INTERNATIONAL COST EFFECTIVE TRANSPORT OF REPROCESSED UO3

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Abstract

Sellafield Limited provides a storage service to its customers for uranium products in the form of UO3; this service is not indefinite so at some point the UO3 belonging to overseas customers requires exporting.

The UO3 to be exported has a range of (U-235) enrichments, some of which meet the IAEA Fissile Excepted Package criteria and some that are marginally outside this criterion, therefore this implies that two package types will be required; a Fissile Excepted package and a Fissile package, the latter will require multilateral approval. The challenge is to minimise the number of shipments by optimising a single package design and the loading arrangement of this design to enable the safe transportation of large volumes of the fissile UO3 material.

To accommodate the higher enriched material the use of an Industrial Fissile (IF) Package is proposed. IF Packages are typically IP-2 qualified packages supported by a criticality safety case. This safety case demonstrates an adequate sub-critical safety margin, without claiming any integrity for the packaging, under accident conditions of transport. This option provides the potential for significant cost savings, particularly with respect to package testing, as the safety of the package need only be demonstrated for normal conditions of transport.

For this specific application research was carried out to establish an acceptable method for:

- maximising payload within the package by mixed loading of UO3 at all enrichments
- maximising the number of packages on the trains; and
- maximising the number of packages on the vessels to minimise shipments.

The approach adopted is somewhat complex requiring both an IAEA Shipment Approval and IAEA Radiological Protection Programme (RPP) for Special Use Vessels.

There has been a great deal of constructive interaction between the plants involved, criticality specialists, project engineers and the UK Competent Authority during the development of this approach. A systematic set of controls has been developed to ensure compliance with IAEA regulations during loading operations and transport which will minimise shipments without compromising safety.

1. INTRODUCTION

The Thermal Oxide Reprocessing Plant (Thorp) at Sellafield in Cumbria reprocesses irradiated oxide fuel from the Advanced Gas-cooled Reactors (AGRs) and from Light Water Reactors (LWRs). Reprocessed Uranium in the form of UO3 and Plutonium in the form of PuO_2 which ARE available to be recycled, make up 97% by weight of the irradiated fuel; the remaining 3% is made up of fission by-products.

Dependent on the initial furl enriched and its irradiation history of the fuel, the enrichment of the reprocessed UO3 produced in Thorp can be in a range of 0.5% wt U-235 to 1.6% wt U-235. In reality the highest enrichment of UO3 produced has been 1.24% wt U-235 and only the Japenese customers with their higher burn up fuel have been allocated UO3 which is over 1% wt U-235,

Approximatially 6000 te of UO3 has been produced in Thorp, almost all of which belongs to Sellafield Ltd's reprocessing customers. The UO3 is contained in 50 Lire specially designed stainless steel drums (see Fig 1) and is stored in the Thorp UO3 store at Sellafield. Several hundred tones of this UO3 has already been exported, however all of this exported UO3 has been under 1% wt U-235 which is the maximum threshold value in the IAEA transport regulations before an IAEA Competent Authority approved Fissile Package is required.

In excess of 2000 te of the UO3 belongs to the Japanese customers and a significant proportion of this has enrichments between 1% wt U-235 and 1.24% wt U-235

Fig 1 Thorp 50 Litre UO3 product drum

The proposed export of this UO3 must satisfy the relevant IAEA transport regulations, which places significant controls on the transport of fissile material that are over specific thresholds, in this case U-235 enrichment. A key challenge for the transporter is that UO3 made available to Japanese customers is at a range of enrichments greater than 0.711 %U235 and is split between the threshold for a fissile package and for a fissile excepted package. Using a traditional approach to compliance with the transport regulations would subject the project to a vast number of shipments due to wasted space both within the package and on the conveyances.

A project was established in late 2004 with the objective to deliver an IAEA compliant cost effective solution for the export of enriched UO3 in both the fissile category and the fissile excepted category. This will enable Sellafield Limited to support individual Japanese customers in their plans to export their enriched UO3 from the Thorp UO3 Store to Russia for eventual recycle of that material back into nuclear fuel.

This paper demonstrates the use of the Industrial Fissile Package category and novel approach to optimization of international shipments.

