The DN30 Package for the Transport of Enriched Reprocessed Uranium - 11111

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ABSTRACT

In the last few years the volume of reprocessed enriched Uranium (RepU) transportation increased considerably and became an important issue. While the transport of enriched commercial grade Uranium in the form of Uranium Hexafluoride (UF_6) is standard practice since decades the transport of RepU presents new challenges.

Reprocessed Uranium is specified in [1]. The limits given there for fission products and actinides are sufficiently low, however the limit specified for U-232 of 0.05 µg/gU leads to considerably consequences.

- The A_2-value of the decay product Th-228 of U-232 is rather small and the U-232 limit specified in ASTM C 996 will exceed the radioactivity allowed in a type A package;
- In the decay chain of U-232 there is the nuclide Tl-208 with a high gamma yield at high energies; and in contrary to the usually expected decrease of dose rates during transport and storage for RepU an increase of the doses must be taken into account;
- After emptying a standardized 30B cylinder used for the transport of RepU in a suitable and licensed protective packaging a small quantity of UF_6 (so called heels), which contains a considerably higher concentration of impurities and decay products, remains in the cylinder, leading to higher dose rates at the package than for a filled cylinder.

The problems to be faced for the transport of RepU are currently not addressed in full extent by the design of packages available on the market. In some countries important for the industry the transport of RepU (filled cylinders or “heels”) is not allowed or special arrangements are in place and/or restrictions apply to the allowable concentration of U-232.

In order to solve these problems Nuclear Cargo + Service GmbH designed the DN30 package for the transport of commercial grade uranium and RepU for quantities up to 2277 kg UF_6 including “heels”. For the DN30 package approvals of type A, IF and B(U)F are applied for in the country of origin France.

INTRODUCTION

Enriched commercial grade uranium hexafluoride (UF_6) is transported since decades in type A packages for fissile material which consist of 30B cylinders as primary containment and protective structural packagings (PSPs) providing mechanical and thermal protection. The 30B cylinders are specified in the international standard ISO 7195 [2], or the U.S. standard ANSI N14.1[3].

The most important issues concerning the transport of enriched commercial grade UF_6 are criticality safety and its significant chemical hazard. To address these issues the 30B cylinder must fulfill certain leak tightness criteria. But neither the radioactivity of the content nor the dose rates at the package are important issues. The A_2 value of enriched commercial grade uranium (max. 5 wt.% enrichment) is unlimited and the dose rates are well below the limits specified in the Regulations for the Transport of Radioactive Material [4]. These conditions change slightly after multiple refilling of cylinders containing heels. Although the A_2 value of the decay products which are concentrated in the heels is not unlimited, the total radioactivity in the package remains well below 1 A_2. The dose rate at a package loaded with a cylinder containing heels quantities of UF_6 is expected to be considerably higher than the dose rate to be expected on a filled cylinder, but is still well below the limits specified in [4].

In the last few years the transport of enriched reprocessed uranium (RepU) became more and more important. For this material physically the same packagings are used as for enriched commercial grade uranium. However, these packagings loaded with RepU cannot be transported as type A packages but require type IF or type B(U)F approvals:

- The A_2 value of RepU is not unlimited but must be determined by using the mixture formula as defined in para. 405 of [4]
- The radioactivity of RepU in a 30B cylinder will in general exceed 1 A_2
- Dose rates at the package are much higher than for enriched commercial grade UF_6 and might exceed the limits given in [4]
- Heels require special attention due to the concentration of the decay products in the small quantity of UF_6 remaining in the cylinder after emptying.

The following presentation will address these issues in more detail. First, the main differences in the nuclide composition of enriched commercial grade and reprocessed uranium are shown. Then, the influence of the most important nuclide U-232 and its decay products on radioactivity and dose rates is discussed. An overview about the new DN30 overpack for the transport of enriched commercial grade and RepU concludes the presentation.

NUCLIDE COMPOSITION OF ENRICHED REPROCESSED URANIUM [1]

The nuclide compositions of enriched reprocessed and commercial grade (natural) uranium are listed in Table I. The comparison of the concentration of the uranium nuclides U-232, U-234 and U-236 and Tc-99 is shown in Fig. 1. The table and figure show that the concentration of U-232 in enriched reprocessed uranium might be 500 times higher than in commercial grade uranium.

