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# Overview on RRSF reprocessing, from spent fuel transportation to vitrified residues storage

J.F. VALERY, X. DOMINGO, P. LANDAU
AREVA NC, 1 place Jean Millier, 92084 Paris La Défense Cedex – France

M. LAUNEY, P. DESCHAMPS, C. PECHARD
AREVA NC La Hague, 50440 Beaumont-Hague – France

V. LALOY, M. KALIFA
AREVA TN, 1 Rue des Hérons, 78180 Montigny-le-Bretonneux – France

## ABSTRACT

AREVA has long experience in transportation and industrial-scale reprocessing of RR UAl spent fuel. Over 23 tons of RR UAl type fuels have been reprocessed at AREVA's facilities in France, both in Marcoule and La Hague plants. Furthermore, More than 100 RR fuels transportations per year are carried out by AREVA (for fresh and spent fuels). Benefiting from its past experience, AREVA proposes to detail in pictures all the stages of a (Research Reactor Spent Fuel) RRSF reprocessing from its evacuation from reactor site to its corresponding post-reprocessing vitrified waste production and management. In order to comply with its customers growing needs in terms of RRSF management, AREVA is also developing new RRSF reprocessing capacities in the La Hague UP2-800 facility based on the same process principles. This new TCP facility is planned to reprocess several types of RRSF including both UAl and $U_3Si_2$ RRSF.

## 1. Introduction

Reprocessing is one of the today-available options for managing back-end of Research Reactor fuel cycle. As described in figure 1 below, this solution offers to RR:

- Non-proliferation: reducing $^{235}U$ enrichment of RRSF from 20-93% to below 2%,
- Final waste management optimization: standardizing final waste package and reducing volume and radio-toxicity, removing IAEA safeguards on final waste,
- Sustainability of RRSF back-end management: long-lasting solution, re-use of valuable material for civilian purposes i.e. saving natural resources, cost-certainty, cost effective solution,….


Fig. 1: RRSF reprocessing basic scheme and advantages

Over the past decades, AREVA has been transporting, unloading, storing and reprocessing RRSF in its French facilities and with its equipment.
This article encompasses pictures and figures for each step of reprocessing operations by AREVA, especially in regards to transport to and reprocessing at the AREVA La Hague site.

## 2. Transportation of RRSF to La Hague

Since early 1990's, around 150 MTR-type RRSF transportation casks have been transported to AREVA La Hague.

### 2.1. Types of transportation cask

The first high-capacity RRSF transportation cask used by AREVA (Cogema Logistics at that time) was the IU04 cask. As of today, AREVA proposes to its customers to use the TN-MTR transportation cask for MTR-types of RRSF, especially for transportation to the La Hague site.
This cask can contain several types of basket, generic or specialized according to the RRSF.
This cask offers the highest RRSF transportation capacity worldwide, with a 68-positions basket.
The TN-MTR cask can be loaded at RR site either under water or using a dry transfer system from pool to cask.

Fig.2: TN-MTR wet loading at RR site

Fig.3: Transfer system for loading TN-MTR at RR site

AREVA can also propose other types of multi-purpose transportation casks, even adapted for non-MTR-type RRSF. As an example a new package, which fabrication will be completed by mid-2015, will be proposed by AREVA: the TN-LC package [1].

Fig.4: View of TN-LC transportation cask

Other casks can be considered for transportation of RRSF to AREVA La Hague, after investigating the following:
- Transportation license from RR site to La Hague (i.e. French transportation license, license in the RR country, and all countries involved in this transportation),
- Receipt and unloading at La Hague (see paragraph 3.2. below).

### 2.2. RRSF transportation experiences

As mentioned before, around 150 MTR-type RRSF transportation casks have been transported to AREVA La Hague up to now.
AREVA has acquired this long-term international experience through multi-modal transportations: maritime, rail and road transportations (see Fig.5 & 6).

Fig.5: RRSF transportation on boat

Fig.6: TN-MTR on a truck

AREVA has notable RRSF transportation experiences in the following countries: Australia, Belgium, Denmark, France, Indonesia, Italy, Portugal, Sweden, Taiwan, United States of America, Uruguay and Venezuela.

## 3. Receipt and unloading of RRSF at AREVA La Hague

The AREVA La Hague plant obtained its first authorizations for receiving and unloading RRSF in the late 1990’s.
Ever since and until end-of 2014, around 150 MTR-type RRSF transportation casks have been received and unloaded at AREVA La Hague, corresponding to around 5 250 MTR-type RRSF assemblies.
As mentioned before, the transportation casks used for these receipts at La Hague were the IU04 and now the TN-MTR.
But RRSF are not only MTR-type of spent fuels. Thanks to the flexibility of its receipt-workshops, AREVA is also able to receive other types of RRSF, and other types of RRSF transportation casks.