2 REGULATIONS FOR UO3 (IN EXCESS OF NATURAL U-235 ENRICHMENT)

UO3 contains relatively low specific activity for each of the radionuclide present in the fingerprint and commonly meets the LSA-II criteria [226b of Reference 1, hereinafter referred to as TS-R-1]. This category of material requires packaging meeting the IP-2 criteria [TS-R-1 table 4][1].

The Thorp UO3 is enriched in U-235 above natural (0.711%) therefore in respect of the transport regulations this UO3 is classed as Fissile material and requires a package meeting the Fissile Package requirements [TS-R-1 paragraph 671][1]. IAEA have recognised that not all material meeting the IAEA TS-R-1[1] definition for fissile material classification presents a criticality risk and this criteria (Exceptions from the requirements for packages containing fissile material) is found in paragraph 672 [TS-R-1][1]. 60% of the Thorp UO3 belonging to overseas customers falls into paragraph 672b, and is therefore Fissile Excepted but the remaining 40% requires the use of a Fissile Package

3 REGULATIONS FOR FISSILE PACKAGES

Various categories of packages can be used to transport nuclear fuel cycle materials, such as enriched uranium hexafluoride, uranium dioxide, fresh fuel and also spent fuel, all of which are capable of sustaining a nuclear chain reaction.

Depending upon the nature and quantities of materials involved, Industrial, Type A, Type B(U) and Type B(M) packages are used for surface transport and the high integrity Type C package for air transport. Packages are classified as fissile packages when they are designed to carry fissile material and they are then categorised as IF, AF, B(U)F, B(M)F and CF. Note IF designs are not a commonly used/accepted package type.

The regulations require that the criticality safety of a package used to transport fissile material is demonstrated during routine, normal and hypothetical accident conditions of transport. This is generally achieved by demonstrating integrity against a series of onerous and costly performance tests. As mentioned above the use of an IF package is identified as an option for this project. This package type gives significant advantages over other fissile package types as IF applications use calculations to demonstrate adequate sub-critical safety margins without claiming any integrity for the packaging under accident conditions of transport. Thus, IF designs are significantly less costly to develop, test and manufacture.

4 THE DEVELOPMENT OF A FISSILE PACKAGE

Initial planning for transport within the UK was based on the use of an Overpack to be applied to each drum of UO3. However, this approach was not cost effective for overseas transports. A Value Management Study was carried out in 2004, which had the objective of identifying a more cost effective, fit for purpose solution. The identified solution was to export the fissile UO3 using a specially designed Industrial Fissile package based on a full height ISO freight design. This design would have the potential to be utilised in transporting all Thorp UO3 regardless of enrichment (up to and including the identified maximum of 1.24% U235) or destination. It was concluded that whilst this was a novel approach and would be viewed as such by the Competent Authorities, International Nuclear Services had the necessary experience with IF applications to be able to successfully develop this design and achieve UK Competent Authority approval and Russian Competent Authority Validation. The IF package project was designated unique design number IF-96 3573.

6 DEVELOPMENT OF THE IF-96 3573 PACKAGE CONCEPT AND PARAMETERS

The package will comprise a full height ISO freight container (Design No 3573). This container is required to have a single end opening door that can wrap around and latch to the side of the container.

The package must be designed with a specific internal load restraint system that will be used to secure the pallets containing drums of UO_3. The internal load restraint system is to be designed to provide safe transport for the laden pallets under normal conditions of transport.

The gross mass of the loaded ISO is to be restricted to 20te due to handling restrictions at some international ports.

7 REGULATORY REQUIREMNTS FOR THE IF-96 3573 DESIGN

The regulations for IF packages are subjective and therefore open to interpretation. From past experience with IF packages it was clear that the design and the concept had to be agreed with the UK Competent Authority ahead of any project commitment.

