REPROCESSING OF RESEARCH REACTOR SPENT FUEL AND MANAGEMENT OF THE ARISING WASTE

X. DOMINGO, F. LEFORT-MARY, J.F. VALERY, V. VO VAN
AREVA NC
1 place Jean Millier, 92084 Paris La Défense Cedex - France

ABSTRACT

Considering the evolution of international and national regulations, and the increasing predictability requirements in spent fuel and radioactive waste management, the identification of a spent fuel management sustainable strategy is one of the major challenges nuclear reactor operators are facing today.

Many Research Reactor operators benefited from fuel return programs such as the US FRRSNF, including spent fuel reprocessing at DOE Savannah River Site. Reprocessing Research Reactor spent fuels provides substantial advantages in stabilization of the radioactive waste and materials on the long term. Waste management after reprocessing is one of the issues Research Reactor operators need to consider when establishing a long term strategy.

AREVA, as the world's nuclear fuel cycle services provider reference, assists its customers on identifying scenarios options and alternatives, safe and reliable technologies, sociopolitical and regulatory comprehensive approach for developing sustainable robust and valuable strategies for their spent fuel and waste management.

1. Introduction

According to the International Atomic Energy Agency (IAEA) Research Reactor Database, more than 60,000 spent fuels assemblies are currently stored in the 774 Research Reactors listed around the world and around 25,000 assemblies are loaded in their cores. A small percentage only is planned to be reprocessed for now, while most of them are wet stored waiting for a final and sustainable solution to be developed and implemented.

According to the World Nuclear Association (WNA), the main objective in managing and disposing of radioactive waste is to protect people and the environment, and in order to be sustainable, a management of spent nuclear fuel needs to:

- "Cover all the steps of spent fuel management until final disposal, in accordance with an

acceptable, practical plan;
- Prove to be feasible with an acceptable impact level by meeting defined key criteria;
- Include a realistic and balanced financing plan;
- Not impose undue burdens on future generations." [1]

Reaching the ending point of a nuclear waste management program can be very challenging considering the numerous issues that need to be addressed: technological feasibility, financial, safety, social acceptance and environmental preservation.

The aim of this paper is to support Research Reactor operators in finding and implementing a radioactive waste and material management program that is sustainable, complies with the national regulations and takes into account the international recommendations.

2. Used fuel and waste management: International regulatory environments

According to the WNA, there is a clear and unequivocal understanding that each country is ethically and legally responsible for its own waste. [2]

The IAEA provides countries with guidelines and good practices in order for them to establish and maintain a sustainable waste management program. To support this aim, the Joint convention on the Safety of Used Fuel Management and on the Safety of Radioactive Waste Management was signed in 2001. [3] It especially emphasizes on:
- each country's rights to reprocess their spent fuels abroad;
- each country's right to return the waste arising from reprocessing to the country of origin and
- the obligation for a country willing to receive foreign radioactive waste and materials to have the technical and administrative resources as well as the necessary regulatory structure to receive and manage them in compliance with the international regulations.

In the European Union, the directive EURATOM 2011/70 [4] is to ensure responsible and safe management of spent fuel and radioactive waste and to avoid imposing undue burdens on future generations. This Directive should be implemented by all Member States through a dedicated national regulation. It especially states that:
- long term storage is an interim solution but does not constitute the end point of a radioactive waste and materials management;
- high level waste (HLW) should be disposed in a deep geological disposal considered to be the safest and most sustainable option for reaching the end point of a radioactive waste and materials management;
- each country has the right to return the waste or an equivalence of the radioactive waste to the country client and
- the ultimate responsibility for the safe and responsible disposal of radioactive waste and materials sent for reprocessing remains with the country of origin. This condition on responsibility stresses the importance to have a final physically and chemically stable material to be disposed
- there is a ban for European countries on sending their radioactive waste and materials for storage or disposal to another country before the start of operation of the disposal facility. Even in case of a country using an existing and operating foreign disposal facility, the final responsibility of the waste or used fuel may remains with the generating country.
- each country is free to choose its fuel cycle policy but there is an obligation for them to:
    - establish a national legislative, regulatory and organizational framework for spent fuels and radioactive waste management;

- establish and maintain a competent and independent authority in the field of safety of spent fuel and radioactive waste management;
- ensure that the national framework require that adequate financial resources be available when needed for the implementation of national program, especially for the management of spent fuel and radioactive waste, taking due account of the responsibility of spent fuel and radioactive waste producer.