Table I: Nuclide Composition of Enriched Reprocessed and Commercial Grade Uranium

Nuclides	Unit	Enriched reprocessed uranium	Commercial grade uranium
U-232	wt. % U	5.0×10^{-6}	1.0×10^{-8}
U-234	wt. % U	2.0×10^{-1}	5.5×10^{-2}
U-236	wt. % U	3.0×10^{0}	2.5×10^{-2}
Fission products	MeVBq/kgU	4.4×10^{5}	-
Tc-99	wt. % U	5.0×10^{-4}	1.0×10^{-6}
Neptunium and plutonium	Bq/kgU	3.3×10^{3}	-

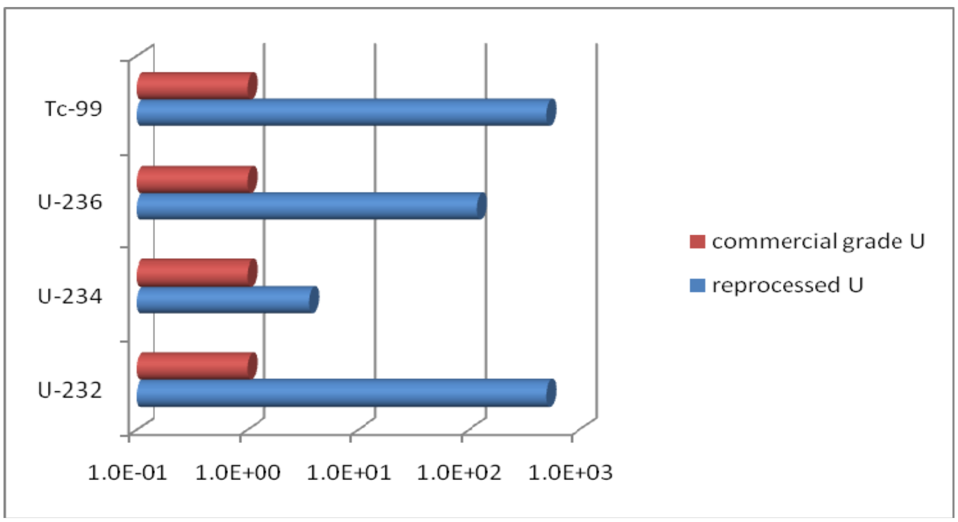

Fig. 1. Comparison of the nuclide composition of enriched reprocessed with commercial grade uranium (logarithmic scale for ratio RepU/commercial grade)

DECAY CHAIN OF U-232 AND RADIOACTIVITY OF REPU

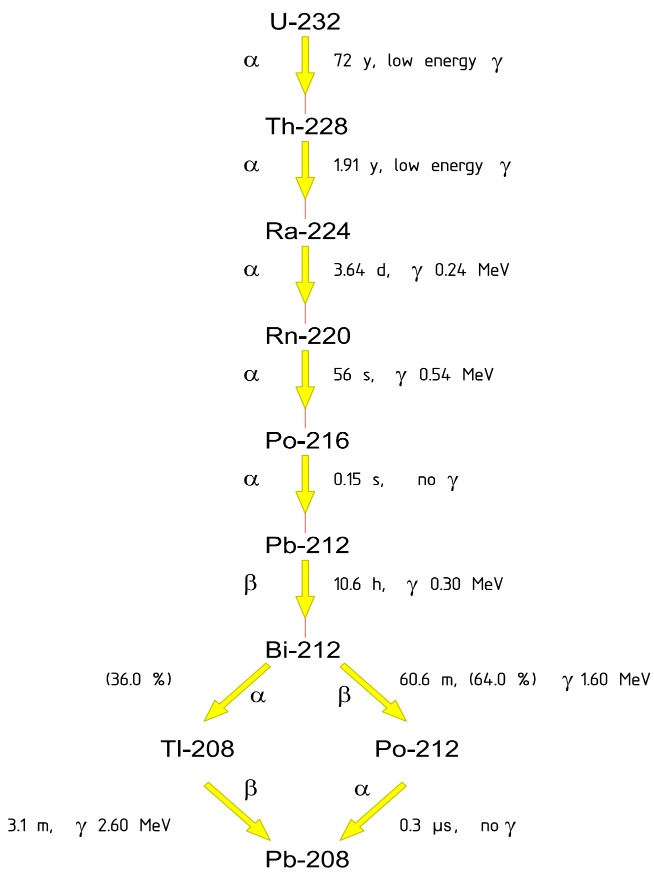

Fig. 2. U-232 decay chain

Decay chain of U-232

The decay chain of U-232 is part of the Thorium decay chain and is shown in Fig. 2.

Radioactivity of filled cylinders

The main nuclides relevant for the determination of the radioactivity in A_2 of enriched reprocessed uranium are U-232 with the decay product Th-228 and U-234. The A_2 value of U-232 does not contain the contribution of Th-228, but the A_2 value of Th-228 contains the contributions of all decay products in the decay chain shown in Fig. 2.

Fig. 3 shows the development of the radioactivity over a time period of 10 years. The contribution of U-234 is constant over this period with in total about 7.9 A_2. U-232 decays slightly (half-life 72 years) from an initial value of 6.3 A_2, and the contribution of the decay product Th-228 increases and reaches after 10 years about 57 A_2. The total radioactivity in a 30B cylinder containing enriched reprocessed uranium is maximal approx. 70 A_2. Assuming a homogeneous distribution of this activity in a quantity of 2277 kg UF_6 leads to a specific activity of 3×10^{-5} A_2/g which is well below the limit for LSA-II. Thus, the package could be transported either as type IF or as type B(U)F package.

