RERTR 2016 – 37TH INTERNATIONAL MEETING ON REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

OCTOBER 23-27, 2016
RADISSON BLU ASTRID HOTEL
ANTWERP, BELGIUM

Reprocessing of Research Reactor Spent Fuel and Management of the arising waste

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ABSTRACT

Considering the evolution of international and national regulations, and their request for clarification of spent fuel and radioactive waste management strategy, the identification of a spent fuel management sustainable solution is one of the major challenges nuclear reactor operators are facing today.
Many Research Reactor operators benefited from the fuel return program 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 a 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 in storage in the 774 Research Reactors listed around the world and around 25 000 assemblies are charged 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. 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 in order to achieve and maintain a high level of safety worldwide.[3] This Joint Convention emphasizes on each country's rights to reprocess their spent fuels abroad, on each country's right to return the waste arising from reprocessing to the country of origin and on 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 emphasizes on the fact that long term storage is an interim solution but does not constitute the end point of a radioactive waste and materials management; and that high level waste should be disposed in a deep geological disposal as it is the end point of a radioactive waste and materials management and considered to be the safest and most sustainable option. The directive states that each country has the right to return the waste or an equivalence of the radioactive waste to the country client and that 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.

The Directive also states that 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.

Finally, according to the directive, 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.

At a national level, each country is responsible of implementing a radioactive waste and materials management program, national policies and regulators. In most of the countries with large nuclear program, we can identify several roles to be assumed, such as: safety bodies (regulatory, technical, and operational), an agency responsible for the radioactive waste management, nuclear-specific law makers, etc. The amount and interdependence of entities assuming these roles can strongly vary from a country to another.

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 that each requires specific considerations and requirement 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 high level waste by the IAEA and the WNA, as well as most of the fission products separated during reprocessing. According to these instances, waste arising from reprocessing of used fuel, if HLW, requires disposal in deep geological facilities providing sufficient isolation and containment over long periods [6] because geological disposal is considered to be the only way of ensuring adequate safety and security in the long term management of HLW. 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 the disposal conditions required mays be less constraining due to their lesser activity, thermal power and shorter lifetime.

3. Example of the French case

Having 58 nuclear reactors providing three quarters of its electricity, one under construction, thirteen reactors shut down, three under dismantling and a reprocessing policy of spent fuels, France early expressed the need to establish clear and strict nuclear safety regulations for radioactive waste management. 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 reprocessing, 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 and provided that no residual radioactive waste resulting from the processing of such substances shall be stored in France beyond the term prescribed by such agreements. The agreements shall include the tentative reception and processing schedules for such substances and, if need be, any prospect relating to the further use of radioactive materials partitioned during the processing. The text of such intergovernmental agreement shall be published in the *Journal Officiel*;

- 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.

The AREVA NC La Hague accountancy system is the EXPER system used to determine the equivalence of waste that needs to be returned to the country of origin after reprocessing. This system of allocation of radioactive waste from reprocessing is compliant with the European directive EURATOM 2011/70 and the 28 June 2006 Act No.2006-739.

The equivalence is determined based on two units being the residue activity unit (UAR, *unite d'activité résiduelle*) based on neodymium content (in dg, because it is a representative indicator that can be effectively measured), and the residue mass unit (UMR, *unite de masse résiduelle*) based on weight of metallic structural components of the spent fuel (in kg). 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 neutrons 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.

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

5. Spent Fuel Reprocessing and Residues Management Options

Over the past decades, AREVA has been transporting, unloading, storing and reprocessing Research Reactor used fuel in its French facilities and with its equipment: since early 1990’s, around 150 MTR-type Research Reactor used fuel transportation casks have been transported to AREVA NC La Hague. The AREVA NC La Hague plant obtained its first authorizations for receiving and unloading foreign Research Reactor used fuel in the late 1990’s. Ever since and to date, around 150 Research Reactor used fuel transportation casks have been received and unloaded at AREVA NC La Hague, corresponding to around 5 500 Research Reactor used fuel assemblies.

