TRANSLATION

Report

Safety Report for the Container Type BU-D for the Transport of Uranium Compounds

0007-BSH-2018-001-Rev0

(based on report NCS 0601 Rev. 3)[1)]

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[1)] Changes from report NCS 0601 Rev. 3 are marked at the right side

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1 Introduction

The BU-D container is currently licensed based on the IAEA regulations TS-R-1 2009 edition /1-1/ and the equivalent national and international regulations (eg ADR 2013 /1-2/) for the transport of non-irradiated uranium with certificate of approval D/4305/AF-96 (Rev. 9) (Appendix 1) as a Type A package for fissile materials for transport by road, rail, sea and air. The validity of this certificate ends on 30.11.2018.

The following report demonstrates that the container also fulfills the requirements of the currently valid IAEA regulations SSR-6 2012 edition /10-1/ and the equivalent national and international regulations (e.g. ADR 2017 /10-2/).

2 Description of the allowable content

2.1 Chemical and physical form

The allowable content consists of depleted, natural and/or enriched uranium with a maximum enrichment (mass content of U-235) of 10%.

The uranium can be present in addition to uranium oxide in the following chemical forms:

- Ammoniumdiuranat (ADU)
- Uranylnitrat solid (UNH)
    - Ammoniumuranylcarbonat (AUC)
    - Uraniumtetrafluoride (UF_4)
    - Sodiumuranate

In the following the essential physical and chemical properties of these compounds are summarized (see also /2-1/).

1. Ammoniumdiuranat (ADU)
- Chemical form: $(NH_4)_2U_2O_7$
- Physical form: Yellow powder with a theoretical density between 4.1 and 5.6 g/cm^3
- Properties: Not water-soluble.
  Decomposes at approx. 300 °C into UO_3 and Nitrogen oxide.

2. Ammoniumuranylcarbonat (AUC)
- Chemical form: $(NH_4)_4\,[UO_2\,(CO_3)_3]$
- Physical form: Yellowish powder with a theoretical density of 2.77 g/cm^3
- Properties: Qualified water-soluble.
  Decomposes between 250 °C and 300 °C into U_3O_8.
  Over 60 °C gradual loss of NH_3 and CO_2 with UO_3 production.

3. Uranylnitrat solid (UNH)
- Chemical form: $UO_2(NO_3)_2 \times 6H_2O$
- Physical form: Yellow powder with a theoretical density of 2.8 g/cm^3
- Properties: Very good water-soluble.
  Decomposes at approx. 200 °C into UO_3 and Nitrogen oxide.
  Additional danger: Class 5.1 (lightly oxidizing)

4. Uraniumtetrafluoride
- Chemical form: UF_4
- Physical form: Dark green powder with a theoretical density of 6.6 g/cm^3
- Properties: Not water-soluble.
  Very inert, together with hot steam production of UO_2F_2.

5. Sodiumuranate
- Chemical form: $Na_2O \times (UO_3)_x$
- Physical form: Green-yellowish or orange powder with a theoretical density of approx. 5.5 – 6.9 g/cm^3
- Properties: Non-soluble in water, very inert. Shows nearly no decomposition even under heavy heating.

The physical form of the material is arbitrary, however for pellets or comparable fis-sile material accumulations which can built grids only a smallest outer dimension of the pellets or fissile material accumulations of 8 mm or more is allowed. Uranium with an enrichment of more than 5% may be present only as uranium oxide and in powder form.

The uranium compounds can additionally contain Gadolinium as a neutron absorber.

In addition to the uranium impurities can be present such as linen fibres, dust, sand, iron hydroxide, whereas the total mass of the content per package is restricted to 90 kg. However not allowed are impurities with additional dangerous properties, with a hydrogen density greater than water and impurities which contain Beryllium or Deuterium in masses greater than 1% of the fissile mass, with exception of Deuterium in natural concentration in water.

If uranylnitrat is present no additional substances which are easy or normal oxidizable shall be present.

The H/U ratio within the package is unlimited, however the material must be in solid form.

2.2 Fuel mass

The maximum allowable mass of U-235 per package in dependence of the enrichment is:

- 0.9 kg for enrichments U-235 ≤ 4 wt.%
- 0.8 kg for enrichments U-235 ≤ 5 wt.%
- 0.65 kg for enrichments U-235 ≤ 10 wt.%

2.3 Radioactivity, Source Strength and Heat Rate

- Radioactivity

The total activity per package must not exceed the value of 1 A_2.

- Source strength

Experiences lasting for years with the transport of the containers show that the gamma dose rates is significantly below the allowable limits (see also chapter 7) and that the neutron radiation can be neglected.

Therefore the gamma and neutron source strength will not be evaluated.

- Heat rate

The heat rate of the content is below 1 W and can therefore be neglected

2.4 Fuel pails

The transported material is contained in up to 3 pails made of stainless steel. The inner diameter of the pails must not exceed 285 mm.

If only one loaded pail is transported, the free space must be filled with empty pails.

A further specification of the pails is not required because in the performed criticality calculations it was demonstrated that also if the pails are not present the criticality safety is guaranteed.

Drawings with examples for pails are shown in Annex 3.

3 Description of the Packaging

3.1 Design

The design of the container is shown in the NCS drawings listed in the following and in data sheet 001-068-00 (see Annexes 2 and 3).

1-001-068-00-00	Container BU-D Overview
1-001-068-01-00	Outer Container complete
1-001-068-02-00	Inner Container complete
2-001-068-03-00	Insulation disc
001-068 c	Part list

The container consists essentially of the following components:

- Outer container with clamping ring
- Inner container with flange lid closure
- Thermal insulation made of light concrete

The outer container is a usual 213 l drum with a steel sheet thickness of 1.2 mm. The drum is closed by a clamping ring over a screw M12 with counter nut. It is coated on the inside and outside with a protective paint. The lid is sealed with an O-ring made of cellular rubber. In the upper mantle region is a boring with d = 8 mm which prevents during the fire accident a pressure increase in the thermal insulation.

The inner container consists of a drum with approx. 65 l capacity with 1.2 mm steel sheet thickness. The bottom is welded to the mantle with help of stiffening rings. The drum is closed by a 5 mm thick lid made of carbon steel.

The lid is screwed to the drum body flange with 12 screws und nuts M 10. The seal-ing is done with a gasket made of EPDM. The drum is coated on the inside and out-side with protective paint. The space between inner and outer drum is filled with a perlite light concrete acting as thermal insulation. Between the lids of the inner and outer drum an additional light concrete disc, clad with steel sheet, is placed after loading.

For centring of the stainless steel pails, which contain the nuclear fuel, in depend-ence of the diameter a distance frame made of aluminium as shown in drawing No. 1-001-068-04-00 or a stainless steel tube as shown in drawing or. 4-001-068-06-00 (see Annex 3) is used.

The container is designed in such a way that the inner drum is the containment system under Type A test conditions and also the confinement system for the con-tent under the required test conditions for demonstration of criticality safety. The light concrete insulation protects together with the outer drum the inner drum against unacceptable mechanical and thermal impacts. The outer drum is designed in such a way that it is water proof in normal conditions of transport

3.2 Main container data

Outer diameter:	approx. 608 mm
Total height:	approx. 890 mm
Tare mass:	approx. 160 kg
Gross mass max.:	260 kg

3.3 Decontamination properties

The container BU-D is only handled in not or only slightly contaminated areas. The decontamination properties of the coating were demonstrated and the certificate is enclosed as annex 4 of this report.

4 Mechanical analysis

In this chapter the design is analyzed and it is shown that the requirements for a package of type AF are fulfilled.

4.1 Calculation basis

4.1.1 Load assumptions

For the proof load assumptions for the following situations are assumed:

- Handling and transport
- Accidental conditions of transport (for the proof of criticality safety)

Handling and transport

The load assumptions for handling and transport (routine and normal transport conditions) are:

- The temperature of the container according to a heat rate of less than 1 W (see chapter 5)
- The values to be taken into regard for handling
- The maximum transport accelerations
- Inner and outer pressure
- Mounting forces
- The tests for normal transport conditions (Type A tests)

These are compiled in Table 4-1.

Accidental conditions of transport

The mechanical load assumptions for accidental conditions of transport for the proof of criticality safety are:

- The Type B (U) tests
- The temperatures at the container according to the Type B (U) test conditions (see chapter 5)
- The Type C tests concerning the criticality safety proof of the single package

These are given in the transport regulations and are shown in Table 4-2.

The drop tests specified in the ADR /10-2/ Rn. 6.4.17.2 c) (IAEA SSR-6 /10-1/ para 727 c) are not relevant for the present package design because the density of the package is:

$$\rho = 260 / 0.213 = 1220 \text{ kg/m}^3 > 1000 \text{ kg/m}^3$$

However because the package is not always fully loaded in the following also this case is evaluated.

