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Prototype Testing of a Protective Structural Packaging for 30B Cylinder

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Abstract

Three drop test campaigns have been performed with DN 30 Protective Structural Packaging (PSP) developed by DAHER NUCLEAR TECHNOLOGIES GmbH (DAHER NT) for the transport of natural, enriched and reprocessed uranium hexafluoride (up to 5 wt%) in 30B cylinders.

The mechanical prototype testing is intended to demonstrate that the package DN30 complies with regulatory requirements under normal and hypothetical accident conditions of transport (NCT, ACT) relevant to IF, AF and B(U)F packages, respectively.

The presentation includes the results of the latest test campaign carried out in 2015/16 at the drop test facility of BAM, Germany with new full scale prototypes of the DN30 PSP and 30B cylinders. Repetition of drop test sequences became necessary after changing to Polyisocyanurate foam as shock absorbing material with variable foam densities. Furthermore, the mechanical behavior of the UF6 content of the 30B cylinder is now simulated by a mixture of cement and steel grid as modified surrogate material; instead of small steel balls. The behavior of this new content simulation is assumed to be more realistic with respect to the properties of real UF6.

Introduction

Enriched uranium hexafluoride (UF_6) is transported in 30B cylinders using an additional protective structural packaging (PSP) for mechanical and thermal protection under normal and accident conditions of transport. DAHER Nuclear Technologies developed the DN30 PSP for the transport of UF_6 containing commercial grade and enriched reprocessed uranium in 30B cylinders. The package DN30 is going to be licensed in France as type AF, IF and B(U)F package for UF_6 up to an enrichment of 5 wt.%.

The German Federal Institute of Materials Research and Testing (BAM) was contracted by DAHER NT to perform the drop test campaigns and a thermal test in context with licensing procedure under

traffic law in France. The experimental tests were performed for normal and accidental conditions of transport according to the regulation [1]. Overall three drop test campaigns and a thermal test have been performed and evaluated; see ref. [2-5]. The protective packaging DN30 was tested in a previous drop test campaign in 2011/2012. Overview of these initially five drop test sequences and results are given at PATRAM 2013 [2]. Due to changes in the PSP design some test sequences were repeated in 2013 taking also Polyisocyanurate (PIR) as modified shock absorbing foam material in to account [3]. As a result, in the actual PSP design variable densities of PIR foam are used and innovative approaches in construction details leads to improved transport and handling safety of the DN30 PSP, see [4].
The performance and results of the actual drop test campaign carried out in 2015/16 at BAM's drop test facility with new full scale prototypes of the DN30 PSP and 30B cylinders are described in the following. Current results of the thermal test are given in [5].

Description of the DN30 PSP

The DN30 package consists of the DN30 PSP, the 30B cylinder according [6] and [7] as well as the content UF_6 (max. 2 277 kg). The DN30 PSP is designed as a cylindrical shell consisting of bottom and top halves which are connected by the closure system comprising of 3 parts on each side of the PSP. The two halves consist of an inner and outer stainless steel shell which encloses PIR foam as shock absorbing material with different densities.
The main parameters and characteristics of the DN30 PSP are listed in Table 1. A sketch of the DN30 PSP is shown in Fig. 1and pictures of the prototype before testing are given in Fig. 2.

Table 1: Main Data of the DN30

Mass approx.:	
DN30 PSP (without 30B cylinder)	960 kg
Max. gross weight DN30 package (loaded with UF_6)	3 900 kg
Dimensions:	
Length	2 435 mm
Width	1 216 mm
Height	1 238 mm

