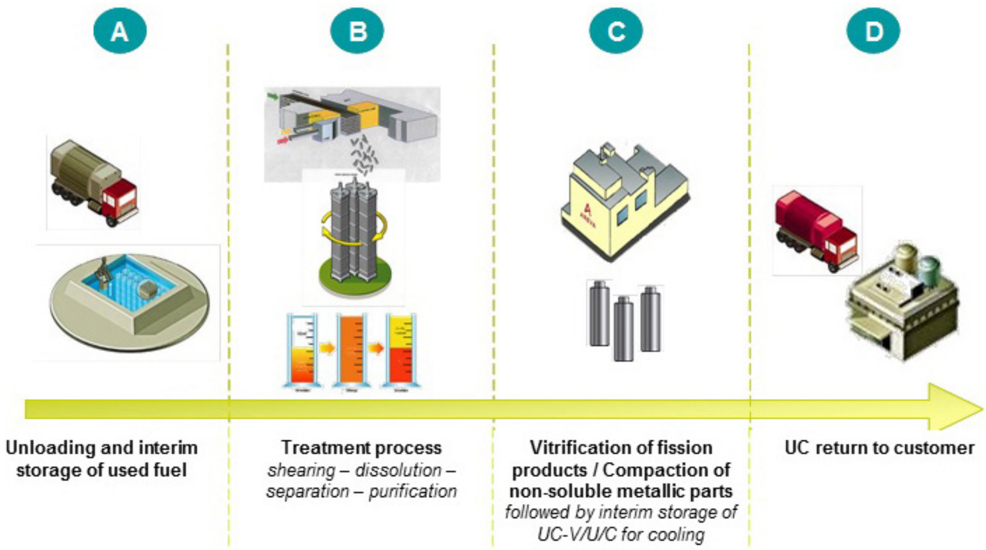


FIG. 3. Typical schedule of a new research reactor SNF reprocessing contract.

2.1.2. Reprocessing facility

2.1.2.1. Applied technology of the reprocessing facility

The reprocessing performed at the AREVA La Hague facility is summarized in Fig. 4.



Note: UC-V/U/C — universal canister of vitrified/compacted waste.

FIG. 4. A schematic view of research reactor fuel reprocessing.

Stepnik et al. [13] report the following steps of the research reactor SNF reprocessing at the AREVA La Hague facility:

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

“B. The dissolution step: the fuel is introduced into the existing dissolver through a pit specially designed for RTR [research test reactor] fuel. The dissolution is realized in a hot nitric acid solution.

At this step, the process is limited by the aluminium concentration to 35–40 g aluminium/L, to manage the risk of precipitation into aluminium nitrate. The resulting solution is then diluted with the solution coming from the dissolution of the UOx fuel (power reactor fuel).

“C. The extraction step: 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. This solution is then ‘vitrified’, i.e. conditioned into a stable, homogeneous and durable glass matrix, and encased in a standard canister, called ‘Vitrified Universal Canister’ (UC-V). The UC-Vs are then stored in a specific interim storage facility at La Hague site for cooling.

“D. The UC-Vs are returned to the foreign customer.”

Other types of vitrified waste based on the same universal canisters and with lower thermal power and dose rate can also be used to return such waste to foreign customers. In order to comply with the regulations and technical constraints of the customer's country, the waste can also be conditioned by other methods.

Universal canisters have already been shipped to AREVA customers in Belgium, Germany, Japan, the Netherlands and Switzerland. New shipments are planned following SNF reprocessing from Australia, Italy and Spain. Hélaine et al. [14] report on the UP3 process steps at the AREVA La Hague plant:

> "The RTR treatment affects every process in use at UP3, from the storage fuel to vitrification, including the analytic laboratories and waste processing.
>
> "The special characteristics of RTR demanded particular demonstration in each field of studies as shown in the following examples:
> - Mechanical field: Gravity feeding of the dissolution pit from the maintenance cell had to be demonstrated for a long term use.
> - Lay-out: The implementation of the pit in the dissolver was a challenge. The space available was just a little bigger than the dimension of the pit.
> - Chemical field: The risk of cristallisation of aluminium had to be managed properly.
> - Safety, criticality: The management of the risk of criticality in the dissolution pit had to be demonstrated, taking into account the high uranium enrichment."

2.1.2.2. Options offered by the reprocessing facility in compliance with the general legal regulations

Projects for reprocessing and recycling research reactor SNF have to be anticipated, in accordance with French and international laws that guarantee the safety and security of operations. Anticipation between AREVA and its customers is also needed in drawing up the reprocessing plan of their SNF.

2.1.2.3. General requirements and boundary conditions for supplied SNF

Reference [15] reports that the reference fuel considered for the design and startup of the UP3 and UP2-800 plants was uranium oxide fuel initially enriched to 3.25% in ^{235}U, with a burnup of 33 GWd/t and cooled for three years. However, right from the very beginning, the AREVA La Hague site was authorized, based on supporting studies, to reprocess other types of fuel as well.

The 2005 ASN Annual Report [16] states that:

> "The revision of the La Hague site nuclear installations authorisation decrees, which was completed on 10 January 2003, is a technical decision designed to allow changes to the activities in the installations in satisfactory conditions of safety and environmental protection, and in conformity with the regulations…. The authorised modifications will combine improved nuclear safety with greater environmental protection through the use of the best techniques available."

SNF of gas cooled reactors, fast breeder reactors, pressurized water reactors (PWRs) and all types of aluminium cladding for MTRs are included in the authorization decree, and are reprocessed at the AREVA La Hague plant. More than 23 t of MTR fuel have been reprocessed in France. The AREVA La Hague reprocessing plants are also technically capable of reprocessing new generations of SNF without any significant modifications [15].

AREVA obtained in 2017 ASN authorization for reprocessing silicide (U_3Si_2) SNF from research reactors, which has been performed at the La Hague plant. The process is similar to the one for uranium–aluminium fuel, with adaptations for silicide. The selected option consists of the centrifugation step at the La Hague plant for UOx treatment to separate the silicide gel from the clarified solution, which can then be treated in the separation process as for uranium–aluminium fuel. This solution is currently being qualified at an industrial scale. Eysseric et al. [17] reports that:

> "The global demonstration of the compliance of the process and related R&D results with La Hague technical and safety referential is then presented in a dedicated process book and qualification file. These documents

will be the basis of the application file to be submitted to the French Safety Authority (ASN) in order to get the authorization for processing silicide fuels in AREVA La Hague plant.

…….

“All the studies performed by AREVA are based on a reference French silicide fuel to be processed in La Hague plant. Considering other silicide fuels, it will be necessary to check the characteristics deviation in comparison with this reference fuel in order to assess their process feasibility through their compliance with the process book, reprocessing rhythm capacity, and their related impacts on the whole reprocessing operations. The following non-exhaustive characteristics can be considered as key data to perform this assessment: geometry (diameter, length…), Si content, high content of element which can have a restrictive impact on the capacity (Mo or Mg content for instance), U content, initial enrichment.

“According to silicide fuels specificities and/or if the characteristics deviation compared with the reference silicide fuels are significant; AREVA will have to tackle with dedicated studies even if the core process operations are similar (centrifugation to separate the Si prior to U & Pu extraction).

“Knowing such information as soon as possible for other silicide fuels will also allow AREVA to take into account these fuels at the earliest stage of the ASN application process, and consequently ease the reprocessing authorization agreement for these specific fuels.

“The period from 2015 to the early 2017 is expected to be dedicated to:
— take into account the feedback of ASN prior to the authorization for the process operations,
— set the industrial conditions of the facilities prior to actual fuels processing operations.

“By the completion of this overall process, and once the green light from the Authority is obtained, AREVA will be able to process UAl and U_3Si_2 fuels in an industrial scale, within the existing UP3 T1B facility.”

A summary of the types of research reactor SNF considered for reprocessing at the AREVA La Hague plant is presented in Table 1.

TABLE 1. AREVA REPROCESSING OPTIONS BY TYPE OF RESEARCH REACTOR SNF

	Type of fuel				
	U–Al	U–Si	UO_2	U–Mo	U–Zr
Reprocessing technology available	Yes	Yes	Yes	Yes	No
Reprocessing services offered	Yes	Yes	Yes[a]	Not yet[b]	No
Government approvals required	Yes	Yes	Yes	No	n.a.[c]
Time limit for fuel acceptance	Based on reprocessing capacity availability				n.a.[c]
Waste return policy	Yes	Yes	Yes	Yes	n.a.[c]

[a] To be provided on a case by case basis.
[b] R&D and authorization needed.
[c] n.a.: not applicable.

2.1.2.4. Extending the range of reprocessed SNF

The 2005 ASN Annual Report [16] states that:

“The actual operations to process the fuels, substances and materials authorised by interministerial orders must, as presently, be the subject of an operational agreement for each particular processing campaign outside the previously authorised domain. This enables account to be taken of the time elapsed between the authorisation to extend the domain and the actual processing operation performance and checks to be made on the compatibility of the performance conditions envisaged by the licensee with installation safety and protection of persons and the environment. The interministerial orders specify that the operational agreement will be issued by the Director General for Nuclear Safety and Radiation Protection."

Based on past activities and experience in reprocessing various types of research and fast reactor SNF, AREVA has decided to launch a new polyvalent fuel treatment facility project at the La Hague site. This project will address various fuel characteristics at the shearing and dissolution steps in order to answer varied customer needs without hampering the current reprocessing capacity of the La Hague plant. The new facility will substantially expand the reprocessing spectrum services of the La Hague plant, and an application to extend the range of fuel to be integrated into the La Hague site nuclear installations authorization decree will consequently be submitted.

Fuel standards are evolving owing to international directives limiting the use of HEU, and maintaining and improving the performance of research reactor fuels. AREVA is carefully following these trends to keep on allowing its customers to consider closing the fuel cycle, optimizing waste management and reducing proliferation risks. Stepnik et al. [13] report that:

"There are two specific characteristics of U–Mo fuel that will have an impact on back end options as compared to U–Al type RTR fuels, and in particular the feasibility of treatment options: the presence of molybdenum, and the presence of silicide.

"The proposed scheme, as for the U–Al fuels, would consist in dissolution in a nitric acid medium followed by dilution of the obtained solution into standard UOX fuel dissolution solutions before treatment by the PUREX [plutonium and uranium recovery by extraction] process.

"In 2005, within the scope of an AREVA–CEA cooperation, the CEA [French Alternative Energies and Atomic Energy Commission, Commissariat à l'énergie atomique et aux énergies alternatives] conducted a research and development program focussing on the dissolution step [18]. Dissolution tests were conducted on non-irradiated U–Mo powder with an Mo content of 7% to determine the necessary conditions for successful dissolution of the U–Mo fuel. Aluminium concentration was found to have an impact on the solubility of molybdenum. The conclusion of the tests was thus that the Al concentration should be less than 15 g/L in order to obtain a clear and stable dissolution solution (instead of 40 g/L for U–Al fuels). The optimal dissolution conditions were then qualified with U–Mo plates irradiated inside the French Osiris reactor. Further studies would be necessary to optimize this point related to the treatment capacity, and to determine the conditions for the extraction and waste conditioning steps, but the treatment R&D program stopped at that time due to the difficulties encountered by the fuel development.

"Due to that, as the U–Mo fuel hadn't achieved the expected performance in reactor, Si was reinserted into the fuel composition, in addition to molybdenum. The industrial treatment of U–Mo fuels is thus directly linked to the R&D program in progress to optimize the silicide fuel treatment, and the possibility of adding the centrifugation step has to be considered, in relation with the quantity of silicide which will be added. Furthermore, some additional points have to be evaluated by R&D:

- Cross-impact of Mo and Si at the dissolution step, that is optimization of dissolution conditions related to the treatment scheme after dissolution. This R&D program has to be conducted on unirradiated and irradiated plates.
- Behaviour at the centrifugation step if necessary.
- Impact of molybdenum on liquid–liquid extraction.
- Impact of molybdenum on the vitrification step.
- Validation of the process treatment at laboratory scale with irradiated material, if necessary."

2.1.3. Environmental aspects

French law requires that AREVA La Hague be responsible for the environmental impact of its activities. The environmental impact is monitored by independent governmental bodies, such as the ASN or the Institute for Radioprotection and Nuclear Safety (Institut de radioprotection et de sûreté nucléaire, IRSN). Each year, as required by Article L125-15 of the Environmental Code [7], AREVA La Hague prepares an annual report, which provides detailed information on environmental measurements and events.

Minimizing the environmental impact of its industrial operations is a priority for AREVA and is tied to a continuous improvement programme based on an environmental management system. The programme is applied to all nuclear sites and through International Organization for Standardization certification (see ISO 14001:2015, Environmental Management Systems: Requirements with Guidance for Use [19]). As part of the programme, AREVA has established comprehensive procedures to monitor releases and the environment. The programme examines all site aspects, from the selection of materials and processes to effluent management and daily environmental monitoring, at all stages in the life of a facility, from its design, construction and operation to its decommissioning.

The requirements limiting any kind of emission from a regulated nuclear facility into the environment are based on ASN decisions and are approved by the ministers in charge of nuclear safety. For environmentally regulated facilities subject to licensing, such as reprocessing and recycling facilities, these requirements are incorporated into prefectural operation licences. The system deployed has to take into account several requirements:

(a) Submission of regulatory information, including reports, to the European Pollutant Release and Transfer Register;
(b) Alignment of greenhouse gas reductions with the French National Allocation Plan;
(c) Adherence to up to date release limits for nuclear facilities.

For radioactive releases, AREVA is committed to an effluent radioactivity measurement standardization programme established in 2007 by the French Nuclear Equipment Standardisation Office (Bureau de Normalisation d'Equipements Nucléaires, BNEN).

Radiological or dose impact is assessed for members of the public most likely to be exposed to radioactive releases. They are expressed in millisieverts per year (mSv/a) of additional effective dose and are a health impact indicator. These members of the public are considered in benchmark groups. Such a group could be the inhabitants of a village located downwind from a site. The impacts are assessed annually by characterizing liquid and gaseous effluent releases that are monitored and measured before release. AREVA reports that [20]:

> "The radiological impacts of the group's large nuclear sites are low, at just a small number of microsieverts per year [see Fig. 5]….
>
> "These values can be compared with the regulatory limit in France of 1 mSv per year for the public, and to the average exposure to natural radioactivity of 2.4 mSv…. Exposure by medical procedures is about 1.3 mSv per year."

AREVA also notes that the radiological impact estimates have been subject to the multidisciplinary research carried out by the Nord-Cotentin radioecology team since 1997, in collaboration with French and international experts and community based associations.

Each of the AREVA group's nuclear operators, notably those involved in the reprocessing of research reactor SNF (La Hague) and recycling (MELOX and FBFC), publishes annual monitoring reports [20]:

> "Data from the monitoring of regulated nuclear facilities are communicated to the Nuclear Safety Authority ASN via a register of testing and monitoring operations that includes counts of the radioactive and non-radioactive substances or substance categories released that are regulated by the ASN.

…….

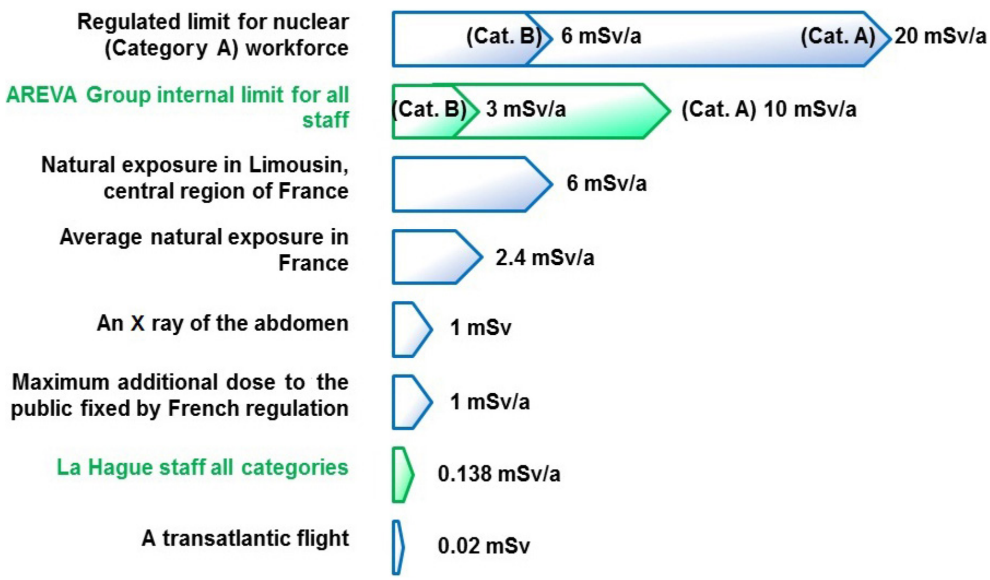


FIG. 5. A comparison of annual exposure of site workers at AREVA La Hague (courtesy of AREVA).

"Subject to water tapping and effluent release permits, an annual program to monitor the receiving environment was set up under the management of the [ASN]…. The purpose of the monitoring is:
- — to verify compliance with the regulatory requirements set in the release permit orders;
- — to monitor the impact of the releases on the environment and the local public;
- — to monitor for accumulation and verify that there are no abnormal peaks in radioactivity through groundwater monitoring, among other methods;
- — to build on knowledge of the radiological and radioecological status and evolution of the site's environment and compare it with the models. This is difficult to achieve, given the very low levels of added radioactivity involved, often under the detection thresholds.

"The monitoring will be done in the following areas:
- — atmospheric monitoring: radioactivity of the air at the site boundary and beyond;
- — land monitoring: vegetation, vegetables, milk, meat, etc.;
- — hydrological monitoring: surface water (rivers, streams, ponds, lakes), groundwater, drinking water sources;
- — aquatic monitoring: wildlife, water and sediments;
- — marine monitoring for coastal sites: marine wildlife, seawater, sediments, sand.

…….

"Nuclear sites have at least one ASN-approved environmental laboratory that belongs to the national environmental radioactivity measuring network…, where environmental samples are analyzed."

2.1.4. Milestones and time frame

The entire research reactor SNF reprocessing and recycling project can be divided into three main parts: the contracting phase, the reprocessing/recycling works and the final waste return. The time frame mostly depends on the project's technical constraints, the governments' relationships and the authorization time frame of the safety authorities involved.

As described, the first phase, from AREVA–customer discussions to contract, including signature of the intergovernmental agreement, is about two years. In that period, AREVA and the customer have both to apply to their safety authorities for authorizations.

Depending on the type of fuel and quantity to be reprocessed, the reprocessing phase can vary from three months to several years. The AREVA La Hague facility workload and production forecasts are also to be considered. The standard intergovernmental agreement generally restricts this period to six years, starting from research reactor SNF delivery to France until it has been reprocessed.

The final waste return is to be planned from the beginning of the project, within the intergovernmental agreement. The timing of this operation can be negotiated according to the customer's country plan for final waste management (see Fig. 6).

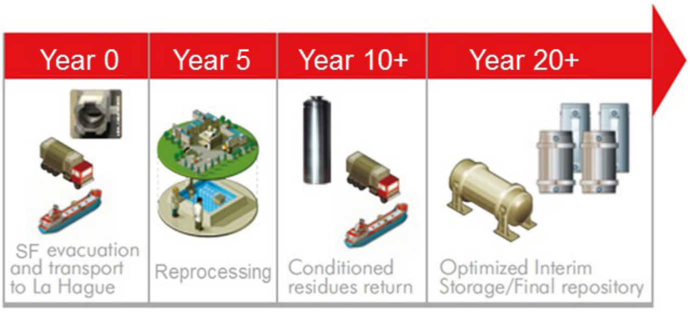


FIG. 6. Timeline for research reactor SNF removal and reprocessing.

2.1.5. Cost structure

The cost structure of a solution proposed by AREVA for the removal and reprocessing of research reactor SNF depends on the design of the solutions, according to the customer's needs. The basic price structure includes:

- Removal costs, as needed for each customer's contract: transport cask design and manufacturing, cask rental, transport costs and cask licensing;
- Receipt costs at the La Hague facility: managing fuel acceptance and receipt authorization, unloading the transport cask, interim storage in La Hague pools, and decontamination of the transport cask;
- Reprocessing costs, depending on the type of fuel: chemical composition and geometry, including the production of universal waste canisters and interim storage of the waste;
- Waste return costs to the country of origin: can be integrated into an overall contract basis, as part of a whole solution, or can be defined in subsequent agreements.

Depending on the research reactor SNF to be removed and reprocessed, the ASN agreement for shipment and reprocessing might have to be extended, resulting in additional costs (see Section 2.1.1.3).

2.2. RUSSIAN FEDERATION: FEDERAL STATE UNITARY ENTERPRISE MAYAK PRODUCTION ASSOCIATION

Since 2000, foreign research reactor operators have been able to ship HEU SNF to the Russian Federation for reprocessing under the RRRFR Programme, supported by the United States Department of Energy (USDOE), and several States have shipped LEU SNF under commercial agreements with Russian organizations.

2.2.1. Legislation in the Russian Federation

The legislative framework for providing interim storage and SNF reprocessing services to foreign nuclear facilities consists of international agreements of the Russian Federation, federal laws, regulatory acts of the Government of the Russian Federation and administrative documents of State executive bodies. The possibility of importing SNF into the Russian Federation is established in the following federal laws:

- Federal Law No. 170-FZ of 21 November 1995 on the Use of Atomic Energy [21];
- Federal Law No. 7-FZ of 10 January 2002 on Environmental Protection [22].

In addition, Decree No. 418 of 11 July 2003 on the procedure for importing SFAs of nuclear reactors into the Russian Federation [23] was issued. There are also many other regulatory documents for aspects concerning SNF import to the Russian Federation, including: preparation of ecological programmes, State ecological expertise[3], radioactive material transport safety assurance, safeguards of nuclear material, export control, and customs.

2.2.1.1. Regulatory requirements[4]

The main provisions of Federal Law No. 7-FZ (para. 4 of Article 48) [22] are the following:

— SNF import is permitted for interim storage and reprocessing.
— The project is to undergo a State ecological expertise review, and the general decrease of radiation effects and enhancement of environmental safety resulting from implementation of the project is to be justified.
— The basis for the import is an international contract between the Russian Federation and the exporting State.
— The law gives preference to the option of returning the radioactive waste resulting from reprocessing to the country of origin of the research reactor SNF.
— Research reactor SNF imports are subject to the annual limits approved by the Government.

Decree No. 418 [23] requires a project preparation procedure. Firstly, an international contract on cooperation on SNF import (both foreign origin and of the Russian Federation) into the Russian Federation is concluded, which has the form of a government–to–government agreement with the other State. In a number of cases, the Russian Federation already has an acting agreement. The international contract should contain provisions for the destiny of radioactive waste resulting from SNF reprocessing. Two options are possible: radioactive waste return to the export State or permanent disposition in the Russian Federation. To initiate the conclusion of an international contract, the authorized body of the export country has to send a corresponding letter to the State Atomic Energy Corporation Rosatom. Secondly, SNF import unified project documentation is prepared, comprising documents on the prospective conclusion of a foreign trade contract (FTC) for operations with SFAs subject to the State ecological expertise. These documents are prepared and approved in compliance with the established requirements, including:

— An FTC draft (containing the required financing for the project implementation, and the expenses for the management of SFAs and products resulting from reprocessing, approved according to an established procedure);
— Special ecological programmes (SEPs) implemented with the funds from foreign trade operations with SFAs;
— Materials to justify a general decrease in the risks of radiation impact and enhancement of environmental safety as a result of the implementation of a unified project, as well as the time frame of interim technological storage of SFAs and reprocessing products, stipulated by the FTC;
— Other materials to be submitted for a State ecological expertise review in compliance with the requirements of legislation of the Russian Federation, including the conclusion of the Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor)[5], and the Ministry of Public Health of the Russian Federation.

The key idea expressed by the legislator in the requirements for unified project development is that the implementation of such a project should result in a decrease in the risks of a radiation impact. This is achieved through the SEPs funded by the project, which enables the ecological situation to be improved in the areas where the organizations managing the SNF and the reprocessing products are located. In compliance with Government Decree No. 587 of 22 September 2003 on the procedure for approving expenses to manage spent fuel assemblies from nuclear reactors and the products of their reprocessing [25], the expenses for SEPs for each project should not

---

[3] A measure in the field of ecological expertise organized and implemented by the federal or regional executive body in conformity with the procedure established by Federal Law No. 174-FZ of 23 November 1995 on Ecological Expertise [24] and other regulatory acts of the Russian Federation. Ecological expertise means establishing the conformity of documentation to the ecological requirements established by technical procedures and regulations in the field of environmental protection, upon assessment of the economic or other activity envisioned by the object of the ecological expertise, with the purpose of preventing a negative impact of such activities on the environment.

[4] This section is based on Refs [1–3].

[5] For further information, see http://en.gosnadzor.ru/activity

be less than 30% of the total cost of the project. The structure of costs for the SNF import project is calculated by the reprocessing plant and approved by Rosatom.

SFAs may be imported into the Russian Federation upon receiving a positive evaluation of the unified project from the State ecological expertise review, developed by the authorized organizations and agreed with Rosatom and the Ministry of Natural Resources and Environment of the Russian Federation. In addition to the import licence, important aspects include the following:

(a) Radioactive waste calculation method: If radioactive waste resulting from SNF reprocessing is to be returned to the export country, the amount of radioactive waste to be returned is to be determined. A special method should be developed which includes both the methodological approach to determine the equivalence between the imported SNF and the radioactive waste to be returned, and a calculation of the radioactive waste quantity to be returned for a particular imported SNF batch. In compliance with regulations of the Russian Federation, the calculation is based on the equivalence of the activity of the imported SNF and the activity of the radioactive waste to be returned. The method describes the physical form, isotopic composition and amount of returned radioactive waste. The method should be agreed between the parties.