Table 4-1: Load assumptions for normal conditions of transport

Temperature:	
Container lid max.	73 °C
Container inner volume	50 °C
Handling:	
Proof for	UVV VBG 9a
- Safety against yield strength	2
- Safety against ultimate strength	3
Transport:	
Accelerations	
- in driving direction	2 g
- lateral to driving direction	2 g
- vertical	2 g
Typ A -Tests: according to ADR /10-2/ (IAEA SSR-6 /10-1/)	
Water spray test Rn. 6.4.15.3 (para 721)	
Free drop test Rn. 6.4.15.4 (para 722)	1.2 m
Stacking test Rn. 6.4.15.5 (para 723)	1300 kg
Penetration test Rn. 6.4.15.6 (para 724)	
Pressure:	
Inner pressure	0.114 MPa
Outer pressure	0.06 MPa
Rn. 6.4.7.11 (para 645)	
Pressure difference (para 621)	0.095 MPa
Mounting:	
Torque of screws	

Table 4-2: Load assumptions for accidental conditions of transport

Typ B test conditions: according to ADR (IAEA SSR-6)	
Drop test I Rn. 6.4.17.2 (para 727(a))	9 m
Drop test II Rn. 6.4.17.2 b) (para 727(b))	1 m
Drop test III Rn. 6.4.17.2 c) (para 727(c))	9 m
max. temperature of the container after the thremal test Rn. 6.4.17.3 (para 728)	800°C
Water immersion test Rn. 6.4.17.4 (para 729)	15 m
Typ C test conditions according to ADR (IAEA SSR-6 para 734 to 737)	
Temperature:	
Outer container	800 °C
Inner container	140 °C
Content	90 °C

4.1.2 Calculation Methods

The mechanical safety analysis for the package BU-D is performed by calculations and tests. Especially the safety proof with documented drop tests and thermal test in /4-1/ Annex 5, /4-2/ Annex 6, /4-3/ Annex 7 and /4-4/ Annex 8 have to be mentioned.

4.1.3 Material data

The used materials are shown in the parts lists belonging to the drawings.

The materials are physically and chemically compatible. Corrosion of the steel parts is prevented by a inner and outer decontamination paint.

In the following Table 4-3 the material data for the different materials which are relevant for the safety proof are summarized.

Table 4-3: Essential data of the used materials

Material	Data	Source
DC01-A-m	ρ = 7,85 g/cm^3 Rs $\leq$ 280 N/mm^2 Rm = 270 - 410 N/mm^2 λ = 46,0 W/mk cp = 460 J/kgK	- DIN EN 10130 DIN EN 10130 VDI-Wärmeatlas /4-5/ VDI-Wärmeatlas /4-5/
Screws and nuts 8.8 resp. 8	R0,2 = 640 N/mm^2 bei RT Rm = 800 N/mm^2 bei RT	DIN ISO 898 DIN ISO 898
1.0038, 1.0117, 1.0577	ρ = 7,85 g/cm^3 Rs = 235 N/mm^2 bei R Rm = 360 N/mm^2 bei RT λ = 46 W/mk cp = 460 J/kgK	- DIN EN 10025 DIN EN 10025 VDI-Wärmeatlas /4-5/ VDI-Wärmeatlas /4-5/
EPDM	σD $\leq$ 1,5 N/mm^2 Allowable operation temp.: -40 °C $\leq$ t $\leq$ 150 °C Allowable short-term max. temperature: see Chap. 4	/4-6/ Manufacturer information
Light concrete	ρ $\geq$ 0,52 g /cm^3 σD $\geq$ 0,8 N/mm^2 Chem. composition ca.: SiO2 23 wt. % CaO 36 wt. % Al2O3 6 wt. % H2O 29 wt. % Others 6 wt. %	Own tests Own tests Own tests

4.2 Normal conditions of transport

4.2.1 Handling

During handling no loads occur which affect the overall integrity of the container.

About 2000 containers of type BU-D were manufactured which are in operation since more than 10 years. The extensive handling experiences with the container in different plant show that it is suitable for all load impacts during routine operation.

The container has no handling devices. Handling is done by drum grips or by hand. For the handling with fork lifts pallets are used.

In the following the sufficient strength of the closures is demonstrated.

- Screws of the inner container

The 12 screws M 10 of the inner container are fastened with a torque of 13 Nm. The required force for a sufficient compression of the gasket is:

F_D = σ_D x A

with σ_D = 1.5 N/mm² (sufficient pressure for compression of the gasket , derived from /4-6/)

A = (430^2 - 356^2) x π/4 = 4.57 E4 mm² gasket area

F_D = 6.85 E4 N

Force per screw:

$$F_S = \frac{6.85E4}{12} = 5.71\ E3\ N$$

$$M = F_S\ (\frac{d_2}{2} \times \tan(\varphi + \rho') + \mu (D_a + D_i)/4)$$

This corresponds to a torque of:

M = F_S x R

with d_2 = 9.026 mm (pitch diameter)

$$\tan\varphi = \frac{P}{\pi \times d_2} = \frac{1{,}5}{\pi \times 9{,}026} = 0{,}053,\ \varphi = 3{,}03°$$

$$\tan\rho' = \frac{\mu}{\cos(\beta/2)} = \frac{0{,}14}{0{,}866} = 0{,}162,\ \rho' = 9{,}2°$$

P = thread pitch

μ = friction coefficient= 0.14

ß = flank angle = 60°

D_a = 1.5 d = 1.5 x 10 = 15 mm (head diameter)

D_i = 12 mm (head rest – inner diameter)

M = 5.71 E3 x 1.923 = 1.10 E4 Nmm = 11 Nm

The present torque of 13 Nm therefore is greater than the required one for getting a sufficient tightness.

The stress in the screw for the present torque is:

$$\sigma_S = \frac{F_s}{A_s}$$

$$F_s = 5.71\ E3\ x\ \frac{13}{11} = 6.75\ E3\ N$$

A_S = 58.9 mm²

σ_S = 116 N/mm²

This corresponds to approximately 20 % of the yield strength of the screw 8.8. The screw is sufficiently dimensioned. A loosening during transport is not possible.

- Screw of the outer container

The screw M 12 at the clamping ring of the outer container is fastened with 16 Nm. This is according to the manufacturer a usual value to get water tightness.

The stress in the screw resulting from this torque is:

$$\sigma_s = \frac{F_s}{A_s}$$

$$F_s = \frac{M}{R}$$

R according to the above equation with:

d_2 = 10.863 mm

φ = 2.94°

ρ' = 9.2°

μ = 0.14

D_a = 18.0 mm

D_i = 14.5 mm

R = 2.31 mm

$$F_s = \frac{16000}{2{,}31}$$

A_s = 84.3 mm²

σ_s = 82 N/mm² ≅ 13 % yield strength

The screw can not get loose during transport because of the counter nut.

Therefore the lid of the outer container can not open during transport.

4.2.2 Transport

The great number of manufactured containers is transported since more than 10 years with all modes of transport mentioned in the certificate of approval. The extensive experience with the container shows that it is suitable for all impacts arising during a routine transport and that a safe stowing and securing is possible.

4.2.3 Thermal stresses

The thermal heat load of the radioactive content is negligible small. Relative extensions caused by the thermal heat load of the content can be excluded. This is also demonstrated by the extensive experiences with the operation of the container.

The maximum temperatures at the container occur during the insolation phase. Only in the region of the lid somewhat higher temperature differences occur caused by the direct sun (see chapter 5). In this region however the design allows a free relative movement of the components. In the container body the temperature differences are small and cause only negligible stresses from relative extensions

4.2.4 Pressure differences

- Inner overpressure caused by temperature increase

From the temperature rise of the inner cavity up to approximately 50 °C caused by the insolation an inner overpressure occurs. This is maximal:

$$P = \frac{273 + 50}{273 + 20}\ x\ 1.03 = 1.14\ bar$$

During the acceptance tests the inner container is subjected to an overpressure test for water tightness with 1.3 bar. During this test no deformation or leaking could be observed.

The inner container therefore keeps its integrity under an inner overpressure caused by a temperature increase of the content.

- Outer lowered pressure according to the transport regulations

According to /10-2/ (/10-1/) it has to be assumed that the outer atmospheric pressure decreases to a value of 0.06 MPa (0.6 bar).

From this results an overpressure in the inner container of 0.04 MPa (0.4 bar). Furthermore it has to be demonstrated for the air transport that the containment withstands a pressure difference of 0.095 MPa (0.95 bar). Because the latter is the covering case the calculation of strength is done for this case.