Radioactivity of cylinders containing heels

During emptying of a cylinder at the destination an unknown amount of the impurities and decay products of uranium remain in the cylinder. Assuming conservatively that most of the decay products remain in the heels the condition for the specific activity of LSA-II is not met anymore and a type B(U) package is required.

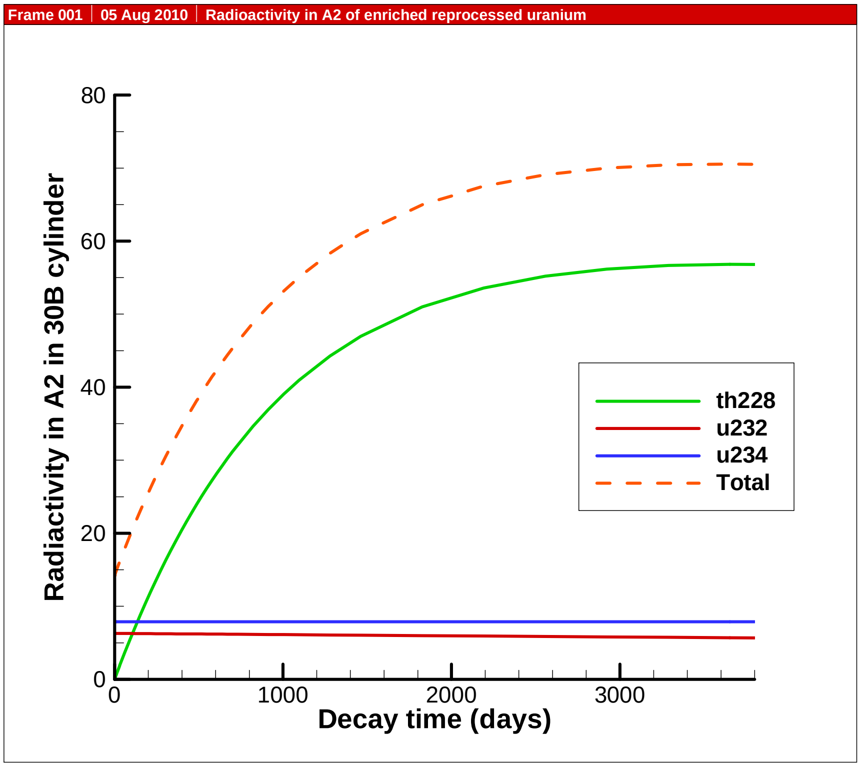

Fig. 3. Total radioactivity in a 30B cylinder filled with enriched reprocessed uranium

GAMMA RADIATION SOURCE TERM AND DOSE RATES

Gamma radiation source term

At the end of the decay chain of U-232 shown in Fig. 2 Tl-208 decays to the stable nuclide Pb-208, emitting hard gamma radiation with intensity of about 100% and energy of 2.6 MeV. The concentration of Th-228 and its decay products increases in equilibrium for about 10 years and decreases then with the parent U-232.

Fig. 4 shows the development of the gamma source intensity over a time period of 10 years. The contribution of U-232 increases considerably with time and is after 10 years more than a factor of 10 higher than the contribution of all other nuclides. The contributions of U-234 and U-236 are constant over this period. The contribution of U-238 increases for about 3 months because of its decay products and remains then constant. The contribution of the fission products with Cs-137 selected here as representative is only relevant for recently processed material and is of minor importance after a relatively short storage and/or transport time.

