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DROP TESTING OF THE NCS 45

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ABSTRACT

The NCS 45 packaging is intended for a variety of contents ranging from irradiated PWR, BWR and FBR fuel pins and parts of fuel pins to non-fissile radioactive material. The rather general content description allows low cooling times and very high burn-up values. For loading/unloading the packaging is equipped with a rotary lock drive on the top end and with a removable plug on the bottom end. Hence, it can be used for dry and wet loading/unloading in vertical and horizontal orientation. Even upside-down loading is a possibility.

The cask is of a stainless steel - lead - stainless steel design. It has a usable inner diameter of 220 mm, a usable length of 4625 mm and a gross mass of 22 500 kg. For drop testing a 1:3 scale model was manufactured which complied in all safety relevant parts with the original packaging. With this model 19 drop tests in 8 drop test sequences were carried out. The drop tests were carried out at the BAM drop test facility in Berlin. Key findings were:

- the shock absorber design protected the lid area from impact of the bar,
- horizontal and slap-down 9 m drop are not redundant,
- the “shear off” test did not cause any serious damage,
- the delayed impact may cause high stresses in the closure system ,
- there was no lead slump at maximum operating temperature,
- one NCS 45 model survived all drop tests.

INTRODUCTION

Details of the design, the safety analysis, the licensing procedure und the results of first drop tests were already presented at PATRAM 2004 [1]. Therefore in the present paper only a short overview of the design is given.

The drop test program was as well presented in [1] but changed due to the results achieved during drop testing. It is hence presented here in the final form. The paper will then focus on the key findings of drop testing and their impact on the design and safety analysis.

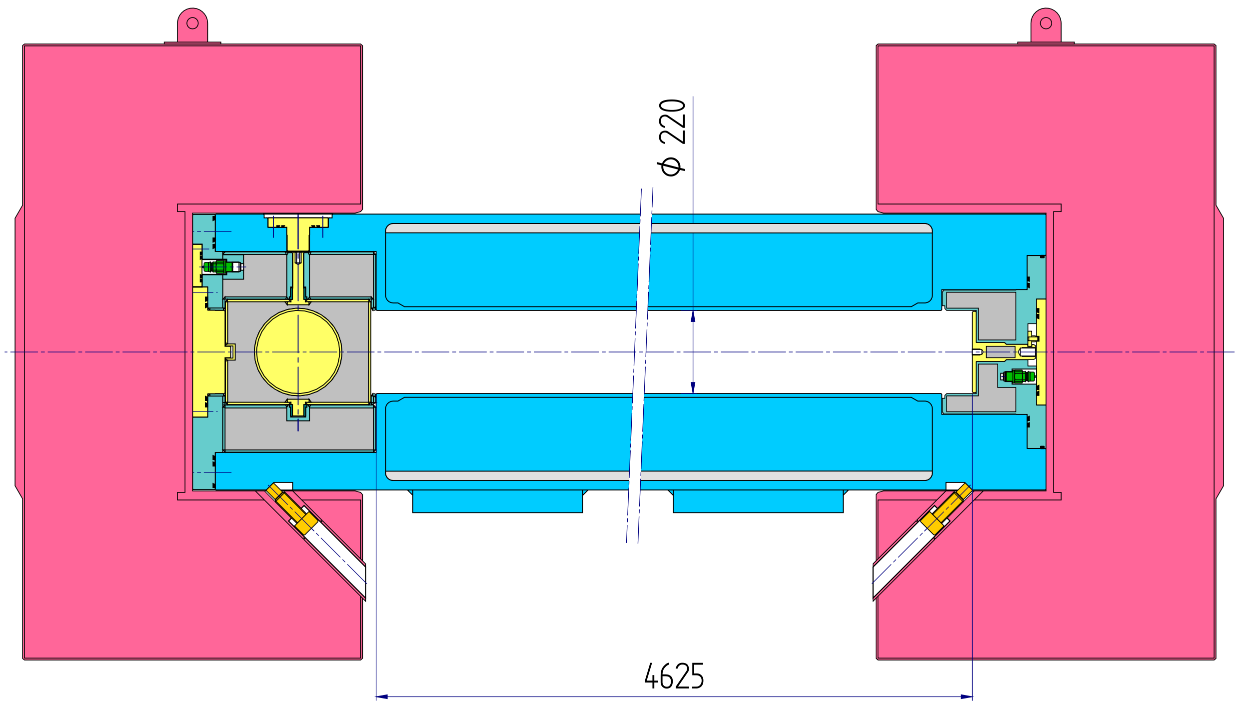

Figure 1. Design of the NCS 45 packaging

THE DESIGN OF THE NCS 45

The NCS 45 has following general design features:

