Transport of Reprocessed Uranium: Regulatory Aspects and Experience

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INTRODUCTION

The reprocessing of spent fuel allows to separate three kinds of materials : uranium, plutonium and, at last, other actinides and fission products. The content in uranium 235 of the recovered uranium is commonly around 1 % and makes it a valuable material. This is why several countries, and particularly France, which have chosen to reprocess their spent fuel have also decided to recycle the reprocessed uranium.

While uranium separated from spent fuel leaves the La Hague reprocessing plant under the form of uranyl nitrate with an enrichment of about 1 %, it has to be transformed into uranium dioxide, with an enrichment ranging from 3.5 % to 4 %, to be incorporated in new fuel assemblies for use in nuclear reactors. Several processes are necessary to ensure this recycling operation. As they are performed in different places, uranium under various forms and enrichments must be transported.

In the first step, uranyl nitrate, a liquid in which uranium with an enrichment of around 1 % is diluted , is shipped in tanks to the conversion plant where it is transformed into tri-uranium octoxide (U_30_8) or into uranium hexafluoride (UF_6) with the same enrichment. Then the material is transferred to the enrichment plant, where the uranium 235 content is increased to reach 3.5 % to 4 %. After that, the uranium hexafluoride is moved to the fuel fabrication plant where the uranium hexafluoride is transformed into uranium dioxide from which are made the pellets incorporated in fuel assemblies. In a last stage, the fuel assemblies are shipped to the nuclear plants to generate electricity. In the future, corresponding spent fuel will also have to be transported.

On a worldwide basis, national and international regulations for the shipment of uranium are governed by the "Regulations for the Safe Transport of Radioactive Material" issued by the International Atomic Energy Agency (IAEA).

The reprocessed uranium to be transported (uranyl nitrate tri-uranium octoxide, uranium hexafluoride with an enrichment lower or higher than 1 %, fresh fuel assemblies) cannot be classified in the same category as the equivalent material coming from natural uranium, due to the presence of additional isotopes.

This paper will present hereafter, at first, how the reprocessed uranium has been classified from a regulatory point of view, according to the chemical compound, and, after that, our actual experience in the transport of this material.

REGULATORY CLASSIFICATION

General

In the case of products made from natural uranium, as long as the enrichment in uranium 235 is less than 5%, the A_2 value is unlimited. Therefore, if they are not fissile, these products can be classified as LSA-I, and transported in an Industrial Package (IP) . Otherwise, they must be classified as LSA-II material and require to be transported in a package able to meet the requirements set forth for packages containing fissile material. For the products involved in the front end, the situation is summarized in the following table.

Materials Issued From Natural Uranium

Material	**Enrichment**	**Material classification**	**Package classification**	**Typical packaging**
Uranyl Nitrate	Natural	LSA-I	IP	Tank
U_30_8	Natural	LSA-I	IP	Drum
UF_6	Natural	LSA-I	IP	48Y cylinder
UF_6	Between 1 and 5%	LSA-II	IP + F	30B cylinder + overpack
UO_2 (Fuel assemblies)	Less than 5%	LSA-II	IP + F	RCC (for PWR)

In the case of reprocessed uranium, the unlimited A_2 value can no longer be considered. The value of A_2 has to be calculated with consideration of the actual isotopic composition of uranium and of all the other radionuclides. This means that the presence of uranium 232 and uranium 236 generated during reactor operation, the higher concentration in uranium 234, the presence of their daughter products, and the residual fission products and actinides must be considered.

Uranyl Nitrate

When uranyl nitrate comes from reprocessing, most of the batches can be classified as LSA-II material.

Nevertheless, it appears that some batches cannot formally be considered as LSA-II material. The specific activity may exceed the criteria set forth for liquid LSA-II material, i.e., 10^{-5} A_2/g. A typical upper value of the specific activity is twice this threshold.

Since its 1985 edition, the regulations provide A_2 values for each radionuclide based on the well known Q system. This approach considers a series of five exposure routes which might lead to either external or internal radiation exposures. It allows to derive five limit values, noted Q_A, Q_B, Q_C, Q_D and Q_E for respectively, external gamma dose, external beta dose, inhalation dose, skin and ingestion dose due to contamination transfer and at last submersion dose for gases.

Considering particularly the inhalation mode, among all the chemical forms under which a radionuclide can exist, the most pessimistic is retained for the evaluation of Q_C : the most restrictive of the Annual Limits of Intake (ALI) values recommended by the International Commission on Radiological Protection (ICRP) is considered.