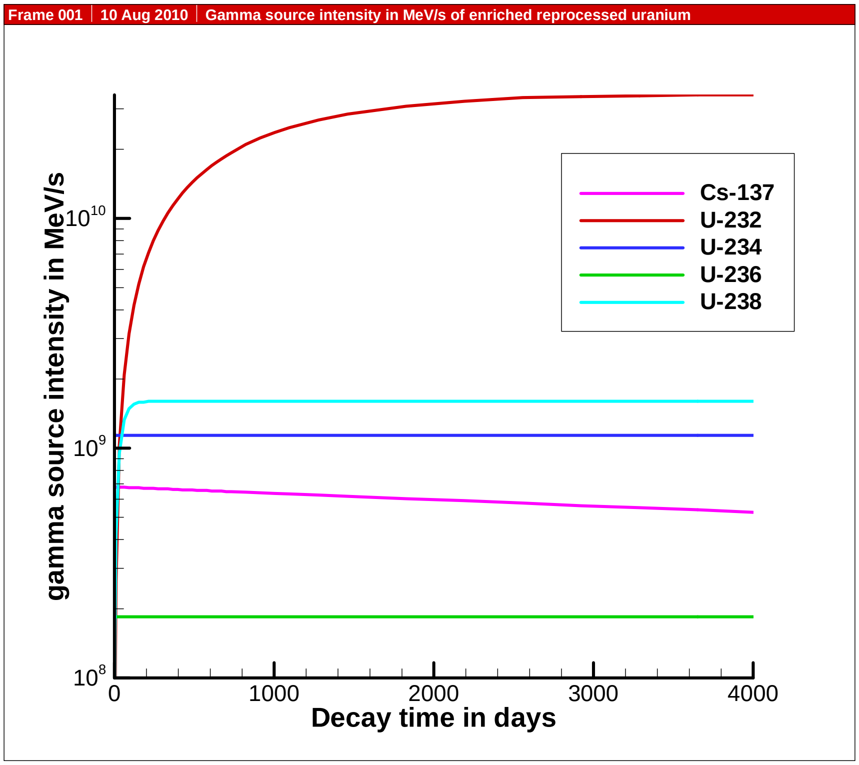

Fig. 4. Gamma source intensity in a 30B cylinder filled with enriched reprocessed uranium

Dose rates at a typical PSP loaded with a filled cylinder

The gamma dose rates at a typical PSP increase considerably with time. Fig. 5 shows that dose rates for RepU are sufficiently small for short times between processing and transport (separation of Th-228). With increasing time after processing the dose rates increase by factors.

The dose rate at the surface of a typical PSP remains well below the limits of the [4]. However, the dose rates in 2 m distance from the vehicle might exceed the limits of the [4] after the accumulation of storage period before transport and transport time reaches a certain limit.

The most important values are the dose rates in 1 m distance from the surface of the package. After about 1.5 years after reprocessing this value exceeds 100 µSv/h which means that the transport index exceeds TI=10. Therefore it might happen that a transport leaves the consignor under not exclusive use conditions but it should arrive at the destination under exclusive use conditions.

Dose rates at a typical PSP loaded with a cylinder containing heels

As discussed above the decay products of uranium are concentrated in the heels after emptying. Depending on the assumed scenario – concentrated bottom pool or contamination of the inner surface of the cylinder – higher dose rates at the surface or in 2 m distance from the vehicle must be expected than for the filled cylinder. It might be required to store the cylinder for some time to allow decay of the nuclide Th-228 and decrease of dose rates below the limits specified in [4]. In any case transport under exclusive use might be necessary.

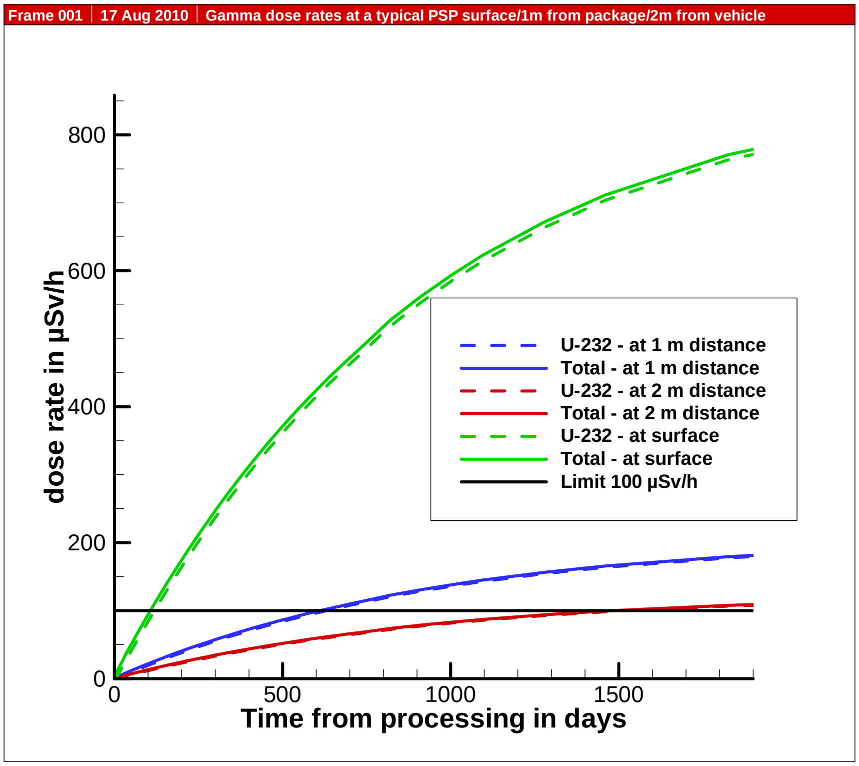

Fig. 5. Dose rates at a typical PSP

DESCRIPTION OF THE NEW DN30 OVERPACK DESIGN

The new DN30 overpack (Fig. 6) is a right circular horizontal loading container which consists of a top and bottom half which are connected with six sliding axis systems. A gasket is fitted on the step-joint part between both halves to prevent water inlet. Sponge rubber strips are pasted on the inner shells of the bottom and top half to prevent direct contact of the inner shell with the 30B cylinder.

The halves consist in principle of an inner and outer stainless steel shell and energy-absorbing and insulating closed-cell phenolic foam of different densities filling the space in between. Lifting and tie-down interfaces permit the safe handling and stowing of the overpack.