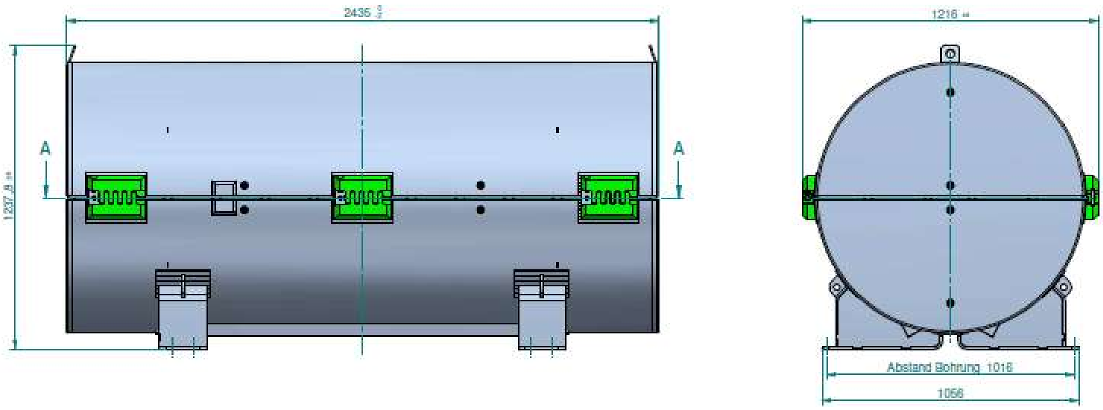


Fig.1: Outer view of the DN30 Protective Structural Packaging

Fig.2: Top and bottom halves of DN30 PSP with 30B cylinder.

Overview of Drop Test Campaigns

Three drop test campaigns have been performed with full scale prototypes of the DN30 PSP. The test specification consists of five drop test sequences with different drop orientations selected to cause maximum damage of the packaging as well as to submit specific mechanical loadings on its design elements. In general, drop orientations of the prototypes are on to the corner at the valve and plug side as well as the vertical slap-down drop, the side drop onto the closing system and the flat drop onto the valve side.

The first test campaign was carried out from August 2011 to May 2012. It comprised five drop test sequences each with three drop tests. The drop test sequences were the same as listed in Table 2. For this drop test campaign in situ poured phenolic foam was used in the design of the DN30 PSP as shock absorbing material and the surrogate material for the UF_6 were loose steel balls of 6 mm diameter. The results of the drop tests were in general:

- Deformations and accelerations pre-calculated by FEM analyses based on measured properties of samples of phenolic foam differed in some cases considerably from the values measured after the drop test sequences.

- The valve remained leaktight only in some drop test sequences. After other sequences the valve seat as well as the thread between valve and cylinder were not leaktight anymore.

The second test campaign was carried out from December 2013 to September 2014. It comprised two drop test sequences each with three drop tests. The drop test sequences were the same as listed in Table 2 as drop test sequence 3 and 4. A further 1.2 m drop test as listed as drop test no. 3.1 in Table 2 was performed. For this drop test campaign the phenolic foam was replaced by prefabricated PIR foam parts which were assembled into the DN30 PSP as shock absorbing material. As surrogate material still loose steel balls of 6 mm diameter was used. The results of the drop tests were in general:

- The differences between pre-calculated deformations and accelerations based on measured properties of samples of PIR foam and measured values were small.
- The valve seat as well as the thread between valve and cylinder were not leaktight after the drop test.
- Even after a 1.2 m drop test the valve was not leaktight.

After the second campaign a root cause analysis of the failure of the prototypes in the drop tests was carried out. As reason for the outcome the surrogate material was identified. By the elasticity of steel balls and cylinder material secondary effects were introduced which are not to be expected for UF_6. These effects were so strong that the impact of the steel balls caused plastic deformations at the interior of the valve. It was then decided by DAHER NT and agreed with by the French competent authority to change the surrogate material to heavy concrete.

The third and final test campaign was carried out from September 2015 to March 2016. It comprised five drop test sequences, one of the sequences with four and all other with three drop tests. The drop test sequences are listed in Table 2. Of this table, drop test sequence no. 7 was performed to prepare the specimen for the thermal test of which the results are presented in another paper at PATRAM 2016 [5]. The following part of the paper will give some details of these drop test sequences and the results.

Description of the Drop Test Program

Specimen

In total five full-scale prototypes of the DN30 package were manufactured for the drop tests, in which one prototype was used twice - in drop test sequence 1 and 2 with a new cylinder for each sequence and one prototype (sequence no. 7) was dropped twice with the same cylinder as preparation for the thermal test. As far as practicable and required the prototypes were assembled with new 30B cylinders from serial production or the cylinders were equipped with a new valve and a new plug.

In order to simulate the original content each 30B cylinder was filled with a solid block of heavy concrete with about 300 kg debris of the same material scattered on top of the solid block. The concrete was a mixture of cement and steel grid, filled in a horizontal position of the UF6-cylinder.