- Inner container shell

The calculation is performed according to the “AD-Merkblatt” /4-7/ B1 without taking into regard the stiffening influence of the light concrete. The required wall thickness is:

$$S = \frac{D_a\ x\ P}{20\ x \frac{K}{S}\ x\ v + P} + C_1 + C_2$$

D_a = 356.4 mm (outer diameter)
P = 0.95 bar
K = 280 N/mm² (yield strength of material)
S = 1.5 (safety factor according to table 2, AD-Merkblatt B0)
v = 1.0 (utilization factor for joint connections)
C_1 = C_2 = 0 (increase factors according to AD-Merkblatt B0)
s = 0.1 mm

The shell of the inner container is with 1.2 mm sufficiently dimensioned.

- Inner container bottom

The inner overpressure of 0.95 bar, corresponding to 0,095 N/mm², stands against the stiffening effect of the light concrete of the bottom with a compression strength of minimum 0.8 N/mm². Therefore no deformation of the container bottom can occur.

- Inner container lid

The calculations are performed according to AD-Merkblatt /4-7/ B5.

The required lid thickness is:

$$s = C \text{ x } D_1 \text{ x } \sqrt{\frac{P \text{ x } S}{10 \text{ x } K}}$$

C = 0.35 (table 1, case d)
D_1 = 400 mm (reference diameter screws)
P = 0.95 bar
S = 1.5
K = 235 N/mm² (yield strength of material)
s = 3.4 mm

The present wall thickness of the inner container lid of 5 mm is sufficient.

- Lid screws

The stress per screw of the lid results in:

$$F = P \ x \ A \ x \ \frac{1}{12} = 0.095 \ x \ 354^2 \ x \ \frac{\pi}{4} \ x \ \frac{1}{12} = 779 \ N$$

The stress is therefore negligible small compared to the preload.

The lid keeps its tightening function.

4.2.5 Type A test conditions

Water spray test according to Rn 6.4.15.3 /10-2/ (para. 721 /10-1/)

An influence onto the mechanical integrity or a penetration of water into the packaging can be excluded because of the metallic surface and the gasket of the outer container lid.

Drop test Rn 6.4.15.4 /10-2/ (para. 722 /10-1/)

After the drop test from 1.2 m height only slight deformations of the container structure are expected because of the stiffness of the outer container. Taking into regards the drop test for demonstrating the accidental conditions (9 m drop height, max. deformation 30 mm) a maximum local deformation of

$$s = 1.2 \text{ x } 30 / 9 = 4 \text{ mm}$$

at the outer container can be estimated.

Stacking test Rn 6.4.15.5 /10-2/ (Para. 723 /10-1/)

The maximum load for the stacking test is five times the mass of the package. This is approximately 1300 kg.

Conservatively the total mass is assumed from one side. With this the compressive strain in the shell region of the outer container is:

$$\sigma = \frac{F}{A}$$

$$F = 13000 \text{ N}$$

$$A = (573^2 - 571^2) \ x \ \frac{\pi}{4} = 2159 \ mm^2$$

$$\sigma = 6 \text{ N/mm}^2$$

Because of this low stress no damage from the stacking test has to be expected.

Penetration testRn 6.4.15.6 /10-2/ (para. 724 /10-1/)

The outer steel sheet is with 1.2 mm sufficiently dimensioned to prevent a deformation or a puncture.

4.3 Strength under accidental conditions

4.3.1 Requirements under accidental conditions

According to the requirements in /10-2/ and /10-1/ the proof of criticality safety of the damaged package has to be done after the performance of the following cumulative tests:

- Free drop test from 9 m height onto an unyielding target in the most damaging orientation
- Free drop test from 1 m height onto a bar in the most unfavourable drop orientation
- Fire test with a temperature of 800°C and 30 minutes duration.

To demonstrate the package behaviour under these loads and to specify the input data for the criticality calculations at the Federal Agency for Material Research and Testing prototype tests were performed.

For the thermal calculations on all sides a maximum dimension reduction of 3 cm is assumed and it is assumed that the lid of the outer container remains fixed so that the isolation disc can not get out of the container. These assumptions were confirmed in the tests.

4.3.2 Performance of drop tests

The performance of the tests is described in detail in /4-1/ to /4-3/ (Annexes 5 to 7).

In total five prototype container were manufactured from which three were used for the tests and two for the qualification of the concrete pouring.

The following tests were performed (see /4-1/, Annex 5):

- 3 drop tests from 9 m height
- 3 bar drop tests from 1 m height
- 1 fire test

One drop test and bar drop test each was performed at -40 °C. The content was simulated in the tests by 90 kg pails filled with granulate.

Ergebnis der Versuche

Test container No. 1:

With test container No. 1 a horizontal 9 m drop at room temperature was performed onto the mantle line of the container, where the clamping ring closure of the outer container was turned 90° from the impact line. Then a bar drop test from 1 m height at room temperature onto the predamaged region was performed.

After the 9 m drop test the maximum flattening in the region of the impact line was approx. 30 mm. The deformation behaviour of the sheets of the outer container was so good that only in the bottom some small cracks occurred and the clamping ring of the outer container still fixed the lid securely in its position. During the following bar drop test onto the already flattened region the bar caused an additional dent of approximately 5 mm depth. The sheet was not punctured and no crack initiations occurred.

Test container 2:

With test container 2 a 9 m drop onto the lid edge was performed where the clamping ring closure of the outer container was displaced by 90° to the point of impact and in the following a bar drop test onto the clamping ring closure of the outer container.

The maximum deformation after the 9 m drop was in the region of the lid edge approximately 90 mm. The clamping ring still fixed the lid of the outer container after the test securely in its position. Cracks in the steel sheets were not detected. After the bar drop test the closure of the clamping ring of the outer container was still intact. Only very slight deformations of approximately 1 mm were detected.

Test container 3:

The third test container was used for a 9 m drop onto the lid edge in the region of the clamping ring closure and was followed by a bar drop test onto the mid of the lid.

The tests were planned at a temperature of -40°C. During the 9 m drop the temperature on the outside of the container at the time of the test was only -15°C to -20°C because of the fast temperature increase at the outer shell.

Because of the good deformation behaviour of the thin steel sheets the following bar drop test was performed at room temperature.

The flattening in the region of the impact area was like for the test container 2 approximately 95 mm. The clamping ring with the deformed clamping ring closure still fixed the lid of the outer container in its position. Cracks in the steel sheets were not detected. In the following bar drop test the lid of the outer container was not punctured and no cracks occurred. The depth of the bar dent was effective approximately 22 mm.

After the tests two of the three outer containers were opened to check the condition of the inner container and the fuel pails. The inspection of the containers showed that there was no damage of the inner containers and that the fuel pails were slightly deformed but as far intact that the escapes of a significant amount of granulate was prevented.

The screws of the inner container were not loosened and the lid was hard to remove because the gasket was sticking between lid and flange. This allows the conclusion that the inner container was sufficiently leak tight against water. The performance of a soap bubble test confirmed this assumption.

The third container (test container 1) was not opened because it was foreseen for the fire test.

After the fire test in an annealing furnace /4-4/ the container was opened and visually inspected and a leak tightness test was performed /4-3/.

The result was that the gasket of the inner container was leak tight. However, the impact of the clamping ring closure of the fuel pail punctured the side wall of the inner container and therefore a leakage between inner container and concrete pouring occurred.

The fuel pails were slightly deformed, however so far intact that the escape of granulate could be excluded.

To prevent the effect of puncture of the inner wall as a result of the tests the distance frame respectively the stainless steel tube as described in chapter 3 were introduced. These additional parts guarantee that no leakage of the inner container can occur and therefore the penetration of water after the tests can be excluded.

In addition to the tests described in /4-1/ (Annex 5) tests were performed where the threads of the inner container flange were „damaged“.

The results are presented in /4-2/ (Annex 6).

4.3.3 Strength of the container in a fire

In /4-4/ and /4-3/ the performance of a fire test and the condition of the BU-D container after the drop tests and the fire test was investigated. The result was the shape of the container was not visible changed by the fire test. There was no effect on the strength.

In section **Fehler! Verweisquelle konnte nicht gefunden werden.** the temperatures at the BU-D container are investigated analytically. The inner wall temperature of the inner container of approximately 140°C has no influence on the integrity of the inner container. The temperature of the content is approximately 110°C. The resulting inner pressure of 1.43 bar (see also section **Fehler! Verweisquelle konnte nicht gefunden werden.**) does not affect the inner container as shown in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**.