As a protection of the valve against mechanical impacts under normal and accident conditions of transport the lower half is equipped with an integrated valve protector as shown in Fig. 7 and 8.

The handling of the complete package is performed by using slings or chains attached to the lifting rings located on the DN30 feet. Handling of the top half is done over lifting rings fixed at the ends of the top half.

Tie-down is performed over holes in the feet of the overpack, the location of which are compatible to other existing overpack designs. The design allows the transport of 4 overpacks on a flatrack. For loading or unloading of the DN30 overpack it is not necessary to remove the overpack from the flatrack. The design fulfills the requirements of [2] and [3].

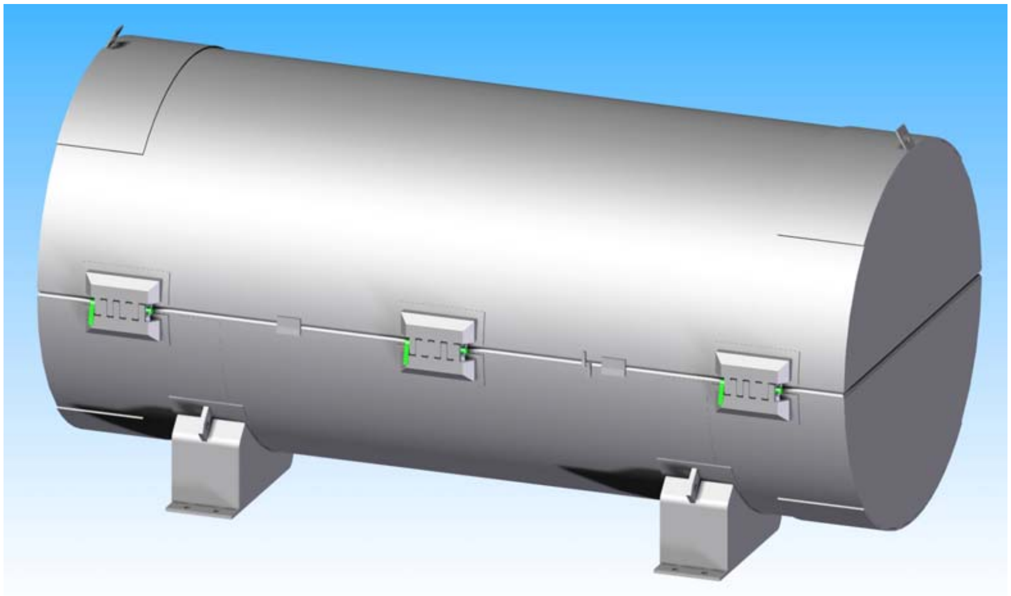

Fig. 6. New overpack design DN30

The main characteristics of the DN30 overpack design are summarized in Table II.

Table II. DN30 Main Characteristics

Masses approx.:	Top half	500 kg
	Bottom half	610 kg
	Total overpack empty	1110 kg
	Max. gross weight package	4100 kg
Dimensions:	Length	2435 mm
	Width	1198 mm
	Height	1218 mm