The classification of radioactive waste and the Waste Acceptance Criteria [5] play a crucial role in the process of implementing policies and waste management strategies. The waste classifications are all adapted from the IAEA's classification and allow the identification of waste categories which require specific considerations for conditioning, handling, transportation, storage, reprocessing and disposal; and the WAC is for assuring safe technologic procedures in all stages of radioactive waste lifecycle.

Spent fuels are considered to be HLW by the IAEA and the WNA, as well as most of the fission products separated during reprocessing. Then as seen above, both spent fuel (if directly disposed of) and waste arising from reprocessing of used fuel, if HLW, require disposal in deep geological facilities. [6] Apart from HLW, other types of waste are generated as a result of reactor operations, reprocessing, decontamination, decommissioning and other activities along the nuclear fuel cycle, and associated disposal conditions may be less constraining thanks to their lesser activity, thermal power and shorter lifetime.

3. Used fuel and waste management: Example of the French case

In France, the Act No.2006-739, dated 28 June 2006, on the Sustainable Management of Radioactive Materials and Waste and the Decree 2008-209, dated 3 March 2008, define how the used fuel management has to be conducted. For foreign spent fuel or waste management, the laws stipulate that:

- No spent fuel or radioactive material shall be introduced in France except for processing, research or transfer between foreign countries;
- The disposal in France of radioactive waste from abroad and that of radioactive waste resulting from treatment of spent fuels and of radioactive waste from abroad is forbidden;
- Any introduction of such spent fuel or radioactive waste shall only be authorized pursuant to intergovernmental agreements which include:
  - the tentative reception and processing schedules,
  - the latest date at which the residual radioactive waste resulting from processing will be sent out of France,
  - if need be, any prospect relating to the further use of radioactive materials partitioned during the processing;
- All operators ensuring (or planning to ensure) the processing of spent fuel or radioactive waste originating from France or from abroad shall implement systems to manage the allocation of the resulting processing waste according to types (waste to be shipped abroad and waste requiring long-term management on French territory) and to allocate the correct share to each party concerned.

Compliant with the directive EURATOM 2011/70 and the 28 June 2006 Act No.2006-739, the AREVA La Hague accountancy system (EXPER system) is used to determine the waste equivalence in order to allocate the waste shares to the reprocessing customers.

The equivalence is determined based on two units being the residue activity unit (UAR) based on neodymium content, and the residue mass unit (UMR) based on weight of non-soluble metallic structural components of the spent fuel. The UAR and UMR are credited into accounts at the time of reprocessing independently of any conditioning of the waste. They are then debited from the accounts at the time of expedition of the residues from La Hague and the incoming activity is considered to be returned to the country of origin when both UMR and UAR accounts are set to zero.

4. Spent Fuel management strategies

Operators of Research Reactors could imagine five options for managing their spent fuels.

The storage of the spent fuels in dry or wet facilities does not constitute a sustainable strategy according to the directive EURATOM 2011/70, or other international guidelines, as it is an interim solution that does not include any final disposal plan.

The direct final disposal of the spent fuels is not an option. Indeed, no facility could technically accommodate the spent fuels without any form of conditioning. There is an international consensus on this point.

Encapsulating or conditioning the spent fuels before disposal in a final repository is not an option available for now as this technology has not been proven yet. However, if developed, the encapsulation of the spent fuels may not be a preferred option for Research Reactor spent fuel management, as it does not reduce neither the volume nor the radiotoxicity of the final waste, does not avoid IAEA safeguards, and may not allow a predictable behavior of the waste in the long term. Moreover, this option is not conceivable for damaged fuels.