The different stages of a spent fuel management strategy including AREVA NC’s reprocessing services are as follows:

- **On-site interim storage** in case of need
- **Preparation** for shipment of the spent fuel
- **Transportation** of the spent fuels from the Research Reactor to the AREVA NC La Hague Facility using AREVA TN transportation cask, such as the TN®MTR
- **Interim Storage** of the spent fuel elements in AREVA NC La Hague pool, waiting for their reprocessing
- **Reprocessing** of the spent fuels, using the dedicated process. The valuable fission products and minor actinides are separated from the uranium and plutonium which are recovered and recycled into nuclear power fuels.

- **Conditioning** of the radioactive residues in Universal Canisters. The fission products and minors actinides are vitrified in a homogeneous glass matrix and conditioned in Universal vitrified residues Canister (UC-V or UC-U). 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.

  Universal Canisters allow 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.

- **Allocation** of the UC to the client using the EXPER accountancy system described in section 3.

- **Return** (in case of spent fuel from abroad) of the radioactive residues to the country of origin. 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.

- **Storage and/or disposal** of the residues in a dedicated facility in compliance with international and national regulations.

6. Alternative Residues Management Options

The comprehensive domestic residues management is mainly affordable for countries with an industrial-scale civilian nuclear power industry and/or with large scaled spent fuel management plans:

- Either they have defined comprehensive national radioactive waste management program including reprocessing after nuclear power generation, and the returned UCs after Research Reactor spent fuel reprocessing are managed along with the greater UCs stream returned from power reactors spent fuels reprocessing (e.g. Belgium);

- Or they already are implementing a clear and sustainable long term strategy for their Research Reactor spent fuel, with the help of foreign industrial partners (e.g. Australia).

However, these technical options cannot be implemented or may not be adapted for all Research Reactor spent fuel management strategies in certain circumstances such as: difficult waste management caused e.g. by public acceptance issues causing delays in the implementation of a disposal solution. In such cases, reprocessing could be disregarded at first glimpse because:

- The quantity of residues to be managed to disposal is too small to motivate the use of a heavy dual-purpose cask;

- Or the quantity or type of residues is not adapted to motivate the implementation of a final disposal facility for radioactive waste after reprocessing.

In order to tackle with these waste management issues after reprocessing, and consequently allow the corresponding countries benefit from reprocessing advantages as part of their Research Reactor spent fuels management strategies, alternative waste management routes and options can be considered, described in the following.

6.1. The return of other types of residues

As mentioned, international recommendations such as the Joint convention and the European Directive EURATOM 2011/70 state that each country is ethically and legally responsible for its own radioactive waste. European Directive notably states that the ultimate responsibility for the safe and responsible disposal of radioactive waste and materials sent for reprocessing remains with the country of origin.

By French Law, the mass and activity of nuclear spent fuels imported to AREVA NC La Hague facility have to be sent out of the French Territory after reprocessing and EXPER is the accountancy system used to attribute a number of UMR and UAR to be sent out of the country at the de-storage of the waste at La Hague site.

- **Waste forms adaptation in France**

Vitrified UC are currently used to return UAR, mainly under UC-V form for large amounts of activity, but UC-U are also compliant with the EXPER accountancy system for returning the activity. They have the exact same external characteristics but the concentration of fission products is highly inferior in UC-U than in UC-V which results in a much lesser thermal power and UAR content. Aside from that, UC-U provides the same advantages as UC-V, being an exemption of IAEA safeguards, a predictable long term behavior of the waste, and a reduced volume compared to the spent fuels. Due to its lower activity, UC-U can be classified as ILW depending on national radioactive waste classification.

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 NC La Hague (pictures in paragraph 4.3). 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." [7]

UC-C is currently the only type of residues being compliant with the mass unit to be returned (UMR).
However, as La Hague Facility implements other types of waste conditioning, other types of residues may be considered to return the activity and the mass instead of compacted (UC-C) and/or vitrified (UC-V or UC-U) Universal Canisters.

- **Other types of waste equivalency**

The EXPER accountancy system used at La Hague is compliant with the Joint Convention, the European Directive and the French regulations. Other accountancy systems exist and may be considered by Research Reactor operators in order to determine further equivalence criteria than the waste mass and activity. For reprocessing in France, this equivalency system must be compatible with the EXPER system in order to be considered for waste calculation.