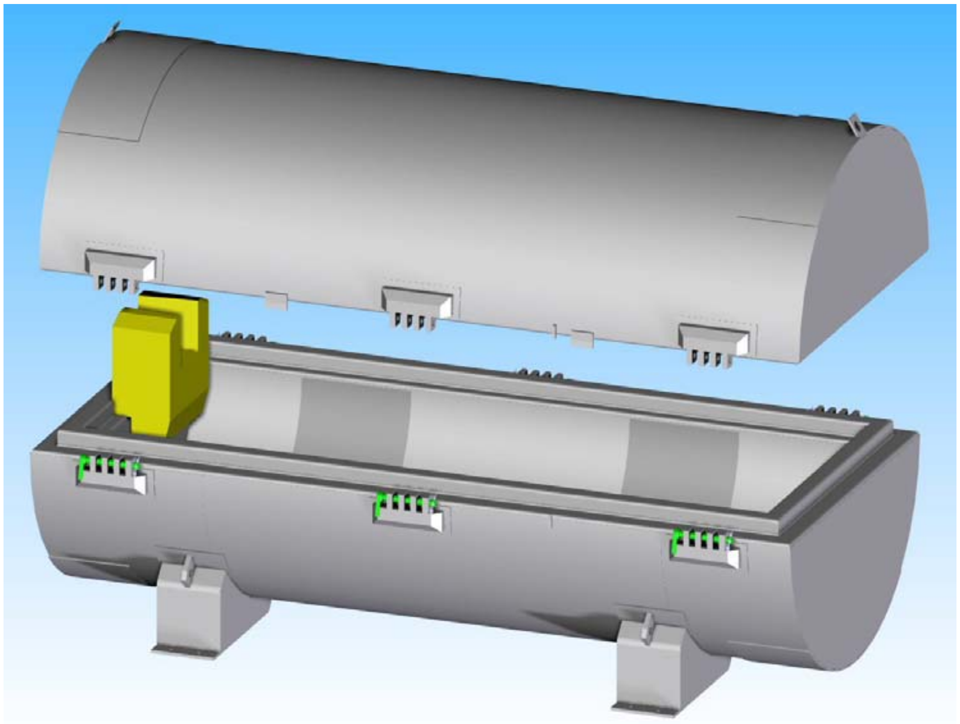

Fig. 7. DN30 lower half with valve protector in transport position

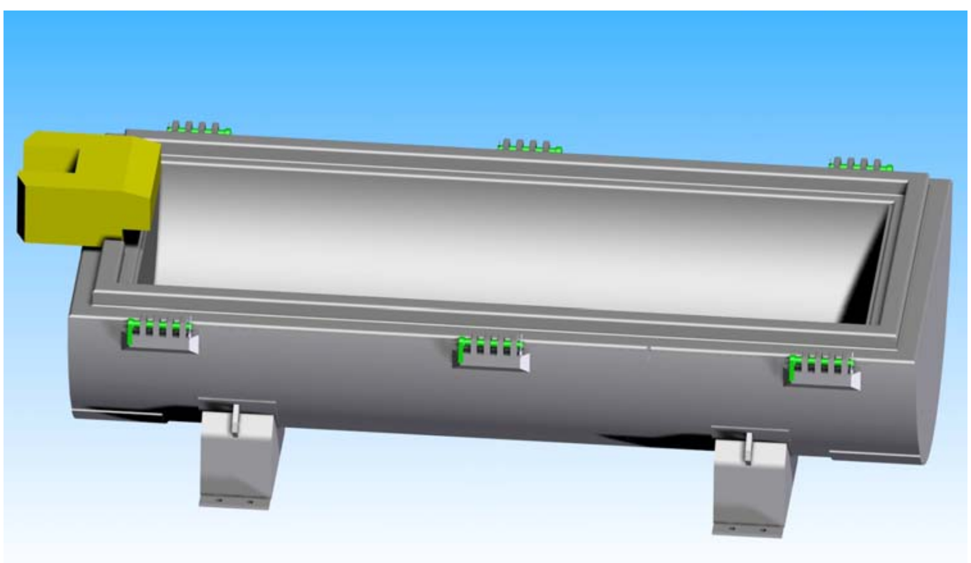

Fig. 8. DN30 lower half with turned valve protector

SAFETY ANALYSIS

The main challenge when designing an UF_6 overpack is to guarantee that the valve and plug of the 30B cylinder are not affected by the impact of the mechanical and thermal tests under normal (NCT) and accidental conditions of transport (ACT).

Therefore special attention was paid to the mechanical behavior of the overpack in these tests. For this extensive FEM calculations by experts of DAHER, the mother company of NCS, have been carried out to optimize the design and to determine the most penalizing drop orientations which cause the maximum damage to the package. Based on the results of these FEM calculations a drop test program was established. In the following the performed FEM calculations and the resulting drop test program are described.

FEM calculations

The FEM calculations were performed with the program LS-DYNA and ANSYS. Examples for the modeling are shown in the Figures 9 to 11.

The drop sequences analyzed consist always of the consecutive drops from 1.2 m (NCT), 9 m and 1 m drop onto the bar (ACT).