The spent fuel Take-Back Policies without residue return, such as the American or Russian program has been an option largely used by Research Reactors. These programs, run in a non-proliferation objective, are available and or limited to Research Reactors operators depending on their countries, type of fuel, enrichment, origin… The US Take-Back policy ended in May 2016 and returns are still possible until 2019, Japan being the only country to benefit from a 10 years extension. For now, the Russian program remains available for Russian origin fuels and no deadline has been communicated yet. From a Research Reactor operator perspective this option can be seen as attractive because they transfer the final disposition responsibility to the corresponding country. Nevertheless, according to the international recommendations, the ethical and legal responsibility of safely disposing the radioactive waste remains with the country of origin (i.e. where the fuels have been used). These countries should then ensure that there is a clear final disposition plan encompassing a technologically available option for their spent fuels, meaning one of the two possible strategies, the once-through fuel cycle with conditioning before disposal and the closed fuel cycle with reprocessing.

Reprocessing the spent fuels is an option available and used by several countries such as France, the UK, Japan, Australia, Belgium, USA, Germany, Netherlands, Italy... This process allows separating the fission products and the structural parts (final waste) and the uranium and plutonium (reusable materials). The final waste is conditioned into Universal Canisters specifically designed for optimized final disposal while the valuable materials can be reused to manufacture nuclear power fuels.
Reprocessing nuclear spent fuels provides substantial advantages in managing the radioactive waste and materials on the long term. Indeed, the volume and radiotoxicity of the final waste is reduced, compared with the storage of unprocessed spent fuels, the waste can be transported in

complete safety and is packaged in a way that it has been designed and manufactured to be standardized, safe and stable for thousands of years and exempted of IAEA safeguards. Therefore, reprocessing contributes to nuclear waste management sustainability through clear predictability on the costs and risks reduction, by providing a proven and industrialized option for stabilization of waste, waiting for disposal.

The available spent fuel management strategies are summarized in Fig. 1 below.

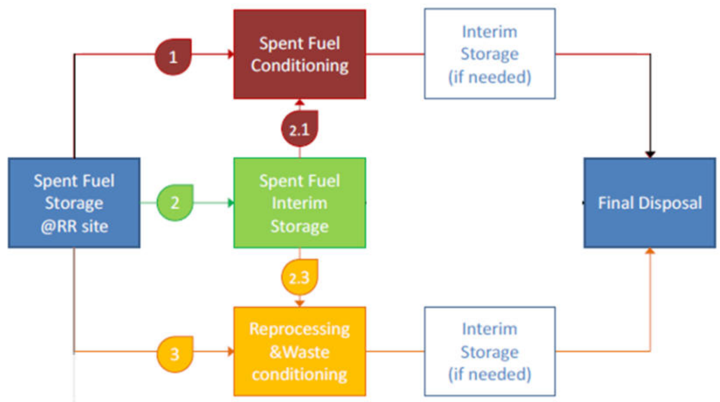

Fig 1. Two available strategies for management of RRSF

Among all Research Reactor spent fuel management strategies, the ones integrating reprocessing as one option are currently the only that allow Research Reactor operators to cover all the steps of radioactive waste management until final disposal of HLW on a sustainable way.

5. Spent Fuel Reprocessing and Residues Management Options

Since early 1990's, AREVA has been transporting, unloading, storing and reprocessing around 5,500 Research Reactor used fuel assemblies (transported in about 150 casks) in its French facilities and with its equipment. The La Hague plant obtained its first authorizations for receiving and unloading foreign Research Reactor used fuel in the late 1990's.

Following spent fuel reprocessing operations at La Hague, the radioactive residues are conditioned in Universal Canisters (UC), this conditioning being the same for waste arising from reprocessing of both Research Reactor spent fuel and power reactor used fuel (see Fig. 2):

- the fission products and minors actinides are vitrified in a homogeneous glass matrix in a UC (UC-V or UC-U, with much lower fission products concentration leading to much lower thermal power than UC-V); this type of conditioning is very stable and ensures containment over thousands of years
- as the case may be (but rarely concerning Research Reactors) structural waste coming from non-soluble-cladded fuels are compacted and conditioned in Universal compacted residues Canister (UC-C) with the same external geometry as UC-V/U.