As well as the general regulatory requirements for all package designs, the regulations specific to this IF-96 3573 design can be split into three sub sections;

- IP-2 Package requirements ([TS-R-1 paragraph 606-616, 681-622][1]
- Criticality requirements [TS-R-1 paragraph 681][1]
- Normal Conditions of Transport requirements [TS-R-1 paragraph 719-724][1]

7.1 IP-2 package requirements

IP-2 packages must be designed such that they can demonstrate containment under Normal Conditions of Transport (NCT). In the regulatory spirit this is demonstrated by subjecting the package to both a free drop test and a stacking test. There are a number of alternative requirements [TS-R-1 paragraph 624 - 628][1] which, if satisfied remove the need to subject the designs to additional testing to demonstrate integrity to the same criteria (NCT). The 3573 package has been designed to carry Thorp UO_3 in solid form and is taking advantage of these alternative requirements which were introduced by the IAEA's 1985 Safety Series No. 6 regulations [5] and remain in current regulations [TS-R-1 paragraph 627):

Experience shows that paragraph 627 can be interpreted inconsistently, for this reason the UK Competent Authority has issued further guidance against this paragraph [2 & 3] and UK industry has been following such guidance by subjecting all IP-2 freight containers to leak tests before, during and after specific ISO 1496/1 type tests [4].

7.2 Criticality requirements

The regulations require a criticality assessment of a single isolated package [TS-R-1 paragraph 677][1]. As no claim is made for water tightness of the ISO it is must be assumed that water can leak into the ISO to any extent and also assumed that the package and drums have lost their integrity, allowing the UO_3 powder to assume the most reactive geometry.

As IP-2 packages are not required to demonstrate containment under accident conditions of transport it will be necessary to consider the state of the packages post the NCT tests [TS-R-1 paragraph

681a,b][1]. The “water spray” NCT test will not need to be performed nor assumed to affect criticality calculations as the package is made from steel and is designed to prevent ingress of water under NCT and this test would occur before the impact test under the IAEA approved sequence.

In respect of accident conditions of transport, the IAEA regulations require an assessment of an array of damaged packages [TS-R-1 paragraph 682][1]. No claim is made for the package integrity under accident conditions, therefore it will be appropriate to assume that the Fissile material in a Group of packages is entirely free to combine and assume the most reactive configuration, with ingress of water.

Finally for a criticality safety control on conveyances, the regulations require the calculation of a Criticality Safety Index (CSI) for a Group of Packages [TS-R1 paragraph 528, 530, 569][1].

7.3 Normal conditions of transport requirements

Again Industrial Fissile Packages do not entirely fit within the general criteria for either IP-2 packages or fissile packages. Even though the NCT tests are the criteria to which the alternative arrangements are compared to demonstrate safety equivalence Competent Authorities will not accept these tests for demonstrating containment when criticality safety cases rely on the package maintaining containment under NCT. Therefore, for IF packages designed to comply with either of the alternative requirements [TS-R-1 paragraph 624-628][1] they must also demonstrate containment post an impact test from the appropriate drop height.

8 DESIGN, MANUFACTURE PROTOTYPE AND TEST THE 3573 IF-96

The 3573 package has been designed and is currently in manufacture, the key features of the design can be seen from Fig 1 below. The design comprises of a specially designed full height ISO freight container fitted with a single door, HEPA filter and an internal restraint system