This approach brings a substantial simplification to those who implement the regulations: they do not have to wonder to which class (used by the ICRP to determine the ALI limits for a family of chemical compound) belongs the material to be shipped. It is also sound since safe: any change in the physical and chemical forms of the material which could occur, due to an accident during transport such as a fire, will not modify the value of A_2 and therefore the classification of the material.

Nevertheless, it also induces a significant conservatism. For many years, there has been a consensus in France between the representatives of the industrial organizations and of the competent authority to consider that, in the case of a material such as uranyl nitrate, this conservatism is undue. A more appropriate approach considers the following:

- the worst case for uranium is class Y, as defined by the ICRP, which includes chemical forms such as uranium dioxide;

- uranyl nitrate belongs to class D (water soluble);

- for this class D, the Annual Limit of Intake (ALI) of uranium, i.e., the mixture of isotopes, is greater that 10 mg, considering the actual isotopic composition of uranyl nitrate; in other words, the A_2 value can be considered as unlimited.

From a formal point of view, it was agreed with the French Competent Authority that an application based on the following considerations should be acceptable :

- the 1996 Edition of the IAEA Regulations should recognize the possibility to consider the A_2 value related to the solubility class as recommended by the ICRP when the chemical form of the materials is known, provided that the modification of material under accident conditions of transport are taken into account;

- values are proposed for A_2 of uranium isotopes for three classes of solubility;

- uranyl nitrate meets the criteria set forth for liquid LSA-II material (10^{-5} A_2/g) considering the A_2 values applicable in the future for this material (fast lung absorption);

- it is recognized that uranium can be transformed from the uranyl nitrate form to other forms, particularly UO_3 and U_3O_8, or even UO_2, in case of fire; for these forms the A_2 values are lower but, as they are solids and the threshold for LSA-II is in this case the basic value 10^{-4} A_2/g, the criterion is still met.

As a consequence, we expect to receive shortly an approval from the French Competent Authority allowing consideration of uranyl nitrate with uranium separated from spent fuel through reprocessing as equivalent to an LSA-II material, in any case. In other words, like for "natural" uranyl nitrate, the material will be allowed to be shipped in an IP tank.

Non-Reenriched Uranium Hexafluoride (UF_6) and Tri-Uranium Octoxide (U_30_8)

When the uranium is issued from reprocessing, we have checked that uranium hexafluoride and tri-uranium octoxide made from reprocessed uranium considering typical isotopic compositions and contents of daughter products, fission products and actinides, comply with the LSA-II criteria.

This has been also verified for what can be considered as envelope isotopic compositions of uranium and other products.

From a practical point of view, we have established procedures to check for each shipment which involves reprocessed uranium that the criteria are duly met.

As far as packagings are concerned, because there is no significant modification of the classification of the material, non re-enriched UF_6 and U_30_8 can be shipped in an Industrial Package (IP).

For uranium hexafluoride :

- when the uranium 235 content is lower than 1 %, the standard 48Y cylinder can be used;

- when the uranium 235 content is higher than 1 %, the package must in addition comply with the applicable requirements for packages containing fissile material : the standard 30B cylinder with its overpack can be used.

For tri-uranium octoxide, and since, in all the cases we have dealt with, the content in uranium 235 is less than 1%, the drums commonly involved in the transport of natural U_30_8 can still be considered.

Reenriched Uranium Hexafluoride

The isotopic compositions of enriched uranium issued either from natural material or from reprocessing are significantly different. Irradiation of uranium creates uranium 232, and increases about three times the content in uranium 234. During the reenrichment process, these light isotopes are concentrated in the enriched product. As a consequence, the specific activity of reenriched uranium hexafluoride exceeds the criteria applicable to LSA-II material, while remaining in the same order of magnitude (about twice the criteria). As well it cannot be classified as LSA-III material, as it would certainly not pass the leaching test.

Beginning of 1992, we applied for an approval. The approach followed in this case was similar to that previously presented for uranyl nitrate because uranium hexafluoride and uranyl nitrate belong to the same class, as defined by the ICRP:

- the worst case for uranium is class Y, as defined by the ICRP, which includes chemical forms such as uranium dioxide;
- uranium hexafluoride belongs to class D (water soluble);
- for this class D, the Annual Limit of Intake (ALI) of uranium, i.e., the mixture of isotopes, is greater that 10 mg, considering the actual isotopic composition of uranium hexafluoride; in other words, the A_2 value can be considered as unlimited.

The French Competent Authority acknowledged the validity of this approach in March 1992.

Since this date the corresponding approval has been renewed on a regular basis.

This approval was also validated by the Competent Authority of the Netherlands in November 1992.