4.3.4 Discussion of the results

The performed tests lead to the following conclusions:

- The inner container and the fuel pails keep their integrity. An escape of significant amounts of fissile material from the pails during an accident can be excluded.
- The clamping ring closure still connects the lid to the outer container. There is no risk that the mounted isolation disc or the inner container can escape from the outer container.
- The occurring cracks in the outer steel sheet are so small that even a partial loss of light concrete isolation has not to be assumed.
- The maximum flattening at the shell is approximately 30 mm, this corresponds to a deformation volume of approximately 2 % of the total volume.
- A general deformation of the front sides by 30 mm is for the thermal calculations (see chapter 5) and the shielding considerations (see chapter 7) a conservative assumption.

4.3.5 Effects of the dynamic crush test

Because the package fulfils the condition of a density of ≥ 1000 kg/m^3 only with a gross weight of 213 kg (corresponding to a payload of approx. 50 kg) for smaller payloads also the effect of the dynamic crush test is evaluated.

For this in report NCS 0810 /4-8/ (Annex 18) it is demonstrated that also after the dynamic crush test the safe containment of the radioactive material inside the inner drum is guaranteed.

4.4 Strength under Type C Test Conditions

There is no information about the condition of the package after the Type C tests. Therefore it has to be assumed that the package is in the most unfavourable case completely destroyed.

4.5 Boundary Conditions for the Criticality Calculations

In deviation to the results of the mechanical tests which show that nor under normal conditions neither under accidental conditions water can penetrate into the container for the performance of the criticality safety proof it is always assumed that the fissile material is optimum moderated, which means that the criticality safety is also guaranteed if water penetrates.

Furthermore as a conservative boundary case calculations were performed which show that the criticality safety is also guaranteed if the fuel pails are not present and the radioactive material is distributed in any way in the cavity of the container.

Under Type C test conditions it is assumed for the criticality safety proof that the content of the package is present in most unfavourable geometry and moderation.

5 Thermal analysis

5.1 Calculation methods

The steady-state and transient temperature distribution under normal conditions and in case of an accident fire is calculated with the program HEATING 7.2 /5-1/. The in-put- und output-files for all calculations can be taken from the CD-ROM in Annex 9.

This program can solve the heat conduction equations in Cartesian and Cylindrical coordinates (one-, two- and three-dimensional). Hereby the implicit difference calculus is used.

The general formulation of the program allows to process apart from a multitude of boundary conditions (radiation, convection etc.) also temperature and position dependent material data.

The present calculation model (see the following Figure 5-1) is made in R, Z geometry and is a geometrical exact simplified representation of the standing container. The following simplifications were made:

- The thin steel sheets of the outer and inner container were not represented as far as they are not necessary for the model.
- The isolation at the bottom is assumed conservatively in general with the minimum thickness at the mid of the bottom.
- Details like lid closures, drum channels or bottom ring of the inner container are not modelled.
- The pails are modelled centred in the inner cavity. The filling of the pails is assumed completely as uranium oxide with density 2.21 g/cm³. Fuel pails with d = 285 mm and also d = 230 mm are investigated.
- The distance frame respectively the centring tube are conservatively neglected.
- The container bottom is modelled conservatively in the steady-state calculations as isolated.
- According to chapter 4 it is assumed for the fire accident that at the same time the lid side and the mantle side dimensions are reduced by 3 cm. This represents the most unfavourable case for the gasket temperature.

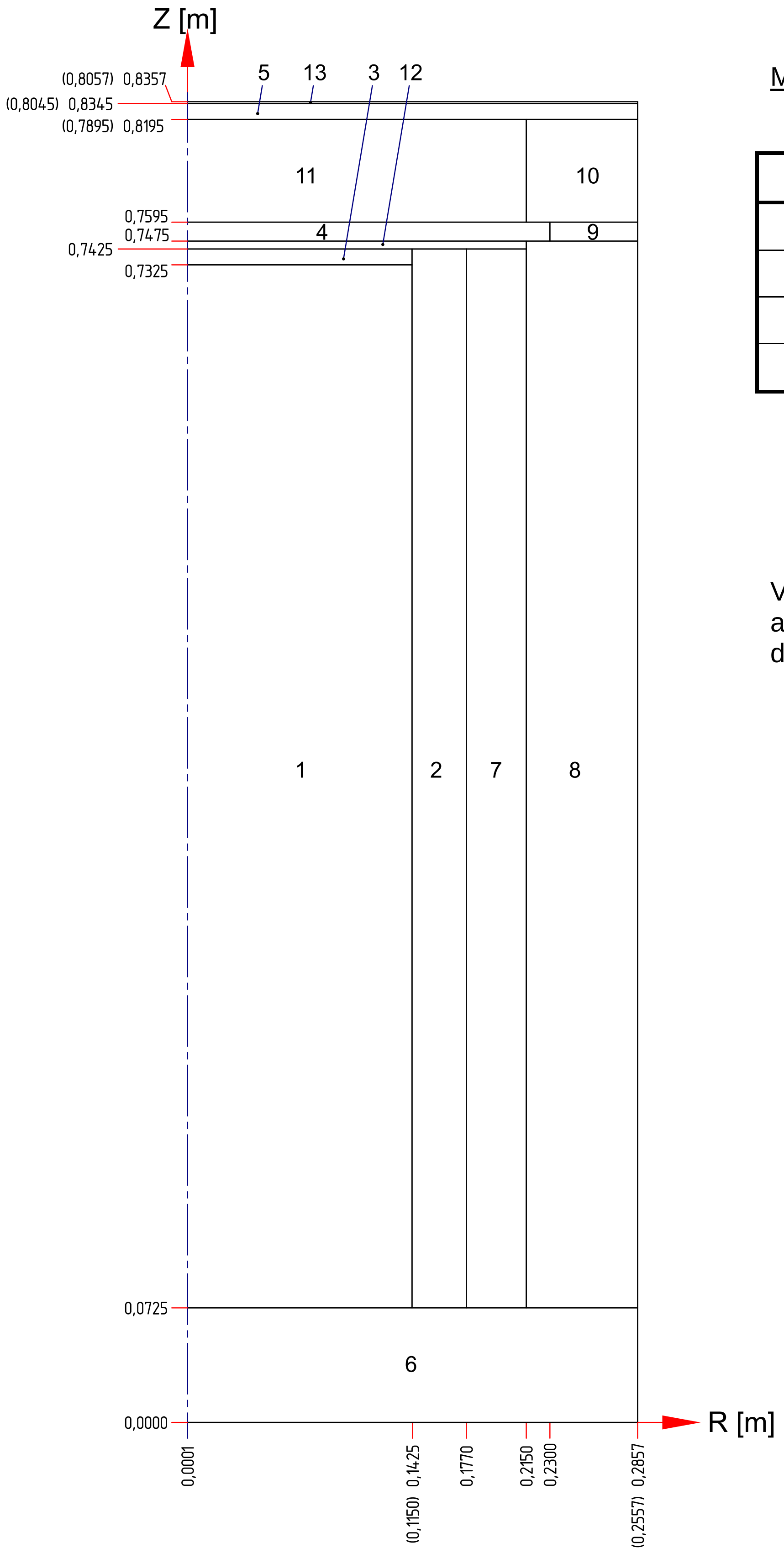


Figure 5-1: Geometry model Heating 7.2 for BU-D container

Materials:

Zone	Material
1	Content
2 – 5	Air
6 – 11	Concrete
12 - 13	Steel

Values in brackets for accident respectively different pail diameters

5.2 Input data

5.2.1 Thermal boundary conditions

The heat rate of the content is neglected.

According to /10-2/ respectively /10-1/ for the steady-state calculations an ambient temperature of 38°C and a thermal input in the container caused by insolation of 800 W/m² for horizontal surfaces (container lid) and 200 W/m² for not horizontal surfaces (container mantle) is assumed. The insolation is conservatively assumed for 24 h (according to /5-7/ the temperatures are overestimated especially in the inner cavity by approx. 9°C)

For the calculation of the steady-state temperature distribution the heat rate is referred to 24 hours. For the calculations therefore with an absorption coefficient of the surface for insolation of $\varepsilon = 0.3$ according to /5-2/ the following heat load:

- Container lid	240 W/m²
- Container mantle	60 W/m²

The accident fire is according to /10-2/ respectively /10-1/ assumed with 800°C and a duration of half an hour. The starting temperature distribution for the calculations is the temperature distribution calculated for steady-state conditions with insolation. After half an hour the ambient temperature is reduced to 38°C and the cooling phase is calculated. During the accident fire no insolation is assumed, in the cooling phase insolation is assumed.

5.2.2 Material data

The relevant material data for the calculations are summarized in Table 5-1.

Table 5-1: Material data of the used materials

Material	λ (W/m K)	ρ (kg/m³)	c_p (J/kg K)
Content	1,9	2210	253
Air	f(T)	1	1000
Concrete	0.12	520	880
Steel	46	7850	460

The material data for air and steel are taken from /4-5/. The material data for the content are taken from /5-3/. There the thermal conductivity is given for an UO_2 density of 10.96 g/cm³. This is corrected for the present case by the density ratio.