(b) Additional review: In the case that foreign origin SNF is imported, a special commission appointed by the president of the Russian Federation reviews the results of the unified project's State ecological expertise findings.

(c) The State ecological expertise positive findings, as well as the special commission's positive findings (in the case of foreign origin SNF) on the unified project are the basis for the organization authorized by the Russian Federation to sign the FTC on SNF management in the territory of the Russian Federation (transport, storage, reprocessing and management of resulting products).

The above procedure for obtaining a licence to import foreign SNF into the Russian Federation is implemented by organizations of the Russian Federation (including the authorized organization, the reprocessing plant and other organizations experienced in SNF shipments to the Russian Federation) under the appropriate contracts with the research reactor. The organization authorized to conclude FTCs on imports of reactor SFAs to the Russian Federation is designated by a government order.

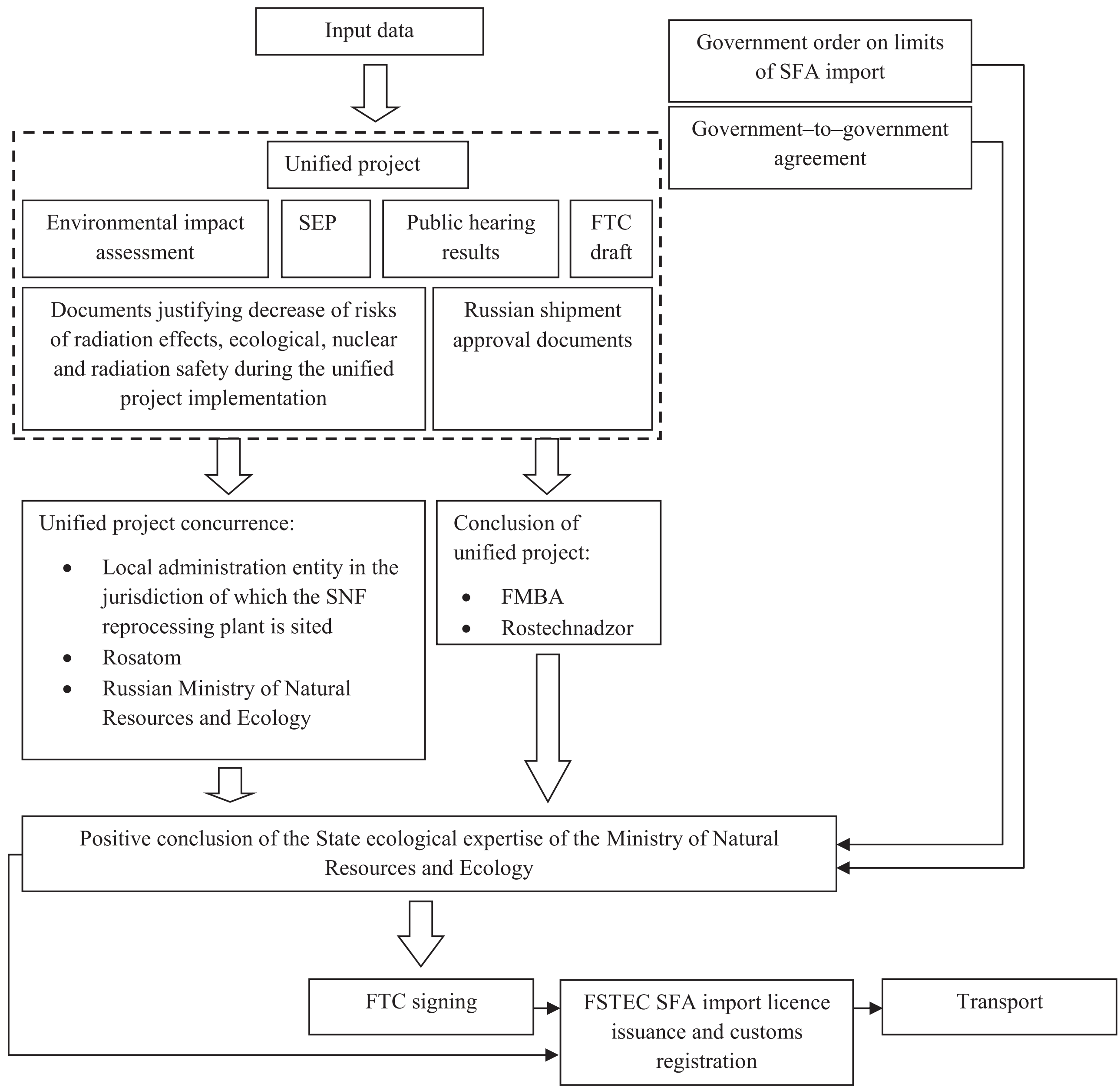
For obtaining an import licence for nuclear commodities and technologies, the participant in foreign economic activities in the organization authorized by the Russian Federation to conclude FTCs submits a licence application to the Russian Federal Service for Technical and Export Control (FSTEC). The same applies for obtaining a one-time export licence for nuclear commodities and technologies for the radioactive waste resulting from reprocessing.

The International Relations Division and the Nuclear and Radiation Safety Directorate — Project Office for SNF Management Systems Development of Rosatom coordinate all research reactor SNF imports into the Russian Federation. A flow chart describing the document preparation for SNF imports into the Russian Federation is shown in Fig. 7.

Regulations of the Russian Federation for the safe transport of radioactive material establish the approvals for package design and shipment approval. Both certificates of approval can be combined into a single certificate, which can contain the shipment conditions for empty packing with radioactive material remains (radioactive contents) and empty packaging with radioactive material used in the design.

The Special Transport Division of Rosatom's Nuclear and Radiation Safety and Organization of Licensing and Approval Activities Department (NSLD) coordinates the preparation of all commercial radioactive material package design and shipment certificates. The procedure for preparing certificates of approval is described in Rosatom Administrative Regulation No. 527 of 10 October 2007 on the realization of the State function issuance of certificates (approvals) for shipments of radioactive materials and their registration [26] and includes the following:

— An application to issue the certificate of approval, including support information (detailed description of the package design, proof of quality assurance during fabrication, characteristics of the radioactive content, shipment route, safety assessment and applicable emergency card);
— Safety assessment of the package design and shipment performed by the expert organizations of Rosatom;
— If necessary, additional independent safety assessments performed by other expert organizations;
— Preparation of the draft certificate of approval, concurrence and approval of the certificate by the competent authorities (Rosatom, Rostechnadzor, and Federal Medical and Biological Agency).



Note: FMBA — Federal Medical and Biological Agency; FSTEC — Russian Federal Service for Technical and Export Control; FTC — foreign trade contract; SEP — special ecological programme; SFA — spent fuel assembly; SNF — spent nuclear fuel.

FIG. 7. A flow chart of document preparation for SNF import into the Russian Federation.

The certificate of approval is revised at the end of its validity and if the package design or the shipment conditions change. In addition, other necessary approval documents include technical specifications for SFA delivery to the reprocessing plant and special requirements for air shipment, if applicable. The technical specifications for the delivery of foreign research reactor SFAs to the Federal State Unitary Enterprise Mayak Production Association (FSUE Mayak PA) radiochemical plant for reprocessing include the following:

— Requirements for the state of the SFA;
— Requirements for the transport means, handling and maintenance;
— Requirements for the transport and technological operations during SFA delivery, transfer from one transport mode to another;
— Obligations and responsibilities of the research reactor and reprocessing plant;
— Requirements for the accompanying documents.

An additional document defines special requirements for air shipment of packages, and Rosatom endorses two emergency cards (see Ref. [27]).

2.2.1.2. Options for SNF and radioactive waste handling from the viewpoint of legislative possibilities

The current legal framework of the Russian Federation allows two options for the final management of radioactive waste resulting from research reactor SNF reprocessing: the radioactive waste can be finally managed in the Russian Federation or it can be returned to the export country. The decision about the back end option is made in the early stages of the project during the elaboration of the government–to–government agreement.

In the case that the radioactive waste remains in the Russian Federation, the FTC will include the corresponding costs of the final disposition of the resulting radioactive waste, along with the costs of SNF reprocessing. If the radioactive waste is returned to the export country, the method used to calculate the quantity of the radioactive waste to be returned and its form has to be determined and agreed upon by the parties.

2.2.1.3. The main steps and time frame of licensing procedures and intergovernmental arrangements

The following three groups of tasks can be defined:

(a) The conclusion of the government–to–government agreement between the Russian Federation and the State of the research reactor about cooperation on SNF import into the Russian Federation: This procedure usually takes 12–18 months if ratification in the Russian Federation is not required; an additional period of 6–12 months is necessary for ratification.
(b) Preparation of the unified project documents for the SNF import (including a draft FTC), concurrence of the unified project, obtaining a positive evaluation from the State ecological expertise, FTC signature and obtaining an import licence: Approximately 12 months is required.
(c) Preparation of the Russian Federation shipment approval documents: In the case of known types of fuel and packages already licensed in the Russian Federation, the time for obtaining the approval documents is approximately 4 months. In the case of foreign SNF import, highly damaged fuel or foreign packages not previously licensed in the Russian Federation, this process can take 12–18 months.

Considering the parallel implementation of the tasks, the overall time frame for all licensing procedures for research reactor SNF import into the Russian Federation is 12–18 months on average, and very much depends on the individual requirements of each project.

2.2.2. Reprocessing facility[6]

2.2.2.1. Applied technology of the reprocessing facility

Federal Law No. 7-FZ [22] stipulates the possibility to import SNF into the Russian Federation for temporary technological storage with subsequent reprocessing. At present, the Russian Federation operates one reprocessing facility — RT-1 reprocessing plant of FSUE Mayak PA, in Ozersk, Chelyabinsk.

FSUE Mayak PA is a complex of interconnected production facilities, which are structurally divided into plants and production units. The facility management is centralized. FSUE Mayak PA implements several kinds of production, principally reactor, radiochemical, chemical, metallurgical and isotopic production. The RT-1 plant was created based on the radiochemical plant and was commissioned in 1977.

All reprocessing facilities worldwide use similar procedures: SNF interim storage underwater, mechanical cutting of SFAs, extraction of the targeted elements by means of the PUREX process, and vitrification of high level waste (HLW). Each of these facilities, however, has its own peculiarities in the organization of the technology.

[6] This section is based on Refs [1–3].

The main distinctive feature of the RT-1 plant is the wide range of reprocessed fuel. SNF of power reactors (WWER-440, RBMK-1000 and BN-600), naval propulsion reactors, commercial scale reactors and research reactors is reprocessed here [28]. The distinctive features of the RT-1 plant's technology include the following:

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

FSUE Mayak PA owns casks for SNF shipments (see Fig. 8). The SNF delivered to the plant is placed into a cooling pool (see Fig. 9), in which more than 3 m of water above the fuel provides reliable biological shielding.

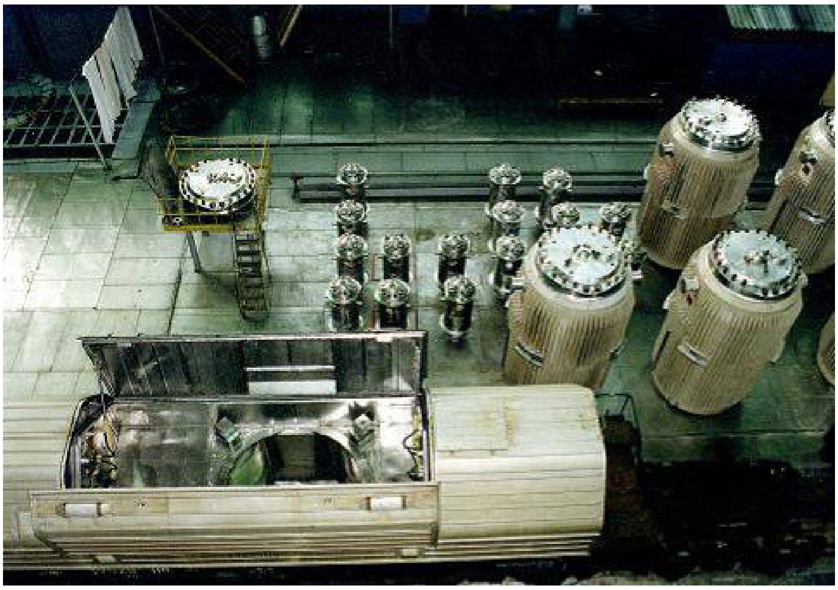


FIG. 8. Casks for SNF transport to FSUE Mayak PA.

FIG. 9. General view of the SNF pool at FSUE Mayak PA.

The duration of SNF interim storage before reprocessing is generally up to two years. The safety of SNF interim storage is ensured by highly efficient pool water purification and radiation monitoring systems [29].

SNF is loaded in batches for dissolving and further reprocessing. The first stage is to cut the SFAs into 60 mm pieces and load them into a batch type dissolver, in which the fuel is dissolved in a nitric acid solution. The fuel composition is then clarified by filtering, and reprocessed by the PUREX process afterwards. The PUREX process allows extraction and separation of the valuable elements. Multistage equipment of a mixer–settler type with air agitation of phases is used during the process. The targeted products of SNF reprocessing are uranyl nitrate melt, obtained from the evaporation of a nitric acid solution of uranium, and triuranium octoxide, obtained from the precipitation by ammonia and subsequent roasting of the precipitate.

In addition to the targeted products, the plant process flow might provide full scale extraction of neptunium and radioactive iodine. Radionuclides, including ^{241}Am, ^{137}Cs, ^{85}Kr, ^{147}Pr and ^{90}Sr, are also separated from the SNF [30].

The safe management of radioactive waste is an important aspect of the operation of the RT-1 plant (see Fig. 10). The principal objective of the vitrification plant, which has been in operation since 1987, is to include HLW and, partially, low and intermediate level waste (LILW), into the matrix of sodium aluminophosphate glass.

In 1996, a fractionation plant was launched into operation at the RT-1 plant. The primary reason for the development of this plant was that many of the high level solutions have a complex salt content, direct vitrification of which has been impossible. The fractionation plant uses the extraction technology of concentrated caesium and strontium from high level nitric acid solutions with the help of cobalt dicarbollide as an extracting agent, and the extraction and precipitation technology of transplutonium and rare earth elements. At present, the plant focuses on separating caesium and strontium from HLW for radioisotope source fabrication.

The directions of further development of the RT-1 plant include the development and implementation of optimized process design solutions, equipment upgrades, an extension of the reprocessed SNF domain, and expansion of the services and products offered [31]. The extended domain of the reprocessed SNF includes uranium–beryllium, uranium–zirconium, uranium metal, plutonium fuels and material, SNF from molten salt research reactors and other types of SNF.

In 2014, the test reprocessing of pyrophoric fuels (uranium metal and nitride fuels) demonstrated the possibility, in principle, of commercially reprocessing such fuels using existing equipment. Nonetheless, in order to enhance safety, plans are in place to make a special upgrade to the crushing and dissolution equipment by 2019 (i.e. construction of equipment for fuel cutting and loading into canisters with a regulated composition of the gaseous phase). Reprocessing the nitride fuel will require additional upgrades to the gas cleaning system. The plant can start pilot reprocessing of pyrophoric fuels in 2017 after upgrading the crushing and dissolution equipment.

FIG. 10. High level waste management at FSUE Mayak PA.

As for uranium–zirconium fuel and other types of composite fuel, the RT-1 plant can start their reprocessing after 2018 after the electrochemical dissolution technology and a prototype industrial dissolution tank are developed, manufactured and commissioned (see Fig. 11). This technology can also be used for reprocessing plutonium material. Retention and expansion of the services and products offered is being considered not only for the period until 2025–2030, but also for the longer term after 2030.

FIG. 11. Electrochemical dissolution tank.

The technology available at the plant yields products that may be used as a source for regenerated mixture of uranium and plutonium oxides (REMIX) fuel. The REMIX fuel developed by the Khlopin Radium Institute, St. Petersburg, is made of a uranium–plutonium mixture regenerated from the reprocessed SNF with additives of natural uranium enriched at 16–17% ^{235}U. The REMIX fuel allows multiple recycling of the entire quantity of uranium and plutonium from the SNF, enabling 100% fuelling of the WWER-1000 reactor core with such fuel [32].

Tozser et al. [3] report that the development and implementation of optimized 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 up part of the SNF reprocessing cycle. The implementation of these processes is anticipated to result in a threefold decrease of operational LILW. New radioactive waste processing facilities (a cementation complex, an HLW vitrification complex and a solid radioactive waste management complex) were planned for construction and commissioning between 2017 and 2025. Simultaneous upgrades to the existing equipment and asset replacement are also included in the plan. The developed concept of the new, multifunctional 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 resulting from reprocessing SNF from the Russian Federation and foreign countries, return of the radioactive waste to foreign SNF suppliers and clearing the storage tanks from the accumulated waste will be ensured.

2.2.2.2. Alternatives offered in compliance with the general legal regulations

In compliance with the provisions on nuclear reactor SFA import (approved by Decree No. 418 of 11 July 2003 [23]), reprocessed products and waste management services can be rendered to the supplier’s country if it complies with non-proliferation principles, which is particularly stipulated in the appropriate international contracts of the Russian Federation.

2.2.2.3. General requirements and boundary conditions for supplied SNF

In compliance with the available licences, the RT-1 plant accepts the following types of spent research reactor fuel assemblies: VVR-K, VVR-C, VVR-S, VVR-2, VVR-M2, VVR-M3, VVR-M5, VVR-M7, MR, IRT-1000, IRT-M, IRT-2M, IRT-3M, IVV2, IVV-2M, PIK, SM-3, MIR, IST-1, ARBUS, ARBUS-1, ARBUS-1M2, ARBUS-2, BOR-60 and VK-50. IIN-3M liquid SNF is now also accepted at the RT-1 plant.

The evaluation of SFAs intended for reprocessing is carried out at the early stages of shipment preparation. It allows a comprehensive analysis of SNF stock to ascertain the basic characteristics needed to certify the shipment, perform the environmental safety assessment and determine further reprocessing parameters. The results of this evaluation and SNF stock analysis show, in particular, which type of cask is required and play an important part in the development of the transport and technological scheme. The methods of determining the SNF characteristics have to be concurred with the reprocessing plant beforehand.

Special canisters are used to transport liquid or failed fuel to the reprocessing plant. The safety of the design of these canisters needs to be assessed and to concur with the reprocessing plant.

2.2.2.4. Extending the range of reprocessed SNF

There is experience in extending the range of reprocessed SNF from other reactors if safe handling of the SFAs during transport, storage and reprocessing is assessed, as well as if the appropriate licences and approvals are prepared. An example of dealing with non-standard tasks is the successful SNF shipment from the mobile Pamir-630D nuclear power station of the Joint Institute for Power and Nuclear Research (JIPNR), Sosny, Belarus, to the Russian Federation.

Preparations for removal of SNF from Belarus commenced in 2008. In addition to the Pamir-630D SFAs, SNF from other experimental installations on the JIPNR site was also to be repatriated to the Russian Federation. The following SNF inventory was identified:

— SFAs from the Pamir-630D;
— Irradiated spherical fuel elements and their components;
— Irradiated EK-10 fuel rods.

During the development of the concept for SNF repatriation to the Russian Federation, specialists from the RT-1 plant of FSUE Mayak PA noted that the Pamir-630D SFAs were not part of the SNF range that the plant would normally handle. In order to prepare the RT-1 plant for receipt and subsequent reprocessing of this new type of SNF, a number of research, design and development activities had to be performed. In particular, studies were conducted to determine the feasibility and methods of upgrading the equipment for shearing the fuel assembly components, as well as to establish whether it could be chemically dissolved and extracted. The following was performed:

— Unirradiated fuel specimens (rods) analogous to the fuel elements of the Pamir-630D were fabricated at FSUE Scientific Research Institute Scientific Industrial Association LUCH to test shearing of the rods' components by the cutting machine of the RT-1 plant. Based on the test results, the shearing procedure and the existing equipment were improved.
— Leaching of the fuel specimens was improved.
— A new procedure for the operation of the hydraulic cylinders was developed and implemented to ensure the quality of reprocessed fuel milling.
— Hydraulic panels were fabricated to improve the operation of hydraulic equipment of the cutting machine control unit and transmission of the SFA supply unit.
— With the improvements made to the process liquid supply in feed lines, the feed line panel was fabricated to be installed into the line of joint supply from all pumps by means of a pump station to the cutting machine

control unit. It enabled the required pressure in the line to be maintained, thus improving operation of all media supply pumps.
— The special press of the cutting machine, the pusher drive with control panel, the hydraulic panels of the cutting machine control unit and transmission of the SFA supply unit were fabricated and installed on the operating line of the RT-1 plant.

As a result, all of the necessary upgrades were implemented in 2009 and 2010 without modifying the basic technological process at the FSUE Mayak PA radiochemical plant.

The SNF was loaded into the ŠKODA VPVR/M packages. The casks were then sealed and placed into four specialized 20 foot ISO containers (one cask per container). The containers were moved from the JIPNR site to a railway station by road. The train with the SNF travelled non-stop to the radiochemical plant at FSUE Mayak PA, arriving in October 2010.

In 2010, specialists from the Sosny Research and Development Company and FSUE Mayak PA joined efforts to evaluate the possibility, cost and time required to reprocess the SFAs and rods of the Norwegian Halden boiling water reactor (BWR), JEEP I and JEEP II, in the Russian Federation. The evaluation involved the assessment of transport technical feasibility, receipt, interim storage, reprocessing of Norwegian research reactor SFAs and treatment of the products resulting from reprocessing at FSUE Mayak PA. There was also a cost estimation of transport, receipt, interim storage, reprocessing of Norwegian research reactor SFAs and management of the products resulting from their reprocessing at FSUE Mayak PA.

The research conducted resulted in a positive evaluation of the technical possibility of research reactor SNF import of a foreign origin into the Russian Federation and its reprocessing at FSUE Mayak PA. Moreover, the products of SNF reprocessing could either be kept on the territory of the Russian Federation or returned to the country of origin.

2.2.3. Environmental aspects

In compliance with Article 1 of Federal Law No. 7-FZ [22], the safety of the environment is ensured if certain measures are taken to protect the environment and vital interests of humans against a possible negative impact of anthropogenic and other activities, natural and human made emergency situations and their consequences under established codes and standards, which determine the conditions of protection presence or absence [33].

In research reactor SNF import projects, the objective of general risk reduction is understood as the reduction of radiation risks. This task is solved through the appropriate level of safety during the implementation of the import project and by implementing additional measures under SEPs funded in compliance with the legislation of the Russian Federation.

SEP measures are aimed at meeting the requirements and provisions of the current radiation safety regulations and codes in raising the level of radiation safety for individuals during the implementation of activities, and examples include the following:

— Reduction of radiation risks around FSUE Mayak PA (special conveyances with a lead cladded driver’s cabin and protective glass against radiation were purchased to preserve the V-9 reservoir);
— Development of dose, radiometric and spectrometric monitoring systems, as well as software and methods of analysis and data processing;
— Remediation of the contaminated territories of FSUE Mayak PA;
— Solutions for processing the accumulated liquid radioactive waste (HLW).

SEPs have been implemented since 2009, funded from SNF imports from research reactors outside the Russian Federation. The implementation of these SEPs is of vital importance to the variety of environmental activities in the Chelyabinsk region in general, and at FSUE Mayak PA in particular.

2.2.4. Milestones and time frame

The general project stages are the following:

(1) Conclusion of a government–to–government agreement between the Russian Federation and the export State about cooperation on SNF import into the Russian Federation;
(2) Evaluation of SFAs;
(3) Design and fabrication of additional package components required for the safety of SNF shipment and reprocessing (e.g. canisters, baskets or other distancing and shock absorbing elements), if necessary;
(4) Research reactor site preparation for SNF removal can include, if necessary, design and fabrication of additional equipment (e.g. for SFA loading into packages and for SNF package handling), site infrastructure modernization and training of personnel;
(5) FSUE Mayak PA preparation for SNF receipt and handling in the case of new fuel deliveries or if using foreign packages for the first time;
(6) Delivery of the empty packaging at the research reactor site, SFA loading and SNF transport;
(7) SNF interim storage and reprocessing, and radioactive waste storage;
(8) Radioactive waste return to the country of origin of the SNF if this is foreseen in the government–to–government agreement.

The time necessary to fulfil Stages (1) to (5) can differ substantially depending on the individual requirements of each specific project. Under the RRRFR Programme, this time was between one and five years. The time to fulfil Stage (7) is defined in the FTC and usually takes around 20 years.

2.2.5. Cost structure

The costs of implementing the unified project for the import of research reactor SFAs to FSUE Mayak PA for reprocessing and subsequent management of the reprocessed products with the resulting radioactive waste to be left (if applicable) on Russian Federation territory, are financed according to the FTC as follows:

(a) The expenses for SEPs for radioactively contaminated sites (according to Decree No. 588 of 22 September 2003 on the procedure for financing special ecological programmes for the recovery of radiation contaminated territorial sites [34]) — 30%.
(b) The expenses for the SFAs and reprocessed product management — 70%, broken down as follows:
  (i) Service costs of the organizations authorized by the Government of the Russian Federation to conclude FTCs on SFA import into the Russian Federation.
  (ii) Service costs of the facility handling the SFAs and their reprocessed products, stipulated by the FTCs:
    — Transport of the SFAs to the Russian Federation for technological storage and reprocessing;
    — Customs duties;
    — SFA handling, including technological storage and reprocessing, obtaining the necessary approval documents;
    — Management of the radioactive waste resulting from reprocessing;
    — Final disposition of the radioactive waste.

3. MANAGEMENT AND LOGISTICS SUPPORT

The two types of management and logistics support are assurance of technical resources and available equipment, and engineering support. For the first type, the support provider offers information to the research reactor operator concerning all of the existing technical resources (certified packages, transport means and support equipment), helping to choose the most appropriate equipment and transport logistics. At this stage, the support provider can also advise on the new technologies and documentation that need to be developed for the project.