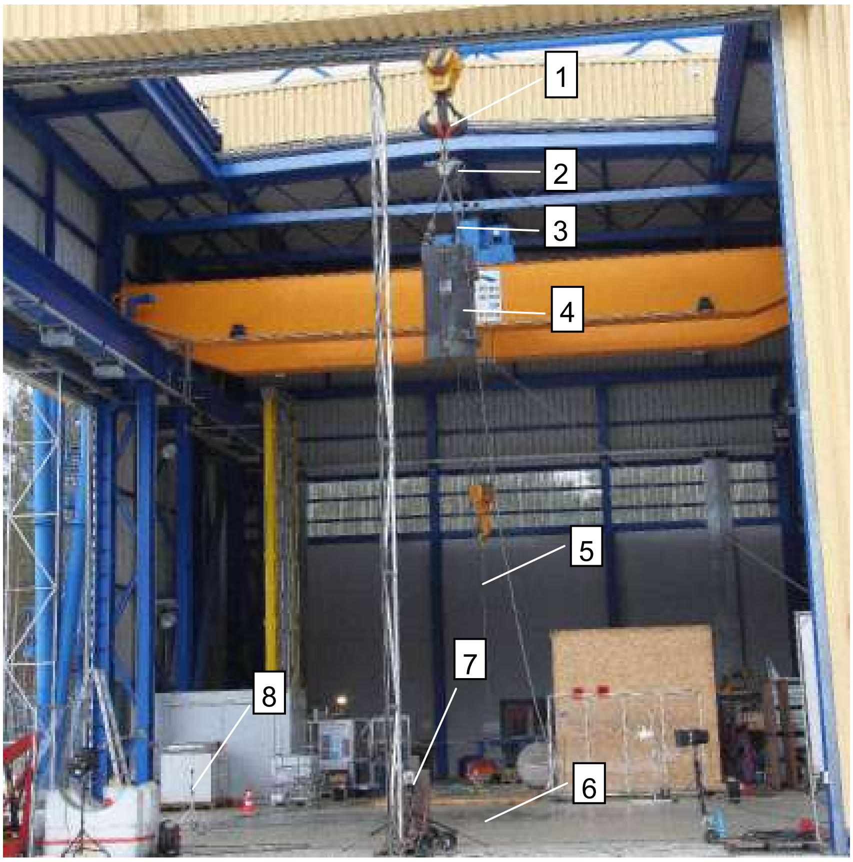
The total mass of a ready assembled specimen for drop testing varied between 3 900 kg and 3 950 kg, and the total mass of a 30B- cylinder between 2 866 kg and 2 912 kg.

Table 2. Performed drop test sequences in chronological order

Sequence		Date	IAEA SSR-6	Drop test and specimen orientation
7	7.1	2015-09-15	722 (a), 727 (a)	10.2 m corner drop test onto valve side / 68°
	7.2	2015-09-15	722 (a), 727 (a)	10.2 m corner drop test onto plug side / 68°
	7.3	2015-09-17	727 (b)	1 m puncture drop test onto corner edge and valve side / declined 68°
	7.4	2015-09-21	727 (b)	1 m puncture drop test onto plug side / declined 68°
3	3.1	2015-11-10	722 (a)	1.2 m flat drop test onto the valve side/ vertical orientation
	3.2	2015-11-10	727 (a)	9 m flat drop test onto the valve side / vertical orientation
	3.3	2015-11-11	727 (b)	1 m puncture drop test onto the valve side, front end/ declined 80°
4	4.1	2015-11-17	722 (a)	1.2 m drop test onto the line of the closure system / horizontal orientation
	4.2	2015-11-17	727 (a)	9 m flat drop test onto the line of closure system / horizontal orientation
	4.3	2015-11-20	727 (b)	1 m puncture drop test onto the middle hinged closure / horizontal orientation
2	2.1	2016-01-26	722 (a)	1.2 m corner drop test onto the plug side / declined 67°
	2.2	2016-01-27	727 (a)	9 m corner drop test onto the plug side / declined 67°
	2.3	2016-01-28	727 (b)	1 m puncture drop test onto the plug side (bottom half / declined 67°
5	5.1	2016-02-23	722 (a)	1.2 m slap down drop on valve side with first impact of plug side (bottom half) / 15° oblique
	5.2	2016-02-24	727 (a)	9 m slap down drop on valve side with first impact of plug side (bottom half) / 15° oblique
	5.3	2016-02-25	727 (b)	1 m puncture drop test onto the outer shell of top half / 25° oblique
1	1.1	2016-03-02	722 (a)	1.2 m corner drop test onto the valve side (top half) / declined 68°
	1.2	2016-03-02	727 (a)	9 m corner drop test onto the valve side (top half) / declined 68° oblique
	1.3	2016-03-03	727 (b)	1 m puncture drop test onto the valve side (top half) / declined 68°

Drop Test Setup

The drop test facility consists of three components basically: drop tower with hoist, assembling hall with movable roof and impact target. The essentially unyielding target is built according to the IAEA regulations for specimens up to 200 000 kg, and described in [8]. The release of the specimen is performed using an electro-mechanical and momentum free working release system, which guaranties that an adjusted drop orientation of a specimen keeps unchanged during release and free fall.The general test setup consists of the following parts (see Fig. 3): Drop tower with IAEA impact target, momentum free release system, two digital high-speed camera systems, and deceleration measurement of the UF6 cylinder.