The thermal conductivity of the light concrete is taken from manufacturer information and the thermal capacity from /4-5/.

The temperature dependent thermal conductivity in the air gaps is also taken from /4-5/.

5.2.3 Heat transmission

For the steady-state calculation besides the thermal conductivity the following heat transmission are used:

1. Radiation in the air gaps 2 and 3

   Surface combination: Stainless steel/Paint

   Stainless steel: ε = 0.29 (from /5-4/)

   Paint: ε = 0.90 (from/5-5/)

$$\sigma \; x \; \varepsilon = \frac{5.67\,E{-}8}{\frac{1}{0.29}\,x\,\frac{1}{0.9}-1} = 1.59E-8\,W/m^2K^4$$

2. Radiation in the air gaps 4 and 5

   Surface combination: Paint/Concrete

   Paint: ε = 0.90

   Concrete: ε = 0.93 (from /4-5/)

$$\sigma \; x \; \varepsilon = \frac{5.67\,E{-}8}{\frac{1}{0.90}\,x\,\frac{1}{0.93}-1} = 4.78\,E-8\,W/m^2K^4$$

3. Radiation and convection outer surface

   - Surface: Paint

     Radiation
     Absorption coefficient: ε = 0.3 (from /5-2/)

     σ x ε = 5.67 E-8 x 0.3 = 1.70 E-8

   - Convection

     $\alpha = 1.3\,\Delta T^{0.3}$ (Approximation formula according to /4-5/)

For the fire accident besides the heat transmission conditions in the air gaps according to the steady-state calculations at the container surface the following is defined:

- Radiation during the fire

  α x ε = 5.67 E-8 x 0.9 x 0.8 = 4.08 E-8

  $\varepsilon 1$ = 0.9 (emission coefficient of the flames according to /5-6//)

  $\varepsilon 2$ = 0.8 (absorption coefficient from /5-6/)

- Radiation after the fire

$\sigma \times \varepsilon = 5.67 \text{ E-8} \times 0.9 = 5.10 \text{ E-8}$

$\varepsilon = 0.9$ (emission coefficient of soothed surface according to /4-5/)

- Convection

As convective heat transmission coefficient during the fire the value of 10 W/m^2 K given in /5-6/ para 728.30 is used. The cooling phase is calculated with:

$\alpha = 1.3 \, \Delta \, T^{0,3}$

- Insolation in the cooling phase

In the cooling phase (soothed surface) the insolation for the mantle is assumed with 0.9 x 400 W = 360 W (curved surface) and for lid and bottom with 0.9 x 200 W = 180 W (vertical surface). The absorption coefficient is in this case assumed like the emission coefficient (ε = 0.9) in deviation to /5-6/ (ε = 0.8).

5.3 Results of the calculation

5.3.1 Normal conditions

The temperature distribution of the standing container due to insolation is maximum at the surface of the container in mid of the lid 73°C and decreases to the outside and the inside to a minimum value of 52°C at the bottom of the container. In the cavity it is approx. 55°C.

Without insolation the container temperature the container temperature is equal to the ambient temperature because of the negligible heat rate of the content.

The temperature distribution for the slightly more unfavourable case with fuel pail diameter d = 230 mm is shown in the following Figure 5-2.

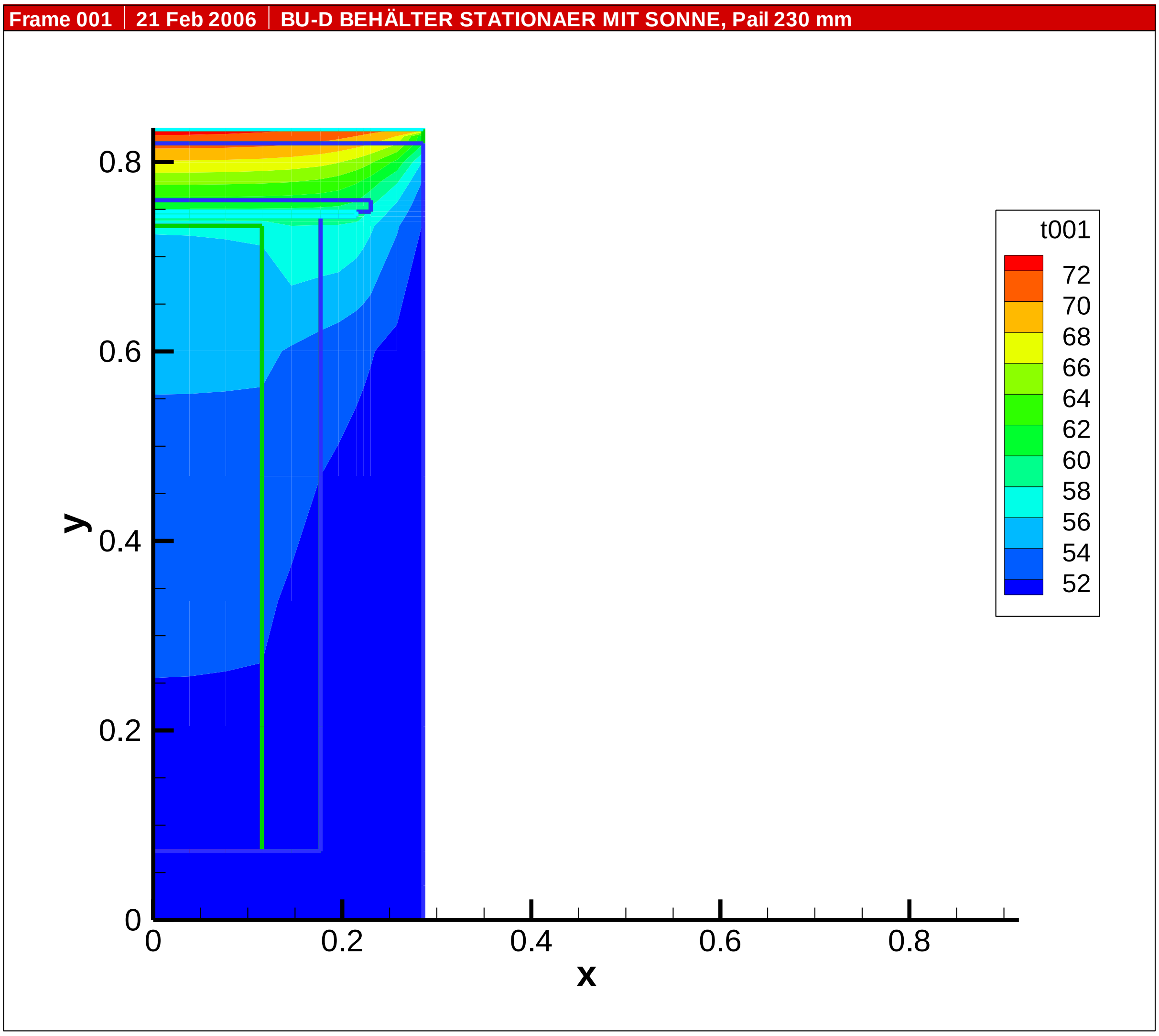


Figure 5-2: BU-D steady-state temperature distribution with insolation (230 mm pail)

5.3.2 Fire accident

The temperature curve during the fire accident is shown for selected points in dependence of the time in the Figures 5-3 and 5-4.

In the tables 5-2 and 5-3 the maximum occurring temperatures for these points are summarized. It shows that the variant with pail diameter d = 230 mm gives slightly higher results in all cases. This is because of the higher thermal capacity of the content with pail d = 285 mm.