At the request of the research reactor, the support provider makes the corresponding resources available. For the second type of support, the provider offers engineering services for the development of new technologies, documentation, licensing support and technical support during practical operations. The management and logistics support providers are presented in Section 3.3.

This section contains information on various suppliers from the Czech Republic, France, Germany and the Russian Federation who provide services for research reactor SNF shipments to France and the Russian Federation, and from the Savannah River National Laboratory, United States of America. Packages, equipment and services from any other suppliers may be accepted in France and the Russian Federation provided that the relevant certificates and licences are obtained.

3.1. AVAILABLE TECHNICAL RESOURCES AND SUPPORT EQUIPMENT

3.1.1. Packages available for shipments

AREVA TN, part of AREVA, owns and operates a fleet of four TN-MTR casks, whose design is based on IAEA safety standards. Specific baskets have been developed for international shipments, and each cask can transport up to 44, 52 or 68 MTR SFAs, depending on the basket used. AREVA TN also propose several other types of cask which satisfy IAEA requirements (TN-MTR-RHF and TN-LC) (see Table 2).

TABLE 2. PACKAGES AND TRANSPORT MODES CERTIFIED IN FRANCE

Package	Road	Rail	Sea	Air
TN-MTR-68	Yes	Yes	Yes	No
TN-MTR-52, 52S, 52SV2	Yes	Yes	Yes	No
TN-MTR-44	Yes	Yes	Yes	No
TN-MTR-RHF	Yes	Yes	Yes	No
TN-LC	Yes	Yes	Yes	No
TN 17/2	Yes	Yes	Yes	No

In addition to AREVA casks, the AREVA La Hague reprocessing facilities can receive casks from other service providers. These casks require certificates of approval from the ASN for transport on French territory and for unloading at the La Hague site.

The transport packages for research reactor SNF shipment operations which have certificates in the Russian Federation are in Table 3. In conformity with the IAEA and Russian Federation regulations for the safe shipment of radioactive material, and on the condition that corresponding safety justification is provided, all transport modes (road, rail, water and air) are possible for research reactor SNF shipments to the Russian Federation.

The transport modes reflect the existing certification and shipment experience. If needed, any package can be shipped by any transport mode provided that the safety assurance of such a shipment is proven at a level not lower than the one required by the applicable regulations. A summary of available research reactor SNF packages is presented in Table 4 and their technical descriptions are given in Appendix I.

TABLE 3. PACKAGES AND TRANSPORT MODES CERTIFIED IN THE RUSSIAN FEDERATION

Package	Road	Rail	Water	Air
TUK19	Yes	Yes	Yes	Yes
TUK-145/C	Yes	Yes	Yes	Yes
ŠKODA VPVR/M	Yes	Yes	Yes	No
Castor MTR2	Yes	Yes	Yes	No
TUK-128 (TUK-135)	Yes	Yes	No	No
TUK-32	No	Yes	No	No

TABLE 4. SUMMARY OF AVAILABLE RESEARCH REACTOR SNF PACKAGES

Package	Service provider	Countries/region	Transport mode	Section in Appendix I
TUK-19	Sosny Research and Development Company	Kazakhstan Latvia Libya Poland Romania Russian Federation Serbia Uzbekistan	Road, rail, water, air	I.1
ŠKODA VPVR/M	ÚJV Řež, a.s. Sosny Research and Development Company	Belarus Bulgaria Czech Republic Hungary Poland Russian Federation Serbia Ukraine	Road, rail, water	I.2
Castor MTR2	DAHER–NCS Sosny Research and Development Company	Germany Russian Federation	Road, rail, water	I.3
TUK-128 (TUK135)	Sosny Research and Development Company FSUE Mayak PA	Russian Federation	Road, rail	I.4
TUK-32	Sosny Research and Development Company FSUE Mayak PA	Russian Federation	Rail	I.5
TUK-145/C	Sosny Research and Development Company	China* Ghana* Hungary Russian Federation Uzbekistan Viet Nam	Road, rail, water, air	I.6

TABLE 4. SUMMARY OF AVAILABLE RESEARCH REACTOR SNF PACKAGES (cont.)

Package	Service provider	Countries/region	Transport mode	Section in Appendix I
TN-MTR-68, 44, RHF	AREVA TN	Australia Belgium Denmark France Italy Portugal USA Bolivarian Republic of Venezuela	Road, rail, water	I.7
TN-MTR-52, 52S, 52SV2	AREVA TN	Australia Denmark France Portugal USA	Road, rail, water	I.7
TN-LC	AREVA TN	France USA	Road, rail, water	I.8
TN-17/2	AREVA TN	Belgium France Italy Netherlands Sweden	Road, rail, water	I.9
NAC-LWT	NAC International	Asia European Union South America USA	Road, rail, water	I.10

Source: Table 1 of Tozser et al. [3].
* With new MNSR basket (TUK-145/C-MNSR).

3.1.2. Accessories and support equipment

Not every research reactor site can ensure SNF loading into packages, owing to the specific characteristics and layout of the site itself and the available equipment. Hence, it is sometimes necessary either to improve the site infrastructure or to develop new technology and equipment. Development of such technologies and equipment for safe SNF loading into packages consists of the following tasks:

- Identification of regulatory requirements for lifting equipment, SNF handling operations, and civil structures requirements and limitations in the research reactor operator country;
- Development of technical requirements for new equipment with regard to research reactor site characteristics (loading capacity of lifting devices, operating area of lifting devices, and allowable loads onto the facility floor);
- Preparation of existing, or development of new, equipment for SNF loading into packages, including safety analysis and decontamination procedures;
- Concurrence of the equipment and technology for SNF loading into packages with the research reactor;
- Fabrication of new equipment (strength and performance tests of the equipment at the manufacturing plant, issuing the corresponding test record sheets and acceptance protocols is mandatory);
- Delivery of the equipment to the research reactor site, its installation, startup and adjustment, and comprehensive testing;
- Training personnel involved in SNF loading into packages.

Technologies for loading SNF into packages include remotely controlled loading in the air, underwater loading submerging the transport cask in the cooling pool, or using a transfer cask and auxiliary equipment for its operation, maintenance and decontamination. Existing technologies for the safe loading of SNF into TUK-19 and ŠKODA VPVR/M casks using transfer casks developed by the Sosny Research and Development Company and the similar technology for the TN-MTR cask developed by AREVA TN are presented in Appendix II.

When SNF is delivered to the reprocessing facility site in packages with which the facility has no prior experience, equipment to handle these packages (for transport inside the facility and SNF unloading) needs to be developed, and can involve the following:

— Review of the specifications of the equipment existing at the reprocessing facility, deciding on the degree of its compatibility and the necessity for modifications or for new equipment;
— Preparation of existing, or development of new, equipment for handling the packages at the reprocessing facility site;
— Concurrence of the developed equipment with the owner of the packaging;
— Fabrication of new equipment (strength and performance tests of the equipment at the manufacturing plant, issuing the corresponding test record sheets and acceptance protocols is mandatory);
— Delivery of the equipment to the reprocessing facility site, its installation, startup, adjustment, personnel training and comprehensive testing.

3.1.3. Transport modes supported

The principal characteristics of the transport modes from the logistics perspective are provided in Table 5.

TABLE 5. PRINCIPAL CHARACTERISTICS OF THE TRANSPORT MODES

Transport mode	Principal characteristics
Shipment by air	Most suitable in the case of small amounts of SNF For long distances from the research reactor site If there are transit countries to cross If maximal physical protection has to be provided Highest cost per unit Demands more labour and time consuming safety analysis
Shipment by water	Most suitable in the case of large amounts of SNF For long distances from the research reactor site If there are any seaports in the export country Special regulations apply for inland waterways
Shipment by rail	Most suitable for States that share common borders with the reprocessing country Lowest cost per unit
Shipment by road	Often the only possible SNF shipment mode over short distances (from the research reactor site to the railway station, airport or 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

Source: Table 2 of Tozser et al. [3].

The United Nations Recommendations on the Transport of Dangerous Goods (Model Regulations) [35] contains all of the internationally applicable requirements for dangerous goods (including Class 7 — radioactive material) shipments by all modes of transport.

3.1.3.1. *Shipment by air*

Research reactor SNF air shipments have so far been completed only to the Russian Federation. For dangerous goods Class 7 air shipments to the Russian Federation, the carrier requires a licence for handling radioactive material during transport, issued by Rostechnadzor. Research reactor SNF air shipments to the Russian Federation require the preparation and approval of special requirements for air shipment, and a certificate of approval for package design and shipment.

Before each shipment, the carrier has to obtain permits from Rostechnadzor and the Federal Agency of Air Transport, and also has to comply with the requirements of the International Civil Aviation Organization (ICAO) Technical Instructions for Dangerous Goods Air Shipment [36] and Order No. 141 of the Ministry of Transport of 5 September 2008 on the approval of Federal Aviation Regulations “Dangerous Goods Shipment by Civil Aircraft” [37].

Type B(U) TUK-19 and Type C TUK-145/C packages are licensed for research reactor SNF air shipments in the Russian Federation. The TUK-19 packages are transported in ISO containers, and aircraft suitable for these shipments can typically carry three to six ISO containers containing TUK-19 packages, or one to three TUK-145/C casks. For air shipments, the applicable regulations limit the activity in each Type B(U) TUK-19 package, while there is no activity limit for the Type C TUK-145/C package. The routes of research reactor SNF air shipments are flexible and can avoid transit countries and shipment in the proximity of high density population areas, environmentally protected areas, nuclear objects and conflict areas [38].

3.1.3.2. *Shipment by water*

At the international level, shipments by sea and inland waterways are governed by a series of international conventions, agreements and codes, including:

— International Convention for the Safety of Life at Sea [39];
— International Maritime Dangerous Goods Code [40];
— International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships (INF Code) [41];
— European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) and the Annexed Regulations [42].

At the national level, these shipments are governed by internal codes and regulations, port procedures and licensing requirements.

Depending on the vessel characteristics, the maritime register assigns it a category limiting the total radioactivity of the cargo:

— INF-1 for SNF cargo with a summed activity of less than 4000 TBq;
— INF-2 for SNF or HLW with a summed activity of less than 2×10^6 TBq and plutonium with a summed activity of less than 2×10^5 TBq;
— INF-3 for SNF or HLW and plutonium with no restriction on the maximum summed activity of the material.

The practice of research reactor SNF shipments demonstrates that INF-2 class vessels are sufficient for the purpose.

To perform sea shipments of research reactor SNF to the Russian Federation, it is mandatory to use a carrier of the Russian Federation that can supervise the fulfilment of all of the applicable requirements, the existence of all required licences, and the preparation of the correct route, in compliance with regulations of the Russian Federation.

J/S ASPOL Baltic Corporation (see Section 3.3.1.2) owns a certified fleet of three sea–river vessels. In 2012, the railway ferry of Anship LLC was certified for INF-2 class shipments across the Black Sea (see Fig. 12). In addition, foreign ships with the appropriate INF Code certificate can be chartered (see Fig. 13) [43, 44].

(a) (b)

FIG. 12. Black Sea INF-2 licensed ships: (a) Anship LLC Slavyanin railway ferry for shipping railway wagons and platforms containing SNF; (b) Mikhail Dudin motor ship of the J/S ASPOL Baltic Corporation.

(a) (b)

FIG. 13. Danish (a) LYNX and (b) PUMA vessels used to ship research reactor SNF to the Russian Federation.

Sea shipments to France implemented on behalf of AREVA TN have been carried out on a dedicated ship meeting the INF Code requirements of the classification [41]. The ships have been chartered by AREVA TN for transport from countries of origin to France at the AREVA La Hague reprocessing plant.

AREVA TN's Cherbourg terminal is used for international transport of SNF, LILW, HLW and fresh mixed oxide (MOX) fuel. The Cherbourg terminal and its special gantry crane for heavy casks is used on a non-regular basis. This requires specific knowledge and methodology to ensure safe and secure cask transfers.

3.1.3.3. Shipment by rail

At the international level, shipments by rail are governed by a series of international conventions and agreements, such as the Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), part of the Convention concerning International Carriage by Rail [45] and the Agreement on International Goods Transport by Rail (SMGS) [46]. At the national level, these shipments are governed by regulations, procedures and licensing requirements.

For rail shipments of some packages, special wagons are available (e.g. TK-5 for TUK-19). However, this arrangement has not been very efficient, since not all research reactor sites have the possibility to load the SNF packages into these wagons. Specialized means that are often not suitable for other sites have to be developed for this purpose. A more flexible option is using ISO containers, which allow easy reloading and can be used on standard railway container platforms (see Fig. 14). Such ISO containers are available for TUK-19, ŠKODA VPVR/M, TUK-128 (TUK-135) and TN-MTR packages [47].

(a) (b)

FIG. 14. ISO containers for research reactor SNF packages.

The ISO containers are equipped with special tie-downs to secure the package. Depending on the length and load capacity (number of axles), the platforms can carry from one to three ISO containers. SNF loaded railway trains (either on flatcars or in dedicated wagons) are formed in compliance with international regulations, and usually contain buffer cars and escort cars (passenger cars for technicians and security guards). During international shipments, the railway line gauge can differ; thus, a standard bogie exchange system can be applied without reloading the containers. The dedicated TK-5 wagon has a standard two-axle bogie, so a gauge change is not a technical challenge at border points.

With a fleet of 40 rail cars, AREVA TN operates the Valognes rail to road transfer terminal, 40 km from the AREVA La Hague reprocessing plant. Each year, more than 400 heavy casks for used fuel or HLW are transferred from rail to road or from road to rail. Many other radioactive material, such as uranyl nitrate (LILW), are also regularly transferred in the Valognes terminal.

3.1.3.4. Shipment by road

At the international level, shipments by road are governed, for example, by the Customs Convention on the International Transport of Goods under Cover of TIR Carnets (TIR Convention) [48] and the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [49]. At the national level, these shipments are governed by internal regulations, procedures and licensing requirements.

Many packages (e.g. ŠKODA VPVR/M, TUK-19, TUK-128, Castor MTR2) are shipped by road in ISO containers on standard trucks and container semitrailers. TUK-145/C packages are shipped by road on a special purpose trailer that can be loaded together with the package onto aircraft (see Fig. 15) [50].

AREVA TN designed, operates and maintains a fleet of 200 industrial vehicles dedicated to all kinds of nuclear material, including a fleet of 12 trucks with 9 wheel lines equipped to meet the French physical protection regulations for category I irradiated material (see Fig. 16). AREVA TN continually qualifies and trains more than 150 drivers.

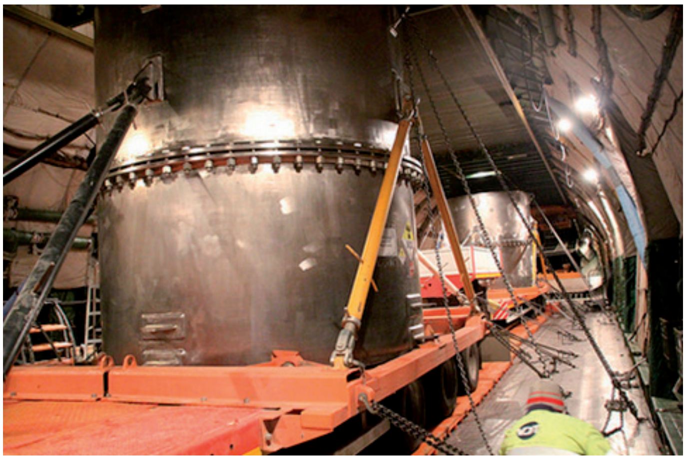


FIG. 15. Special purpose trailer used for ŠKODA VPVR/M and TUK-145/C packages.

FIG. 16. AREVA TN truck for SNF transport.

3.1.4. Transport selection considerations

During shipment preparation, a transport and technological scheme is developed and generally comprises of the following:

— Logistics (selection of route and transloading sites);
— Optimal technical solutions (transport modes, packages and transloading equipment);
— Legislative background (legal requirements);
— Determination of contractors (characteristics, responsibilities and work schedules).

The transport and technological scheme serves mainly to ensure maximum safety by assessing each shipment related procedure. In addition, the transport and technological scheme makes it possible for companies engaged in SNF dispatch, shipment and receipt to coordinate their actions to ensure the compatibility of transport modes and reloading equipment. The transport and technological scheme also serves as a basis for the detailed shipment cost estimation.

The transport route and mode options are selected together with the customer and main contractors. The basic selection criteria include the following:

— Geographical position of the research reactor and available transport infrastructure, including remoteness from the reprocessing facility's country borders, probable transit countries and access to the sea;
— Packages that can be used for the shipment and their technical characteristics;
— Costs according to different transport and technological schemes;
— Political expediency and customer requirements.

3.1.5. International conventions and agreements

While organizing research reactor SNF international shipments, important international conventions and requirements have to be followed by the participating States:

(a) Dual-use:
- United Nations Security Council resolution 1540 [51];
- For EU Member States: Council Regulation (EC) No. 428/2009 of 5 May 2009 setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items (Recast) [52].

(b) Physical protection:
- Convention on the Physical Protection of Nuclear Material [53].

(c) Safeguards:
- IAEA safeguards agreements and additional protocols[7];
- For EU Member States: Articles 77–85 of the Treaty establishing the European Atomic Energy Community (Euratom)[54];
- For EU Member States: Commission Regulation (Euratom) No. 302/2005 of 8 February 2005 on the application of Euratom safeguards [55].

(d) Safety:
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9].

(e) Emergency conventions:
- Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency [56];
- Convention on Early Notification of a Nuclear Accident [57].

(f) Third party nuclear damage liability:
- Vienna Convention on Civil Liability for Nuclear Damage [58];
- Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage [59];
- Convention on Third Party Liability in the Field of Nuclear Energy of 29th July 1960, as amended by the Additional Protocol of 28th January 1964 and by the Protocol of 16th November 1982 [60] (commonly known as the Paris Convention).

Specific requirements resulting from these conventions and agreements can differ from country to country, depending on their adherence to one or another legal instrument or on their geographical location. Bilateral agreements between the States involved (research reactor, reprocessing facility and transit countries if applicable) contain provisions regarding the applicable international legal instruments, as well as concrete specifications of the competent authorities and authorized organizations of the parties, their interactions and the point of the SNF ownership transfer. The research reactor is responsible for the shipment organization and bears the liability for the SNF up until this point. SNF ownership can be transferred at the border crossing of the reprocessing facility's country (for land shipments), at the departure or arrival airport or seaport (for air or sea shipments), or at the research reactor site in the case that the reprocessing facility takes full liability for the material from the departure point.

3.1.6. Shipment coalitions

Since the amounts of SNF produced as a result of research reactor operation or decommissioning can be comparatively small, its export by a single State or research reactor might not be economically feasible. In such a case, the research reactor operator might consider the possibility of forming a shipment coalition in order to optimize costs. This suggests grouping the SNF of several research reactors, even if they are in different countries. This can be achieved by preliminary fuel shipments to one site; that is, the research reactor, storage facility, railway station, or port or airport suitable for these purposes, from where the SNF is further transported to the reprocessing facility in a single shipment (by rail, water or air).

[7] See www.iaea.org/topics/safeguards-legal-framework

Such a shipment, for example, was arranged under the RRRFR Programme to remove fresh fuel originating from the Russian Federation from two Romanian research reactors in 2003. The organization structure of importing legal entities prior to 1989 made provisions for two storage locations of fresh fuel originating from the Russian Federation: at the VVR-S reactor in Magurele and at the TRIGA reactor in Piteşti. At that time, the most appropriate variant was first to deliver the fuel from the VVR-S research reactor to the TRIGA reactor and then to load all of the fuel into S-16 casks for a one-flight shipment to the Russian Federation. Engineering, administrative and transport support was provided by Sosny Research and Development Company specialists.

Research reactor operators from different countries can implement similar, combined export operations. A good example is the USDOE requirement to organize shipments from several participating countries into one sea shipment to the United States of America under the FRR SNF Acceptance Program. Engineering, administrative and transport support to coordinate the whole project and to provide research reactors with certain types of services can be arranged in the following ways:

— Selection of possible participants for a coalition with regard to prior experience in the transport of SNF from several countries, and similar research reactors with SNF suitable for export;
— Analysis and arrangement of a preparatory phase through development of a justification (feasibility study; strengths, weaknesses, opportunities, threats (SWOT) analysis) of each possible variant (packages, route and transport modes) for separate research reactors and a coalition as a whole;
— Development of government–to–government agreements to establish the general legal cooperation procedures and requirements of the participating States;
— Facilitation of licensing through development of a combined initial certificate of approval for package design and shipment for a coalition; and licensing support for each member of the coalition and for transit countries;
— Improvement of transport and technology with regard to the needs of each member of the coalition and the requirements for the formed consignment;
— Selection of licensed carriers, management of technical contracts with all of the carriers involved and licensing support for them.

When forming a research reactor coalition, the key criterion is the optimization of the project costs and the technical feasibility. Thus, the research reactor SNF amount for one shipment is to be calculated so that the maximum number of packages is transported in a single shipment by rail, water or air, considering the technical capabilities of the given transport mode and the restrictions of the regulations for the safe transport of radioactive material. Based on the specific calculation, the optimal number of coalition members can be determined.

The cost of each shipment to the collecting point, as well as the cost of the shipment to the reprocessing facility can vary significantly, depending on the location of the coalition members. However, the costs of the shipment from the collecting point to the reprocessing facility can be significantly reduced for each coalition member by sharing these costs.

3.2. ENGINEERING SUPPORT FOR PROJECT PREPARATION AND IMPLEMENTATION

3.2.1. Feasibility studies

The services relating to engineering support described in Section 3.1 will generally be more effective if presented in the form of a feasibility study at the earliest stages. Feasibility studies, offered by the providers of engineering support services, provide justified solutions to issues such as the following:

— Feasibility of reprocessing types of fuel not included in the plant's authorized SNF range;
— Development of a transport and technological scheme for separate research reactors or a coalition;
— Licensing and risk assessment of complex routes that include different variants for transit countries or for combined shipments;
— Final disposition of radioactive waste resulting from SNF reprocessing (e.g. disposition in the Russian Federation or return to the export country).

The contents of a feasibility study are developed together with a research reactor or a coalition and are based on the engineering support provider's proposals, with account taken of previous experience. The aim is to reflect all of the most important questions that require solutions when arranging a shipment. A feasibility study could, for example, include the following:

— Definition of the scope of the operation (i.e. the disposition of the research reactor SNF);
— Description of the SNF content (type) and inventories for disposition;
— Evaluation of disposition alternatives;
— Selection of disposition service provider;
— Transport considerations to transfer the research reactor SNF to the disposition service provider;
— Development of a transport and technological scheme for separate research reactors or a coalition;
— Safety basis considerations in transport and disposition;
— Radiation protection (shielding/dose) considerations;
— Licensing considerations;
— Security and safeguards plan;
— Risk management plan;
— Assessment of facility modifications;
— Design and development of handling equipment;
— Transport operations and implementation plan;
— Final disposition of radioactive waste resulting from SNF reprocessing;
— Cost considerations.

3.2.2. Contracting support

The engineering support offered by the service providers permits the project on a turnkey basis. An example of a contract flow chart applied for a Serbian research reactor SNF shipment to the Russian Federation under the RRRFR Programme is shown in Fig. 17. This contract flow chart is based on a trilateral agreement (contract), concluded by a funding authority (e.g. IAEA, European Bank for Reconstruction and Development, and ministerial departments in charge of funding in the export countries), a research reactor or institute and a project coordinator responsible for technical support. Such a variant can also be applicable in a bilateral agreement if the research institute provides its own financing with no external parties involved, or in a multilateral or consortium agreement for a coalition. The principal decisions on project implementation are made at this level. In addition, general supervision and coordination are performed. An FTC between the consignor (owner of the research reactor SNF) and the authorized consignee (reprocessing plant) is then concluded. Other contracts can be supported by the

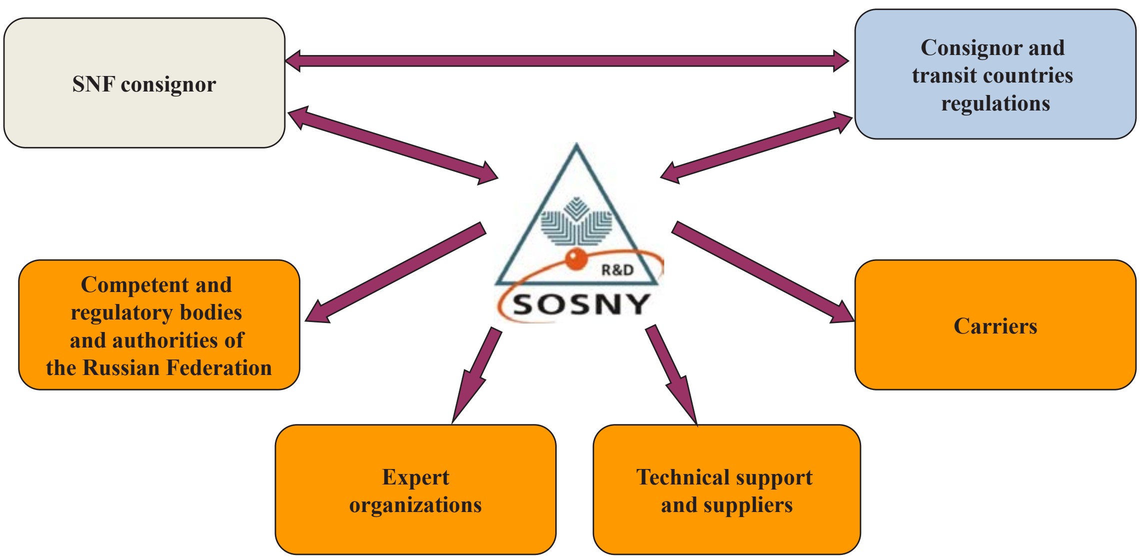


FIG. 17. An example of a contract flow chart implemented during Serbian SNF removal to the Russian Federation.

project coordinator. When implemented, the flow chart in Fig. 17 results in a high quality of work performance, compliance with regulatory requirements and high efficiency at all stages.