1…Crane hook of the 200 t hoist

2…Electro-mechanical release system

3…Nylon slings for attachment of the specimen to the release system

4…Specimen (DN30 package)

5…Measuring cables with connected accelerometers

6…IAEA target

7…High-speed camera

8…Mechanical trigger for data acquisition

Figure 3: General test setup of 9-m drop test with DN30 prototype

Tests and Measurement Techniques

Instrumentation and Deceleration Measurements at the UF6 Cylinder

All drop tests excluding drop test sequence no.7 were carried out with instrumented UF6 cylinders to measure the decelerations during impact. For the instrumentation, an instrumentation plan had been set up by DAHER NT and agreed with the French competent authority.

Each UF6 cylinder was instrumented with various accelerometers. One uniaxial as well as triaxial piezoresistive accelerometers have been used in six-wire Wheatsone Full-Bridge circuit. Furthermore, redundant deceleration measurement by a piezoelectric accelerometer has been applied. The data acquisition was carried out using a multi-channel measuring device with wideband differential bridge amplifiers for direct connection of the accelerometers.

During drop testing high-speed colour video cameras have been used in order to control the orientation of the package at the point of impact onto the IAEA target as well as to check the mechanical response of the package by motion analysis.

Leak-Tightness Test of the 30B Cylinder

Leakage tightness test of the 30B cylinder was determined by measurement of the helium leakage rate according to the test instruction before (zero measurement) and after each drop test sequence. The 30Bcylinder was surrounded by an outer box which was filled with helium under the assumption of a 500 hPa partial pressure, so that the helium standard leakage rate, which is related to 1 013 mbar of helium, could be calculated after measuring.

Measurements in the Course of Test Sequences

Before and after the drop test further measurements have been performed, e.g.

- Dimensional and visual controls (exterior, interior)
- Control of valve and plug mounting, torque control of the 30B cylinders
- Weight control of the cylinders and DN30 PSPs
- Drop height and angle adjustments of the test package
- Check of the PSP's closure system
- Gap measurements between top and bottom halves of the PSP

Results of Drop Tests

Drop Test Sequences 1, 2 and 7

The orientation of the specimen during the drop test sequences 1, 2 and 7 was declined so that the center of gravity was vertical above the corner of the specimen, i. e. the first impact of the specimen onto the target. The pre-calculations showed for this orientation maximum deformations and hence maximum reduction of the foam thickness protecting the valve and the plug.

The specimen is shown in Figure 4 after the full regulatory drop test sequence 1 followed by the full regulatory drop test sequence 2. The main results were:

- There was no rupture of the welding seams of the outer shell.
- At the plug side there was a crack caused by the puncture test but no full penetration.
- At the inner shell there were some minor cracks and fractures in the impact area of the skirt of the 30B cylinder, at the side of the valve protecting device and at the plug protecting device.
- The closure system was intact and fully functional.
- Neither valve nor plug came in contact with any other part of the DN30 PSP or the 30B cylinder other than its thread.
- Valve and plug were leaktight after each drop test sequence.