### 3.1. Receipt of transportation casks at the AREVA La Hague site

At their arrival at the La Hague site (see Fig.7), and before unloading, the RRSF transportation casks are temporarily stored for a few days.
At its arrival, the transportation truck is controlled for exterior and interior contamination (see Fig.8), before control of the transportation cask itself (see Fig.9).
In preparation for unloading the cask is lifted and handled in a preparation hot-cell, next to the unloading pool (see Fig.10).
After additional controls, and notably internal sipping tests on the cask in order to detect any nuclear material leakage from RRSF assemblies, the transportation is wrapped in plastic sheet (to prevent the body of the cask from possible contamination during unloading, and consequently to facilitate the preparation of the next shipment), and moved from the preparation cell to the unloading pool (see Fig.11).

Fig.7: Truck with RRSF transportation cask arrival at AREVA La Hague


Fig.8: Control on RRSF transportation truck at AREVA La Hague

Fig.9: Radiological control on RRSF transportation cask, without shock absorber

Fig.10: Cask handling to the preparation cell, before unloading

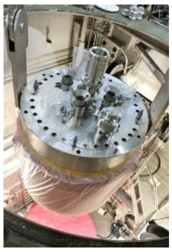

Fig.11: Cask handling from preparation cell, to unloading pool

### 3.2. Wet unloading of RRSF

Until 2015, the MTR-type RRSF transportation casks are unloaded in the pool HAO-Nord. Starting 2016, RRSF transportation casks will be unloaded in the NPH (Nouvelle Piscine de la Hague) pool.
Thanks to its flexibility, the NPH pool workshop and related tools can be adapted to a wide range of transportation casks. For example, the TN-17/2 cask, used for Fast Reactor spent fuel transportation, is also unloaded in NPH pool.
Nevertheless, in case a new cask needs to be received at La Hague, feasibility studies, a safety report application to Safety Authority /authorization, design and fabrication of new equipment and possible modifications to the workshop are necessary.

After introduction of the transportation cask in the pool (see Fig.12) the top-lead of the cask is removed in order to access to RRSF. All the handling operations during unloading are performed manually, by AREVA operators (see Fig.13), but are controlled by automatism and Instrumentation & Control.

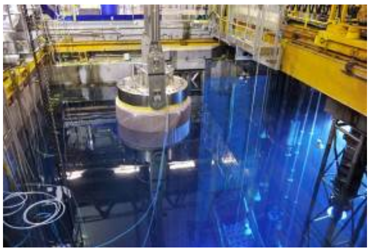

Fig.12: RRSF transportation cask introduction in HAO pool

Fig.13: La Hague operator handling RRSF in HAO pool

The RRSF are handled from the transportation cask to an intermediate unloading-basket, and then in a position into the interim-storage basket (see Fig. 14) to be transferred in the pools dedicated to wet interim storage (see Fig. 15), before reprocessing.

Fig.14: The baskets used for RRSF transfer to wet storage

Fig.15: RRSF storage-basket transfer to wet storage

## 4. RRSF wet interim storage at AREVA La Hague

Taking into account (i) the time needed for cooling down the RRSF, (ii) industrial reprocessing scheduling of the La Hague plant and (iii) regulatory and legal obligations related to safety authorizations and intergovernmental agreements, RRSF are stored in the La Hague storage pools for some months/years (see Fig. 16) before transfer to reprocessing facilities.

Fig.16: La Hague wet storage “piscine C”

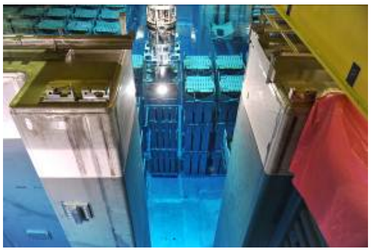

Fig.17: RRSF storage-basket transfer to reprocessing

RRSF storage uses La Hague-standard types of baskets with dedicated inners, adapted to each type/category of RRSF.