3.2.3. Licensing support

According to IAEA transport regulations [61], SNF is transported in Type B(U)F or Type C packages (for fissile material), which require multilateral approval of package design and shipment. In compliance with the applicable requirements, the first certificate of approval for package design and shipment is the certificate issued by the country of the owner of the package (initial country).

After the first certificate of approval is issued by the initial country, its multilateral approval can take place in all other countries simultaneously (i.e. the import, export and transit countries). This process is carried out in conformity with the legislation of the countries involved. Although the basis of the national legislation is usually the IAEA transport regulations [61], the procedures for receiving the approvals differ from country to country.

For international licensing, the competent authorities and regulatory bodies can be provided with safety analysis reports that the initial country developed as support documentation to issue the first certificate. These reports are prepared in conformity with the requirements of the IAEA transport regulations [61] and the regulations of the initial countries. The safety of package design and shipment are justified using certified, up to date software when performing strength, thermal, nuclear and radiation analyses, both in normal and emergency conditions of transport. Shipment of damaged SNF demands additional fire and explosion safety analysis. Newly designed packages can undergo testing, including mock-up tests imitating the conditions specified in the IAEA transport regulations [61].

The specialists of the service providers can also facilitate the interaction with the competent authorities and regulatory bodies on approval of certificates and issue of shipment permits and approvals. For multilateral approval, the shipment coordinator facilitates the interaction of the research reactors' government and the competent authorities in the country of the reprocessing facility to questions arising from the independent safety analysis.

An efficient approach towards international licensing management was applied during the preparation of the research reactor SNF shipment from Serbia to the Russian Federation under IAEA coordination. This project was the most difficult among the other return projects of fuel originating in the Russian Federation. Its implementation required simultaneous usage of two packages (TUK-19, Russian Federation, and ŠKODA VPVR/M, Czech Republic), as well as three combined transport modes (road, rail and sea). The route ran through several countries: Serbia, Hungary, Slovenia and the Russian Federation (see Fig. 18).

For this transport route to be licensed, safety assessments had to take into account the specific requirements of each country through which the SNF would pass. The package design and shipment licensing procedure took about one year. The shipment was organized involving ten transport companies from the Czech Republic,

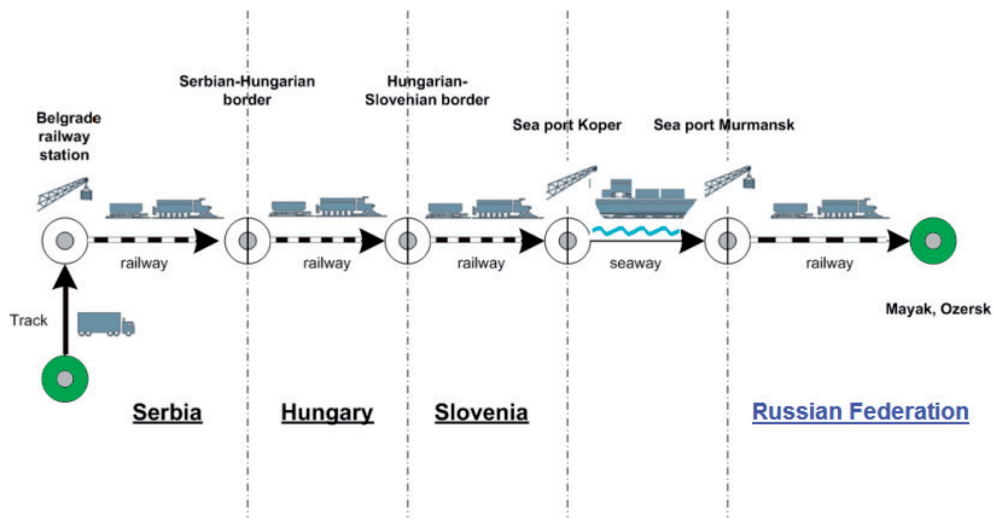


FIG. 18. Transport and technological scheme for the Serbian SNF shipment to the Russian Federation.

Denmark, Hungary, the Russian Federation, Serbia and Slovenia. The Sosny Research and Development Company was authorized to act on behalf of the research reactor owner (i.e. Public Company Nuclear Facilities of Serbia) during licensing in the transit countries Hungary and Slovenia (see Fig. 17) [62]. A coordinator of the contractors in the Russian Federation, it organized the shipment and controlled the compliance with the schedule of activities, including approval of certificates in the transit countries, shipment permits and approvals, licensing of radioactive material carriers in the corresponding countries, coordinating the companies and preparing consignment documents.

Similarly to the export country, licensing support in the transit country includes coherent interaction with the relevant competent authorities and regulatory bodies, efficient communication, quick safety document transfer, and compliance with regulatory requirements for timely receipt of all necessary permits and licences.

International shipments in transit in EU Member States need to comply with Council Directive 2006/117/Euratom on the supervision and control of shipments of radioactive waste and spent fuel [63]. The objective of the directive is to standardize the procedures and to facilitate the process of receiving authorizations for international shipments of SNF and radioactive waste at the European level. Compliance with the directive suggests that the first transit EU Member State is responsible for the coordination of the whole process of information, authorization and distribution in the rest of the transit countries by means of standard documentation and an established procedure.

For the validation of certificates of the Russian Federation in other countries, the Sosny Research and Development Company develops applications and package safety analysis reports based on the initial licensing documents and in compliance with the transit countries' regulations.[8]

SNF can be transported to the reprocessing facility in foreign designed packages. In the past, owing to the necessity to speed up the RRRFR Programme and to facilitate the shipment preparation procedure in the export country, the possibility of using Czech and German designed packages for SNF shipments to the Russian Federation was explored. The Czech issued certificate of approval for the ŠKODA VPVR/M package design and the German issued certificate of approval for the CASTOR MTR2 package design, intended to transport research reactor SFAs, were approved in the Russian Federation for the specified purposes (see Fig. 19).

As the certification process involves the participation of multiple organizations (manufacturer, research reactors, reprocessing facility, carriers, expert organizations, competent authorities and regulatory bodies), the issuance of certificates of approval for a foreign design package and shipment requires comprehensive coordination — including preparation of the necessary initial data, to expert support during the certificate concurrence and approval. The coordination facilitated by a service provider allows the unification and optimization of the costs and schedule.

(a) (b)

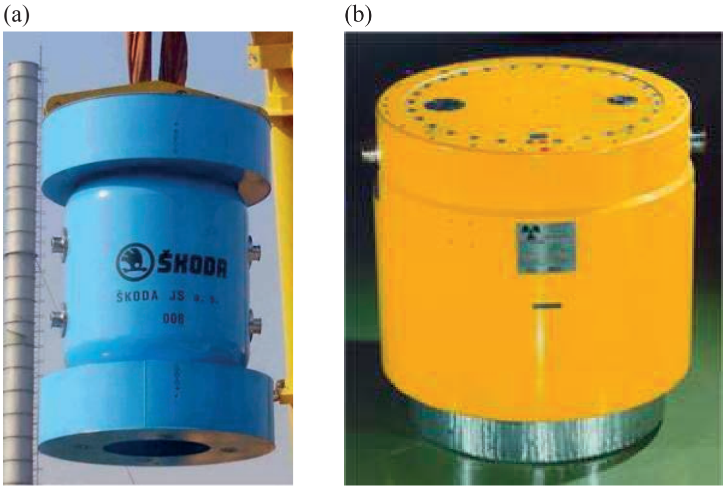


FIG. 19. (a) ŠKODA VPVR/M package; (b) CASTOR MTR2 package.

[8] For example, see https://ec.europa.eu/energy/sites/ener/files/documents/20131018_trm_technical_guide.pdf

3.2.4. Support for research reactor facility preparation

Upon SNF receipt, the reprocessing facility is governed by the applicable regulatory documents (in particular, nuclear material safeguards procedures), as well as by the requirements of the on-site SNF handling technology. The reprocessing facility provides the research reactor with a number of conditions necessary to ensure SNF acceptance:

- The reprocessing facility's concurrence of the necessity and the methods for SNF preparation (repackaging into canisters, marking, cutting into fragments, and removing the old packaging and foreign objects);
- The reprocessing facility's concurrence of the methods to develop an SNF inventory;
- Preparation of the description of the SNF inventory items (SFAs and canisters with SNF), SNF passports and a total inventory list;
- SNF inspection at the research reactor site with the support of, and in the presence of, the reprocessing facility's representatives;
- Access of the reprocessing facility's representatives to the research reactor site during SNF preparation, loading into packages and the preparation of the documents accompanying the consignment.

Authorized representatives of the reprocessing facility can participate in the activities intended to meet the requirements specified above. In order to plan the work at the research reactor site, it is important to first decide on how to prepare the SNF for shipment. The aspects in Sections 3.2.4.1–3.2.4.3 can be taken into consideration.

3.2.4.1. Availability and specifications of the packages in which the SNF is stored at the research reactor site

The question is whether such a package is appropriate for safe shipment and should it be removed. Furthermore, the influence of the package parameters on the reprocessing technological process and its costs should be taken into consideration. For example, the presence of certain materials (i.e. aluminium, graphite and neutron absorbers) can complicate and increase the cost of reprocessing; there are also requirements for package material strength (which are determined by the specifications of the fuel cutting equipment before dissolution). Thus in some cases, the SNF package is to be removed, whereas sometimes it is more reasonable to deliver the SNF in the existing package.

3.2.4.2. Quantity and dimensions of spent fuel assemblies

The necessity of SFA preparation (e.g. removing constructive parts and repackaging) could be required for a more compact load to minimize the number of packages and shipments.

3.2.4.3. The SNF state

It is necessary to determine whether the SFAs are leaktight (no damage resulting in unacceptable leaks), properly and legibly marked, and whether there is any damage to the load gripping elements or significant geometrical deviations from the design. It can sometimes be more efficient to develop new SNF canisters which can allow the fulfilment of several reprocessing facility requirements at the same time. If an SNF inventory item is not leaktight (the fuel composition is in contact with the pool water), a decision on the necessity to ensure leaktightness (by way of loading into leaktight canisters) needs to be made together with the reprocessing facility, with account taken of the actual rate of radioactive substance emission into the pool water.

To meet the reprocessing facility's requirements for the SNF state and characteristics, SFAs attestation is usually performed in two stages. The first stage is concurrence of the methods used by the research reactor to determine the SNF data (e.g. calculations to determine the uranium and plutonium contents, fuel burnup, heat and activity, and leaktightness) with the reprocessing facility. The second is the assessment by the reprocessing facility of the available operating documents on SNF handling and storage, as well as to SNF inspection.

Based on the inspection results, the SNF inventory and the possibility of SNF delivery to the reprocessing plant are then confirmed. The received information is used to assess the shipment and reprocessing safety and the environmental risks, and to estimate the cost of work.

The following SNF preparation activities can be required:

(a) The design of a new SNF package, canister or basket is developed. The safety of the package is assessed, including nuclear and radiation safety, explosion and fire safety, strength analysis, thermal regimes and containment (see Fig. 20).
(b) The technology and equipment for SNF preparation (e.g. repackaging, marking, cutting into fragments, removing foreign objects, and restoring load gripping devices) are developed. The SNF preparation technology is agreed with the reprocessing facility.
(c) The technology and equipment to handle the packaging at the reprocessing facility site are developed and agreed upon with the package owner (receipt, handling, unloading and decontamination).
(d) The design of the research reactor site infrastructure modifications is prepared if this is necessary to ensure safe SNF preparation and loading into the packages. The infrastructure modifications may involve preparation of working areas (clearing the space, providing lines of water, compressed air and power supply) and safety barriers, installation of lifting devices of the corresponding capacity, assessment (and strengthening, if needed) of the building structure from the perspective of allowable loads in the course of package handling, repairs of active ventilation and sewerage, radiation monitoring and power supply systems, and even construction of new major objects, such as premises for package handling, new pools for SNF repackaging and hot cells. For example, to handle SNF packages at the Serbian research reactor, the optimal solution was to use a rail trolley and a forklift, whereas at the Ukrainian research reactor, it was necessary to build new premises with a new SNF pool attached to the reactor building.
(e) All of the actions necessary to receive regulatory approvals for SNF preparation and package handling at the research reactor are taken. The procedure is established by the State's legislation and usually includes: a detailed safety analysis containing anticipated dose rates for the personnel and radioactive substance releases into the environment; assurance of the quality of the fabricated equipment and of the modifications made on-site; and assurance of appropriate personnel training.
(f) New SNF preparation and package handling equipment is fabricated and delivered to the research reactor and the reprocessing facility. The equipment is installed, adjusted and tested as a whole complex to confirm its operability and safety.
(g) Operating procedures (including those on emergency response) are developed.
(h) The personnel engaged in SNF preparation and package handling is trained. In general, training includes both theoretical familiarization of the personnel with technologies and principles of equipment operation and practical training. Special attention is paid to safety related issues of work performance, including the actions to be taken if incidents or accidents occur. Based on the results of the training, the personnel is authorized for work.
(i) Actual work implementation (e.g. SNF preparation, loading and transport).
(j) Preparation of the accompanying documentation for the SNF shipment. This is performed in compliance with the national requirements of the export and import States, and with international regulations. The accompanying documentation includes passports for inventory items and packages with SNF, package leak test reports, radiation survey certificates, accompanying notes and customs documents.

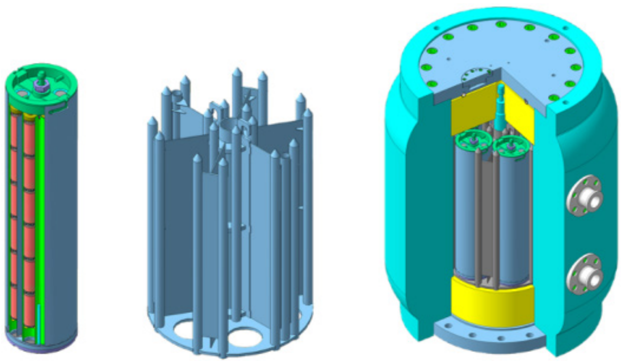


FIG. 20. Canister TC2 and basket TC3, used to load the SNF of the Vinča Institute of Nuclear Sciences, Serbia, into ŠKODA VPVR/M packages.

(k) In general, issues such as SNF preparation for shipment to a reprocessing facility, the selection of a package for shipment and logistics are considered together in order to determine the best concept that will allow implementing the project within a reasonable period of time and with minimal financial expenses.

3.2.5. Shipment support

3.2.5.1. Support for shipments to the Russian Federation

An independent, experienced Russian organization providing technical support can develop an optimal transport and technological scheme for a research institute or authorities of the Russian Federation. Its development will involve innovative solutions that will further be supported with scientific and research work, necessary to implement these solutions. The following are examples of the experience gained:

(a) In the course of implementation of the RRRFR Programme, research reactor SNF air shipment was developed. The organization responsible for technical support implemented different tasks, including:
  - Development of ISO containers and tie-downs to place and fix the TUK-19 packages in compliance with the air shipment standards and technical capabilities of an aircraft;
  - Assistance in preparation and issuance of the first certificate of approval for package design and shipment of research reactor SNF in Type B(U) packages by air in accordance with the new requirements of Ref. [64];
  - Development of technology;
  - Safety assurance and preparation of transport documentation.

(b) Technical support and development of safety related documentation for carriers and seaport operators during first licensing of the Russian port of Kavkaz for Class 7 dangerous goods transport (see Fig. 21).
(c) The design of refitting sea vessels in compliance with the requirements for Class 7 dangerous goods and SNF shipments.
(d) Development of the first Type C package for air shipment of research reactor SNF with no limitations on activity.
(e) Development of comprehensive radiation risk assessments of different transport technological schemes.
(f) General management and support of all carriers and shipments from the research reactor to the final destination point.
(g) Preparation of transport documentation.

FIG. 21. First shipment of Class 7 dangerous goods by Anship LLC's ferry over the Black Sea from the port of Kavkaz (empty TUK-19 casks, UN 2907).

3.2.5.2. Support for shipments to France

AREVA TN designed and owns and manages several terminals in France for the transfer of heavy casks between road, rail or sea transport flows. It ensures all maintenance operations for safe and secure handling equipment. It also performs all on-site radiological inspections of the casks and the transport means before shipment, such as dose rate and non-contamination measurements. AREVA TN provides the following shipment support:

(a) Risk management and regulatory experience: It provides both technical and administrative services to ensure that all transport operations are carried out safely, securely and in full compliance with regulations.
(b) Regulatory compliance: It is involved in all international organizations that establish transport regulations (IAEA, International Maritime Organization, and Organisation for Economic Co-operation and Development) and best practices (World Nuclear Association, and World Nuclear Transport Institute). Regulatory changes are thus anticipated, making certain that all products and services are ready to meet the many complex and strict regulations.
(c) Transport risk management: It developed a specific methodology for transport risk management and has proven skills in analysing and managing transport risks.
(d) Tracking shipments in real time: The AREVA TN centre manages and coordinates all shipments. It also ensures shipment tracking which guarantees that all unscheduled situations are identified in a timely manner, that alerts are sounded when necessary, and that corrective actions are proposed and implemented. In the case of a transport crisis, it is immediately staffed with experts to provide real time support.
(e) Hotline 24/7: Any shipment participants can contact AREVA TN at any time in case of unplanned situations, for example during cask operations or during transport. Its experts are immediately available to solve the issue.
(f) Emergency response planning: To deal with any incidents or accidents during the shipment, its emergency response plan covers the alert, situation assessment and response phases in the field, with specialized personnel and equipment on a 24/7 basis. Several crisis exercises with various stakeholders are performed each year to keep the team trained.

3.2.6. Support for post-shipment activities

If the radioactive waste is to be kept in the Russian Federation, the research reactor exporting the SNF will not participate in post-shipment activities. In the case that the radioactive waste is returned to the export country, the shipment can be technically supported in the same way as was described above. To date, no radioactive waste resulting from reprocessing research reactor SNF in the Russian Federation has been returned to the export countries that shipped the SNF. If this were necessary, new packages, development of a transport and technological scheme, and safety assurance, corresponding to the regulations in force at the moment of the shipment, may be required. The cost of shipment to return radioactive waste to the border of the Russian Federation is included in a radioactive waste return FTC, and the receiving party, to whom the radioactive waste is returned (research reactor or radioactive waste management agency), organizes the remaining part of the shipment from the border of the Russian Federation to the final destination.

According to French legislation, radioactive waste remaining after reprocessing of foreign SNF has be sent out of France (usually back to the country where the fuel was irradiated). AREVA regularly performs radioactive waste shipments to the countries of origin and provides support for these activities. UC-V/U and UC-C are standardized waste forms: safe, stable, compact forms, ready for highly reliable, long term storage before being placed in a final repository. They are guaranteed for extended periods of time (>300 years) when appropriately stored.

Concerning AREVA's experience of handling such products, more than 700 UC-Vs and more than 1400 UC-Cs are produced each year. By the end of 2013, more than 13 000 UC-V/Us had been produced. The production of UC-V/Us and UC-Cs is in accordance with a stringent quality management system, with a constant focus on quality at all stages of the production and validation of the quality system by a third party audit.

UC-V/U and UC-C allocation relies on internationally accepted specifications (such as in Australia, Belgium, Germany, Japan, Netherlands, Spain, Switzerland and United Kingdom; the process is ongoing in Italy). UC-V/U returns started in 1995. By the end of 2015, more than 5200 UC-V/Us had been returned to their countries of origin.

UC-V/U handling is an activity that benefits from internationally shared experience. This activity, from production to return to the country of origin, is performed by AREVA on a routine basis.

3.2.7. Project cost distribution

The distribution of costs in research reactor SNF shipment projects strictly depends on the specifics of each project, for example the amount and technical condition of the SNF, the type of cask used, transport modes and specific routes. The main project activities for a research reactor SNF shipment to the Russian Federation is as follows (including the cost distribution):

- Shipment preparation (6%): Evaluation of costs, contract preparation, insurance and customs;
- Environmental safety (17%): Preparation and implementation of SEPs for rehabilitation of contaminated areas and other procedures required for the import of SNF;
- Technical documentation preparation (8%): Safety analyses, transport and technological scheme, special requirements for air shipment, technical specifications for SNF import, procedures and manuals for equipment operation;
- R&D of new technologies and equipment (4%): Development of technology for loading the SNF into packages and of means for transporting the packages by the corresponding conveyances (special freight containers and fixing system);
- Project management (1%);
- Fabrication or acquisition of new equipment (12%);
- Radioactive waste management (9%): At FSUE Mayak PA and final disposal in the Russian Federation;
- Authorization (10%): In the Russian Federation, the export country and transit countries of the package design and shipment, of all of the equipment, and of operations involving SNF handling for the research reactor operators and carriers;
- Operations with SNF (14%): Including inspections, loading into packages at the research reactor, reprocessing and interim storage at FSUE Mayak PA;
- Shipment of SNF (19%): From the research reactor site, empty packaging delivery and return of spare parts and auxiliary equipment for package handling to the owner.

3.3. ENGINEERING SUPPORT PROVIDERS

The available engineering support providers and their services, according to defined categories, are summarized in Table 6, and their characteristic features are presented in the following subsections.

TABLE 6. SUMMARY OF ENGINEERING SUPPORT PROVIDERS

	Contractors from				
	Russian Federation	France	Germany	Czech Republic	USA
Support of the preparatory phase of the decision in the reprocessing country	Yes	Yes	No	No	No
Contracting support in the reprocessing country	Yes	Yes	No	No	No
Licensing support	Yes	Yes	Yes	Yes	Yes
Support for research reactor facility preparation	Yes	Yes	Yes	Yes	Yes
Shipment support	Yes	Yes	Yes	Yes	Yes
Support for post-shipment activities	Yes	Yes	Yes	Yes	Yes

3.3.1. Russian Federation

Russian contractors who provide logistical support have significant experience in developing similar projects under international programmes. Particular attention is paid to the following aspects:

(a) Technical expert and engineering support at the preparatory phase:
- Assessment of the required safety and physical protection level;
- Assessment and selection of the best route, transport modes and equipment;
- Inspection, accountability and repackaging of the fuel;
- Emergency preparedness.

(b) Research and engineering support of the project tasks:
- Development of new technologies and improvement of existing ones;
- Development or upgrade of equipment;
- Technical document preparation (procedures and operation manuals);
- Training of operators.

(c) Management of enterprises and contractors of the Russian Federation:
- Provision of the most appropriate equipment;
- Scheduling cask usage;
- Logistics (carriers, ports and transport modes);
- Legal aspects of import (customs and insurance).

(d) Interactions between institutions of the Russian Federation and Government authorities:
- Development of a transport and technological scheme;
- Certificates of approval for package design and shipment;
- Licensing;
- Development of the unified project.

(e) Any kind of support and services required in the export country:
- Technical preparation at the research reactor site;
- Subcontractor management;
- Certification of package design and shipment;
- Licensing;
- General management of the project.

(f) Similar support for interaction with transit countries.

The scope of work offered by Russian organizations permits the project on a turnkey basis. The advantages of engaging the companies that specialize in such activities are general safety improvement, cost and schedule optimization.

3.3.1.1. Sosny Research and Development Company

The Sosny Research and Development Company was established in 1992 in Dimitrovgrad, Russian Federation, and its subdivisions are now located in Dimitrovgrad, Electrostal and Moscow. The company's main activities are focused on R&D in the field of nuclear energy. It began its development with deliveries of SFAs from nuclear power plants of the Russian Federation to the State Scientific Centre Research Institute of Atomic Reactors, Dimitrovgrad, for post-irradiation examinations, development of equipment, SNF research and analysis of the results. The company took part in the implementation of the RRRFR Programme under which research reactor fresh and spent fuel originating from the Russian Federation was returned to the Russian Federation from Belarus, Bulgaria, the Czech Republic, Germany, Hungary, Kazakhstan, Latvia, Libya, Poland, Romania, Serbia, Ukraine, Uzbekistan and Viet Nam. The role of the company in the RRRFR Programme is to develop technologies and equipment for SNF loading into packages, provide training services for research reactor operators on handling Russian packages and equipment, and prepare regulatory documents, including safety assessments. In support of SNF shipment organization projects, the Sosny Research and Development Company has provided many technical solutions:

— Foreign package certification in the Russian Federation (ŠKODA VPVR/M in 2005, CASTOR MTR2 in 2010) and FSUE Mayak PA technology adaptation for handling new packages;
— Development of an overpack for the TUK-19 package shipment by any conveyance, including air;
— Vessel modernization for research reactor SNF shipments;
— Development of transfer casks for SFA loading into 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 of radioactive material, by any conveyance, including air, with no restrictions on the radioactivity content.

The company specializes in solving non-standard tasks for SNF management from nuclear power plants, research reactors and propulsion reactors, for example:

— Liquidation of consequences resulting from the SFA destruction at the WWER-440 Paks nuclear power plant, Hungary;
— Preparation and transport of damaged SNF from the RA research reactor of the Vinča Institute, Serbia, to the Russian Federation;
— Research of options, feasibility study and shipment organization for the reprocessing of non-conforming RBMK-1000 SNF at FSUE Mayak PA;
— Research of options for the EGP-6 SNF removal from the Bilibino nuclear power plant, Russian Federation, to FSUE Mayak PA for reprocessing;
— AMB-100 and -200 research reactor SNF preparation for shipment from Beloyarsk nuclear power plant, Russian Federation, to FSUE Mayak PA;
— SNF removal from the Institute of Physics and Power Engineering site, Russian Federation, to FSUE Mayak PA.