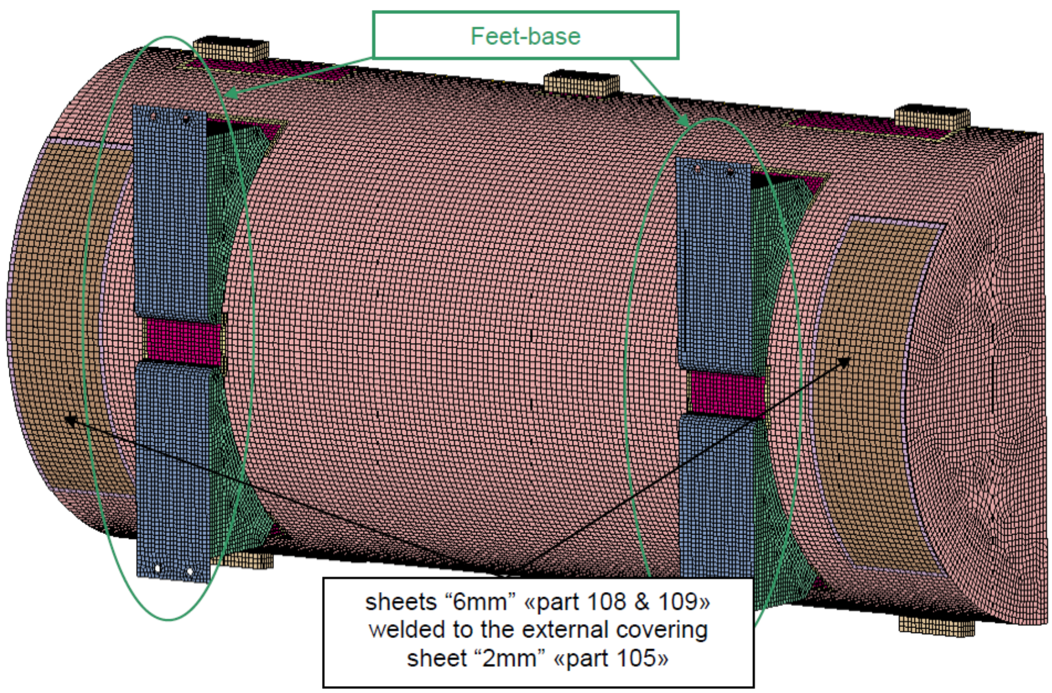

Fig. 9. DN30 lower half with feet

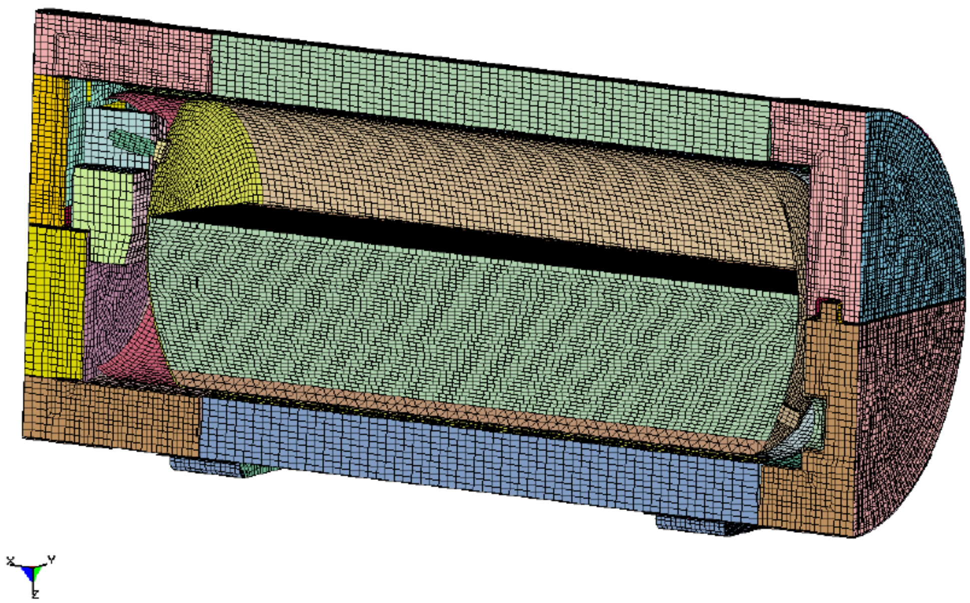

Fig. 10. Section of DN30 loaded with 30B cylinder

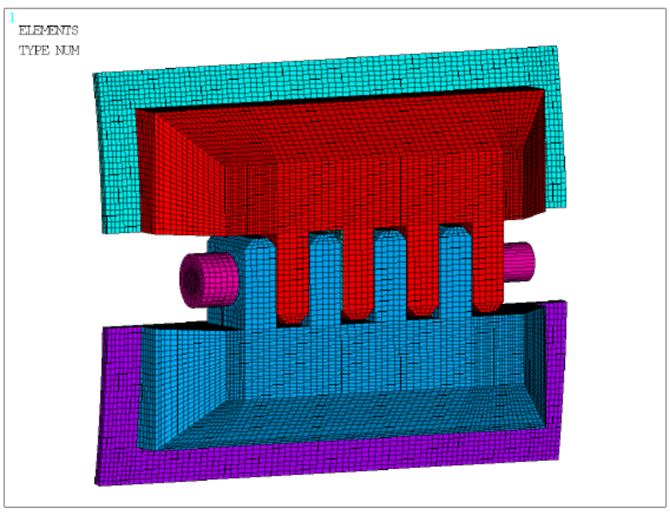

Fig. 11. Detail of DN30 closure system

The following variations were analyzed for different drop orientations:

- Different UF_6 filling configurations
- Temperatures at max. NCT and at -40°C
- Filling ratio 0% (empty) and 60.4% (max. 2277 kg UF_6)

The analyzed drop orientations are summarized below:

- Vertical drop onto the valve side
- Vertical drop onto the plug side
- Corner drop onto the valve side
- Corner drop onto the plug side
- Horizontal drop onto the top
- Horizontal drop onto the feet
- Horizontal drop onto the side of the closure system
- Slap down drop with first impact on plug side

The final results for the vertical drops on the valve and plug side (1.2 m + 9 m + 1 m bar drop) are shown in the Figures 12 and 13.

Drop Test Program

For the performance of the drop tests 3 prototypes of the DN30 overpack and the 30B cylinder are manufactured.