- Outer and inner shell made of stainless steel
- Lead shielding and thermal insulation
- Double O-rings in all lids
- Rotary lock at the lid side
- Removable plug at the bottom side
- 4 trunnions for vertical and horizontal handling qualified according to KTA
- Openings at the lid and bottom side for venting and draining
- Shock absorbers at both ends

The design is shown in Fig. 1 and basic data are given in Tab. 1.

DROP TEST PROGRAM

For drop testing, a 1:3 drop test model was used which complied in all safety relevant parts with the original design. Outer and inner dimensions were scaled down accurately. Plates and bolts were scaled down accurately as well wherever possible. If certain dimensions were not available, a conservative approach was taken (e.g. a 10 mm sheet was scaled down to a 3 mm sheet).

For the tests one drop test model was used. Parts which were damaged d uring the drop tests were replaced (e. g. shock absorbers) or repaired (e. g. the load dummy). In total, 19 drop tests in 8 sequences were carried out. The program is shown in Tab. 2. Alle drop tests were carried out at the BAM drop test facility in Berlin. The preparation, instrumentation and the measurements were done by the coauthors of this paper who summarized the evaluation in the drop test report.

Table 1. Basic data of the NCS 45

Characteristic	unit	
Total length with shock absorbers	mm	6 207
Total width with shock absorbers	mm	1 630
Length without shock absorbers	mm	5 307
Width over trunnions	mm	1 038
Cask body diameter	mm	730
Usable length max.	mm	4 625
Usable diameter	mm	220
Empty mass	kg	21 800
Payload	kg	700
Max. total mass	kg	22 500

Table 2. Drop test program

Sequence no.	drop test no.	drop height (m)	orientation	puncture test
1	0-1	0.3	lid, 90°	no
	9-1	9.0	lid, 90°	no
	1-1	1.0	lid, 86°, rotary lock lid	yes
2	9-2	9.3	bottom, 90°	no
	1-2	1.0	bottom, 90°, center push plug lid	yes
3	0-2	0.3	lid corner, 80°	no
	9-3	9.0	lid corner, 80°	no
	1-3	1.2	lid corner, 80°	yes
4/1	9-4	9.3	bottom corner, 84°	no
	1-4	1.22	bottom corner, 84°	yes
4/2	9-5	9.3	bottom corner, 74°	no
	1-5	1.3	bottom, 74°, center bottom	yes
5	9-6	9.3	horizontal	no
	1-6	1.0	body center, 30°	yes
6	0-3	0.3	horizontal	no
	9-7	9.0	slap-down, drop angle 20°	no
	1-7	1.0	shear off test	yes
7	9-8	9.3	lid, operating temperature	no
	1-8	1.3	lid, 86°, rotary lock lid	yes

RESULTS OF DROP TESTS

In the following, the results of the tests are described by focusing on key findings.

Shock Absorber Design and Puncture Test

The initial design of the shock absorbers consisted of a thick inner shell and a thin outer shell, see Fig. 2, left. During drop test sequences 1 and 3 the bar penetrated the outer shell, hit the inner shell of the shock absorber, and caused plastic strain in the lid area. Although leak tightness was kept, the face of the shock absorber was reinforced with a steel plate to prevent penetration by the bar, see Fig. 2, right. In drop test sequence 4/2 and 7 the bar did not penetrate the outer shell any more. A plastic deformation of the lid or bottom area can hence be excluded.