The company currently offers the following services:

— Development and supply of equipment for nuclear power plants, research reactors, subcritical assemblies, nuclear fuel cycle facilities and radioactive waste management facilities, destined for the production, reprocessing and transport of nuclear fuel and radioactive material;
— Research and engineering services to operators of facilities involving handling and transport of nuclear material and radioactive substances;
— Safety assessments, development and obtaining certificates for conveyances and packages for radioactive material (including that of foreign origin) in the Russian Federation, and those originating from the Russian Federation in other countries.

The company's staff includes research, safety analysis, and design and process engineers with experience in SNF R&D of unique nuclear equipment and radioactive material. The management system is evaluated and certified by the National Quality Assurance Limited for compliance with the necessary ISO standards.

The company has all of the necessary licences for the development of equipment for the safe preparation, shipment and radiochemical reprocessing of research reactor SNF, including packages and means of transport, and for the organization of radioactive material shipments.

3.3.1.2. J/S ASPOL Baltic Corporation

The J/S ASPOL Baltic Corporation transports a wide range of fresh and spent nuclear fuel with its fleet of re-fitted sea and river vessels. Its first transport of such material was successfully implemented in 2008 with the management of the USDOE and the Idaho National Laboratory under the RRRFR Programme. Since then, the company has transported cargo to and from European ports (Belgium, France, Germany, Netherlands, Poland, Sweden and United Kingdom) as well as US ports with Class 7 material on board, including HEU SNF.

Under the management of the USDOE, the corporation arranged the use of the northern route for the return of INF-2 cargo originating from the Russian Federation from various European ports to the port of Murmansk on a regular basis using the infrastructure of the J/S Atomflot. At the beginning of 2013, it completed a shipment of research reactor SNF from the Czech Republic via the port of Gdynia, Poland. Later in the year and working for customers from the Czech Republic and the United States of America, it shipped Class 7 cargo from the port of Koper, Slovenia, to the port of Vung Tau, Viet Nam, via the Suez Canal. It has also re-opened the northern sea route, successfully completing the return voyage of cargo in the Viet Nam HEU repatriation project, from the port of Vung Tau to the port of Szczecin, Poland, via the Bering Strait and northern seas. The corporation thus showed that the northern sea route could be used for shipments of different cargo, not only under the RRRFR Programme but also under other shipment programmes.

Its new transport scheme was developed to meet all necessary criteria for the safe transport of dangerous goods. The corporation has participated in INF-2 cargo transport all over the world, including:

- Russian Federation: Baltic Sea, North Sea, Norwegian Sea, Barents Sea, Red Sea, Black Sea, Caspian Sea, Volga–Don Shipping Canal, Volga–Baltic Waterway and White Sea–Baltic Canal.
- Danube River: It is currently exploring the possibility of reaching the premises of the Paks nuclear power plant and other destinations located in the Danube River Basin subject to permission from the Hungarian Atomic Energy Authority and other competent authorities, as well as in close cooperation with the IAEA.
- West European ports (France, Germany and United Kingdom) sailing from the Russian Federation through the Kiel Canal and the Skagerrak Strait.
- United States of America: The positive experience of UF-6 cargoes and the other Class 7 material using the different ports located on the east coast (Charleston, New Orleans and Wilmington) with the possibility to call at any other US ports.
- Great Lakes of Canada and the United States of America (Erie, Huron, Michigan, Ontario and Superior) across the Atlantic Ocean.
- Mediterranean Sea and Red Sea destinations with passage through the Suez Canal.

Presently, the Corporation has a fleet of three vessels with the following characteristics:

- Sea–river class, which allows sailing all over the world, with all major seas as well as main rivers suitable for navigation;
- The capability of approaching as close as possible to the goods storage places for safe loading and to eliminate additional cargo trans-shipment efforts;
- The possibility of transporting cargo not only on the traditional sea-going routes but also on newly developed routes on request from customers.

3.3.1.3. Volga-Dnepr Airlines

Founded in 1990, Volga-Dnepr Airlines has supported peacekeeping operations in Africa, Asia, Europe and the Middle East. In addition to governmental and humanitarian flights, it is involved in commercial flights worldwide, supporting aerospace, aviation, and oil and gas exploration, as well as automotive, energetics and heavy equipment manufacturers. It has been primarily involved in the air transport of dangerous goods, with experience in Class 7 fissile nuclear material including SNF — more than 690 flights between 1996 and 2016. Volga-Dnepr Airlines has the following certificates and licences:

(a) Operator certificate: The basic document issued by the State aviation authorities, confirming that the airline can perform domestic and international flights of cargo aircraft, and transport goods, including dangerous goods (all classes of dangerous goods, including Class 7 fissile nuclear material).
(b) Licence of Rostechnadzor for handling nuclear material and radioactive substances during transport: Sanitary–epidemiological certificates have been issued for all cargo aircraft, which allows transport of radioactive material on any of the company's aircraft.
(c) Certificate of compliance for aircraft maintenance.
(d) Certificate of compliance for organizational support of commercial air transport, which allows the following:
    - Obtaining permission from the aviation authorities of the Russian Federation and other States to perform flights (landing and overflight) for foreign carriers and those of the Russian Federation;

— Organizing aircraft maintenance of Russian and foreign carriers at landing airports (return flights);
— Tracking aircraft position.

(e) Certificate of compliance for providing cargo maintenance (including dangerous cargo) at the Ulyanovsk Vostochny airport for domestic and international air transport.

(f) Licence to perform space activities (namely the transport of space technology and rocket fuel components).

According to the aviation safety requirements for the transport of dangerous goods, the aircraft captains, loadmasters and senior engineers (technicians) require certificates to authorize conducting activities in the atomic energy field for flight and technical staff, and for ground handling operations of dangerous goods. At the aviation training centre, a simulator of the AN-124-100 aircraft allows flight staff training and modelling of any airfield, adverse weather conditions and possible technical failures during flight operations.

The air transport operations centre performs daily, non-stop aircraft traffic monitoring. When interacting with the airport security services for the transport of dangerous goods, the necessary set of measures aimed at the physical protection of special cargo from the moment of its arrival at the airport until the departure of the aircraft is provided. Before being transported, any cargo goes through the technical expert assessment performed by the load planning specialists to determine the aircraft able to transport the cargo, options for the type of special loading equipment required for loading and unloading, as well as recommendations for safe transport. The TUK-145/C aircraft transport project performed at the request of the Sosny Research and Development Company is an example of such an assessment.

3.3.2. France

3.3.2.1. AREVA TN

AREVA TN has over 50 years of experience in the design, manufacture and deployment of packaging systems for nuclear front end and back end transports, including research reactor fuel assemblies. Its main activity is to design, manufacture and deploy packaging systems for nuclear material for both nuclear power plants and research reactors. The logistics business unit has acquired significant experience in designing nuclear packages and transporting nuclear material, and has a combined resource pool of 800 experts in various transport disciplines. AREVA operates the largest fleet of transport casks and organizes more than 3000 multimodal shipments of nuclear material each year; more than 70 shipments are in progress at any given time. AREVA's logistics business unit has extensive experience with the transport of irradiated research reactor fuel elements (e.g. TRIGA, MTR and DIDO), for which the TN-MTR cask is often used.

Among other packages, the TN-MTR, were used for the FRR SNF Acceptance Program to transport nuclear fuel to the Idaho National Laboratory and the Savannah River Site, United States of America, from countries all over the world (including Austria, Denmark, Indonesia, Japan, Netherlands and Portugal) as well as to the AREVA La Hague reprocessing plant (from Australia, Belgium and France). AREVA TN also transports irradiated targets, irradiated fuel pins and irradiated hardware to hot cells and other research facilities using the smaller TN-106 cask. It has extensive experience with shipments of unirradiated uranium, both LEU and HEU shipments, using TN-BGC1 packages. This includes a shipment of LEU and HEU from the USDOE/National Nuclear Security Administration (NNSA) Y-12 site in Oak Ridge to France, and the shipment of fresh MTR and TRIGA fuel elements and radioisotope production targets from France to numerous countries, including Australia, Indonesia, Japan, the Netherlands, Norway, South Africa, Sweden and the United States of America. Guibert [65] reports that (see also Section I.8):

> "[It] operates a comprehensive fleet of licensed packages for a wide spectrum of radioactive material shipments worldwide. Some of AREVA's licensed packages, such as the TN-106 or the TN-MTR are dedicated to the shipments of irradiated material or used fuel from research reactors."

3.3.3. Germany

3.3.3.1. DAHER–NCS

Located in Hanau, Germany, DAHER–NCS is a freight forwarder specialized in the transport of radioactive material and all related services for nuclear power plants, fuel manufacturers, enrichment and irradiation facilities and hospitals, research centres and waste treatment facilities. It plays a significant role in the worldwide return of MTR and TRIGA SNF, as well as of HEU and plutonium material to the Russian Federation and the United States of America. It has its own fleet of vehicles, with the possibility of carrying all common ISO containers, as well as platform trailers and tarp covered trailers. The ordinary vehicles and trailers are equipped according to the ADR regulations and are capable of shipping category II (irradiated) or category III material. In addition, it can organize unirradiated categories I and II material shipments by road using its own armoured vehicles. Specialized tractors (up to a capacity of 330 t) and the necessary escort vehicles are available. All drivers are trained in the transport of Class 7 material and have ADR licence security clearance from the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS).

DAHER–NCS possesses the following packages and transport containers: open hardtop ISO containers with a stainless steel floor (IP-2); Type A, AF, B(U) and B(U)F packages. For the transport of irradiated material to and from research facilities, it can provide the packages TN 7/2, GNS 16 and NCS 45.

In addition to transport services, it provides engineering and construction services (e.g. handling, development, and complete design and production of Type B(U)F packages) and provides technical support for the necessary approval and validation procedures of transport packages. Its quality assurance programme is certified according to the necessary ISO and German standards.

3.3.4. Czech Republic

3.3.4.1. ÚJV Řež, a.s.

ÚJV Řež, a.s. is an engineering and research company in the area of applied research. It operates in the field of nuclear power plant safety, areas relating to lifetime extension of nuclear power plants, material research and monitoring, and the qualification of equipment. Its current focus is on the development and manufacture of radiopharmaceuticals, in particular positron emission tomography radiopharmaceuticals. It offers radioactive and non-radioactive waste management projects, with a focus on the service period and the back end of the nuclear power plant fuel cycle, and participates in various projects in the area of the development of new types of nuclear reactor.

It has participated in research reactor SNF shipments within the RRRFR Programme under the GTRI from the very beginning of the programme. The Czech Republic is the second SNF shipping country under the RRRFR Programme (after Uzbekistan), and the pilot country using the ŠKODA VPVR/M cask. It has participated in research reactor SNF shipments from eight countries (Belarus, Bulgaria, Czech Republic, Hungary, Poland, Serbia, Ukraine and Viet Nam) to the Russian Federation using the ŠKODA VPVR/M transport packaging system (TPS). Thirteen successful shipments using a total of 106 casks have already been completed without incident or accident. In the future, the ŠKODA VPVR/M TPS will be used in the project for the repatriation of irradiated HEU from Chinese miniature neutron source reactors. Svoboda et. al [66] report that:

> "The ŠKODA VPVR/M cask [see Fig. 19 in Section 3.2.3.] is a type B(U) and S cask system designed and licensed for the transport and storage of SNF from research reactors of Russian origin.
>
> "The unique design of the cask allows for easy use at almost any research reactor facility. The cask is closed by means of a system of two upper and two lower lids. The cask is loaded from the bottom, being placed above the SNF storage pool. It eliminates the need for a transfer cask, thereby reducing the number of manipulations and increasing the level of nuclear safety and radiation protection. The cask has a capacity of 36 FAs, and 16 casks are now available. This means that 576 FAs can be transported in one shipment."

Special equipment for the SNF loading from the top at a facility, which does not allow for the disposition of the cask on the storage pool was designed and developed by the Sosny Research and Development Company. The use of this cask has reduced the number of research reactor SNF transports and has accelerated the schedule of the RRRFR Programme. The ŠKODA VPVR/M TPS can be used not only for road, rail and water transport but also for air transport within the energy absorption container forming the TUK-145/C Type C package developed by the Sosny Research and Development Company.

The services of ÚJV Řež, a.s. in the field of SNF management include the following:

— Design, development and fabrication of equipment for SNF handling, including hot cell facilities;
— SNF inspection, handling and repackaging;
— ŠKODA VPVR/M TPS leasing, providing service and maintenance inspections of the TPS, transport and documentation;
— TPS modification according to the user's needs (in cooperation with the TPS manufacturer);
— Support for development and approval of licences and certificates for shipment authorization;
— Instructions, recommendations and modifications for TPS acceptance at reactor facilities; preparation and review of user cask handling operational procedures;
— Project management of SNF shipment preparation and performance;
— Demonstration of procedures and training of personnel in cask handling and SNF loading;
— Technical oversight and expert supervision during cask handling and SNF loading;
— Cask closing and sealing, drying and helium leak testing.

It implements and continually upgrades its integrated management system to the necessary ISO standards. Since 1998, TÜV NORD Czech, an independent certification agency has performed extensive management system audits.

3.3.4.2. DMS s.r.o.

DMS s.r.o. was established in 1993 and has focused on dangerous goods transport of Class 7 radioactive substances, performing the majority of the transport of nuclear material in the Czech Republic since 1995. Since 2011, it has also performed all of the transport of fresh nuclear fuel in Slovakia, and it became a member of the ALTA Group in 2012. DMS provides services in the field of transport of all forms of radioactive material, including the following:

— Fresh nuclear fuel for power, research and training reactors in the Czech Republic and Slovakia;
— Other nuclear material including uranium concentrate;
— Radioactive waste from nuclear power plants and nuclear research institutes;
— Other radioactive substances from the lowest to the highest activities.

It arranges and performs transport by any mode and in various combinations (road, rail, air and sea) in compliance with the IMDG Code [40], RID [45], ADR [49] and the Dangerous Goods Regulations [67]. It cooperates with leading carriers, the police and organizations in various countries, and has fulfilled the following tasks under the RRRFR Programme:

— Road transport of high enriched fresh nuclear fuel in categories I and II;
— Logistics of empty cask sets and service equipment for research reactors for Belarus, Bulgaria, the Czech Republic, Hungary, Poland, Romania, Serbia, Ukraine and Viet Nam;
— Processing authorization for transport, complex arrangement and performance of road and rail transport, physical protection, radiation protection and emergency preparedness during transport of research reactor SNF from ÚJV Řež, a.s. to the Russian Federation through the Czech Republic and Slovakia (2007), and the Czech Republic and Poland (2013);
— Road transport of research reactor SNF for shipments from Hungary (2008 and 2013);
— Transport of SNF under the RRRFR Programme in ŠKODA VPVR/M and TUK-145/C packages.

DMS s.r.o. has established and certified a quality management system according to ISO standards, and employs experts in the field of radioactive substance transport, nuclear material handling, radiation protection, emergency preparedness and physical protection, as well as driver specialists. In addition to the Czech Republic and Slovakia, DMS has received authorizations for the transport and handling of nuclear material and radioactive substances in Germany and Sweden, and is certified by the Czech Republic to work with information at the Secret level.

It owns a fleet of vehicles suitable for transport of cargo up to a total weight of 30 t per vehicle and extensive experience with transport of various types of cask sets for transport of nuclear material and radioactive substances in the Czech Republic, Germany, Hungary, Moldova, Poland, Slovakia, Sweden, Romania and Ukraine.

3.3.4.3. ŠKODA JS, a.s.

Providing engineering services and supplies for the nuclear energy industry for 50 years, a key activity of ŠKODA JS is manufacturing equipment for SNF management, such as the production of storage structures for SNF. Examples of such developments include the ŠKODA VPVR/M cask for the transport of research reactor SNF, carried out for ÚJV Řež, a.s., and the PETA 6 lead container for the transport of radiation sources.

3.3.5. United States of America

3.3.5.1. Edlow International

Edlow International provides services in transport management and material procurement. It transports all forms of radioactive material, including uranium ore concentrates, LEU and fuel assemblies to HEU, SNF and plutonium.

3.3.5.2. Holtec International

Holtec International provides services for the back end of the nuclear power cycle for commercial nuclear power plants. Its wet and dry storage and transport systems provide confinement, radiation shielding, structural integrity, criticality control and heat removal for SNF.

3.3.5.3. NAC International

NAC International offers SNF transport services to utilities and international organizations, including preparing and performing cask loading and unloading operations. It provides services such as route assessment and approval, preparation of transport and security plans and escort coordination, carrier booking, notifications and shipment tracking.

3.4. RESEARCH REACTOR SNF SHIPMENTS FOR REPROCESSING

3.4.1. Summary of take back programmes of high enriched uranium originating from the Russian Federation and the United States of America

3.4.1.1. Programme development and achievements

As reported in Ref. [68]:

> "International activities in the back-end of the RR nuclear fuel cycle are at present dominated by the RR spent fuel take back programmes, the United States of America Foreign Research Reactor Spent Nuclear Fuel (FRRSNF) acceptance programme and the Russian Research Reactor Fuel Return (RRRFR) programme. The major goal of the separate take-back programmes for USA and Russian origin fuels is to eliminate inventories

> of Highly Enriched Uranium (HEU) by returning RR spent nuclear fuel to the country where the fuel was originally enriched."

They are part of the GTRI Nuclear and Radiological Material Removal programme of the NNSA to remove and dispose of excess, disused or unwanted nuclear and radiological material from civilian sites worldwide which could be used in weapons of mass destruction — reducing the threat of the material being used for malicious purposes.

In 1996, the IAEA Director General, sent a letter to the US Energy Secretary that helped to revive the US take back programme, that shipped back to the United States of America more than 12 000 spent fuel elements from countries in Africa, America, Asia and Europe from 1963 to 1989 [68]. After termination of the FRR SNF Acceptance Program, the irradiation of materials eligible for shipment had to be stopped by 12 May 2016, and all shipments have to be completed by 12 May 2019. The more recent RRRFR Programme, which accepts fresh or spent fuel enriched in the former Soviet Union or the Russian Federation is also close to completion. In support of the take back programmes, the IAEA published Refs [68, 69]. Reference [68] reports that:

> "The RRRFR Programme originated in 1999 from a tri-partite initiative of the Russian Federation, the United States of America, and the International Atomic Energy Agency (IAEA)…. The initiative was complemented in May 2004 with an agreement signed between the Government of the United States of America and the Government of the Russian Federation Concerning Cooperation for the Transfer of Russian-Produced Research Reactor Nuclear Fuel to the Russian Federation.
>
> …….
>
> "It is evident from the individual presentations that every shipment operation is unique and likely to face different technical and administrative challenges. Different scenarios will require specific approaches in relation to licensing processes, multinational agreements, casks loading issues, transport procedures, public acceptance and also political aspects. Nevertheless, based on the experience accumulated so far worldwide, it is possible to conclude that both programmes, FRRSNF and RRRFR are being quite successful in safely transporting RRSNF back to the country of origin. In this way, these programmes are efficiently contributing to the global objective of minimizing and eventually eliminating the use of non-proliferation concerning nuclear materials, especially HEU, in civilian applications."

3.4.1.2. IAEA involvement

Over the years, the IAEA has participated in a variety of repatriation missions in partnership with the GTRI to return HEU fuel to its country of origin and to convert research reactors to using LEU fuel. The IAEA successfully completed, under a technical cooperation programme, a €4 million procurement of ten dual purpose (transport and storage) high capacity ŠKODA VPVR/M casks that are presently available on a 'lease-free' basis to the RRRFR Programme. The role the IAEA plays has sometimes been to coordinate the entire project (e.g. SNF removal from Vinča, Serbia) or to apply IAEA safeguards to verify the successful transfer.

For the fresh HEU removal under the RRRFR Programme, the IAEA was one of the contracting parties. From 2002 to 2013, under contract agreements of the IAEA, 24 shipments were achieved, with around 790 kg of fresh HEU returned safely to the Russian Federation. A representative example of successful international cooperation is the fresh and SNF removal from Vinča, Serbia [70]:

> "The amount of fuel at Vinča was unusually large, and some of it contained 80-per cent enriched uranium, approaching the purity needed for nuclear weapons. The urgency of the situation heightened after the 2001 terrorist attacks in the USA, so US officials and the Nuclear Threat Initiative (NTI) agreed to fund the removal of fresh HEU fuel from Vinča in 2002….
>
> …….

“[The] seed money triggered contributions from a variety of governments, turning the Vinča project into the IAEA’s largest technical cooperation endeavour ever, involving about US $55 million in total. Most of the project’s technical assistance to Serbia was overseen by the Department of Nuclear Energy’s Research Reactor Section and the Department of Nuclear Safety. Project management was provided by the Technical Cooperation Department and the Office of Nuclear Security. Additionally, the NNSA contributed to the project, as did Slovenian, Hungarian, Romanian and Czech nuclear authorities and companies. On the Serbian side, the project was coordinated through the Public Company Nuclear Facilities of Serbia (PC NFS), which was created by the Serbian government in 2009 to be the entity responsible for the safe removal of spent nuclear fuel from Vinča.”

In 2002, all of the fresh nuclear fuel was shipped back to the Russian Federation. Thus, Serbia was the first IAEA Member State to return fresh HEU fuel to the Russian Federation; this was followed by a further 23 shipments [71]. An IAEA officer reports in Ref. [70] that:

“After that, intense planning began for repackaging the corroded spent fuel elements. We carried out several studies of the fuel and the surrounding fuel pond. The fuel was stored in two types of containers: aluminium barrels, and fuel channel holders. Both had been stored in water of poor quality in the pool for years.

“We knew that re-packing the fuel would be difficult, because it needed to be done underwater to protect operators from being irradiated and to avoid dispersion of radioactivity during the process. So we knew that we needed to bring in a lot of purpose-designed equipment to help out with the repacking. We also knew we’d need large numbers of transport casks for the fuel.

…….

“We received bids from several companies to lead the project; the IAEA helped Serbia analyze these bids and select the best option. Ultimately, a consortium of Russian companies was selected to carry out the work, and in 2006, a tripartite contract between the IAEA, the Vinča Institute and Sosny-Mayak-Tenex was signed.

“Before the contract was signed, the IAEA had helped to draw up the regulations that Serbian nuclear authorities would use and to carry out studies to determine the condition of the fuel assemblies and water. The IAEA had also given advice on the technical and legal details of bids for the fuel repackaging and assisted with the technical negotiations surrounding the contract itself.

“After the contract was signed, the contracted companies started repackaging the spent fuel.

“This involved opening all the barrels underwater, repackaging the spent fuel into new containers and baskets, and then loading the baskets into shipping casks. The loaded casks were vacuum dried, checked for contamination and air tightness [see Fig. 22].

Reference [72] reports that:

“Today’s delivery marked the end of a four-week journey from Serbia which started on 18 November [2010], when 16 shipping containers holding the fuel were loaded onto heavy cargo trucks. At 2:30 a.m. on 19 November, the convoy pulled out of Vinča and drove 200 kilometres — along roads closed to all other traffic and protected by thousands of Serbian security personnel — to the Hungarian border where crews moved the containers to a waiting train.

“In another early morning departure, the train left Serbia and transited Hungary and Slovenia before arriving on 21 November at the port of Koper, where longshoremen moved the containers once more, this time onto a cargo ship. After a few hours at the dock, the ship embarked for a three-week sail to the Russian port of Murmansk [see Fig. 23]. Once there, containers were loaded back to a train for the journey’s final leg to Mayak.”

FIG. 22. Shipping cask operations in the reactor building at the Vinča site, Serbia.

(a) (b)

FIG. 23. Serbian SNF leaving the port of Koper, Slovenia, and being reloading onto a train at the port of Murmansk, Russian Federation.

Reference [70] reports that:

“The final contract called for the permanent disposal of the high-level waste that would be generated after reprocessing of the spent fuel, since Serbia didn’t have the facilities to take back the waste after Russia recovered the still usable uranium components of the spent fuel.

…….

“The entire project has taken about 8 years — from the first shipment of fresh fuel in 2002, to the final shipment ending in December 2010.

“The Institute shipped 8030 fuel elements — some 2.5 tonnes of material. Approximately 17 percent of those fuel elements contained HEU.

…….

“[During reprocessing], the [high] enriched uranium will be downblended to lower enrichment levels and used as nuclear power reactor fuel, thereby changing the material into a form that presents a substantially lower security risk.

“The high level waste is expected to be vitrified and stored in Russia.”

Other IAEA support for the take back programmes is in the organization of annual RRRFR lessons learned meetings, which bring together authorities from the Russian Federation and the United States of America, programme coordinators and contractors, as well as authorities and research reactor operators worldwide, to share their experience in implementing SNF shipments for reprocessing. Some non-regular meetings are organized when States are affected by particular developments, for example when the new EU regulatory framework on SNF transboundary shipments was adopted or when several States had to negotiate transit conditions with the Russian Federation and transit countries. The non-regular meetings had the purpose of offering research reactor operators the chance to hold discussions and to receive clarification from the European Commission and governmental representatives of the States involved to improve understanding of new procedures and to ease decision making processes in adopting different routes.

3.4.2. Low enriched uranium SNF shipments

Three shipments from Romania that took place in 2012 provide an example of a commercial import (the financial resources were directly covered by the foreign State operating the foreign nuclear facility) of LEU research reactor SNF to the Russian Federation for reprocessing (for a full account, see Ref. [73]).

4. CONCLUSIONS

This publication offers a description of the services available for reprocessing and recycling research reactor SNF, and addresses aspects such as the legal and regulatory framework, technologies, service providers and experience of the HEU take back programmes. For many countries with only research reactors and no nuclear power programme, reprocessing and recycling of research reactor SNF based on mature technologies is an available option for the management of the back end of the research reactor nuclear fuel cycle.