The DN30 prototypes are manufactured of nominal dimensions but the steel materials are chosen under the aspect that the drop test energy absorption capacity of the prototype steel is lower than for the later serial overpack. The 30B are manufactured from low grade steel ASTM A516 grade 60 with a reduced wall thickness of 12 mm (nominal 12.7 mm) and the bending of the skirts is conservatively increased to 30 mm (nominal 25 mm). The UF_6 content will be simulated by small steel balls.

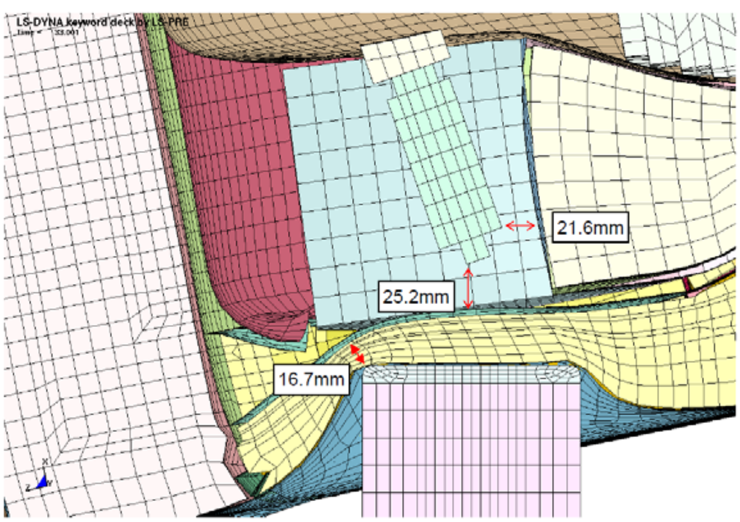

Fig. 12. Valve area after the consecutive vertical drops on the valve side

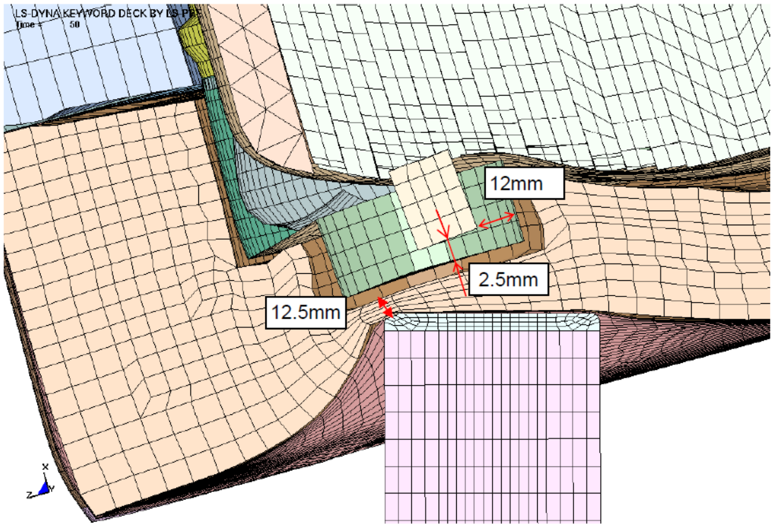

Fig. 13. Plug area after the consecutive vertical drops on the plug side

The drop tests will be performed at RT and the following drop test program is planned based on the results of the FEM calculations:

Sequence 1 (Prototype 1)

- 1.2 m corner drop valve side
- 9 m corner drop valve side
- 1 m bar drop valve side
- 1 m bar drop mantle side

Sequence 2 (Prototype 2)

- 1.2 m corner drop plug side
- 9 m corner drop plug side
- 1 m bar drop plug side

Sequence 3 (prototype 3)

- 1.2 m vertical drop on valve side
- 9 m vertical drop on valve side
- 1 m bar drop on valve side

Sequence 4 (prototype 3)

- 1.2 m horizontal drop on closure system
- 9 m horizontal drop on closure system
- 1 m horizontal bar drop on closure system.

During each test the accelerations and after each test the outer deformations will be measured. After each test sequence the inner deformations will be measured, a helium leak test (criteria 1×10^{-4} Pa m^3 s^{-1}) and a visual control of valve/plug will be performed and the torques of valve/plug will be measured.

CONCLUSIONS

The new DN30 overpack design will fulfill all the requirements toward a package design for the transport of commercial grade and enriched reprocessed uranium up to an enrichment of 5 wt.%. Depending on the kind of allowable content it will be licensed as Type AF, IF or B(U)F. Therefore the DN30 overpack design is a convincing alternative to existing overpack designs and can play an essential role in ensuring the sufficient availability of overpacks for the transport of UF_6 in the front end fuel cycle.

REFERENCES

[1] ASTM C 996 “Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 % U-235”

[2] ISO 7195, Nuclear Energy – Packaging of uranium hexafluoride (UF_6) for transport

[3] ANSI N14.1, Uranium Hexafluoride – Packaging for Transport

[4] IAEA, Regulations for the Safe Transport of Radioactive Material, 1996 Edition