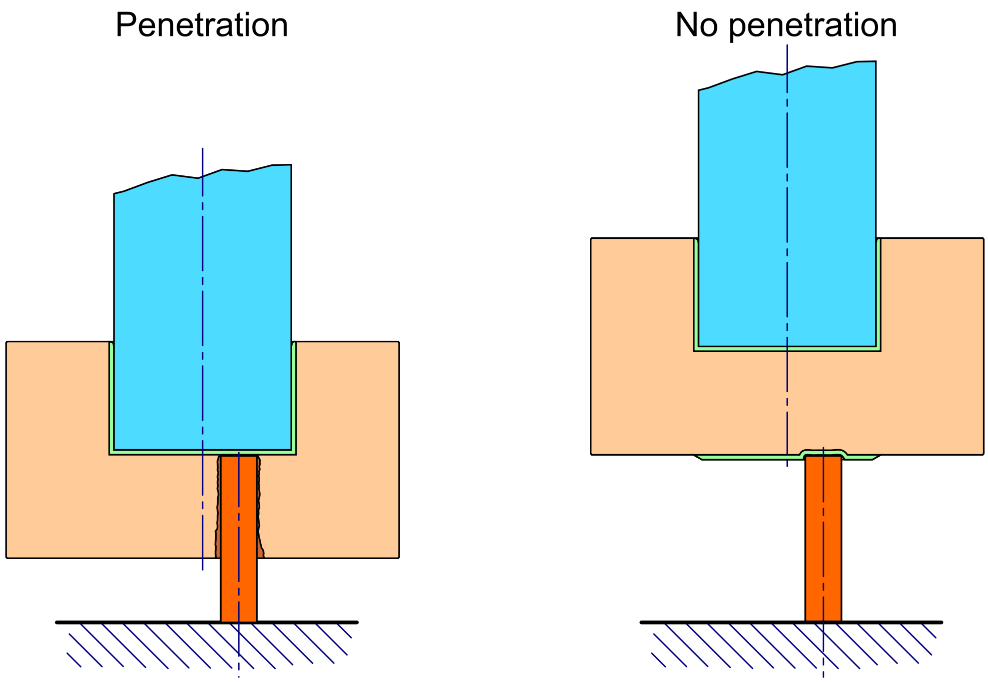

Figure 2. First and Final Design of Shock Absorber

Horizontal Drop and Slap-down Drop

As expected, the horizontal drop caused maximum center of gravity acceleration while the slap-down drop test caused maximum acceleration at the secondary impact side.

Due to the length to diameter ratio of the packaging body of more than 7 the horizontal drop caused a rather large bending moment in the center of the packaging which resulted in a measurable curving of the packaging body, see Fig. 3. However, the original packaging will experience much less bending because the properties of the steel used for the original are much better than of the material used for the drop test model.

During the slap-down drop test the bending moment in the packaging body was less than during the horizontal impact resulting only in a very small curving of the body. The accelerations at the secondary impact side however, were measured to be approx. 40% higher than during the horizontal drop, see Fig. 3.