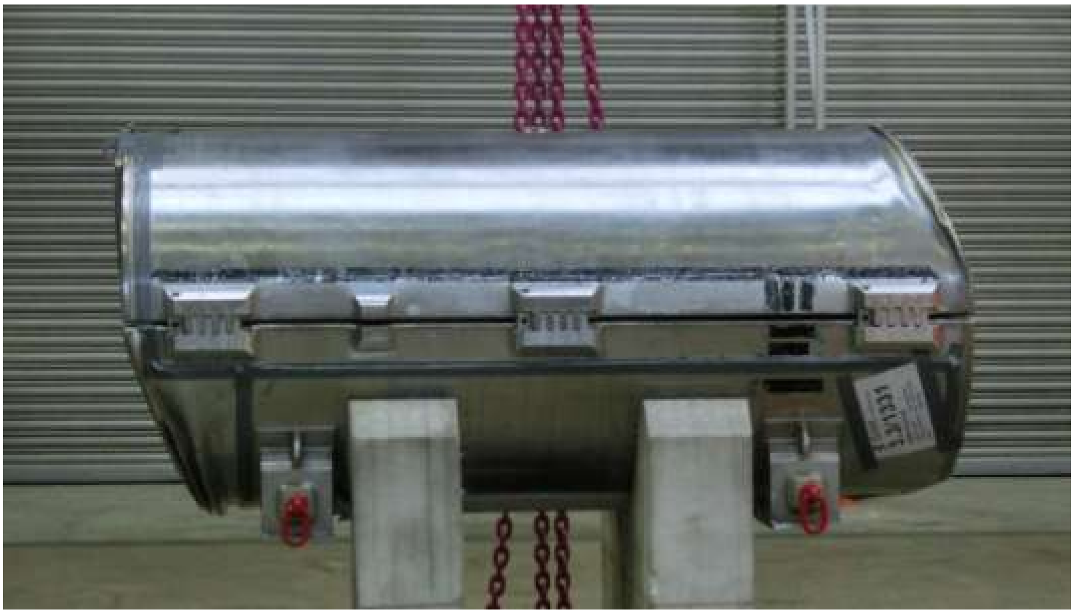


Figure 4: DN30 prototype after drop test sequence 1 followed by drop test sequence 2

<u>Drop Test Sequence 3</u>

The orientation of the specimen during drop test sequence 3 was flat onto the valve side. The pre-calculations showed for this orientation maximum decelerations due to the large and flat impact area and hence maximal forces at the valve.

The specimen is shown in Figure 5 after drop test sequence 3. The main results were:

- There was no rupture of the welding seams of the outer shell.
- At the inner shell there were some minor cracks and fractures in the impact area of the skirt of the 30B cylinder and at the side of the valve protecting device.
- The closure system was intact and fully functional.
- The DN30 PSP could only be opened by brute force as the two halves of the PSP were securely clamped together by the deformed flange.
- Neither valve nor plug came in contact with any other part of the DN30 PSP or the 30B cylinder other than its thread.
- Valve and plug were leaktight after the drop test sequence.

Figure 5: DN30 prototype after drop test sequence 3

<u>Drop Test Sequence 4</u>

The orientation of the specimen during drop test sequence 4 was horizontal onto the closure system. The puncture test was carried out directly onto the central closure system. In this drop test sequence maximum shear forces at the closure system were expected. The specimen is shown in Figure 6 after drop test sequence 4.

Figure 6: DN30 prototype after drop test sequence 4

The main results of drop test sequence no. 4 were:

- There was no rupture of the welding seams of the outer shell.
- There was no rupture of the welding seams of the inner shell.
- The closure system was deformed at the point of impact but still securely closed.
- The DN30 PSP could only be opened by brute force as the two halves of the PSP were securely clamped together by the deformed flange.
- Neither valve nor plug came in contact with any other part of the DN30 PSP or the 30B cylinder other than its thread.
- Valve and plug were leaktight after the drop test sequence.

<u>Drop Test Sequence 5</u>

The orientation of the specimen during drop test sequence 5 was oblique by 15°, a slap-down drop test onto the feet of the specimen. The pre-calculations showed for this orientation that maximum tensile forces might to be expected at the closure system due to diametrical movements of cylinder and DN30 PSP.

The specimen is shown in Figure 7 after drop test sequence 5. The main results were:

- There was no rupture of the welding seams of the outer shell.
- The feet of the DN30 PSP were deformed but not broken.
- There was no rupture of the welding seams of the inner shell.
- The closure system was intact and fully functional.
- Neither valve nor plug came in contact with any other part of the DN30 PSP or the 30B cylinder other than its thread.
- Valve and plug were leaktight after the drop test sequence.

Figure 7: DN30 prototype after drop test sequence 5

Conclusions

The extensive drop test program with prototypes of the new DN30 package proved on the one hand that pre-calculations of deformations and decelerations are feasible with sufficient precision if the dynamic properties of the shock absorbing materials are available. On the other hand, the real tests proved the “no contact” condition for valve and plug and the leak-tightness of these parts after each of the drop test sequences. Especially, the leak-tightness condition cannot be proved in calculations but only in real tests. Extensive test data were collected during the drop test campaigns and evaluation of these data makes a detailed assessment of the safety of the DN30 package possible. The analysis of the test data can have a considerable feedback effects on the determination of load assumption for PSPs of 30B cylinder.

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