Several designs and fuel-types of MTR RRSF are stored in La Hague pools, but other RRSF than MTR-type can be stored, if the corresponding authorization is delivered by the French Safety Authority, after review of the receipt-storage-reprocessing-related safety file.
Depending on the RRSF type, the storage capacity of one basket varies up to more than 60 fuel elements.
After storage, RRSF are transferred to the reprocessing facilities. The first operation is to bring the storage basket (see Fig. 17) to a dedicated workshop to transfer the RRSF from the storage basket to a shuttle-basket, this operation being performed by an AREVA operator (see Fig. 18). After this transfer, RRSF in shuttle basket is ready to be sent to the dissolution facility (see Fig. 19).

Fig.18: RRSF transfer from storage to shuttle basket

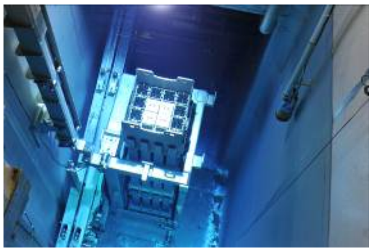

Fig.19: RRSF shuttle basket ready to go dissolution facility

**5. RRSF reprocessing operations**

**5.1. Current reprocessing operations**

From the interim wet storage pool to the dissolution facility (T1 facility in La Hague UP3 reprocessing plant), the transfer of RRSF is performed with a shuttle basket.
The RRSF is inserted one by one from the storage area to the dissolution area through the "insert-cisaille" gate (see Fig.20). The RRSF is then placed into a dedicated canister, positioned on a rack, waiting for dissolution (see Fig.21). All these operations are performed by operators with dedicated cranes and tele-manipulators (see Fig.22).

Fig.20: video of RRSF *going* through the "insert-cisaille" gate

Fig.21: RRSF-canister 12-positions rack in dissolution cell

Each canister is then positioned on the top of the dissolution pit (see Fig. 24). The RRSF are then loaded in the dissolution pit one by one by directly dropping them in the boiling nitric acid.

Fig.22: operator handling RRSF
with tele-manipulator

Fig.23: RRSF canister on top of
the T1 dissolution pit

The dissolution process is the same for UAl-type and USi-type of RRSF, and is controlled thanks to a dedicated camera placed on the top of the dissolution pit. The dissolution process is over once the RRSF totally disappeared from the pit (see Fig.24 & 25).


Fig.24: RRSF being dissolved


Fig.25: Dissolution pit empty

However, after the dissolution step and prior to the mix with the LWR dissolution solution entering the liquid/liquid extraction for Al management, there is an additional operation performed in the case of USi-type RRSF. This additional operation consists in separating the silicon from the dissolution solution because the whole silicon quantity cannot proceed through the extraction. The concentrated silicon solution is managed through the "fines" line and vitrified with the fissions production solutions at the end of the process.

After dissolution of a RRSF batch, uranium and plutonium are separated from the fission products solutions thanks to the PUREX process. Fission product solutions are then concentrated before their vitrification.

The following Figure 26 & 27 give an overview of the whole reprocessing steps performed for UAl and USi RRSF.

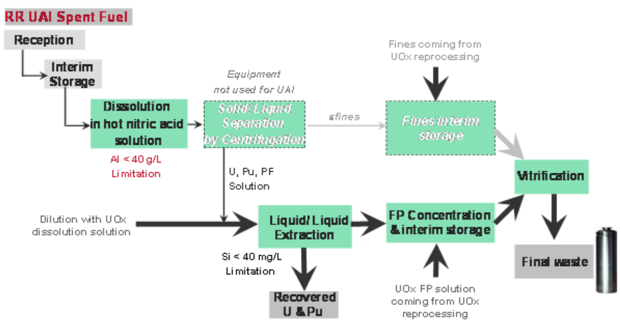


Fig. 26: Process diagram for UAl RRSF reprocessing
in AREVA La Hague plant

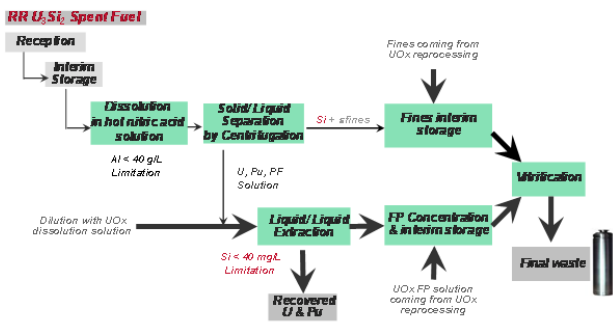


Fig. 27: Process diagram for USi RRSF reprocessing
in AREVA La Hague plant

Starting at Marcoule plant and up to the 90's, 18 tons of UAl-type RRSF from 21 reactors from 11 countries have been reprocessed with the similar reprocessing operations as the La Hague ones.
Since 2005 and as of end-of 2014, over 7.25 tons of UAl-type RRSF fuels have already been reprocessed at industrial scale at the AREVA La Hague plant.
AREVA is currently finalizing the studies in order to obtain the authorization to reprocess USi-type RRSF from the French Safety Authority (ref. [2]).