Table 5-2: Maximum temperatures during the fire accident for selected points (pail diameter d = 230 mm)

Node No.	Position	T(at t = 0s)	T max	at t =
133	Centre lid Inner container	60 °C	219 °C	2400 s
66	Centre mantle Inner container	52 °C	140 °C	4800 s
25	Centre bottom Inner container	52 °C	110 °C	10200 s
127	Gasket Inner container	59 °C	226 °C	3000 s
61	Centre of content	53 °C	113 °C	12600 s

Table 5-3: Maximum temperatures during the fire accident for selected points (pail diameter d = 285 mm)

Node No.	Position	T(at t = 0s)	T max	at t =
133	Centre lid Inner container	60 °C	216 °C	2400 s
66	Centre mantle Inner container	52 °C	132 °C	4800 s
25	Centre bottom Inner container	52 °C	102 °C	11400 s
127	Gasket inner container	59 °C	220 °C	3000 s
61	Centre content	53 °C	103 °C	12600 s

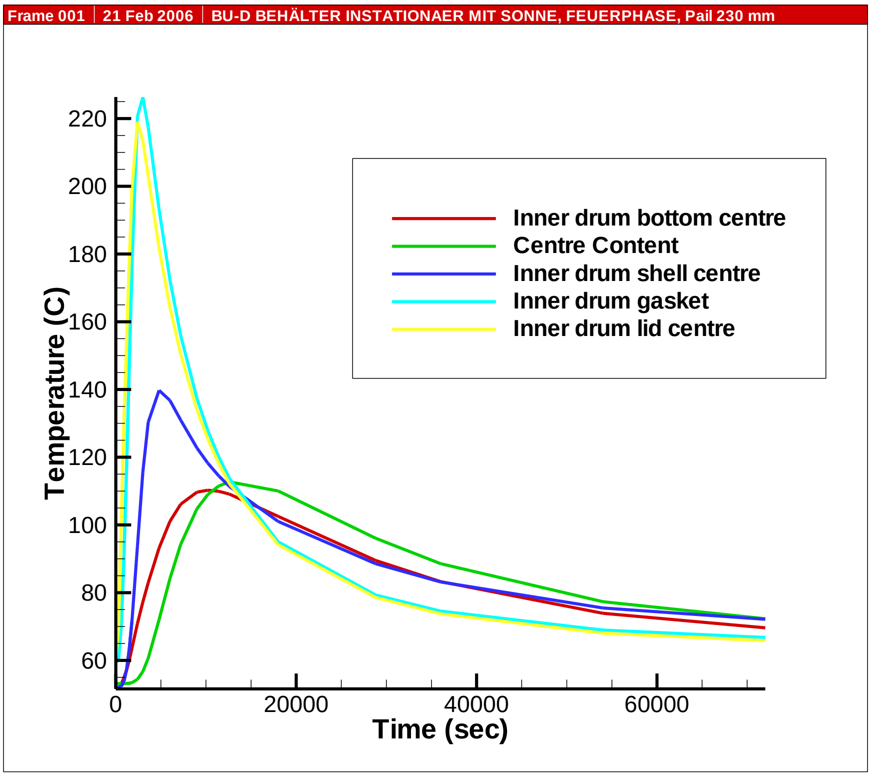


Figure 5-3: Temperature curve during the fire accident for selected points (pail d = 230 mm)

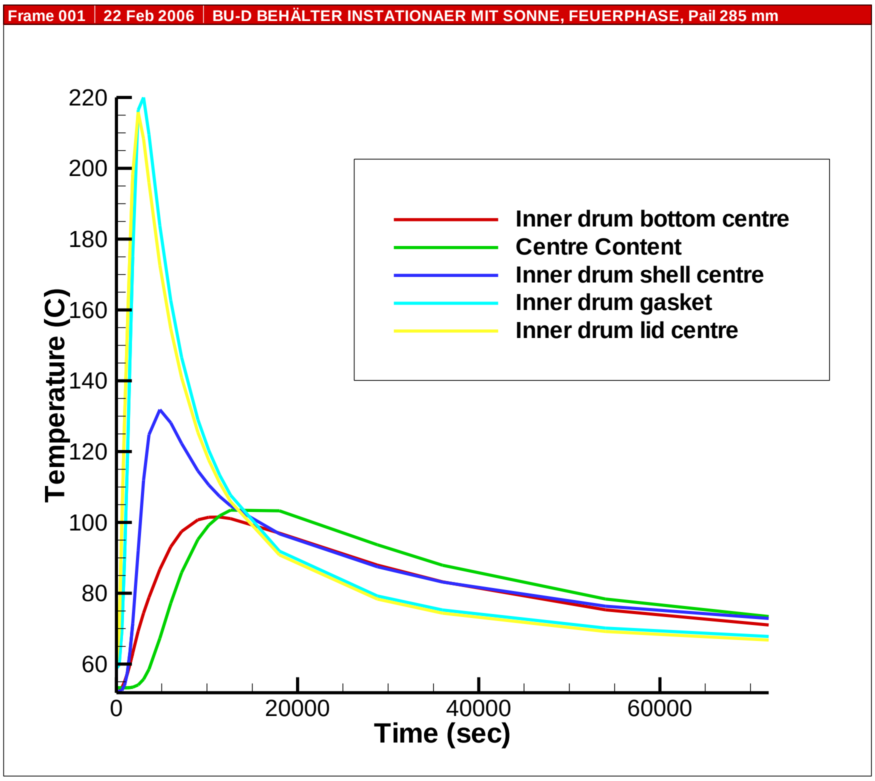


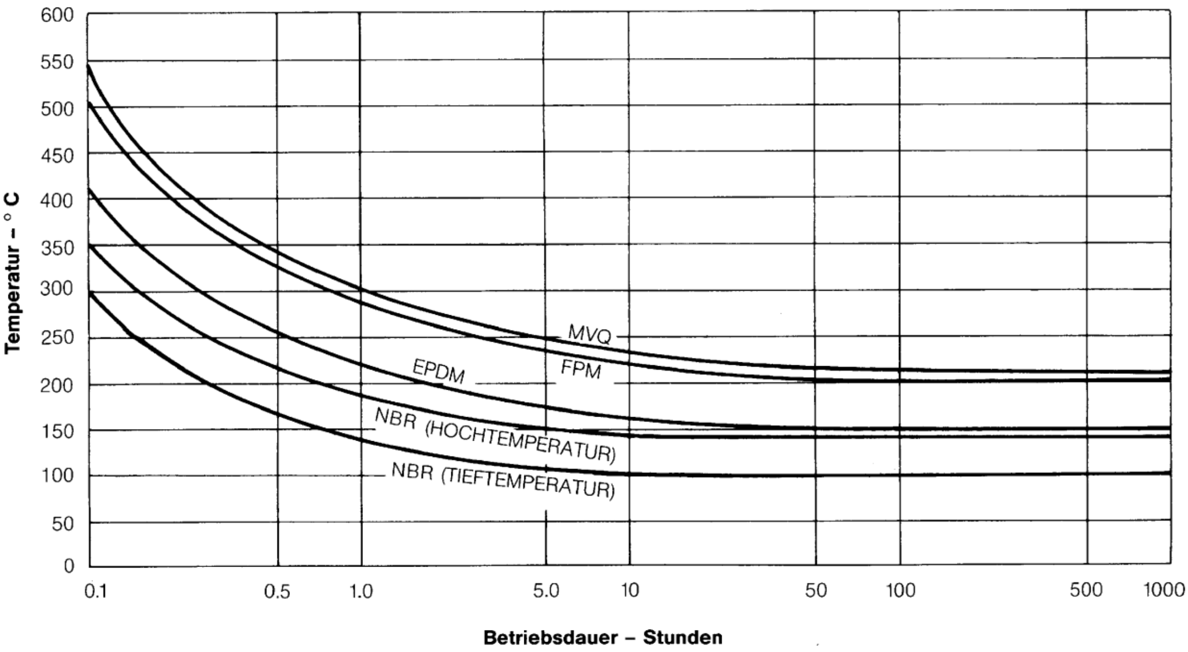
Figure 5-4: Temperature curve during the fire accident for selected points (pail d = 285 mm)

The calculations show that the temperatures are within the allowable limits. Most of the light concrete will dry out, the resulting water vapour can escape over the existing bore hole in the upper mantle region so that no damage of the packaging will occur due to an inner pressure. This was confirmed in the fire test. The reduced thermal conductivity due to the drying-out is conservatively neglected.

The maximum temperature of the gasket of more than 200°C (max. 226°C) for a short period of less than 1 h is acceptable for the used material for a short term. For this see the following table from the catalogue of company Parker.

Table 2 High temperature limits for various elastomere materials

Tabelle 2 Hochtemperaturgrenzen verschiedener Elastomer Werkstoffe



Die Tabelle kann nur als Richtlinie verwendet werden. Die tatsächliche Lebensdauer einer Dichtung bei überhöhter Temperatur ist unter anderem abhängig vom Einsatz der Dichtung und dem abzudichtenden Medium.

The content heats up to approx. 110°C. Under the assumption that the residual moisture is present as water in free form this corresponds to a vapour pressure of 1.43 bar in saturated form. This inner pressure is as already shown in chapter 4 acceptable for the containment. An impairment of the package due to the fire test can be excluded.

In the following figures 5-5 to 5-9 the temperature distribution is shown for different times for the pail diameter d = 230 mm.