UC allow for an easy transport of the radioactive residues, easy on-site handling conditions, minimization of handling and transportation means thanks to standardization, volume saving in storage/disposal facilities, high stability of the residues demonstrated for the very long term, exemption of IAEA safeguards and rationalization of the ultimate waste policy through standardized type of waste. For example, residues arising after Research Reactor spent fuel reprocessing can be managed along with the greater UCs stream resulting from power reactors spent fuels reprocessing (e.g. Belgium).

Fig 2. Universal waste Canisters for waste arising from spent fuel reprocessing
Left: UC-V/U; Right: UC-C

After conditioning, the different stages of residual waste management are as described in the following.

5.1. Waste allocation

Use of EXPER system for waste allocation
The types and quantities of UC are allocated to the reprocessing customer using the EXPER accountancy system (see 3).

Use of alternative waste equivalency systems
Other accountancy systems than EXPER may be considered by Research Reactor operators in order to determine further equivalence criteria than the waste mass and activity, being understood that the chosen system needs be compatible with EXPER.
For instance, the Integrated Toxic Potential (ITP) [7] is a methodology developed by UK INS in order to establish an equivalency between two waste streams based on the radiological toxic potential of the waste integrated over a period of years. The ITP has been approved by the national regulatory authorities of several countries, such as the Netherlands, Germany, Japan, Italy…
Depending on the country regulation and specificities, Research Reactor operators could highly benefit from a range of residue type options, seeking for harmonized final waste inventory to be

disposed of which results in simplified handling operations and disposal estimated cost reduction.
AREVA as an experienced waste management solution provider is ready to help its customers implementing such solutions.

5.2. Logistics solution

In case of spent fuel from abroad, the residual waste needs to be shipped out of France, using proven casks solutions adapted to large quantities or casks solutions optimized for small quantities.

Solutions adapted to large quantities of waste
Proven solutions for such shipments are based on use of AREVA casks like the TN®28 transportation cask or the TN®81 transportation and storage cask. The TN®28 is already licensed and regularly used in France, Great Britain, Belgium, the Netherlands, and in Japan while the TN®81 is licensed in France, Switzerland, Australia, Spain, and in the United Kingdom, and has already been used in Switzerland, and in Australia late 2015 for ANSTO residues return after HIFAR's spent fuel reprocessing. [8]

Solutions adapted to small quantities of waste
For management of small quantities of waste, the TN®MW cask [9] is an optimized solution. It is a triple purpose cask designed for waste packaging, transportation and long term storage. This light cask is adapted for a large variety of waste (type, volume and activity from LLW to HLW), can be wet or dry loaded/unloaded, and is easy to handle. The fabrication, licensing and delivery of the first TN®MW casks are scheduled for 2017. This first TN®MW casks version is a B(U)F type cask dedicated to fissile materials transportation and storage. Other TN®MW casks models are currently under development, one of which being adapted for transportation and storage of small quantity of residues arising from reprocessing (see Fig. 3).

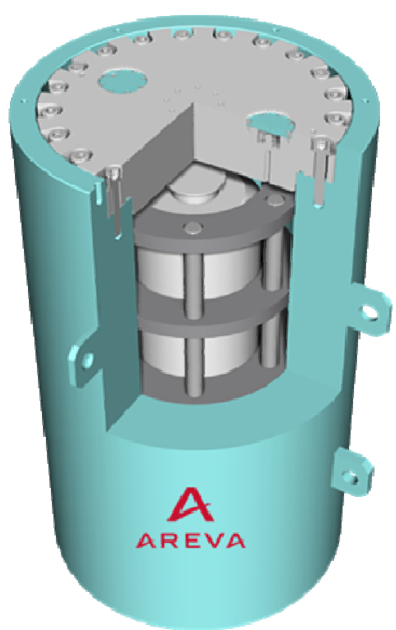

Fig. 3 TN®MW cask design adapted for transportation and storage of one Universal waste Canister

This cask provides Research Reactor operators with solutions for packaging, transportation and long term storage of UC-C, UC-U and potentially other types of waste. It is not adapted to UC-V due to their high thermal power; however, in the case of a return of a small quantity of residues, the return of UC-U is anticipated to be considered as the best option.

