Proceedings of the 19th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2019
August 4-9, 2019, New Orleans, LA, USA

ASSESSMENT OF SAFETY DEMONSTRATIONS RELATIVE TO PACKAGES CONTAINING UF_6

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ABSTRACT

The safety demonstrations realized by applicants in the case of approval request for the package designs containing enriched UF_6 have to take into account some specific technical issues. Concerning the shipment of enriched UF_6, the package designs consist in general of a filled 30B cylinder surrounded by an overpack.
The description of the content, considering the UF_6 origin, i.e. natural or reprocessed, shall be clearly justified especially when the UF_6 isotopic composition exceeds the limits specified in ASTM standards.
Concerning the containment of the UF_6, the applicant shall demonstrate in all conditions of transport the leak-tightness of the valve and plug of the cylinders filled with enriched UF_6. In this regard, when mechanical justifications are based on numerical calculations or experiments, the absence of contact between these components of the cylinder and the internal surfaces of the overpack after the regulatory drop tests shall be shown to respect the IAEA regulations.
Furthermore, the representativeness of the ballast used to simulate the behaviour of the UF_6 loaded within the cylinder shall be justified if drop tests are performed. The representativeness of the ballast should also be justified for numerical calculations.
In addition, the applicant shall demonstrate that the melting temperature of the valve and the plug, including the tinned joint, will not be exceeded during the regulatory fire test.
Finally, specific provisions relative to the use of plugs and the maintenance of cylinders should be included in the safety analysis report.

INTRODUCTION

The package designs used for the shipment of enriched UF_6 shall fulfil, according to its composition, the IAEA requirements [3] applicable to type B(U) packages and packages containing fissile material. As a consequence the IAEA requirements relative to the transport of radioactive materials, in terms of containment and shielding, shall be fulfilled. The main objective is that after regulatory tests simulating normal and accident conditions of transport, the package remains leak tight (leak rates measured at the valve and the plug shall not exceed 10^{-4} Pa m^3 s^{-1} (standard leakage rate - SLR)) and the dose rate measured on the package remains below the regulatory criteria.
Storage, on-site and public transport of UF_6 are carried out in steel cylinders that are defined in terms of design, manufacture, use, inspection and maintenance by ISO 7195 [1] and ANSI N14.1 [2] standards.

The main cylinders used for UF_6 supply of fuel cycle plants are the 30B and 48Y cylinders. These cylinders can be transported full, partially full or empty (containing only heels).
The package designs used for public transport of enriched UF_6 consist in general of a cylinder surrounded by an overpack. Overpacks have in general a cylindrical shape and consist of two half-shells, enclosing the 30B cylinder, filled with shocks absorber and insulation materials. Four types of overpack are currently approved for such transports: UX-30 (American design), COG-OP-30B (French design), MST-30 (Japanese design) and DN30 (German design).

ISOTOPIC COMPOSITION

The results of the containment and external dose rate analyses and the package classification depend on the composition of the UF_6 loaded within the cylinder and also the residues under solid form accumulated (like corrosion products or UF_6 solid derivative) named heels. In this regard, the ASTM C996 standard [6] specifies limits applicable for some isotopes (^{232}U, ^{234}U, ^{236}U, ^{99}Tc) present in UF_6 enriched from natural or reprocessed uranium. It has to be noticed that these values correspond to the initial composition of the UF_6 just after its production.
Nevertheless, the composition of the heels should be evaluated considering the filling history of the cylinder (filling/emptying cycles, possible washes, storage time of the material in the cylinder) and the UF_6 origin, i.e. natural or reprocessed.

UF_6 from natural uranium

In 2010, measurements performed after cylinders washing operations were used to determine the composition of 30B cylinder heels. Cylinders concerned were loaded with enriched UF_6 from natural uranium. The average isotopic composition was determined and it was shown that the composition given in ASTM C996 standard [6] covers enriched UF_6 from natural uranium. Nevertheless, the values given in ASTM C996 standard should be clearly mentioned in the chapter of the safety analysis report relative to the content description and be specified in the certificate of package design approval.
When the isotopic composition of the UF_6 to be transported exceeds the limits specified in ASTM C996 standard, additional justifications should be provided, especially to demonstrate that the limits considered in the safety demonstrations (exceeding ASTM C996 standard limits) cover the maximum UF_6 isotopic composition.

Evolution of UF_6 composition with time

The isotopic composition of the UF_6 evolves differently with the time, depending whether the cylinder is full or empty with heels. The conclusion of the study performed in 2010 allowed to determine the storage time of a cylinder, full or empty, leading to the isotopic composition which maximizes the number of A_2, taking into account the concentration of ^{234}Th, ^{234}U and ^{228}Th. Based on this isotopic composition, the maximum activity was therefore evaluated considering a storage time of UF_6 of 5 years, which corresponds to the maximum time between two inspections of the cylinders defined in the standards. For an empty cylinder (containing heels), the study showed that the maximum activity is obtained immediately after the emptying operations of a UF_6 cylinder that stayed full during 5 years.