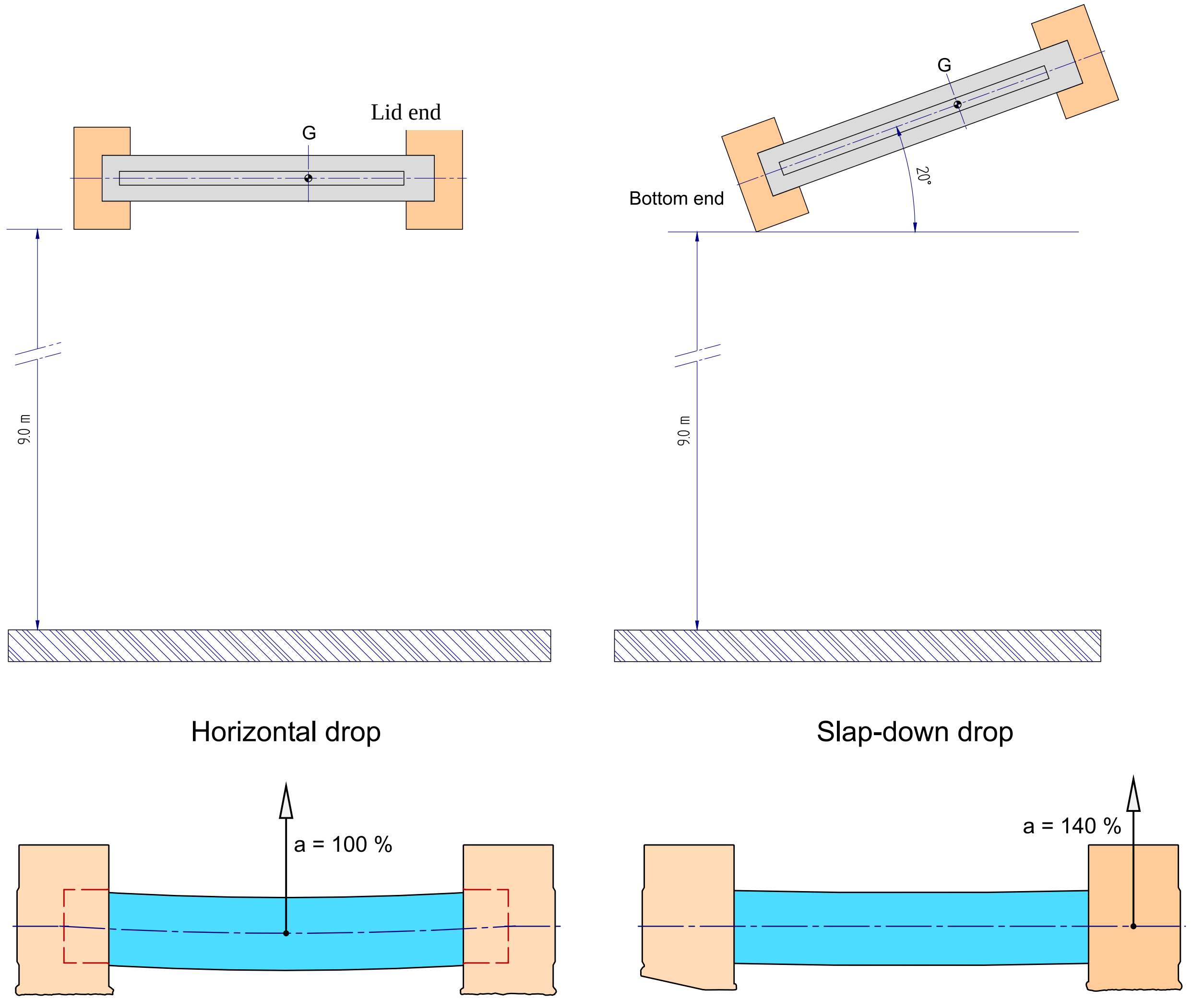

Figure 3. Horizontal and Slap-down Drop

Shear off Test

The shear off test was a new requirement of the competent authority. This test was intended to prove that the shock absorbers cannot be sheared off by a very long bar, thus exposing the naked side of the packaging body to a subsequent 9 m drop and/or a thermal test without adequate protection, see Fig. 4. During the test, the bar punctured the shock absorber, but did not penetrate the shock absorber. The fixation of the shock absorbers on the packaging body was not affected by the test and remained undamaged.

Delayed Impact of the Content

The vertical drop tests sequences 1 to 4 showed, that the behaviour of the content is an important factor for the safety of the package. In all of these 9 m drop tests the content hit the inner side of the lid or bottom later than the shock absorber touched the target. This behaviour is of no concern for 90° drop tests flat onto the shock absorber face because the lid or bottom are supported by the shock absorber. For oblique vertical drops however, the content might hit the inner side of the lid or bottom when these parts are not fully supported by the shock absorber.