For instance, the Integrated Toxic Potential (ITP) [8] 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 Integrated Toxic Potential 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. Indeed, other types of residues could potentially allow an easier management at each stage of the waste management (transport, storage and disposal), require less regulatory constraints, resulting in a reduction of the final disposal estimated cost.

AREVA NC as an experienced waste management solution provider is ready to help its customers implementing such solutions.

6.2. A solution adapted to small waste quantities

AREVA TN has developed the TN®81 and TN®28 casks for transportation of large radioactive waste quantities. These casks are currently used but may not be adapted to the return or storage of small quantities of radioactive residues.
An alternative residues management solution would therefore be the return of the radioactive residues under the same conditions, but using an individual cask adapted to small waste quantities.

The TN®MW cask [9] 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. According to the country regulation, the TN®MW casks can then be stored in a simple storage hall without any additional specific radioprotection measure for up to 50 years and without any maintenance in normal conditions. The fabrication, licensing and delivery of the first TN®MW casks are scheduled for 2017. This first TN®MW casks version will be 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.

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. The TN®MW cask 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.

After storage, Research Reactor operators remain responsible for the safe final disposal of the waste. The combination of reprocessing option and TN®MW cask solution provides cost certainty and operations flexibility until a final disposition solution is identified.

6.3. A regional or international radioactive waste repository

As mentioned in section 2, the Joint Convention states that it is an 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.

As of today, one of the biggest issue 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. This option would also highly benefit countries either unable, or unwilling, to implement a local repository for radioactive waste, especially for ILW or HLW.

However, establishing a regional or international repository 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, international nuclear community agrees on that "*National programs are high priority and it is important that exploring the multinational repository concept not impact them negatively. Further development of the multinational repository concept should not wait for the completion of national programs, but it is clear that progress will depend on the success of national programs*." [11] This implies that even if international or regional repositories projects move forward, countries should define their own national program notably reducing risks and cost uncertainties.

Residues from reprocessing conditioned in Universal Canisters 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. They do not only simplify the management of the residues until the availability of the disposal, but also provide certainty to the Research Reactor operators that the residues will not deteriorate until then. 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.

7. 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 management.

8. References

[1] World Nuclear Association website: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-waste-management.aspx

[2] World Nuclear Association website: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/international-nuclear-waste-disposal-concepts.aspx

[3] The Joint convention on the Safety of Used Fuel Management and on the Safety of Radioactive Waste Management entered in force on June 18, 2001.

[4] Council Directive 2011/70 EURATOM "Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste", July 19, 2011.

[5] "Classification of Radioactive Waste – General Safety Standards No. GSG-1", IAEA Safety Standards, Vienna, 2009.

[6] Lumir Nachmilner "Waste Acceptance Criteria for Radioactive Waste – A New IAEA Document", IAEA/DBE Tech. International Workshop on Waste Acceptance Criteria for Disposal of Very Low and Low Level Waste, Peine, Germany, September 28-30, 2010.

[7] R. Finlay, X. Domingo, "Australian Research Reactors Spent Fuel Management: The Path to Sustainability", RRFM, ANSTO, AREVA NC, 2016.

[8] DR. G. Varley, M. Kennard, "Review and Audit Report on Proposed Implementation of Radioactive Waste Substitution Arrangements Related to British Nuclear Group Overseas Reprocessing Contracts", NAC Worldwide Consulting for Nuclear Decommissioning Authority, United Kingdom, New York, USA, September, 2006.

[9] F. Lefort-Mary, G. Clement, "An Optimized Cask Technology for Conditioning, Transportation and Long Term Interim Storage of "End Life Nuclear Waste"", RRFM IGORR, AREVA, 2016.

[10] World Nuclear Association website: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/international-nuclear-waste-disposal-concepts.aspx

[11] M. Scott "International Framework for Nuclear Energy Cooperation (IFNEC) Status of reliable nuclear fuel services working group activities on multinational repository concept", USA DOE, Asia Nuclear Business Platform, China, May, 2016.