UF_6 from reprocessed uranium

Concerning enriched UF_6 from reprocessed uranium, measurements should be performed to confirm that the limits considered in ASTM C996 standard are penalizing. Currently, as there is no study of the heels from reprocessed uranium, the isotopic composition of 30B cylinders which had several filling/emptying without washing is unknown; as a consequence, systematic washing of the cylinder is necessary.

LEAK-TIGHTNESS OF THE VALVE AND THE PLUG AFTER REGULATORY DROP TESTS

The containment of UF_6 is ensured by the cylinder, its valve and plug. Leak-tightness tests of the containment are performed:

- at the valve, at the end of cylinder manufacturing operations, before shipment, and during maintenance;
- at the plug, after cylinder manufacturing operations and during maintenance.

The leak rates measured at the valve and the plug shall not exceed 10^{-4} Pa m^3 s^{-1} (SLR) as defined in ISO 7195 [1] and ANSI N14.1 [2] standards.

Furthermore, the package designs used for the shipment of UF_6 shall fulfil, in accordance with its composition, the IAEA requirements [3] applicable to type B(U) packages and packages containing fissile material. The package designs used for public transport of enriched UF_6 (in general a filled 30B cylinder surrounded by an overpack) shall be submitted to the regulatory drop tests simulating accident conditions of transport (ACT). At the end of these tests, the control of the cylinder containment function is in general based on the residual leak rate which shall be lower than the criteria of 10^{-4} Pa m^3 s^{-1}.

The main way to guarantee the leaktightness of the cylinder, is to ensure that there is no contact between the valve or the plug and the internal surface of the overpack in all conditions of transport. To demonstrate and justify the cylinder leak-tightness after ACT tests, drop tests and numerical calculations are performed. According to the current IAEA regulations [3], the absence of unlimited water penetration within the cylinder after ACT tests can be considered if there is no physical contact between the valve and any other component of the packaging (in the future applicable regulations [4], the condition of no physical contact between the plug and any other component of the packaging will be added). In addition, the prevention of contact between valve (or plug) and any other component ensures the integrity of the package containment.

The drop tests are performed in most cases at ambient temperature and/or using specimen whose representativeness in terms of minimum mechanical properties of the package design components is not guaranteed. To take into account these points, applicants perform additional calculations, based on finite elements models, to evaluate the maximum deformation of the overpack considering, on the one hand the components behaviour within the regulatory temperature range and, on the other hand, the most penalizing attitude of the package during the drops. These calculations in combination with the experimental drop test results allow assessing the regulatory valve/plug contact criteria under ACT.

If any, the maximum loading acting on the plug should be evaluated. Then the leak-tightness of the cylinder should be confirmed on the basis of dedicated tests. Such approach was considered to confirm the leak-tightness of a 30B cylinder in ACT [5]. Additional compression and leakage tests were performed on a hex head plug of a 30B cylinder considering three directions of load. The maximum loading acting on the plug was determined by numerical calculations and it was checked during dedicated tests that the remaining leak rate was lower than the standard leakage rate (SLR) defined in [1].

REPRESENTATIVENESS OF THE BALLAST USED TO SIMULATE UF_6 IN DROP TESTS

Representativeness of the ballast used to simulate UF_6 content is quite a challenge to justify.
Due to the geometric complexity of UF_6 (presence of crystals, heterogeneous solidification etc.) and the absence of relevant tests to characterise its material behaviour within the regulatory temperature range (traction, compression, resilience, hardness etc.), the justification of the ballast representativeness is in general based only on the mass and bulk density of UF_6 considering also the cylinder filling rate.

However, other parameters can influence the results of the drop tests as well. The load on the cylinder valve due to internal impacts during the drop test depends on, the bulk density, the diameter of the shots, the energy absorption capacity of the ballast materials.

In addition, the filling configuration of the cylinders shall be considered as well. In this regard, it has to be noticed that during natural cooling after the filling of a cylinder, a crust is formed in contact with the colder steel wall of the cylinder. Simultaneously, a part of liquid UF_6 volatilizes and crystallizes, in contact with the upper surface of the cylinder, forming a crust (see image 2 of Figure 1) with a few centimeters thickness.