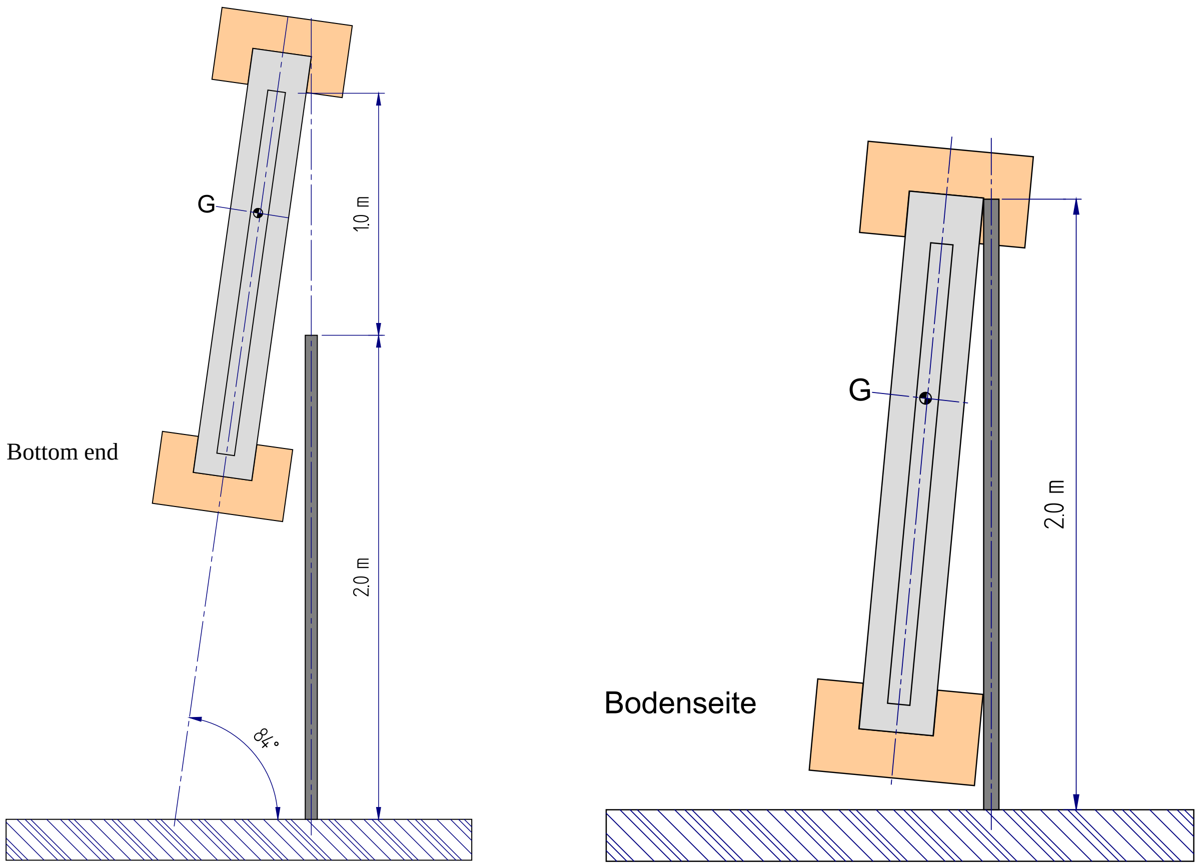

Figure 4. Shear off Test

Furthermore, the accelerations experienced by a rigid content might be much higher than the accelerations measured for the whole packaging protected by the shock absorbers. This might lead to high stresses in the lid bolts and in the lids. Fig. 5 shows a typical example of this behaviour. The acceleration of the packaging body is in this figure almost zero when the conten t hits the inner side of the lid. The intern al force from the content caused high stresses in the bolts after the package came to a complete rest.

Lead Slump

In order to prove that the lead shielding is unaffected after the mechanical tests a 9 m drop unde r operating conditions was carried out. For this, the drop test model was heated up with an internal heat source to the maximum normal operating temperature (MNOP) calculated for normal conditions of transport taking into account an ambient temperature of 38°C and insolation. The main parameters for this test are given in Tab. 3.