Following reprocessing and recycling of research reactor SNF, the safety and security measures necessary for the resulting radioactive waste are much less complex and less costly than for the SNF. Thus, the reprocessing and recycling of research reactor SNF option is in line with the provisions of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9]:

“**ARTICLE 4. GENERAL SAFETY REQUIREMENTS**

“Each Contracting Party shall take the appropriate steps to ensure that at all stages of spent fuel management, individuals, society and the environment are adequately protected against radiological hazards.

“In so doing, each Contracting Party shall take the appropriate steps to:

…….

“(ii) ensure that the generation of radioactive waste associated with spent fuel management is kept to the minimum practicable, consistent with the type of fuel cycle policy adopted”.

A potential outcome of the implementation of research reactor SNF reprocessing and recycling project that should be analysed in the future is the possibility to return to the research reactor operator not the HLW resulting from the SNF reprocessing, but an equivalent quantity of LILW for which proper repositories exist in many countries.

Appendix I

RESEARCH REACTOR SNF PACKAGE TECHNICAL SPECIFICATIONS

I.1. TUK-19 PACKAGE

The specifications of the TUK-19 package are given in Table 7. The main components are (see Fig. 24):

- — Cask 19 (body and lid);
- — Basket 50;
- — SFA support.

TABLE 7. SPECIFICATIONS OF THE TUK-19 PACKAGE

Parameter	Value
Capacity (SFA* pieces)	4
Weight of empty cask (kg)	4725
Gross weight (kg)	4750
Outer diameter (mm)	680
Height (mm)	2170
Internal medium	Air

* Spent fuel assembly.

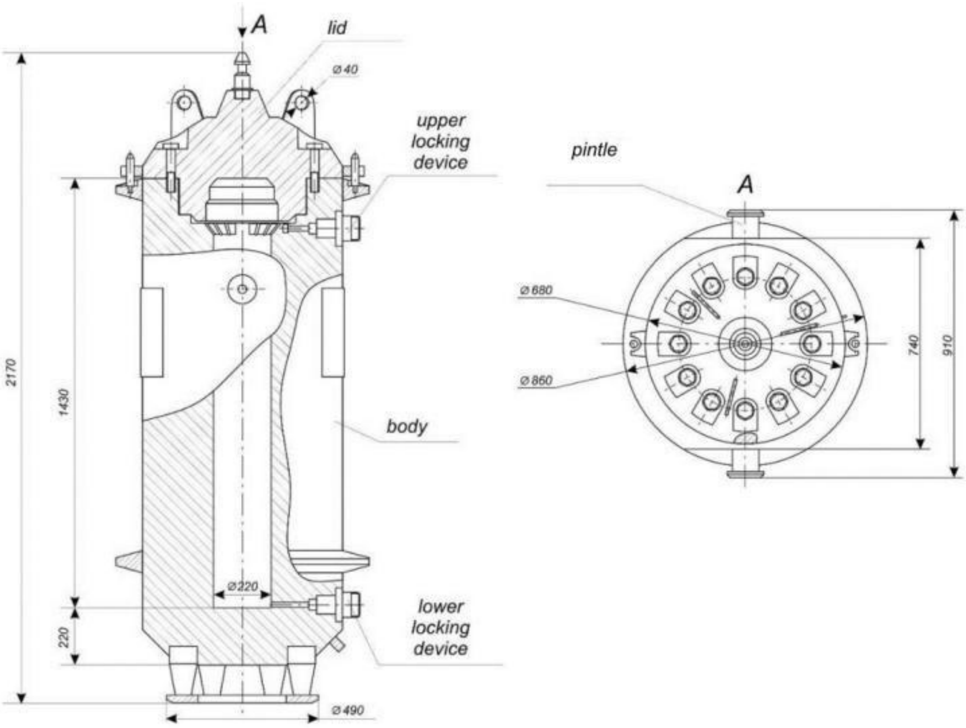


FIG. 24. Outline of the TUK-19 package.

Further information on the TUK-19 package is given in Table 8.

TABLE 8. ADDITIONAL INFORMATION ON THE TUK-19 PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	SM-2, VVR-K, VVR-C, MR, VVR-S, VVR-2, IRT-1000, IRT-M, IRT-2M, IRT-3M, VVR-M, VVR-M2, VVR-M3, VVR-M5, VVR-M7, IVV-2, IVV-2
Shipments of research reactor spent fuel performed in the RRRFR Programme (2006–2014)	Kazakhstan, Latvia, Libya, Poland, Romania, Serbia, Uzbekistan
Allotment holder	Rosatom/SFA transports from research reactors of the Russian Federation
Know-how	JSC ATOMPROEKT, FSUE RFNC — VNIIEF, FSUE Mayak PA, Sosny Research and Development Company
Designer	JSC ATOMPROEKT
Manufacturer	Izhorskiye Zavody (part of the JSC OMZ Group)
Cask owners	FSUE Mayak PA (16 pieces), JSC INM (4 pieces)
Service provider	Sosny Research and Development Company

* Spent fuel assembly.

I.2. ŠKODA VPVR/M PACKAGE

The specifications of the ŠKODA VPVR/M package are given in Table 9. The main components are (see Fig. 25):

— Cask body;
— Upper (inside and outside) lids;
— Lower (inside and outside) lids;
— Basket for SFAs;
— Shock absorbers.

TABLE 9. SPECIFICATIONS OF THE ŠKODA VPVR/M PACKAGE

Parameter	Value
Capacity (SFA* pieces)	36
Weight of empty cask (kg)	10 700
Gross weight (kg)	12 390
Outer diameter (mm)	1 200
Height with shock absorbers (mm)	2 155
Thickness of wall (mm)	300

TABLE 9. SPECIFICATIONS OF THE ŠKODA VPVR/M PACKAGE (cont.)

Parameter	Value
Internal medium	Helium
Max. normal operating pressure (MPa)	0.07

* Spent fuel assembly.

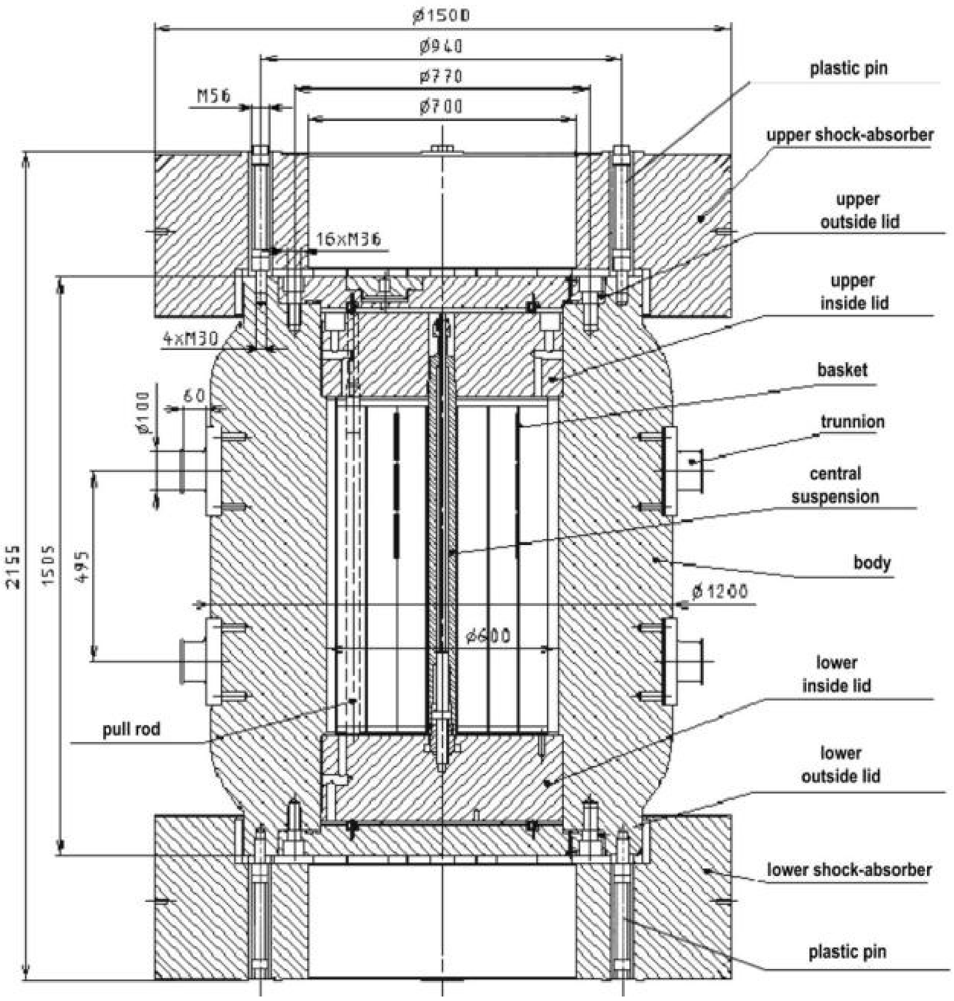


FIG. 25. Outline of the ŠKODA VPVR/M package.

Further information on the ŠKODA VPVR/M package is given in Table 10.

TABLE 10. ADDITIONAL INFORMATION ON THE ŠKODA VPVR/M PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	EK-10, S-36, VVR-M, VVR-M2, VVR-M5, VVR-M7, VVR-(S)M, IRT-2M, IRT-3M, IRT-4M, TVR-S
Shipments of research reactor spent fuel performed in the RRRFR Programme (2006–2014)	Belarus, Bulgaria, Czech Republic, Hungary, Poland, Serbia, Ukraine
Allotment holder	IAEA, USDOE/RRRFR Programme
Know-how	ÚJV Řež, a.s., ŠKODA JS, a.s., FSUE RFNC — VNIIEF, FSUE SSC RF — IPPE, FSUE Mayak PA, Sosny Research and Development Company
Designer	ŠKODA JS, a.s.
Manufacturer	Izhorskiye Zavody (part of the JSC OMZ Group)
Cask owner	ÚJV Řež, a.s. (16 pieces)
Service provider	ÚJV Řež, a.s., Sosny Research and Development Company

* Spent fuel assembly.

I.3. CASTOR MTR2 PACKAGE

The specifications of the CASTOR MTR2 package are given in Table 11. The main components are (see Fig. 26):

— Cask body (including primary and secondary lids);
— Basket for load units;
— Load units for SFAs;
— Shock absorbers;
— Pull rods for shock absorbers.

TABLE 11. SPECIFICATIONS OF THE CASTOR MTR2 PACKAGE

Parameter	Value
Weight of empty cask, max. (kg)	15 170
Gross weight, max. (kg)	17 930
Outer diameter (mm)	1 430
Height without shock absorbers (mm)	1 631
Height with shock absorbers (mm)	2 071
Outer diameter of cask with shock absorbers (mm)	1 800
Internal medium	Helium
Max. normal operating pressure (MPa)	0.08

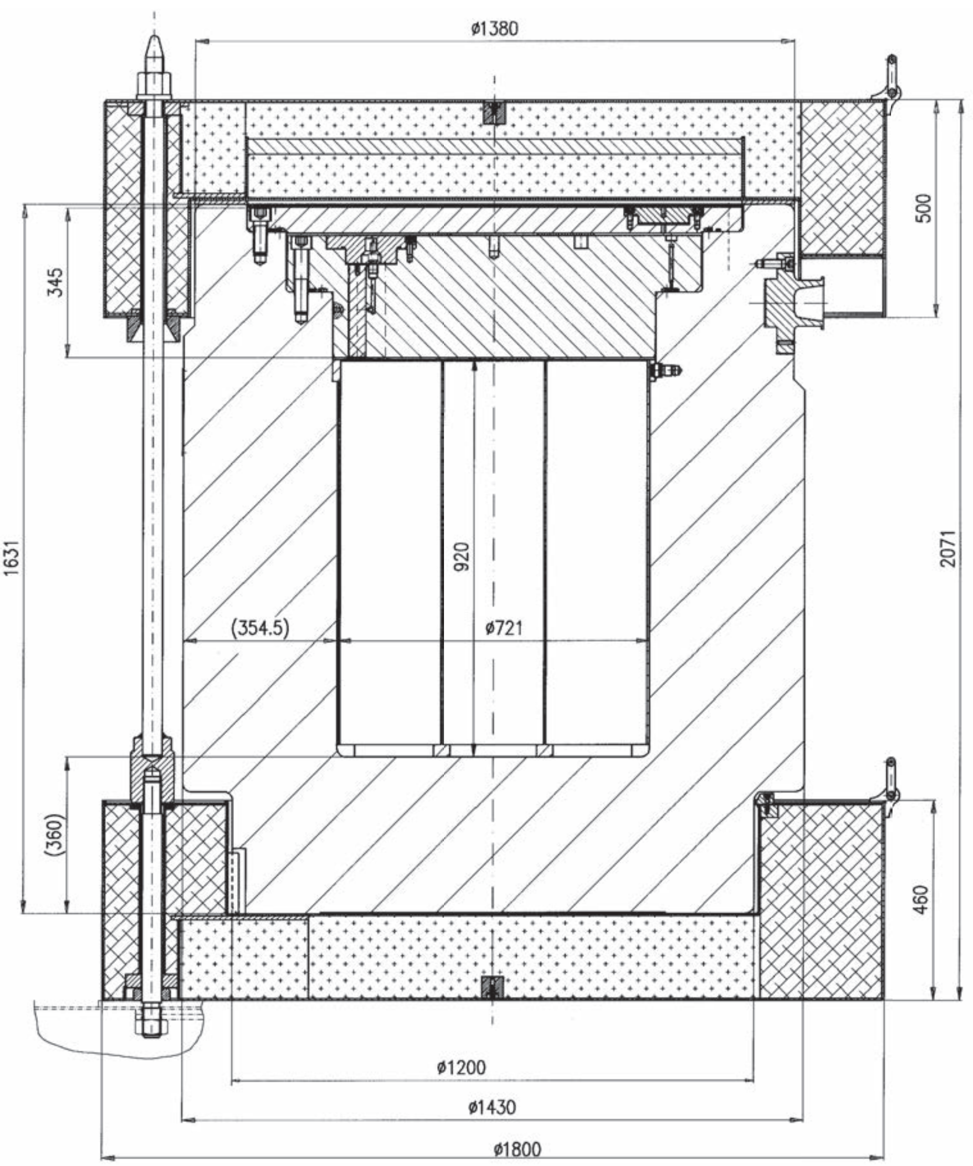


FIG. 26. Outline of the CASTOR MTR2 package.

Further information on the CASTOR MTR2 package is given in Table 12.

TABLE 12. ADDITIONAL INFORMATION ON THE CASTOR MTR2 PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	VVR-M, VVR-M2, EK-10
Allotment holder	VKTA
Know-how	DAHER–NCS, GNS Gesellschaft für Nuklear-Service mbH, GNB Gesellschaft für Nuklear-Behälter mbH, FSUE RFNC — VNIIEF, FSUE SSC RF — IPPE, FSUE Mayak PA, Sosny Research and Development Company
Designer	GNS Gesellschaft für Nuklear-Service mbH
Manufacturer	Izhorskiye Zavody (part of the JSC OMZ Group)
Cask owner	VKTA (18 pieces)
Service provider	DAHER–NCS (road and sea shipment, customs), Sosny Research and Development Company

* Spent fuel assembly.

I.4. TUK-128 (TUK-135) PACKAGE

The TUK-128, TUK-128/1 and TUK-135 packages are almost identical, differing only in the design of their baskets, which transport different types of SFA. The specifications of the TUK-128 and TUK-128/1 packages are given in Table 13. The main components are (see Fig. 27):

— Cask;
— Basket;
— Shock absorbers (upper and lower).

TABLE 13. SPECIFICATIONS OF THE TUK-128 (TUK-128/1) PACKAGE

Parameter	Value
Capacity (SFA* pieces)	20 (48)
Gross weight, max. (kg)	11 670 (11 730)
Outer diameter (mm)	1 450
Height with shock absorbers (mm)	2 220
Wall thickness (mm)	290
Internal medium	Air

* Spent fuel assembly.

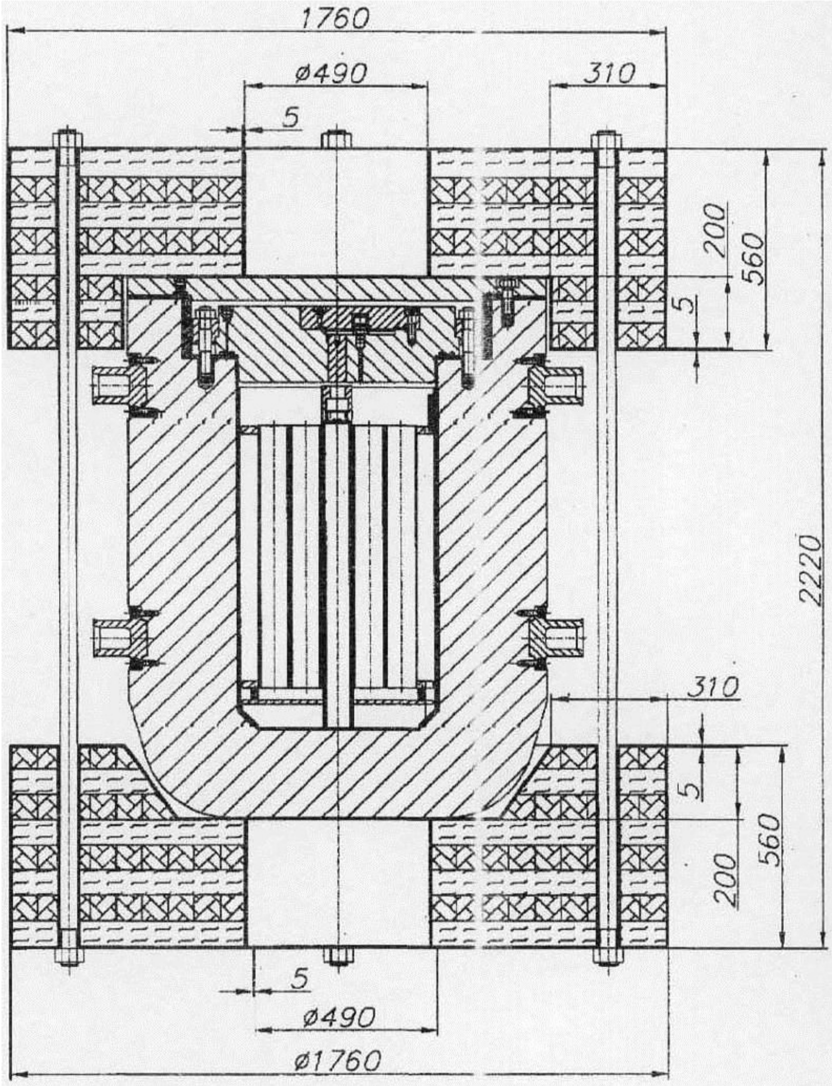


FIG. 27. Outline of the TUK-128 package.

Further information on the TUK-128 (TUK-128/1) package is given in Table 14.

TABLE 14. ADDITIONAL INFORMATION ON THE TUK-128 (TUK-128/1) PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	EK-10 (IRT-1000, VVR-2), S-36, IRT-2M, IRT-4M, IVV-2M, VVR-C, VVR-K, TVR-S, three-tube SFAs — e.g. VVR-M2, VVR-M3, VVR-M5 — VVR-M7 with minimal cooling for 4 years, RT-3M with minimal cooling for 5 years (TUK-128/1 applicable for transport of one-tube SFAs: VVR-M2, VVR-M3, VVR-M5, VVR-M7, TVR-S with minimal cooling for 3 years)
Allotment holder	Rosatom/SFA transports from research reactors of the Russian Federation
Know-how	FSUE Mayak PA, Sosny Research and Development Company
Designer	NPO ECNC OJSC

TABLE 14. ADDITIONAL INFORMATION ON THE TUK-128 (TUK-128/1) PACKAGE (cont.)

	Comment
Manufacturer	OJSC Petrozavodskmash
Cask owner	FSUE Mayak PA (12 pieces)
Service provider	Sosny Research and Development Company, FSUE Mayak PA

* Spent fuel assembly.

I.5. TUK-32 PACKAGE

The specifications of the TUK-32 package are given in Table 15. The main components are (see Fig. 28):

— TUK-32 cask;
— Basket for SFAs.

TABLE 15. SPECIFICATIONS OF THE TUK-32 PACKAGE

Parameter	Value
Height (mm)	4582
Height of internal volume (mm)	3530
Outer diameter (mm)	1405
Inner diameter (mm)	775
Wall thickness (mm)	315
Bottom thickness (mm)	250
Lid thickness (mm)	144
Capacity (baskets)	7
Weight with loaded baskets (t)	40
Internal medium	Air
Allowable temperature of external surface (°C)	82

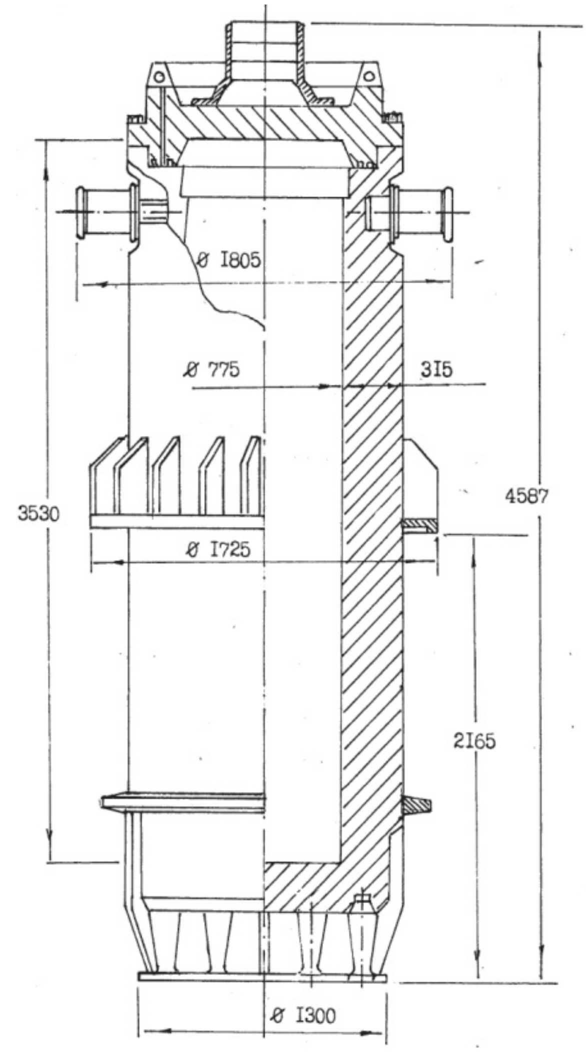


FIG. 28. Outline of the TUK-32 package.

Further information on the TUK-32 package is given in Table 16.

TABLE 16. ADDITIONAL INFORMATION ON THE TUK-32 PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	SM-2, MIR
Allotment holder	Rosatom/SFA transports from research reactors of the Russian Federation
Know-how	JSC ATOMPROEKT, RIAR
Designer	JSC ATOMPROEKT
Manufacturer	Izhorskiye Zavody (part of the OJSC OMZ Group)
Cask owner	RIAR (3 pieces, TUK-32)
Service provider	Sosny Research and Development Company, FSUE Mayak PA

* Spent fuel assembly.

I.6. TUK-145/C PACKAGE

The TUK-145/C package is a Type C package (in contrast to the packages already described, which are Type B(U) packages), designed to transport fissile material by air. The TUK-145/C package represents a package-in-package design solution: the energy absorption container of the TUK-145/C package accommodates the ŠKODA VPVR/M package converting this Type B(U) package into a Type C package. The specifications of the TUK-145/C package are given in Table 17. The main components are (see Fig. 29):

— ŠKODA VPVR/M cask (see Section I.2);
— Energy absorption container.

TABLE 17. SPECIFICATIONS OF THE TUK-145/C PACKAGE

Parameter	Value
Capacity (SFA* pieces)	36
Weight of empty cask (kg)	29 200
Gross weight (kg)	29 650
Width (lug-to-lug dimension, mm)	3 168
Height (mm)	3 065
Thickness of wall (mm)	300
Internal medium	Helium
Max. normal operating pressure (MPa)	0.07

* Spent fuel assembly.

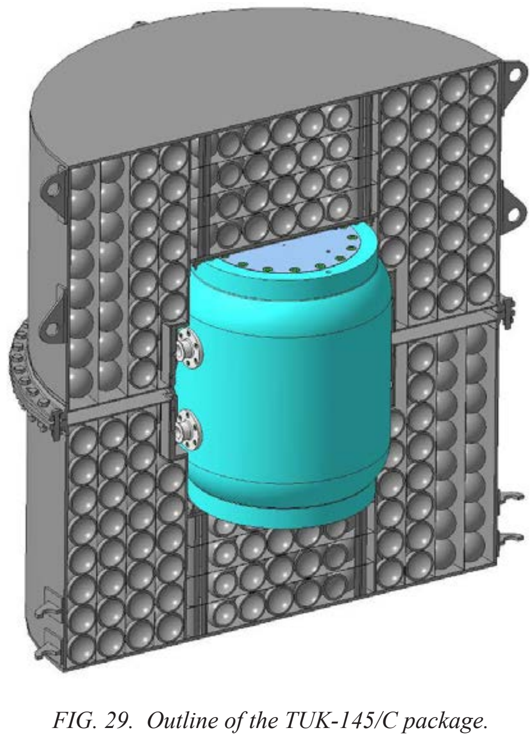


FIG. 29. Outline of the TUK-145/C package.

Further information on the TUK-145/C package is given in Table 18.