The practical consequence is that the standard 30B cylinder with its protective overpack can be used.

In addition to the previous study, it was also decided to qualify one specific overpack (the NCI-21PF-1 overpack) in such a way that the corresponding package can be approved as type B. To this aim, additional drop tests were performed in the Moronvilliers facility in France in May 1992.

The original Safety Analysis Report was modified to incorporate the necessary modifications to justify that the package complies with the type B requirements. Finally, the U.S. Nuclear Regulatory Commission issued the certificate USA/9234/B(U)F in August 1994. This certificate was immediately validated in France and since this date in all the other countries involved.

Fresh Fuel Assemblies

When uranium dioxide is made from re-enriched reprocessed uranium, its specific activity complies with the criteria applicable to LSA-III material.

To be used as fuel in a nuclear power plant, uranium dioxide is sintered to constitute pellets, which fill zircalloy tubes to constitute the rods of the fuel assemblies. It has been extensively shown that sintered uranium dioxide can withstand the leaching test applying to LSA-III material.

As these two requirements are fulfilled, such material belongs to the LSA-III category. The widespread RCC containers, which were approved as AF packages when loaded with fresh fuel assemblies for Pressurized Water Reactors (PWR), had their approval extended by the French Competent Authority to the case of reprocessed uranium in November 1993.

Synthesis

Reprocessed uranium, under any form in the fuel cycle, can be transported with the standard equipments, thanks to the demonstration which has been made that the material does not need to be classified in a more stringent category than natural uranium, or that the qualification of the equipment can be upgraded to an upper level.

It should be emphasised that these developments have been echoed on an international ground by the issue of a TECDOC from the International Atomic Energy Agency in June 1994 (IAEA-TECDOC-750: Interim Guidance for the Safe Transport of Reprocessed Uranium).

Some of these principles, such as the possibility to take into account the physical and chemical form of the material in the calculation of the A_2 value, and consequently in the classification of the material, should be included in the forthcoming revision of the IAEA Regulations.

TRANSPORT EXPERIENCE OF REPROCESSED URANIUM

The French industry is involved in the reprocessed uranium cycle through the following steps :

- spent-fuel is reprocessed in the COGEMA La Hague plant, and uranium is shipped out of this facility under the form of uranyl nitrate;

- uranyl nitrate is transported to the Pierrelatte site where it is converted either to tri-uranium octoxide (U_3O_8), or into uranium tetrafluoride (UF_4) and then uranium hexafluoride (UF_6), in the same site where the conversion is made for natural uranium;

- uranium is then shipped to the enrichment plants to be re-enriched;

- finally, uranium hexafluoride comes back to FBFC plants after enrichment, to be stored and/or transformed into uranium dioxide for incorporation in fuel assemblies.

As explained earlier, standard transport packagings are used:

- for uranyl nitrate, LR 65 tanks belonging to the IP-2 category are in operation;
- for uranium hexafluoride, when the enrichment is lower than 1 %, 48Y cylinders are considered ; when the enrichment is higher than 1 %, 30B cylinders are used, with any overpack as authorized by the relevant competent authorities, or with the NCI-21PF-1 overpack under the provisions of the corresponding type B approval;
- for tri-uranium octoxide, drums are used, fitted in a 20 foot ISO container;
- for fresh fuel assemblies, the RCC containers are used as for natural uranium.

Many transports of reprocessed uranium are now performed. For instance, between 1976 and 1993, the LR 35 tank was in use and nearly 500 shipments of uranyl nitrate were performed between La Hague and Pierrelatte representing 7,500 tank movements or 6,000 tons of uranium. In 1994, a new model of tank (LR 65) was comissioned. It will allow to transport in 1996 the uranyl nitrate corresponding to 1,600 tons of uranium.

Furthermore, in the last 3 years, 11 shipments of non reenriched uranium hexafluoride were performed from Pierrelatte to the enrichment plants, representing 58 cylinders (48 Y) and 57 cylinders (30 B) with a total amounting to 550 tons of Uranium. In the meantime, 5 shipments of reenchiched UF6 representing 58 cylinders (30 B) or 88 tons of Uranium were performed between the enrichment plants and the fuel fabrication facilities.

At last, it can be mentioned that 68 new fuel assemblies have been shipped to the EDF Cruas power plant.

CONCLUSION

The French industry has now gained the technical expertise which allows to provide the clients with the necessary authorizations for the transport of the reprocessed uranium, all along its cycle. Efficient but operationally simple solutions have been implemented. The transport of reprocessed uranium is now virtually made in routine conditions.