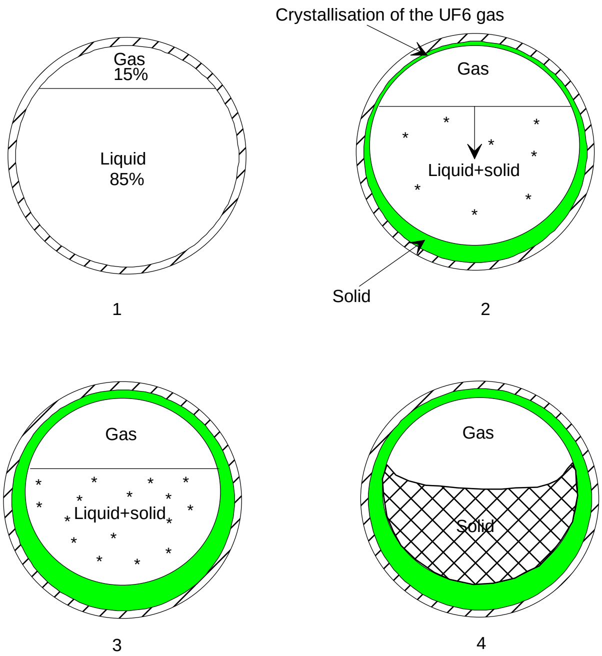

Figure 1. Stages of solidification of UF_6 during filling operations

The fracture of the crust seems possible under the conditions of drops simulating normal and accident conditions of transport. Such phenomenon could induce a quantity of fragments, whose mass has been estimated between 200 kg and 400 kg for a filled 30B cylinder. The values are estimated from TENERIFE experiments [7]. The random size of these fragments, from dust to large fragments, can induce internal impact on the valve.

Several approaches have been considered to simulate UF_6. Many kinds of ballasts used for drop tests performed in the past were made of iron balls, steel or lead shots with different diameters, embedded or not in paraffin wax.

The use of a mixture made of paraffin and steel shots leads to a unique solid block. Nevertheless, due to the low shear strength of this block, ballast fragments will constitute a soft body that does not seem to impact the valve with the same energy than those implied in case of internal impacts of solid fragments of UF_6. This approach reduces internal solicitations applied to the valve due to the high energy absorption capacity of the materials. In this regard, the representativeness of the ballast, in comparison with the actual behaviour of UF_6 during impact, is not ensured.

Concerning the ballasts made of lead balls, its fluidic behaviour and its important capacity to absorb energy will underestimate the effect of ballast impact on the valve.

Recent drop test campaigns were performed to qualify a new package design. The ballast used to simulate UF_6 during these tests was made of cement and steel grit matrix, taking into account:

- mixture of cement and steel grit to form the main block;
- debris of this mixture simulating UF_6 debris resulting from crust damage. The hardness of the steel grit in the cement would ensure a consistent impact on the valve, assuming that the hardness of UF_6 is greater than cement's one and smaller than steel's one.

Moreover, the representativeness of the modelled ballast used for numerical calculations was justified.
Such approach is considered acceptable by IRSN and BAM to simulate the behaviour of filled 30B cylinders in ACT.

THERMAL BEHAVIOUR IN ACCIDENT CONDITIONS OF TRANSPORT

The leak-tightness of the connection between the valve/plug and the cylinder is assured by the tinning of the thread of the valve/plug. The ISO 7195 [1] and ANSI N14.1 [2] standards specify that the tinning should be made of a tin-lead alloy, in accordance with ISO 9453 [8] or ASTM B32 [9] standards which specify that the melting temperature ranging starts at 183°C (softening temperature).
Therefore, the maximum temperature of the valve and plug threads reached during the regulatory thermal test shall be lower than 183°C.
This maximum allowable temperature should be considered as a relevant criterion to guarantee the leak-tightness of the connection between the valve or plug and the cylinder.

It is also important to consider that a temperature higher than this criterion, even if controls performed after fire test show that the leak rate of the cylinder is below the SLR criterion, could question the cylinder containment function. Due to the properties of the tin-lead alloy present on the tested specimen, it cannot be excluded that its softening temperature will be higher than 183°C. Nevertheless, it could not be guaranteed that this behaviour covers all cylinders which are manufactured according to the standards.

To meet the temperature criterion mentioned, an appropriate overpack design in view to regulatory thermal impact is of great relevance. Protecting the valve/plug area, to reduce high temperatures due to fire testing and possible flammable pyrolysis gases are in focus of package design safety assessment.

USE AND MAINTENANCE

Leak-tightness tests

The periodic inspection and tests performed on cylinders at intervals not exceeding 5 years are described in ISO 7195 [1] and ANSI N14.1 [2] standards; these operations include especially a hydrostatic pressure test of the cylinder and a leak test of the valve and the plug after removal, inspection and replacement of the components.
During the discussions in the revision process of the ISO 7195 [1] standard, it was proposed in the draft standard the possibility to perform alternative controls during manufacturing (reinforced controls of the welds of the cylinders). Considering these alternative controls proposed in the draft standard, the hydrostatic pressure test would not be performed during the periodic inspection. Moreover, the possibility to demonstrate leak-tightness by a simple contamination check when no valve or plug change has occurred was introduced.