### 5.2. Towards a specific dissolution facility for treatment of specific fuels

In order to reprocess diverse fuel types, an innovative and polyvalent shearing and dissolving cell is planned to be put in operation in about 10 years at La Hague. This installation, called TCP (French abbreviation for polyvalent fuel treatment), will be set up at the La Hague reprocessing plant. The TCP shearing tool and dissolving equipment will benefit from AREVA's industrial feedback, while taking part in the next steps towards a fast reactor fuel cycle development using innovative treatment solutions. Feasibility studies and R&D trials on dissolution and shearing are currently ongoing. This new installation will allow AREVA to propose new services to their customers, in particular in term of Fast Reactors and Research Reactors fuel treatment. In addition to current reprocessing process at UP3, TCP will bring more flexibility, address a larger quantity of fuels and open the door to dedicated solutions for specific features (i.e. innovative Al or Si management).

## 6. Final waste production and management

### 6.1. Final waste attribution to customers

According to the applicable European Directive [3] and to French law [4], the introduction on French territory of spent nuclear fuels for a reprocessing purpose has to be framed by an intergovernmental agreement (IGA) between France and the SF country of origin. This agreement settles "a forecasted schedule for reception and processing of the material and, if any, the later planned use of the material separated during reprocessing". Article L542-2 of the French Environmental Code specifies also that disposal in France of radioactive waste from abroad is forbidden, including waste resulting from RRSF reprocessing.
In regards to spent fuel reprocessing at the AREVA La Hague plants, France already signed IGAs with Italy, the Netherlands and Belgium.
Another application of French law [4] concerns the final waste calculation method.
In order to comply with this regulation, AREVA applies a material accountancy system including a unique activity unit for waste (UAR, Unité d'Activité de Résidu) and a unique mass unit for waste (UMR, Unité de Masse de Résidu).
This system allows AREVA to calculate the amount and type of waste to be sent back to its customers. This system called EXPER (EXPEdition des Résidus) has been approved by decree, and has been implemented since October 2008 for all new RRSF reprocessing operations.
This system states that the UAR and UMR quantities imported in France are to be sent back from France.
In the case of silicide-type RRSF reprocessing, if all the material is dissolved, the only remaining waste corresponds to the UAR system, based on the Nd quantities imported in France in the RRSF.
The UAR system implies two possible types of vitrified residues: CSD-V (Conteneur Standard de Déchets Vitrifiés) and CSD-U (Conteneur Standard de Déchets U).
The CSD-V concentration in FP is highly superior than the CSD-U one.

The thermal power is consequently higher in CSD-V than in CSD-U.
According the regulation of each country regulation, CSD-V and CSD-U can be considered respectively as HLW and ILW.
AREVA proposes to study the conditions under which the final waste can be managed with the RR operators and their regulatory bodies.
Two different examples can be underlined for final waste management:

- Belgium
  After reprocessing of BR2 RRSF, corresponding CSD-Vs have been jointly sent back to Belgium with residues from Belgian utilities SF reprocessing. As the LWR SF reprocessing results in much higher volumes of CSD-V than RRSF reprocessing, the residues return was almost insignificant for the BR2 operator (SCK).
- Australia
  Australia does not operate any Nuclear Power Plant. Australia does not have any HLW to manage. The CSD-U was consequently the best option for Australia as it is managed as ILW and does not need large investments for long term management (in comparison with final HLW disposal).

Depending on each country regulations and specificities, AREVA can propose either CSD-V or CSD-U for a responsible and sustainable waste management.

## 6.2. Final waste production and interim storage

### 6.2.1. Final waste production

After the reprocessing operations, the concentrated fission products solutions are vitrified in the AREVA La Hague plant and the resulting glass matrix poured in universal canisters.
Currently there are two types of vitrified residues containing concentrated fission products solutions produced with two technologies:

- The CSD-V: these vitrified residues are produced thanks to the hot melter lines in AREVA NC's vitrification facility. They are mainly the result of the reprocessing operations for UOx and MOx spent fuels coming from Light Water Reactor and they represent the nominal glass residue production in the La Hague Plant.
- The CSD-U: these vitrified residues are produced thanks to the cold crucible line in AREVA NC's vitrification plant. They are the result of the reprocessing operations for spent fuels coming from past Gas Cooled Reactor and their production will be limited (number of items and time production). In comparison with CSD-Vs, these CSD-Us have a lower activity content and a lower related thermal power (~50 W versus 2000 W). Regarding French regulation, CSD-Us are High Level Activity Waste as CSD-Vs but, given their characteristics, these residues can be considered and managed as Intermediate Level Activity Waste in other countries (Australia for instance).