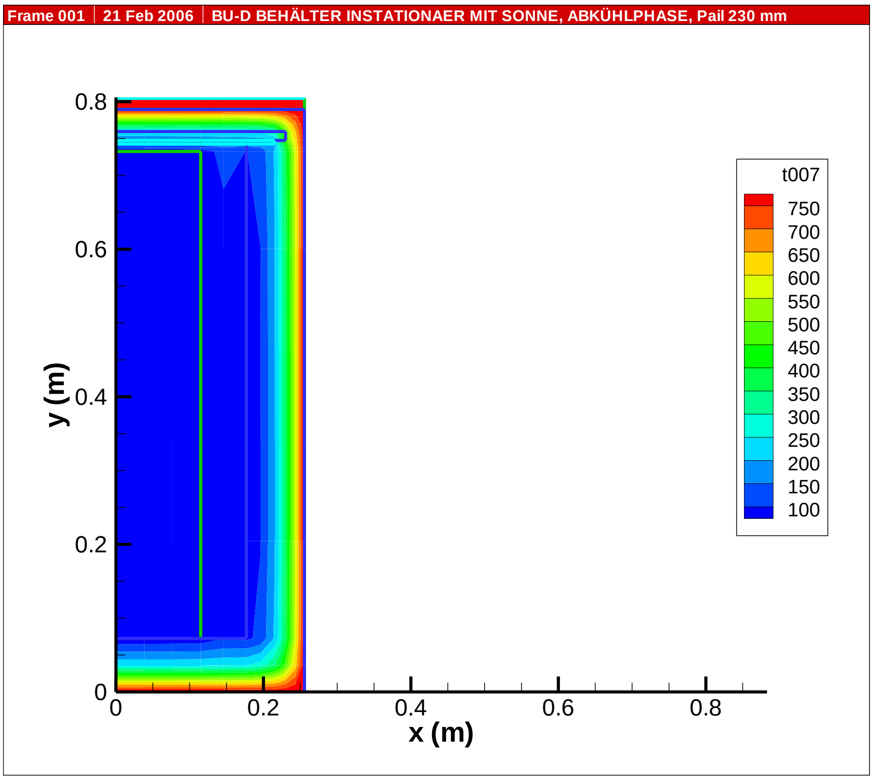


Figure 5-5: Temperature distribution in the accident fire (t = 1800 s)

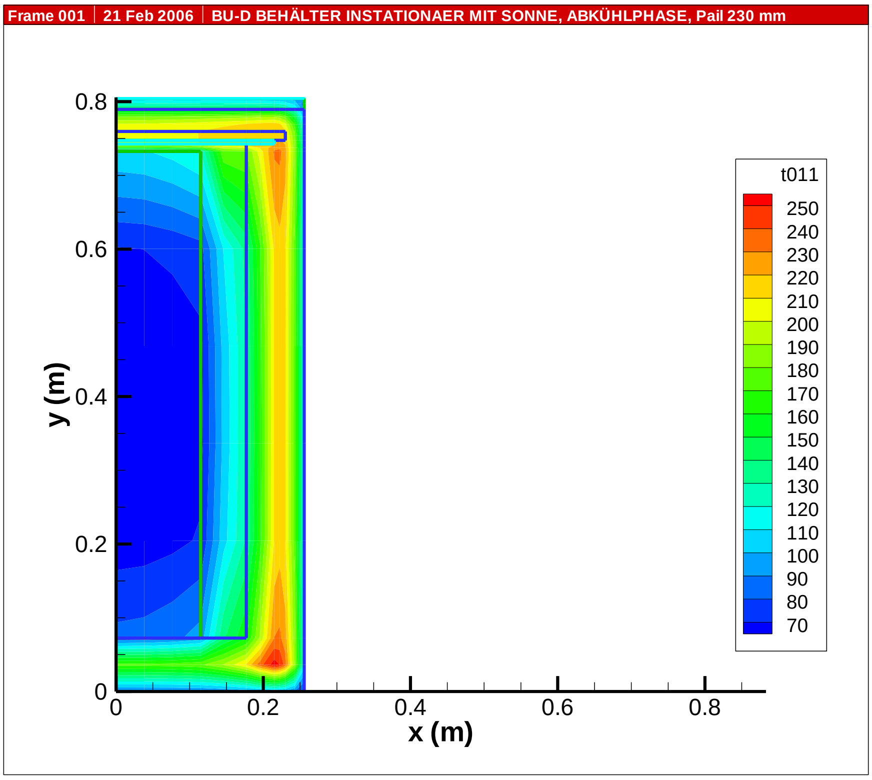


Figure 5-6: Temperature distribution in the accident fire (t = 3600 s)

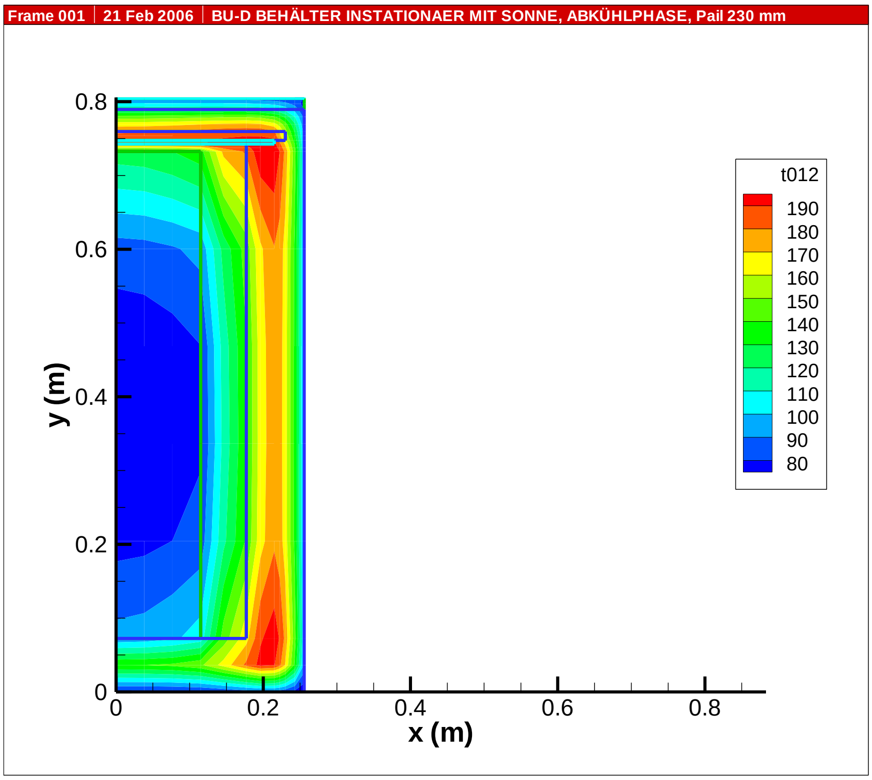


Figure 5-7: Temperature distribution in the accident fire (t = 4800 s)

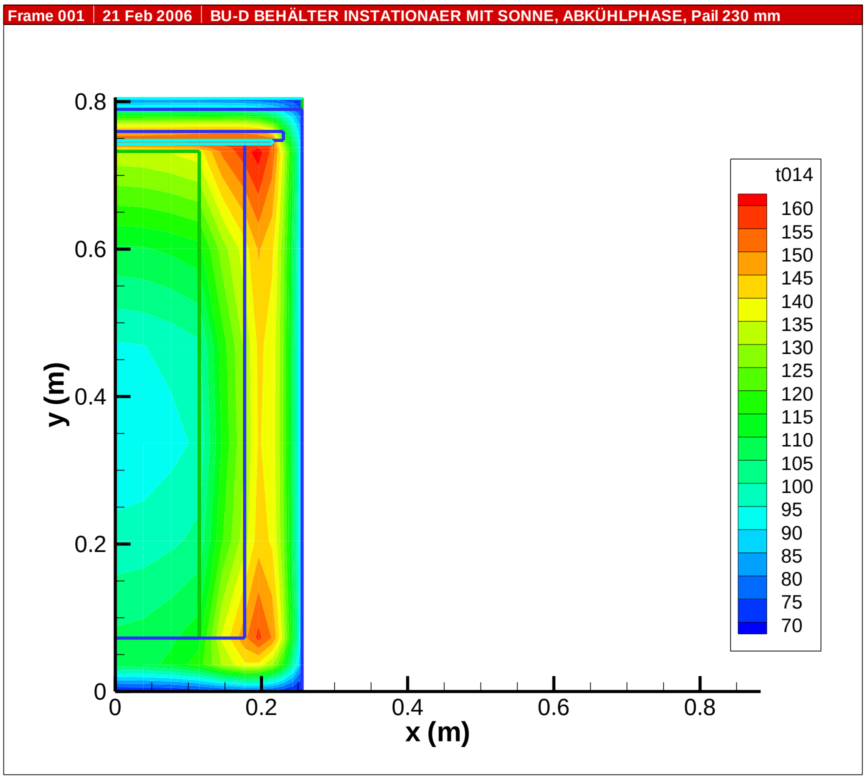


Figure 5-8: Temperature distribution in the accident fire (t = 7200 s)