TABLE 18. ADDITIONAL INFORMATION ON THE 145/C-TUK PACKAGE

	Comment
Certified in the Russian Federation for transport (types of SFA*)	EK-10, S-36, VVR-M, VVR-M2, VVR-M5, VVR-M7, VVR-(S)M, IRT-2M, IRT-3M, IRT-4M, TVR-S, IIN-3M (liquid)
Allotment holder	USDOE/RRRFR Programme
Know-how	Sosny Research and Development Company, FSUE RFNC — VNIIEF, FSUE SSC RF — IPPE, Volga-Dnepr Airlines, FSUE Mayak PA
Designer	Sosny Research and Development Company
Manufacturer	VSMPO-AVISMA Corporation
Cask owner	ÚJV Řež, a.s. (16 pieces, ŠKODA VPVR/M), FSUE Mayak PA (two sets of energy absorption containers)
Service provider	Sosny Research and Development Company

* Spent fuel assembly.

The energy absorption container (EAC) consists of two halves (top and bottom parts) joined with sixty M36 bolts. The ŠKODA VPVR/M cask is installed in the EAC to decrease the dynamic loads under accident transport conditions. The upper and bottom parts of the EAC, similar in their design, are welded bodies, made of a titanium alloy with shock absorbing elements (hollow titanium spheres). Four air shipments of research reactor SNF from Hungary and Viet Nam were performed in 2013 under the RRRFR Programme.

I.7. TN-MTR PACKAGE

Ohayon and Mariette [74] report that at the end of the 1990s, AREVA TN developed a new cask, TN-MTR (see Fig. 30), in accordance with IAEA transport regulations (see SSR-6 [61]), to replace the IU04 cask. The IU04 cask fleet was managed by AREVA TN. It was often lent to the FRR SNF Acceptance Program and has been used in many countries (e.g. Denmark, Italy, Portugal and Bolivarian Republic of Venezuela). The TN-MTR cask was used to transport up to 68 used fuel elements to the AREVA La Hague plant under reprocessing contracts of AREVA. The shipments were from French reactors (of the CEA and Laue-Langevin Institute) as and other countries (Australian Nuclear Science and Technology Organisation, ANSTO, and BR2 in Belgium).

To comply with the different requirements and geometries of the SFAs, AREVA TN has designed several types of basket for the transport of up to 68 used fuel elements:

- — MTR-68 (up to 68 used fuel elements);
- — MTR-52 (up to 52 used fuel elements), MTR-52S and 52SV2;
- — MTR-44 (up to 44 used fuel elements);
- — MTR-RHF.

Specific types of basket (TN-MTR52S and 52SV2) have been developed to satisfy US requirements. They can transport up to 52 fuel elements and were used in the following shipments:

- — From the Risø reactor, Denmark, in 2001;
- — From ANSTO between 1999 and 2004 (four shipments from Australia to the AREVA La Hague reprocessing plant, ~1000 SFAs);

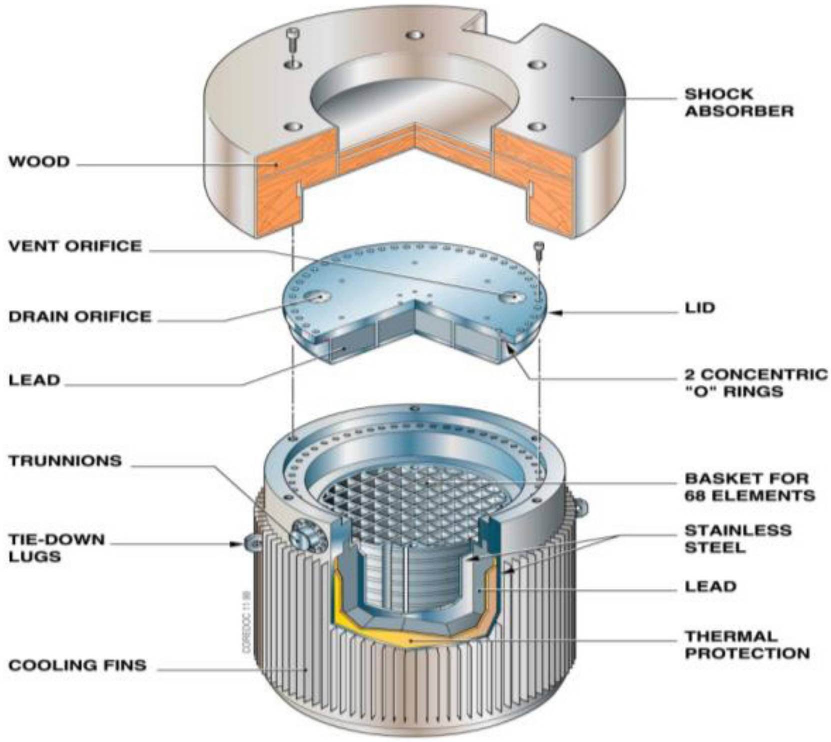


FIG. 30. TN-MTR cask.

— From the ITN reactor, Portugal, in 2008;
— From Indonesia in 2009;
— To the Savannah River Site, United States of America.

The TN-MTR cask was validated and used successfully at the Savannah River Site facilities. The TN-MTR is certified for a large number of MTR and TRIGA fuels, and is suitable for all types of loading/unloading (wet or dry). The last TN-MTR B(U)F certificate of approval for package design was obtained in January 2011 for a period of five years.

Further information on the TN-MTR cask is given in Table 19.

TABLE 19. ADDITIONAL INFORMATION ON THE TN-MTR CASK

	Comment
Allotment holder	CEA
Know-how	AREVA TN
Designer	AREVA TN
Manufacturer	European manufacturers
Cask owner	AREVA TN (4 pieces), CEA (1 piece)
Service provider	AREVA TN

I.8. TN-LC PACKAGE

Guibert [65] reports that (see Figs 31 and 32):

"In order to respond to new shipment needs and to support future USA domestic and international transports, Transnuclear Inc., the AREVA Logistics Business Unit entity in the USA, has developed a new transport package design, named the TN-LC. The TN-LC package offers a specific and customized solution for research reactor and laboratories shipments. In December 2012, the TN-LC package was licensed for transportation by the US NRC and is currently being manufactured. It will be available to support US domestic and international shipments by the end of 2014.

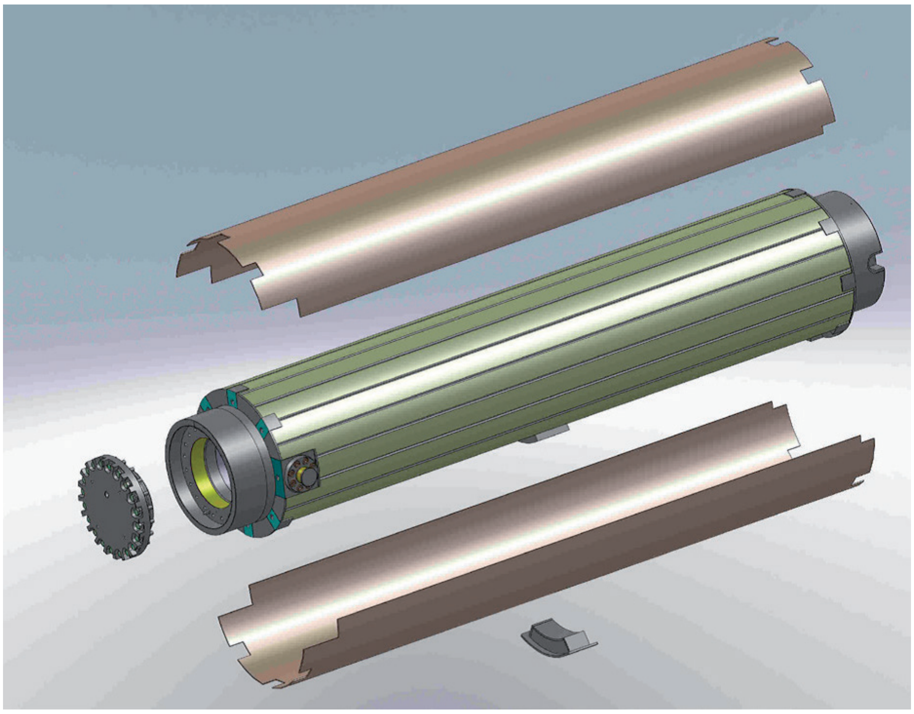


FIG. 31. TN-LC package design.

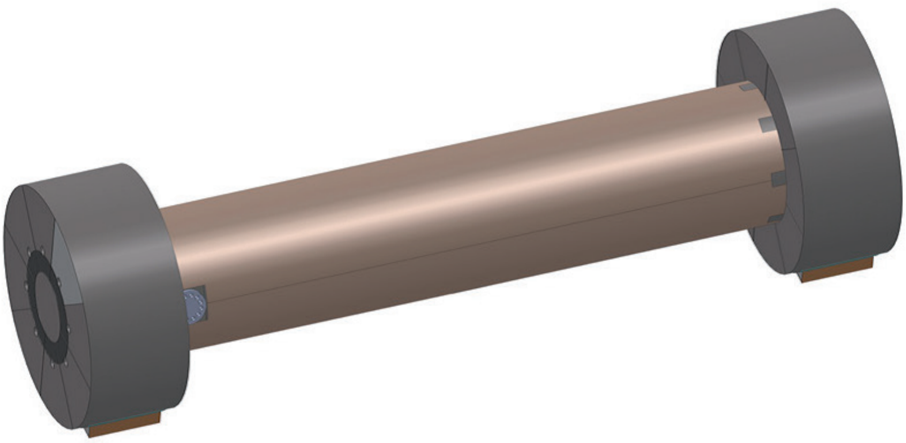


FIG. 32. TN-LC package in transport configuration.

"The TN-LC ('Long Cask') is a new type B(U)F package that features different basket designs that can fit into the TN-LC cavity, thus it can accommodate used fuel from research reactors (MTR, TRIGA, NRU/NRX, etc.), full length commercial irradiated fuel assemblies (PWR, BWR), irradiated pins (EPR, MOX, PWR, BWR) to support Post Irradiation Examinations or other irradiated contents. The total package weight is 25 metric tons, thus is ideally suited for use in many research reactors and laboratories. The TN-LC package has been designed to allow versatile on-site operations and can be loaded and unloaded in vertical or horizontal orientation, in wet or dry conditions, underwater or using a hot cell.

“The TN-LC package has been developed to meet the most recent IAEA standards and safety requirement of the US NRC and international regulators. Its design benefits of the recognized experience in the transport package design and fabrication of the AREVA Business Unit Logistics. Some of the most innovative technical improvements developed by the AREVA Business Unit Logistics over the recent years have been incorporated in the package design and fabrication.

“Due to the TN-LC package operational flexibility, it can be used in commercial power plants as well as in research reactors and laboratories.

“Transnuclear Inc. currently supports nearly 800 shipments of radioactive material annually and, with the TN-LC package, anticipates global expansion of its used fuel transport capabilities.

…….

“The TN-LC, with the longest and largest cavity in the market, will accommodate a larger payload resulting in more cost-effective transports. For each package, the maximum number of assemblies that can be shipped is:
- 1 PWR/BWR assembly
- 25 PWR/BWR/EPR/MOX pins
- 26 NRU/NRX assemblies
- 54 MTR assemblies
- 180 TRIGA elements

…….

“The maximum burnup licensed by the US NRC is based on the type of fuel, on the enrichment and on the cooling time of the fuel. As there are a wide range of contents, a variety of combinations are authorized:
- For the MTR fuel, the maximum enrichment is 94%wt. in U-235, the maximum burnup is 660 GWd/tU and minimum cooling time of 740 days.
- For the PWR or BWR fuel assemblies, the maximum burnup is 62 GWd/tU.
- For the UO_2 fuel rods transported in the pin can, the maximum burnup is 90 GWd/tU.
- For the EPR or MOX fuel rods transported in the pin can, the maximum burnup is 62 GWd/tU.”

Further information on the TN-LC package is given in Table 20.

TABLE 20. ADDITIONAL INFORMATION ON THE TN-LC PACKAGE

	Comment
Allotment holder	USDOE
Know-how	AREVA TN
Designer	AREVA TN
Manufacturer	US manufacturers
Cask owner	AREVA TN (1 piece in 2017)
Service provider	AREVA TN

I.9. TN-17/2 PACKAGE

AREVA and the CEA signed a contract in 2011 for transport in TN-17/2 casks and reprocessing of Phénix reactor fuel at AREVA La Hague. Located on the Marcoule site in France, this fast breeder reactor was operated jointly by the CEA and Electricité de France from 1973 to 2009. Since then, the CEA has been actively preparing for dismantling it, which is to take place over several decades.

Between 2011 and 2023, AREVA TN is expected to perform up to 60 shipments, in TN-17/2 casks, representing 43 t of heavy metals from Phénix fuel rods between the CEA in Marcoule and the AREVA La Hague reprocessing plant. The TN-17/2 is designed for SFAs and fuel rods, and is licensed in Belgium, France, Italy, the Netherlands and Sweden (see Table 21).

TABLE 21. ADDITIONAL INFORMATION ON THE TN-17/2 PACKAGE

	Comment
Allotment holder	European utilities
Know-how	AREVA TN
Designer	AREVA TN
Manufacturer	European manufacturers
Cask owner	AREVA TN (9 pieces)
Service provider	AREVA TN

I.10. NAC-LWT PACKAGE

The NAC-LWT cask is currently used for the shipment of research reactor SNF, nuclear power plant SFAs and fuel rods, and other irradiated materials (see Table 22).[9]

TABLE 22. ADDITIONAL INFORMATION ON THE TN-17/2 PACKAGE

	Comment
Allotment holder	USDOE, US research reactors
Know-how	NAC International
Designer	NAC International
Manufacturer	US
Cask owner	NAC (8 pieces; 3 dry transfer systems)
Service provider	NAC International

[9] For further information, see www.nacintl.com/transport

Appendix II

TECHNOLOGY FOR SPENT FUEL ASSEMBLY LOADING IN PACKAGES

II.1. TUK-19 CASKS

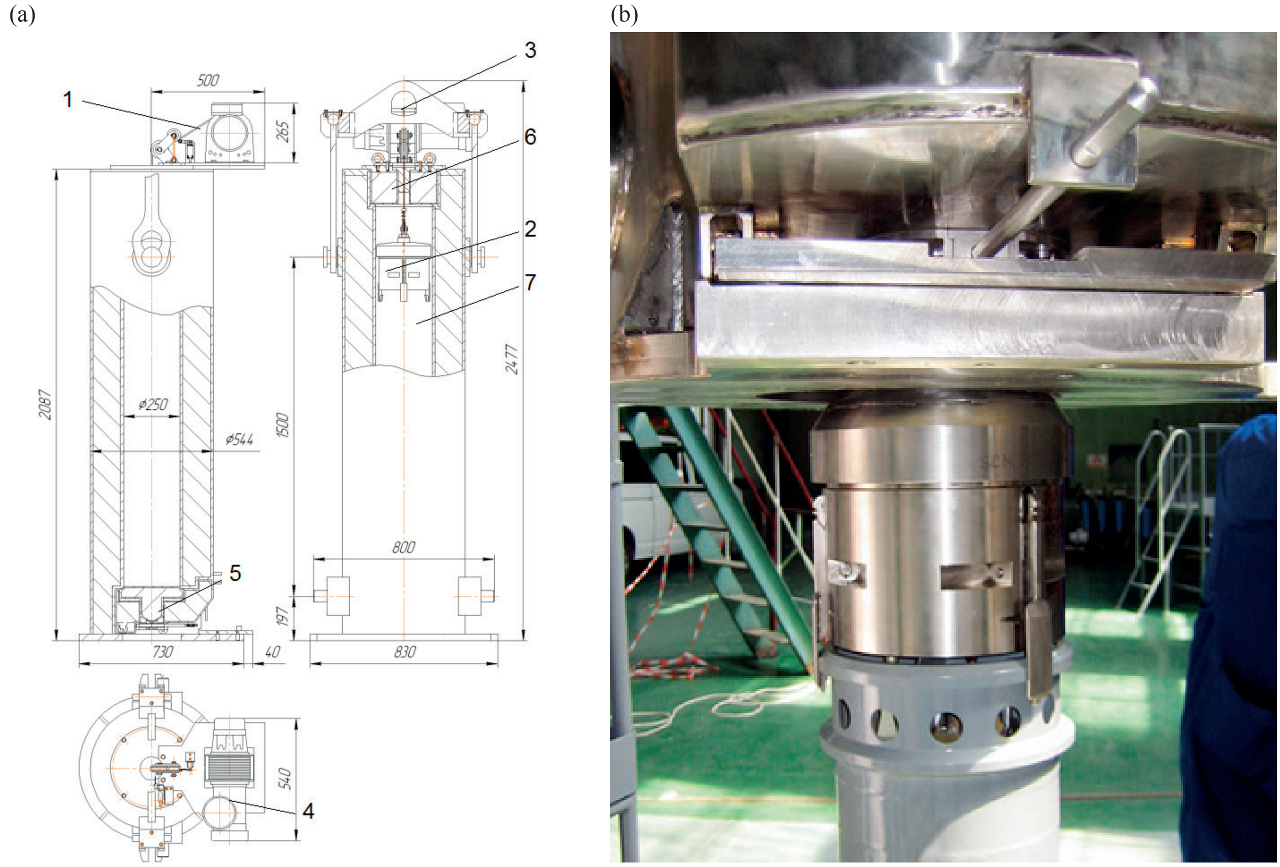
The transfer cask is used to load SFAs of research reactors in baskets 19-1-50 and 19-1-51 from the cooling pool in the TUK-19 cask. The main characteristics are in Table 23 (see Figs 33 and 34).

TABLE 23. MAIN CHARACTERISTICS OF THE TUK-19 CASK

Parameter	Value
Transfer cask mass (kg)	≤4540
Mass of the loaded transfer cask (kg)	≤4650
Dimensions (mm)	2477 × 830 × 832
No. of SFAs (pieces)	up to 4
Body wall temperature (°C)	≤40

(a) (b)

FIG. 33. Spent fuel assembly loading into the TUK-19 cask using transfer casks in Romania and Serbia.



Note: (1) motor; (2) automatic gripping device; (3) traverse; (4) supporting plate; (5) mobile gate; (6) upper shielding plug; (7) body.

FIG. 34. Transfer cask for TUK-19 package.

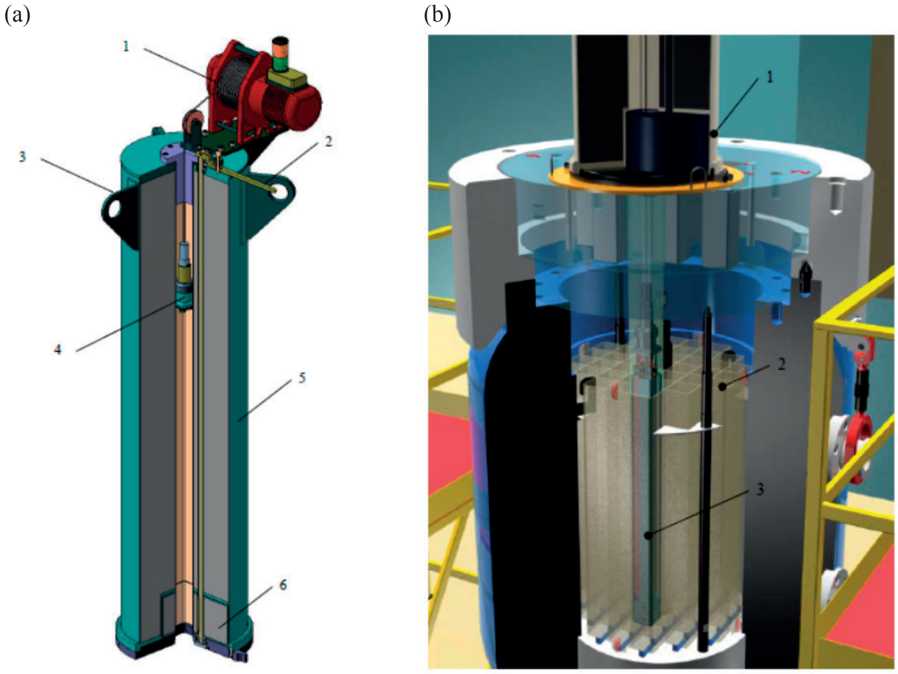
Auxiliary equipment (platforms for access of the operators to the transfer cask and TUK-19 cask elements, for equipment leak test performance and decontamination, and intermediary equipment for the installation of the transfer cask on the cooling pool opening) and tools (bridge crane of the reactor hall, slings and gripping devices, hand tools and supports) are required for the technical support of the loading process and operations.

II.2. ŠKODA VPVR/M CASKS

The main characteristics of the transfer cask for SFA loading into ŠKODA VPVR/M casks are (see Fig. 35):

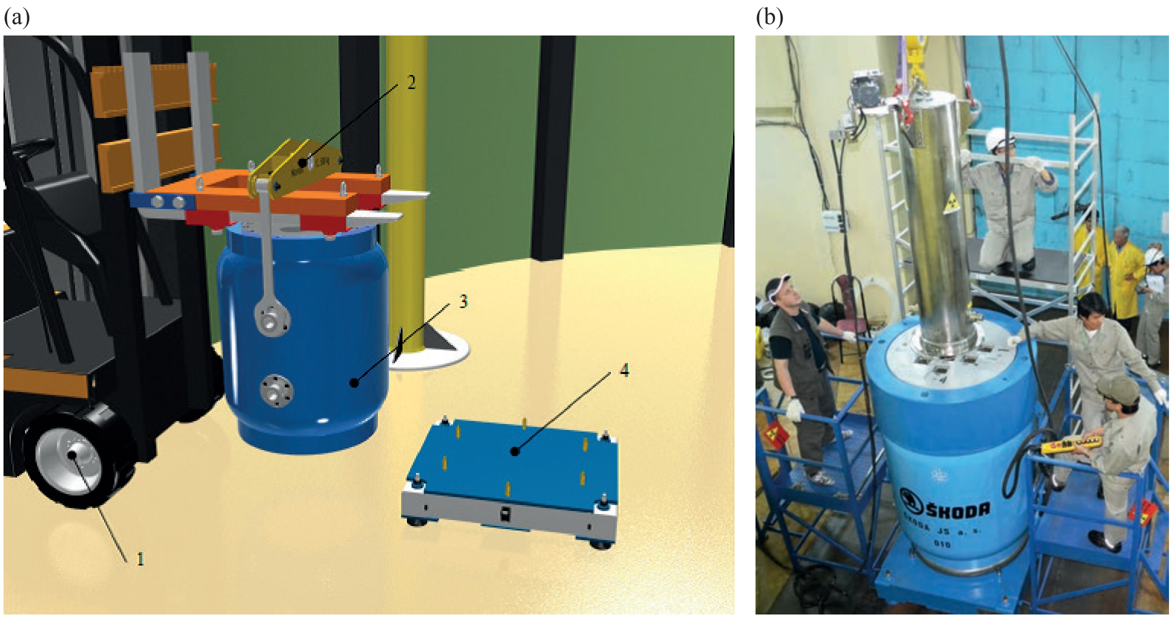
— Empty transfer cask mass: 2400 kg;
— Dimensions of the inner cavity of the container (square): 75 mm × 75 mm;
— External diameter of the container: 395 mm;
— Lead shield wall thickness: ≥116 mm;
— Lifting capacity of the electrical motor: 30 kg.

For the technical support of SFA loading into the transfer cask process and auxiliary operations, supplementary equipment is required (e.g. intermediary equipment for the installation of the transfer cask onto the cooling pool opening; other instruments: SFA gripping device; underwater crossbar lamp and camera). The empty ŠKODA VPVR/M cask can be handled in the reactor hall with the help of a forklift. The upper and lower lids are removed from the cask, and the transfer plate and a guiding element are mounted in their place (see Fig. 36).



Note: (a): (1) electrical motor; (2) handle; (3) lug; (4) automatic grapple; (5) body; (6) shielding gate. (b): (1) transfer cask; (2) basket; (3) spent fuel assembly.

FIG. 35. Transfer cask for the ŠKODA VPVR/M cask.



Note: (a): (1) forklift; (2) traverse; (3) ŠKODA VPVR/M cask; (4) support platform.

FIG. 36. (a) Transfer cask with spent fuel assembly mounting on the ŠKODA VPVR/M cask; (b) ŠKODA VPVR/M cask handling in the spent fuel assembly loading area.

II.3. TN-MTR CASKS

For small research reactors that cannot accommodate underwater TN-MTR package loading (see Fig. 37), AREVA TN makes available a transfer system for loading SFAs. The system comprises a radiological protection element 2 m high, which is placed on the cask previously filled with water, and a transfer system allowing the fuel elements to be transferred in complete safety. The TN-MTR package remains outside of the pool and fuel assemblies are loaded, one by one, with the transfer system of the pool (which contains a skirt and transfer hood). This transfer system has already been used with the IU04 cask (e.g. in France, Italy and Bolivarian Republic of Venezuela) and with the TN-MTR cask (in France).