Both types of vitrified residues (CSD-V and CSD-U) are the result of the encapsulation of Fission Products in a stable, homogeneous, and durable glass matrix with a long-term predictable behaviour. Furthermore, their fissile material contents are very low and allow an exemption of safeguards for their interim storage and final disposal.

### 6.2.2. Interim storage at La Hague

The interim storage of vitrified residues is performed in pits with ventilation by natural convection in the AREVA NC La Hague plant (EEVSE and EEVLH facilities).

Fig. 28: Universal Waste Canister (CSD) – Vitrified wastes

Fig.29: Outside view of La Hague EEVSE facility

As mentioned in paragraph VI.A, the duration of interim storage of vitrified residues coming from foreign RRSF reprocessing is agreed between France and the RR's country before starting importation in France of the RRSF, through an IGA.

De-storage of the residues and preparation for transportation, including loading in the dedicated transportation cask are performed in the *DRV* facility in AREVA La Hague. AREVA customers can witness these de-storage and preparation for transportation operations.

Fig.30: De-storage facility control room

Fig.31: De-storage operations for CSD-V

### 6.3. Final waste transportation and management in the RR country

According to their UAR content (see paragraph 6.1), CSD-Vs and CSD-Us can be considered to send back final residues to foreign customers.

Transportation casks that can be used for the transport vary according to the customer's final waste interim storage policy: storage in pits/vaults, or storage in the transportation cask itself on a storage area

### 6.3.1 Solutions for waste transportation

If the dedicated RR country makes the choice of interim waste management in pit/vaults, like in the AREVA La Hague plant, the TN-28 and the TN-81 residue transportation casks can be used to ship CSD-Vs or CSD-Us to the customers with a maximum of 28 universal canisters per cask. This choice has been made by Belgium for management of its final waste after RRSF reprocessing at La Hague.

In the case of an interim storage in cask, the TN-81 cask can be used as a "dual-purpose" cask ie for both residue transportation and interim storage, with a maximum of 28 universal canisters per cask. This choice has been made by Australia for management of its final waste after RRSF reprocessing at La Hague.

If needed, other types of transportation casks can be considered by AREVA for loading CSD-Vs or CSD-Us, according to customers' needs. Nevertheless, as for RRSF receipt, feasibility studies, safety report application to Safety Authority /authorization, design and fabrication of new equipment and possible modifications to the workshop are necessary.

Fig.32: AREVA TN-81 dual purpose cask

Fig.33: AREVA TN-28 transportation cask

### 6.3.2 Experience

AREVA has a wide experience in residues shipment to foreign customers.
In the case of residues return related to RRSF reprocessing, AREVA has already returned small quantities of CSD-V to RRSF customers, based on a joint residues management with NPP and RRSF customers (Belgian feed-back). Indeed, in case of a nuclear power country that made the choice of reprocessing its NPP spent fuels in France, a joint return is efficient, cost effective, and reduces the number of nuclear transportations. When there is no NPP spent fuel reprocessing in France in the RR country, and no associated return of vitrified waste, another solution can also consist in performing a CSD-U shipment CSD-U with a dedicated transport program (Australia), and benefiting from the associated advantages (see paragraph 6.2.1).
AREVA has also experience in designing, licensing and constructing the facilities dedicated to interim storage of final waste.

## 7. Conclusion

AREVA acquired a long-term experience on RRSF management, encompassing international and multi-modal transportation, reprocessing and waste management.
Thanks to its experience, and thanks to the high-quality of its operators, its plants and equipment, AREVA is ready to set up sustainable partnerships with its RR customers in order to robustly manage the back-end of their fuel cycle.

## 8. References


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[3] 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: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:199:0048:0056:EN:PDF

[4] French Environmental Code resulting from the law of June 28, 2006 on the sustainable management of radioactive materials and waste, and application decree no. 2008-209 of March 3, 2008 on procedures applicable to the reprocessing and recycling of foreign spent fuel and radioactive waste specifies certain conditions