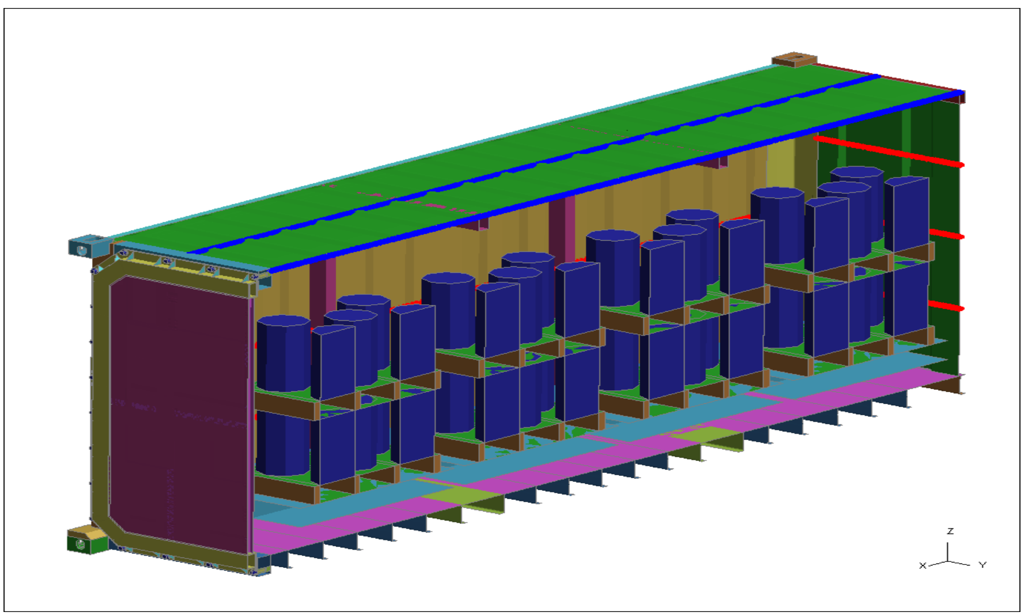

Fig 2 3D illustration of the 3573 IF-96 design courtesy of Nexia Solutions UK

Testing will be carried out in compliance with the DfT Guidance [3] which insists on additional leak testing under side wall loading, end wall loading, longitudinal racking and transverse racking tests from the ISO 1496/1 Type tests [4].

8.1 Impact testing

The prototype will not be subjected to any impact testing, Finite Element Analysis (FEA) has been carried out to demonstrate containment integrity post impact testing. Again this IF-96 3573 design reveals another interpretation issue within the regulations, this time with table 8 of TS-R-1 free drop distance for testing packages against NCT tests. This design is required to transport between 1 and 64 drums, therefore the Gross weight could potentially vary over 3, out of the 4 thresholds, in table XIII of TS-R-1 [1] which denote different free drop heights.

Using an energy argument against the thresholds in table 13 of TS-R-1 [1], it shows that the highest energy of all thresholds occurs with a mass of 15te dropped from 0.6m (88.29kJ). Therefore, modeling this drop provides us with a bounding case to enable the design to comply with the regulations and operate the package across the varying gross weights from >5 to <20 te.

The FEA modeled the 3573 as if three lifting points had failed simultaneously dropping the container onto the door corner edge from 0.6m. This demonstrated a worst case orientation within the spirit of NCT tests and the results revealed minimal plastic set deformation, and no loss of containment.

9 PACKAGE CRITICALITY SAFETY CASE

IAEA transport regulations always require a worst case scenario assessments, therefore the 3573 criticality safety case was based on optimized spheres of UO3 and close fitting reflectors, and no credit was taken for the increased neutron leakage and thermal neutron absorption that would result from transporting the UO3 in primary drums and the 3573 ISO Container.

The UO3 powder bounded by this safety case is that with enrichments from 1% to 1.24%. To both simplify the assessment and for convenience of the export operation a close range of enrichment bands were chosen and safe masses of U-235 were calculated at the upper boundary value

These shipments are to take place under exclusive use; this allows a relaxation in the regulations in respect of “Fissile Package Grouping” for criticality safety.

“Fissile Package Grouping” - the regulations place restrictions on the stowage during transit of fissile packages. Each group of packages, where the sum of criticality safety indexes totals 50, must be spaced from any other such groups by a distance of a 6m envelope [TS-R-1 paragraph 569, 570][1].

The results of the assessment gave indicative working limits for safe masses of U-235 per enrichment band for a group of fissile packages in that enrichment band. This could be equated to a safe mass of U(>1%)O3 per group, further more to numbers of U(>1%)O3 drums at that enrichment band per 3573 package.

This analysis revealed that 3573 packages containing U(>1%)O3 in enrichment bands over approx 1.15% would not be fully loaded (for example <10 drums total for 1.24% enriched UO3 compared with a possible 64 drum as the intended total package capacity). Meaning that one individual package in that enrichment band would be designated with a CSI of 50 (the IAEA critical safe mass).

It is permitted by IAEA to increase the CSI per group of packages to 100 [TS-R-1 paragraph 571][1] providing exclusive use can be claimed. The regulations permit this approach providing a Shipment Approval is obtained from the Competent Authority [TS-R-1 paragraph 820c][1].

By raising the CSI to 100 for a group of fissile packages, this increases the critical safe mass of fissile material per group and as such for UO3 at enrichment bands >1.15%, increases the fissile mass per package meaning a greater number of U(>1%)O3 drums per package by almost a factor of 2.