(a) (b)

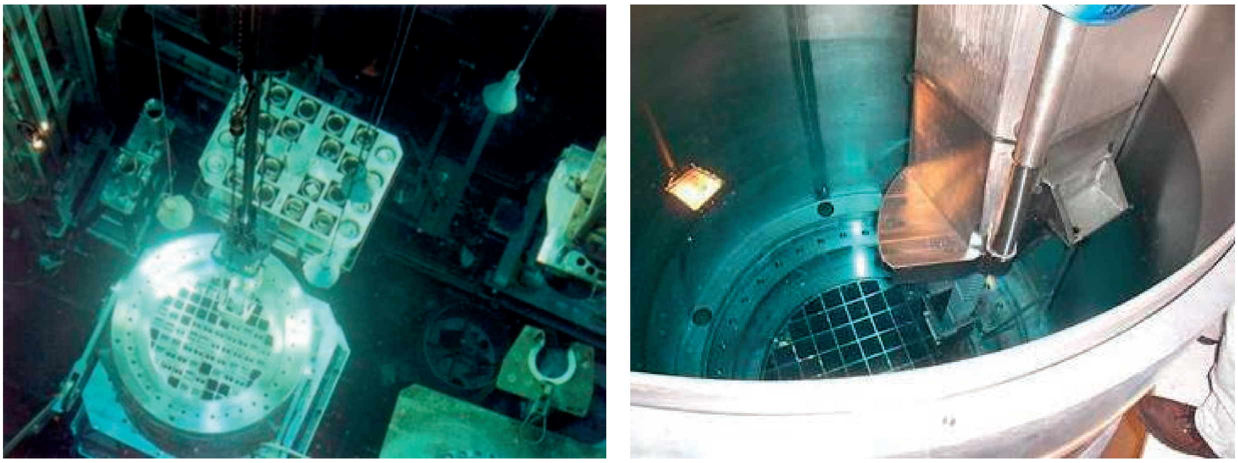


FIG. 37. Loading of the TN-MTR cask in a pool (a) and using a transfer system (b).

Appendix III

SERVICE DESCRIPTION TEMPLATE

A service description helps in the evaluation of reprocessing and recycling options. This template covers areas such as:

— Accepted types of fuel and conditions;
— Packages and prerequisites for their handling at the research reactor, as well as package selection criteria;
— Available transport modes and their applicability;
— Licensing and regulatory matters;
— Logistics support to be provided by the reprocessing facility;
— Options for final disposal of the processed products;
— Time frames and cost estimates.

III.1. INPUT DATA

(1) Fuel characteristics:
  (a) Type;
  (b) Supplier;
  (c) Inventory;
  (d) Physical state (not damaged, slightly damaged that can be handled normally, seriously damaged that requires special safety measures);
  (e) Availability of reprocessing and recycling services for the given type and fuel characteristics.
(2) Site characteristics:
  (a) Fuel storage location (cooling pool in the reactor building, wet or dry storage away-from-reactor);
  (b) Building state (new/old building, undamaged/damaged);
  (c) Maximum acceptable loads of building structures;
  (d) Available handling space in the given storage location;
  (e) Lifting systems capacity;
  (f) Availability and state of transport routes on-site (roads, railway);
  (g) Availability and state of transport routes off-site (roads, railways, river/sea ports, airports).
(3) Options for final disposal of the research reactor SNF/reprocessed products:
  (a) Availability of HLW/LILW repository/long term storage;
  (b) Acceptance criteria of HLW/LILW repository/long term storage;
  (c) Operation licence conditions of HLW/LILW repository/long term storage (operational life of the facilities, life extension).
(4) Legal aspects:
  (a) Existence of government–to–government agreements;
  (b) Responsible organizations (research reactors, reprocessing plant, regulatory bodies);
  (c) Legal framework (contracts, other agreements);
  (d) Regulatory framework (laws, regulations, requirements, standards, guides);
  (e) Third party nuclear liability applicable requirements.

III.2. OUTPUT DATA

(1) Packages:
  (a) Existing/modified/new package design characteristics (capacity, weight, content acceptance criteria, licensed modes of transport);
  (b) Quantity of packages required;

  (c) Existing/modified/new package/fuel handling technologies;
  (d) Existing/modified/new overpacks;
  (e) Safety assessments;
  (f) Package design certification requirements.

(2) Shipment route:
  (a) Available existing/modified/new routes;
  (b) Point of sending;
  (c) Point of delivery;
  (d) Transit countries;
  (e) Available transport means;
  (f) Reloading points from one conveyance to another;
  (g) Physical protection;
  (h) Emergency preparedness;
  (i) Safety assessments;
  (j) Shipment certification requirements.

(3) Coalitions:
  (a) Existence in other countries of similar research reactor SNF inventories planned for shipment for reprocessing and recycling;
  (b) Concordance between the technical reprocessing and recycling solutions for the identified research reactor SNF;
  (c) Concordance between the possible shipment technical solutions;
  (d) Existence of government–to–government agreements;
  (e) Availability of political support.

(4) Available support services:
  (a) Available support service providers;
  (b) Offered support services;
  (c) Experience of support service providers.

(5) Time frame:
  (a) Estimated duration of government–to–government agreement development;
  (b) Estimated duration of contract preparation and conclusion;
  (c) Estimated duration of preparation works (fuel inspection, technology design, manufacture, supply, commissioning, training, licensing, subcontracting);
  (d) Estimated duration of regulatory works (preparation of safety assessments, obtaining all required certificates of approval and licences);
  (e) Estimated duration of SNF loading into shipping packages;
  (f) Estimated duration of shipment (including reloading from one conveyance to another);
  (g) Estimated duration of storage, reprocessing and recycling;
  (h) Estimated time of radioactive waste return (if applicable);
  (i) Estimated duration for developing/making available research reactor SNF disposal technology.

(6) Cost estimates:
  (a) Cost estimates for output data points 1–4 of Section III.2 above;
  (b) Cost estimate for radioactive waste return project;
  (c) Cost estimate for disposal services in the country of reprocessing/recycling;
  (d) Cost estimate for recycled product reuse in the nuclear fuel cycle;
  (e) Cost estimate for radioactive waste disposal services in the country of research reactor SNF origin;
  (f) Cost estimate for developing and implementing disposal of unprocessed research reactor SNF.

III.3. CONCLUSIONS

(1) Most suitable reprocessing/recycling service provider(s) from technical and economical point of view;
(2) Available/most suitable support service provider(s);
(3) Project justification/preliminary feasibility for decision making.

REFERENCES

[1] TOZSER, S.M., ADELFANG, P., BRADLEY, E., BUDU, M., CHIGUER, M., Available reprocessing and recycling services for research reactor spent nuclear fuel, atw Int. J. Nucl. Power **60** (2015) 309–313.

[2] TOZSER, S.M., ADELFANG, P., BRADLEY, E., BUDU, M., CHIGUER, M., "Available reprocessing and recycling services for research reactor spent nuclear fuel (introduction of a new IAEA report)", RRFM European Research Reactor Conference 2014 (Trans. Conf. Ljubljana, 2014), European Nuclear Society, Brussels (2014) 308–317.

[3] TOZSER, S.M., MARSHALL, F., ADELFANG, P., BRADLEY, E., BUDU, M., CHIGUER, M., "Available reprocessing and recycling services for research reactor spent nuclear fuel (a new IAEA report)" (X Int. Nuclear Forum ATOMTRANS-2015, St. Petersburg, 2015).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Spent Fuel Reprocessing Options, IAEA-TECDOC-1587, IAEA, Vienna (2008).

[5] ADELFANG, P., SOARES, A.J., GOLDMAN, I.N., "Spent nuclear fuel from research reactors: International status and perspectives", Safety Related Issues of Spent Nuclear Fuel Storage (LAMBERT, J.D.B., KADYRZHANOV, K.K., Eds), Springer, Dordrecht (2007).

[6] UNITED STATES DEPARTMENT OF ENERGY, Spent Nuclear Fuel Management at the Savannah River Site: Amended Record of Decision, Federal Register **78** (2013) 20625–20628.

[7] Act No. 2002-276 of 27 February 2002 on the Environmental Code.

[8] Programme Act No. 2006-739 of 28 June 2006 on the Sustainable Management of Radioactive Materials and Wastes.

[9] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997).

[10] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, Official Journal of the European Union, No. L199, Publications Office of the European Union, Luxembourg (2011).

[11] Act No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field.

[12] Decree No. 2008-209 of 3 March 2008 concerning the procedures applicable to foreign spent nuclear fuel and radioactive waste reprocessing.

[13] STEPNIK, B., et al., "AREVA involvement in UMo fuel manufacturing and research test reactor fuel treatment", RRFM European Research Reactor Conference 2012 (Trans. Conf. Prague, 2012), European Nuclear Society, Brussels (2014) 122–131.

[14] HÉLAINE, E., BERNARD, P., EMIN, J.-L., LEPOITTEVIN, D., GOUYAUD, F., "Research and test reactor fuel treatment at AREVA NC La Hague", Research Reactor Fuel Management (RRFM) and Meeting of the International Group on Reactor Research (IGORR) (Trans. 11th Int. Top. Mtg, Lyon, 2007), European Nuclear Society, Brussels (2007) 13–20.

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Status and Trends in Spent Fuel Reprocessing, IAEA-TECDOC-1467, IAEA, Vienna (2005).

[16] NUCLEAR SAFETY AUTHORITY, ASN Annual Report 2005, ASN, Paris (2006).

[17] EYSSERIC, C., et al., "Status of silicide fuels reprocessing at La Hague Plant", RRFM European Research Reactor Conference 2014 (Trans. Conf. Ljubljana, 2014), European Nuclear Society, Brussels (2014) 298–307.

[18] HERLET, N., FERLAY, G., DANCAUSSE, J.P., JUVENELLE, A., "Reprocessing U–Mo spent fuels: Dissolution experiments on non-irradiated and irradiated materials", RRFM European Research Reactor Conference 2005 (Trans. Conf. Budapest, 2005), European Nuclear Society, Brussels (2005) 169–173.

[19] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Environmental Management Systems: Requirements with Guidance for Use, ISO 14001:2015, ISO, Geneva (2015).

[20] AREVA, General Inspectorate Annual Report: Status of Safety in Nuclear Facilities, AREVA, Paris (2012).

[21] Federal Law No.170-FZ of 21 November 1995 on the Use of Atomic Energy, as amended 2016.

[22] Federal Law No. 7-FZ of 10 January 2002 on Environmental Protection, as amended 2013.

[23] Decree No. 418 of 11 July 2003 on the procedure for importing spent nuclear fuel assemblies of nuclear reactors into the Russian Federation, as amended 2012.

[24] Federal Law No. 174-FZ of 23 November 1995 on Ecological Expertise, as amended 2009.

[25] Decree No. 587 of 22 September 2003 on the procedure for approving expenses to manage spent fuel assemblies from nuclear reactors and the products of their reprocessing.

[26] Rosatom Administrative Regulation No. 527 of 10 October 2007 on the realization of the State function issuance of certificates (approvals) for shipments of radioactive materials and their registration.

[27] Rosatom Order No. 1/183-P of 14 March 2011 on the entry into force of the Emergency Cards Nos 701 and 702 for immediate actions in case of an accident during automobile, railroad, air or water transport of cargo with radioactive materials replacing the effective emergency cards.

[28] SAVKIN, V., “Reprocessing of research reactor spent nuclear fuel at the FSUE Mayak PA” (Workshop Technical and Administrative Preparations for Shipment of Russian-Origin Research Reactor Spent Fuel to the Russian Federation, Řež, 2008).
[29] KIRILLOV, S., “Implementation of environmental measures” (Mtg SNF Removal from Germany to the Russian Federation, Berlin, 2009).
[30] KOLUPAEV, D., “Handling SNF at FSUE Mayak PA” (Mtg SNF Removal from Germany to the Russian Federation, Berlin, 2009).
[31] IVANOV, K., “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).
[32] FEDOROV, U., ZILBERMAN, B.Ja., BIBICHEV, B., “Possible solution to SNF reprocessing issue with multiple recycling of the REMIX fuel in thermal reactors” (AtomEco-2012 Conf. Moscow, 2012).
[33] BARANOV, S., “Radioactive waste management after spent fuel reprocessing at FSUE Mayak PA” (RRRFR Lessons Learned Workshop, Jackson Hole, WY, 2010).
[34] Decree No. 588 of 22 September 2003 on the procedure for financing special ecological programmes for the recovery of radiation contaminated territorial sites.
[35] UNITED NATIONS, Recommendations on the Transport of Dangerous Goods: Model Regulations, Vols I and II, 19th revised edn, United Nations, New York and Geneva (2009).
[36] INTERNATIONAL CIVIL AVIATION ORGANIZATION, Technical Instructions for the Safe Transport of Dangerous Goods by Air: 2015–2016 Edition, ICAO, Quebec (2014).
[37] Order No. 141 of the Ministry of Transport of 5 September 2008 on the approval of Federal Aviation Regulations “Dangerous Goods Shipment by Civil Aircraft”.
[38] BUDU, M.E., et al., “Seven SNF air shipments in type B packages: Summary and lessons learned” (Int. Symp. Packaging and Transportation of Radioactive Materials (PATRAM), San Francisco, CA, 2013).
[39] International Convention for the Safety of Life at Sea, International Maritime Organization, London (1974).
[40] International Maritime Dangerous Goods Code, 2016 edn, International Maritime Organization, London (2016).
[41] International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Waste on Board Ships (INF Code), International Maritime Organization, London (1999).
[42] UNITED NATIONS, European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) including the Annexed Regulations, applicable as from 1 January 2011, Vol. 1, United Nations, New York and Geneva (2010).
[43] J/S ASPOL BALTIC CORPORATION, “Sea transportation logistics of spent nuclear fuel shipments” (IAEA Regional Workshop Russian Research Reactors Fuel Return Programme: Lessons Learned, Jackson Hole, WY, 2011).
[44] INTERNATIONAL ATOMIC ENERGY AGENCY, Hungary Completes High Enriched Uranium Research Reactor Fuel Removal (2013),
www.iaea.org/newscenter/news/2013/hungaryheu.html
[45] Convention concerning International Carriage by Rail (COTIF) Appendix C: Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), Intergovernmental Organisation for International Carriage by Rail, Berne (2015).
[46] Agreement on International Goods Transport by Rail (SMGS), Organization for Cooperation between Railways (2009).
[47] DOROFEEV, A., IVASHCHENKO, A., KOMAROV, S.N., KOMAROV, S.V., BARINKOV, O., “Multimodal shipments under program on Russian-origin research reactor SNF return to the Russian Federation” (Int. Symp. Packaging and Transportation of Radioactive Materials (PATRAM), San Francisco, CA, 2013).
[48] Customs Convention on the International Transport of Goods under Cover of TIR Carnets (TIR Convention), Economic Commission for Europe, New York and Geneva (1975).
[49] European Agreement concerning the International Carriage of Dangerous Goods by Road, Economic Commission for Europe, Geneva (1957).
[50] KOMAROV, S.V., KASHKIROV, S., NGUYEN NHI DIEN, MOSES, S.D., “Removal of research reactor spent fuel from Dalat nuclear research institute to the Russian Federation for reprocessing” (Int. Symp. Packaging and Transportation of Radioactive Materials (PATRAM), San Francisco, CA, 2013).
[51] United Nations Security Council resolution 1540, S/RES/1540, United Nations, New York (2004).
[52] Council Regulation (EC) No. 428/2009 of 5 May 2009 setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items (Recast), Official Journal of the European Union No. L134, Office for Official Publications of the European Communities, Luxembourg (2009).
[53] Convention on the Physical Protection of Nuclear Material, INFCIRC/274, IAEA, Vienna (1979).
[54] Treaty establishing the European Atomic Energy Community (Euratom) (1957).
[55] Commission Regulation (Euratom) No. 302/2005 of 8 February 2005 on the application of Euratom safeguards, Official Journal of the European Union No. L54, Office for Official Publications of the European Communities, Luxembourg (2005).
[56] Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, INFCIRC/336, IAEA, Vienna (1986).
[57] Convention on Early Notification of a Nuclear Accident, INFCIRC/335, IAEA, Vienna (1986).
[58] Vienna Convention on Civil Liability for Nuclear Damage, INFCIRC/500, IAEA, Vienna (1996).

[59] Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage, INFCIRC/566, IAEA, Vienna (1998).
[60] Convention on Third Party Liability in the Field of Nuclear Energy of 29th July 1960, as amended by the Additional Protocol of 28th January 1964 and by the Protocol of 16th November 1982, Organisation for Economic Co-operation and Development, Paris (1960).
[61] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2012 Edition, IAEA Safety Standards Series No. SSR-6, IAEA, Vienna (2012).
[62] KOMAROV, S.V., IVASHCHENKO, A., SAMSONOV, A., AMOSOV, A., "Preparation for transportation of damaged SNF from Serbian Research Reactor RA" (VII Int. Nuclear Forum ATOMTRANS-2012, St. Petersburg, 2012).
[63] Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel, Official Journal of the European Union No. L337/21, Publications Office of the European Union, Luxembourg (2006).
[64] Order of the Federal Environmental, Industrial and Nuclear Supervision Service of 15 September 2016 on the approval of Federal Rules and Regulations in the Atomic Energy Use "Safety Regulations during Transport of Radioactive Materials (NP-053-16)".
[65] GUIBERT, N., "The newest cask design for international shipments in support of research reactors and laboratories: TN-LC package", ENS RRFM 2013 (Trans, St. Petersburg, 2013), European Nuclear Society, Brussels (2013) 219–224
[66] SVOBODA, K., PODLAHA, J., SVITAK, F., "Russian research seactor spent nuclear fuel repatriation from the reactor country to the Russian Federation for reprocessing" (Proc. WM2014 Conf. Phoenix, 2014).
[67] INTERNATIONAL AIR TRANSPORT ASSOCIATION, Dangerous Goods Regulations, 58th edn, IATA, Montreal (2017).
[68] INTERNATIONAL ATOMIC ENERGY AGENCY, Return of Research Reactor Spent Fuel to the Country of Origin: Requirements for Technical and Administrative Preparations and National Experiences (Proc. Tech. Mtg, Vienna, 2006), IAEA-TECDOC-1593, IAEA, Vienna (2008).
[69] INTERNATIONAL ATOMIC ENERGY AGENCY, Experience of Shipping Russian-origin Research Reactor Spent Fuel to the Russian Federation, IAEA-TECDOC-1632, IAEA, Vienna (2009).
[70] INTERNATIONAL ATOMIC ENERGY AGENCY, Cleaning up Vinča: Completion of an eight-year project to secure Serbia's spent fuel, Fuel Cycle and Waste Newsletter **7** (2011).
[71] PEŠIĆ, M., ŠOTIĆ, O., HOPWOOD, W.H., Jr., Transport of high enriched uranium fresh fuel from Yugoslavia to the Russian Federation, Nucl. Technol. Radiat. Prot. **17** (2002) 71–76.
[72] INTERNATIONAL ATOMIC ENERGY AGENCY, Massive Operation Safely Secures Serbian Nuclear Fuel in Russia (22 Dec. 2010),
www.iaea.org/newscenter/news/massive-operation-safely-secures-serbian-nuclear-fuel-russia
[73] BARYSHNIKOV, M., et al., Repatriation of low enriched uranium spent nuclear fuel to Russia for reprocessing, Nucl. Environ. Saf. **2** (2013) 34–37.
[74] OHAYON, D., MARIETTE, L., "TN International Transport Issue: Supporting Non Proliferation Initiative", ENS RRFM 2006 (Trans 10th Int. Top. Mtg, Sofia, 2006), European Nuclear Society, Brussels (2006) 188–191.

ABBREVIATIONS

ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
ASN	Nuclear Safety Authority (Autorité de sûreté nucléaire)
BWR	boiling water reactor
CEA	French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives)
FRR SNF Acceptance Program	US Foreign Research Reactor Spent Nuclear Fuel Acceptance Program
FSUE Mayak PA	Federal State Unitary Enterprise Mayak Production Association
FTC	foreign trade contract
GTRI	Global Threat Reduction Initiative
HEU	high enriched uranium
HLW	high level waste
LILW	low and intermediate level waste
ISO	International Organization for Standardization
JIPNR	Joint Institute for Power and Nuclear Research
LEU	low enriched uranium
MTR	materials testing reactor
NNSA	National Nuclear Security Administration
NRC	United States Nuclear Regulatory Commission
PUREX	plutonium and uranium recovery by extraction
PWR	pressurized water reactor
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
Rosatom	State Atomic Energy Corporation Rosatom
Rostechnadzor	Federal Environmental, Industrial and Nuclear Supervision Service
RRRFR Programme	Russian Research Reactor Fuel Return Programme
RTR	research test reactor
SEP	special ecological programme
SFA	spent fuel assembly
SNF	spent nuclear fuel
TPS	transport packaging system
UC-C	universal canister of compacted waste
UC-V/U	universal canister of vitrified waste
USDOE	United States Department of Energy

CONTRIBUTORS TO DRAFTING AND REVIEW

Adelfang, P.	International Atomic Energy Agency
Arkhangelskiy, N.	State Atomic Energy Corporation Rosatom, Russian Federation
Baryshnikov, M.	Techsnabexport, Russian Federation
Bennett, P.	Institute for Energy Technology, Norway
Böck, H.	Technical University of Vienna, Austria
Bolshinsky, I.	Idaho National Laboratory, United States of America
Budu, M.E.	Sosny Research and Development Company, Russian Federation
Chiguer, M.	AREVA, France
Derganov, D.	Sosny Research and Development Company, Russian Federation
Diegelmann, C.	DAHER, Germany
Domingo, X.	AREVA, France
Dorofeev, A.	State Atomic Energy Corporation Rosatom, Russian Federation
Gusakov-Staniukovitch, I.	JSC Federal Center for Nuclear and Radiation Safety, Russian Federation
Ipatov, V.	State Atomic Energy Corporation Rosatom, Russian Federation
Ivashchenko, A.	Sosny Research and Development Company, Russian Federation
Iyer, N.	Savannah River National Laboratory, United States of America
Komarov, S.N.	Sosny Research and Development Company, Russian Federation
Komarov, S.V.	Sosny Research and Development Company, Russian Federation
Laloy, V.	AREVA, France
Lazarev, E.	Volga-Dnepr Airlines, Russian Federation
Leroy, J.-F.	AREVA, France
Marshall, F.	International Atomic Energy Agency
Mercier, V.	AREVA, France
Naletov, S.	ASPOL Baltic Corporation, Russian Federation
Novikov, A.	JSC Federal Center for Nuclear and Radiation Safety, Russian Federation
Podlaha, J.	ÚJV Řež, a.s., Czech Republic
Svitak, F.	ÚJV Řež, as., Czech Republic
Tozser, S.	International Atomic Energy Agency
Tschiesche, H.	DAHER, Germany

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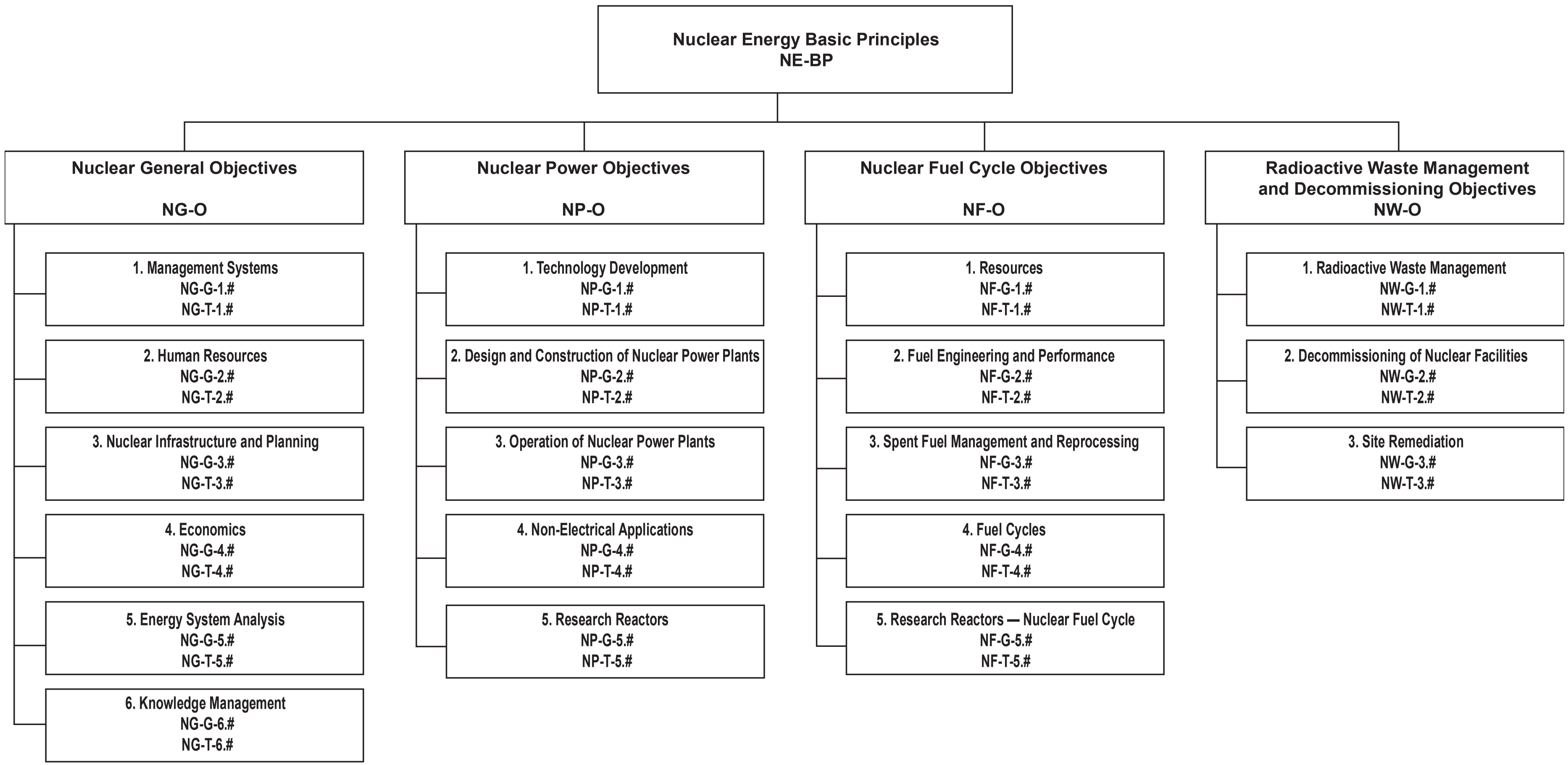

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