Table 3. Main Parameters for Test at MNOP

Characteristic	unit	
Lead height	mm	4 500
Lead temperature	°C	100
Acceleration	g	100
Impact side	-	lid

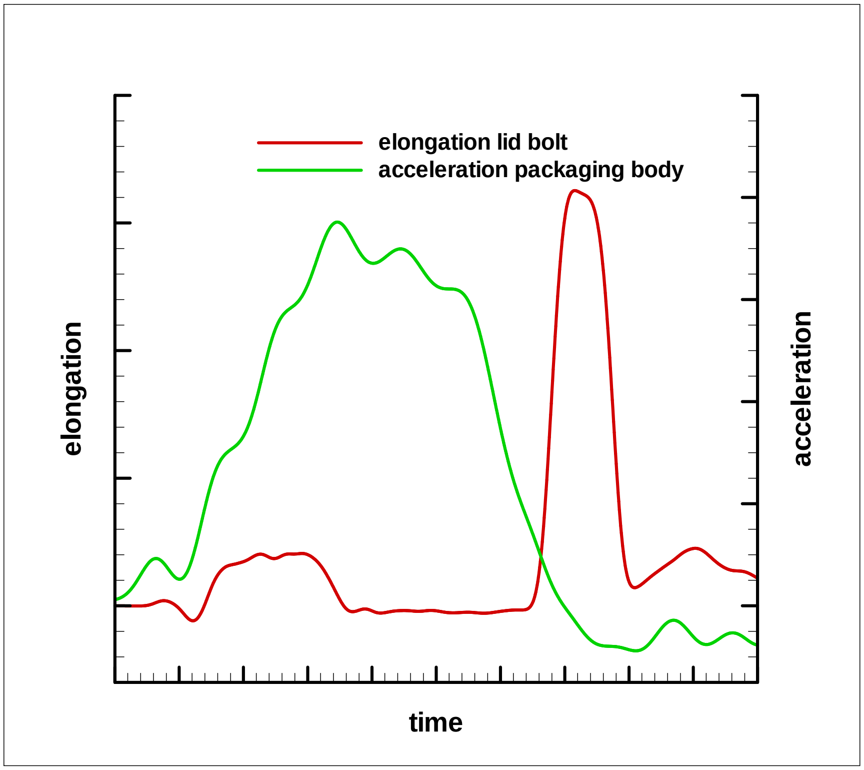

Figure 5. Delayed Impact of the Content

After the completion of the drop test program the packaging body was cut along the longitudinal axis to allow visual and dimensional control of the lead shielding. In Fig. 6 the cut section is shown in the drop orientation. The steel bottom of the packaging is shown on top, the lead is shown below. The result of the inspection was that lead slump could be definitely ruled out. Between lead and steel shell there was no measurable gap.

CONCLUSIONS

In order to prove safety of the packaging NCS 45 under accident conditions of transport 19 drop tests in 8 drop test sequences were carried out. Results of the drop tests lead to considerable design improvements. Other results of the drop tests answered open questions.

The bar drop tests showed that a full penetration of the shock absorber and subsequent direct impact of the bar onto the closure system should be avoided. A practible and sufficient solution is the reinforcement of the outer surface of the shock absorber with a steel plate. The vertical 9 m drop tests indicated that the behaviour of the content must be considered with special care in the safety analysis. In case of axial gaps between content and lid or bottom the impact of the content might be delayed with respect to the impact of the packaging onto the unyielding surface. This might cause high stresses in the closure system.

The comparison of the results of the horizontal and slap-down drop tests showed, that the center of gravity accelerations are higher for the horizontal drop test than for the slap-down drop test. But the accelerations for the slap-down drop test at the secondary impact side are higher than the center of gravity accelerations for the horizontal drop test. Hence, both drop tests should be included in a drop test program. The shear off test did not affect the safety of the packaging; it proved that an adequate design ensures that the shock absorbers remain fixed to the packaging body under all test conditions. The drop test at MNOP showed that lead slump is not to be expected and shielding is preserved under accident conditions of transport.

Figure 6. Cut Through the Bottom Part of the Drop Test Model – no Lead Slump

REFERENCES

[1] W. Bergmann, F. Hilbert: The NCS 45 Cask Family, an Updated Design Replaces an Old Design – Lessons Learned during Design, Testing and Licensing , PATRAM 2004