5.3. Shipment

In case of spent fuel from abroad, the post-repocessing residues are sent out of France.

Return to the country of origin
After reprocessing, the residues are sent out of France, usually back to the country of origin.
For instance, UC-U were returned in 2015 to Australia in a single TN®81 cask after ANSTO's HIFAR Research Reactor used fuels reprocessing in AREVA La Hague. Australia does not have any nuclear power plant and no HLW to manage, this option has thus been chosen as the Australian waste classification determines UC-U to be ILW, and therefore their management required less investment in comparison with the disposal of HLW. The TN®81 is currently stored at ANSTO in a dedicated facility while a national radioactive waste repository is under studies. "The return of the residues has been an excellent exercise in demonstrating to the Australian public that the waste arising from the long term operation of a reactor can be managed in a safe, secure and effective manner." [8]

A regional or international radioactive waste repository
One of the biggest issues within Research Reactor spent fuel management strategy identification lies on final disposition solution uncertainties.
As encouraged by the IAEA [10], centralized or international radioactive waste repository has considerable advantages in terms of management, cost reduction, safety, security and non-proliferation compared to smaller local repositories. However, such a project represents a real challenge in terms of regulations compliance, safeguards standard, business model definition, public acceptance, environmental impact…
For instance, Australia is currently tackling this challenge as in May 2016, the South Australian Nuclear Fuel Cycle Royal Commission expressed their aspiration to be involved in the nuclear fuel cycle through the establishment of an international repository for radioactive waste. This project is currently in a phase of public consultation and business model definition. As stated in the Royal Commission Final Report, the geologic repository could enter into operation 28 years after final investment decision in the project.
Other projects are considered worldwide such as the European Repository Development Organization (ERDO), gathering 14 European countries, South East Asian or Gulf initiatives.
Nevertheless, there is an international consensus on the need for each country to define their own national program notably reducing risks and cost uncertainties even if international or regional repositories projects move forward. [11]
Residues from reprocessing conditioned in UC have the advantages of being stable, standardized, exempted of IAEA safeguards, and of having their volume reduced compared to spent fuels. These characteristics greatly facilitate public acceptance with regard to repository implementation. Therefore, spent fuel reprocessing minimizes the risk of noncompliance with the Waste Acceptance Criteria of the future disposal facility, facilitating the availability of the possible international or regional disposal option, making the spent fuel management strategy even more sustainable.

5.4. Storage and/or disposal

The final stage of residues management is the disposal (with possible prior long-term storage) in a dedicated facility in compliance with international and national regulations.

6. Conclusion

Considering the evolution of international and national regulations, and their request for clarification of used fuel and radioactive waste management, the identification of a used fuel management sustainable strategy is one of the major challenges nuclear reactor operators are facing today.

A sustainable management path for such material implies a set of different options, from on-site management to final disposal facility, encompassing transportation, storage or reprocessing activities.

Reprocessing option offers a set of solutions for waste selection, transportation, storage and disposal, adapted to each country situation, thus strongly contributes to its used fuel management strategy sustainability. These options considerations become critical for countries managing small inventories of used nuclear fuel.

AREVA, as a nuclear fuel cycle service provider reference, assists its customers on identifying scenarios options and alternatives, safe and reliable technologies, sociopolitical and regulatory comprehensive approach for developing sustainable robust and valuable strategies for their used fuel and waste management.

7. Acronyms

EXPER	Waste shipping system (*EXPEdition des Résidus*)
FRRSNF	US Foreign Research Reactor Spent Nuclear Fuel acceptance program
HLW	High Level Waste
ILW	Intermediate Level Waste
ITP	Integrated Toxic Potential (waste equivalence system)
UAR	Activity unit for waste (*Unité d'Activité de Résidu*)
UC	Universal waste Canister
UC-C/U/V	Universal waste Canister, compacted/U vitrified/vitrified type
UMR	Mass unit for waste (*Unité de Masse de Résidu*)
WAC	Waste Acceptance Criteria

8. References

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