It should be noted that to satisfy the requirements of the Shipment Approval, in addition to the general requirements of a Package Design Safety Report (PDSR), a complete review of the entire shipment/transport process must be completed to demonstrate an adequate level of control at all stages.

However, even with a CSI for the group at 100 and, where appropriate, an individual package with a CSI of 100, both the number of packages and voyages required would not be optimised .So, further investigations were completed to maximise the volume of UO3 able to be transported in any one shipment.

10 ASSESSMENT OF OPTIMIZATION OF PAYLOADS FOR PACKAGES

In the introduction of this paper it was noted Sellafield Limited customers also own UO3 with enrichments below 1% wt U-235. This is transported in fissile excepted packages, overpacked in General Purpose Freight Containers to assist International handling. There appeared to be an opportunity to use either the general purpose Freight Containers filled with UO3 enriched to <1% U235 or the individual drums to

- fill the 6m spaces between groups of fissile packages for the rail and sea journey and/or
- to mix load the 3573 package with both <1% and >1% up to 1.24 %U235 enriched UO3.

This was termed “group infill” and “package infill”.

Group infill
This concept refers to filling the 6m spacing between groups of fissile packages with general purpose freight containers loaded with UO3 <1% (fissile excepted packages).

Package infill
As explained above, for enrichments >1.15% the 3573 package will be part loaded and the remaining space is potentially wasted within the package. It is proposed have an option to fill this space with drums of UO3 <1% enrichment. Therefore a new set of fissile limits was generated for use when opting for the package in-fill approach. It must be noted that there was a minor reduction in the numbers drums containing UO3 >1% per group/package when package infill is chosen as a loading option.

11 ASSESSMENT OF OPTIMIZATION OF NUMBER OF VOYAGES REQUIRED FOR EXPORT

By demonstrating that the vessel fully loaded with enriched UO3 (above natural and up to 1.24% wt U-235) maintains an adequate sub-critical safety margin under hypothetical accident scenarios, the vessel can be exempted from taking account of the CSI and the mandatory 6m spaces between groups of 100 CSI. This allows the vessel cargo space to be completely optimised, hence reducing the number of voyages required. This concept is known as a Special Use Vessel [TS-R-1 paragraph 576][1].The regulations demand that the flagstate of the vessel approves this assessment as a part of a

Radiological Protection Programme for the vessel. In this instance the general RPP must be supplemented with this vessel criticality safety case and shielding assessment, to enable the ship to claim Special Use Vessel. Note that for the criticality assessment of the vessel IAEA does not insist that their extremely pessimistic guidelines for accident condition assessments are followed. However, a large number of calculations covering normal and credible accident conditions (e.g. flooding etc) were considered and shown not to result in a criticality.

The PDSR, Shipment Approval and RPP for the Special Use Vessel will be submitted to the UK Competent Authority later this year for Approval; Russian validation is required post UK approval.

12 CONCLUSIONS

The 3573 project has identified potential new pathways through the regulations to maximise package loading efficiency and minimise voyages for International shipments of Reprocessed UO3 (fissile) without any loss or reduction in safety margins. As a result of its success so far, a significant cost saving for the recycling of enriched UO3 has been achieved. Additionally, during this novel approach a number of regulatory interpretation issues have been identified which could benefit from further investigation by the IAEA to ensure future consistency. It is hoped that this paper will serve to inspire others to explore interpretations of the transport regulations for identifying cost saving opportunities for the transport of nuclear fuel cycle materials.

REFERENCES

1 TS-R-1), "Regulations for the Safe Transport of Radioactive Material", IAEA Safety Standards Series, (2005 edition).

2 TS-G-1.1 (ST-2) "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material", IAEA Safety Standards Series, Safety Guide)

3 A DfT Guide to the Approval of Freight Containers as Type IP-2 and Type IP-3 Packages, DfT/RMTD/0002 (Freight Containers) Issue 2 July 2005

4 ISO Standard. Series 1 Freight Containers - Specification and testing - Part 1: General cargo containers, (ISO 1496/1-1978), ISO, Geneva (1978).

5 IAEA Safety Standards No.6 Regulations for the Safe transport of Radioactive Material 1985 Edition.