European competent authorities indicated that this proposition is not in accordance with ADR [10] requesting a leak-tightness test with a sensitivity of at least 10^{-6} bar l s^{-1}. It has also been reminded that different aspects of the valve should be tested including the valve seat, the valve packing and the (tinned) tapered thread connection with the half-coupling.
According to IRSN and BAM opinion, the pneumatic leak tests of the plug and the valve should be performed at each five-years inspection of empty (washed) cylinders even if no valve or plug has been changed.

Finally, the possibility to conclude on the leak-tightness by contamination checks has been withdrawn from the draft, and the leak test to be performed at each five-years inspection has been reintroduced. For cylinders which contain UF_6 (including heeled cylinders), the leak test shall be performed on the valve seat only. After the next emptying, the cylinder shall be cleaned and washed out, and a complete leak test (not only the valve seat) should be performed.

Cylinder’s plug designs

Cylinder’s plug was defined initially as hex head plug. Nevertheless, it was put in the light that this type of plug are exposed to direct mechanical shocks in case of drops, leading to a risk of leak-tightness loss.
An alternative non-protuberant socket head plug concept has been developed and added to the latest version of ANSI N14.1 standard [2]. This new plug design reduces the risk of a direct impact due to its dimensions and the reduced height.
It was proposed to harmonize the standards and to include in the new revision of the ISO 7195 this new plug design. The main objective was to gradually equip the 30B and 48Y with this new type of plug.

However, difficulties have been reported by many users during the assembling and disassembling operations of these plugs (leading sometimes to cracking of plugs with a 1 1/2” diameter). Subsequently, a working group, including members of the World Nuclear Transport Institute (WNTI) has elaborated a guidance presenting best practice to facilitate the use of socket head plugs. This guidance recommends, for instance, removing tinning from the first two threads, to facilitate the insertion of plugs, and using specific tools to apply the requested torque.

In addition, a complementary testing program has been requested by French Nuclear Authority to evaluate the behaviour of this plug considering the number of assembling and disassembling

operations and also the pressure and temperature effects taking into account the filling and emptying operations of the cylinders. In this regards, it can be noticed that the internal pressure of the cylinder may reach several bars during the filling operations.
In the meantime, the use of hex head plugs is recommended in France.

Finally, discussions have been initiated between ASN (French competent authority), IRSN and French applicants to evaluate the relevance of the torque values applied to the cylinder plugs, notably socket head plug, which are mentioned in the standards. The objective is to confirm their relevance and to exclude any plastic deformation of the plug considering its mechanical properties and its using temperatures.

CONCLUSION

Recent assessments by IRSN of the safety demonstrations transmitted by applicants in support to their approval request for the shipment of cylinders containing UF_6 raised up several technical issues. In particular, it was highlighted that attention should be paid on the ballast used to simulate UF_6 during the regulatory drop tests. In addition, the real characteristics of the UF_6 should be considered, notably the presence of debris within the cylinder cavity resulting from the upper crust damage. The movement of these ones during drop tests could increase the valve damage.
In addition, the applicant shall demonstrate that the melting temperature of the valve, including the tinned joint, will not be exceeded during the regulatory fire test. In that case, IRSN considers that the criterion should be assimilated to the minimum value equal to 183°C as mentioned in the ISO 9453 [8] and ASTM B32 [9] standards.
Finally, difficulties reported by many users during the assembling and disassembling operations of the socket head plugs put in the light the necessity to evaluate the torque specifications mentioned in the standards and to evaluate the stress resulting from the cylinders filling and emptying operations. The results of a dedicated test campaign performed by French applicants will give complementary information in the future.

REFERENCES

[1] International Standard ISO 7195 "Packaging of uranium hexafluoride (UF_6) for transport" (2005 edition).
[2] American National Standard ANSI N14.1 "Uranium Hexafluoride – Packaging for Transport" (2012 edition).
[3] IAEA No. SSR-6, Regulations for the Safe Transport of Radioactive Material, 2012 Edition.
[4] IAEA No. SSR-6 (Rev.1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition.
[5] Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2016, "Integrity of 30B cylinder plug for physical contact", Hiroshi Takahashi and al.
[6] ASTM International C996 "Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 % ^{235}U (2010 edition).
[7] IPSN report DSMR-98.016, "Research on behavior of UF6 containers exposed to fire – Final French synthesis report – IAEA coordinated research program", September 1998, Gilles Sert, Eric Pinton and Pierre Lelong.
[8] International Standard ISO 9453 "Soft solder alloys — Chemical compositions and forms" (2014 edition).
[9] ASTM International B32 "Standard Specification for Solder Metal" (2014 edition).

[10] ADR "European Agreement Concerning the International Carriage of Dangerous Goods by Road", applicable as from 1 January 2017.