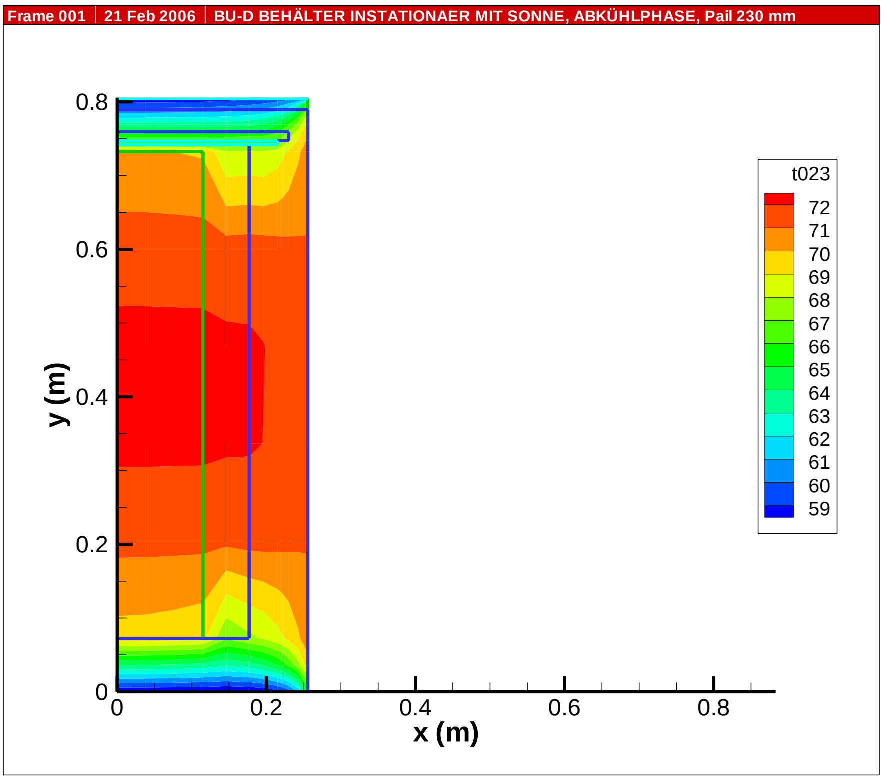


Figure 5-9: Temperature distribution in the accident fire (t = 72000 s)

5.4 Fire test

To demonstrate the behaviour of the container in an accident fire in addition to the calculations a fire test was performed /4-4/, Annex 8. In there the details of the test performance and the results are described.

The test shows especially – confirming the results of the transient thermal calculations – that the gasket of the inner container is not damaged in such a way that the loss of leak tightness has to be expected.

6 Activity release

6.1 Leak tightness under normal conditions of transport

Under normal transport conditions the content is inside closed pails in the inner container.

The containment in the sense of the transport regulations is built by the inner container with gasket and the lid screwing. The inner container therefore is subjected after manufacture to a leak tightness test for waterproofness by an overpressure test.

In chapter 4 it is shown that the inner container keeps its integrity and leak tightness under normal operation conditions and Type A test conditions, so that a release of the content under these conditions can be excluded.

6.2 Leak tightness under accident conditions

Under accidental conditions from the radiological view point it is allowed to release the complete content because the content has a maximum value of A_2.

For criticality safety reasons however it has to be prevented that significant amounts escape from the container. This is guaranteed by the inner container which has also after the accidental conditions, as demonstrated in the drop tests, a sufficient leak tightness to prevent the penetration of water or the escape of the radioactive content.

For the proof of criticality safety however it is conservatively assumed that the inner container is not leak tight and that water can penetrate.

7 Dose Rates

7.1 Dose rates under normal conditions of transport

As already discussed in chapter 2, only a very low dose rate at the surface of the package and in 1 m distance has to be expected. The experience shows that it is in the range of 5 to 10 µSv/h at the container surface.

An explicit calculation of the dose rate to demonstrate that the allowable dose rate values of ≤ 2 mSv/h at the container surface and ≤ 0.1 mSv/h in 1 m distance is therefore not necessary.

The dose rate also does not change under the Type A tests, because no significant geometry changes occur.

7.2 Dose rates under accidental conditions

After an accident according to chapter 4 the maximum deformation to be expected is 3 cm. Therefore the light concrete layer is reduced by this value.

A simple assessment shows that the dose rates at the container is increased by this by approx. 30 % and is therefore still very low and significantly below the allowable values.

8 Criticality Safety

The boundary conditions for the criticality safety proof and the results of the calculations are presented in three separate reports /8-1/, /8-2/ and /8-3/ (Annex 10 to 12). In these reports it is shown that the criticality safety for the allowable contents as defined in chapter 2 is guaranteed for the requirements of the transport regulations /10-2/ respectively /10-1/.

Additionally, extremely pessimistic heterogeneous fuel arrangements are investigated and proven to be safely subcritical in calculation report /8-4/, Annex 19. This demonstrates that criticality safety is ensured even for covering assumptions that go beyond physically realistic arrangements.

The confinement system of the radioactive content is built under normal transport conditions and under accidental conditions by the inner container with inner lid, gasket and screwing. Under Type C test conditions it is assumed that the confinement system fails and the complete content of the package is released

According to the requirements for packages containing fissile materials for an allowable number of N = 70 (CSI = 0.71) the following proofs have to be performed:

- Package in isolation undamaged or damaged according to the tests for accident conditions. Fully flooded and fully reflected at the outside
- 5 times the number of undamaged packages with a 30 cm water reflector around the array.
- 2 times the number of damaged packages with outer water reflector around the array and optimum moderation between the packages.
- Single package under Type C test conditions with a 20 cm water reflector around it.

A calculation for the package in isolation is not necessary because the transported masses of U-235 each are below the safe mass (45 % of the critical mass) under most unfavourable geometry and moderation conditions.

In all cases optimum moderation of the content is assumed and for the fissile material always UO_2 is assumed, because this is the most reactive uranium compound.

Any amounts of the neutron absorber Gadolinium present in the fuel are conservatively neglected.

The results of the calculations show that 5 times the number of undamaged packages with optimum moderated allowable content is always more reactive than twice the number of damaged packages with optimum moderated content so that further proofs can be restricted to this configuration.

In additional calculations it is demonstrated that the criticality safety for all allowable contents is also guaranteed if the inner fuel pails fail or are not present.

The allowable value for the reactivity of $k_{eff} + 2\sigma \leq 0.95$ is kept for all calculations with fuel pails. Under the assumption that the fuel pail is not present slightly higher values result (< 0.96). This is acceptable because of the conservatism of the assumption.

9 Quality assurance

Basis for the quality assurance requirements is the BAM-GGR 011 /9-1/.

The quality assurance system of company DAHER NUCLEAR TECHNOLOGIES GmbH is laid down in the Integrated Management Handbook /9-3/. It is based on DIN EN ISO 9001 /9-4/ and KTA 1401 /9-5/ and covers all phases of the development and use of packagings.

The manufacture, handling, maintenance and periodic inspection are regulated in the following documents:

- Manufacture:

  Specification-Nr.: SB-02-02 Rev. 2 (Annex 13)

  This was released by BAM in connection with the manufacture of new packagings in 2013.

  This specification is concerning its content essentially identical to the specification No. 2627-SB-1.0 and SB-02-02 Rev. 1 used for the manufacture of the already present containers. Thus the already-made containers that were manufactured on the basis of the applicable documents at the time of manufacture, PTB / BAM QA Policy /9-2/ or TRV 006 /9-6/, fulfill the requirements of BAM-GGR 011.

- Handling and maintenance:

  Handling Instructions No.: HA-97-09 Rev. 3 (Annex 14)
  and the instructions PA-03-04 Rev. 1 (Annex 15) and
  PA-03-05 Rev. 0 (Annex 16) referred to therein

  These instructions are based on the already released documents in earlier certificates of approval and take into regard actual requirements.

- Periodic inspections:

  Testing Instruction No.: PA-00-01 Rev. 3 (Annex 17)

10 Conformance with the transport regulations

In the following it is shown by using the structure of ADR 2017 /10-2/ (sections in brackets) and the identical IAEA Regulations SSR-6 /10-1/ (para in parenthesis) that the safety requirements for the package are fulfilled.

10.1 General requirements for all packagings and packages

[6.4.2.1] (607) The package with a maximum gross mass of 260 kg and a volume of approx. 213 l in the form of a cylindrical drum can be transported easy and safe. During a transport in 20`- or 40` containers the securing normally is done by close packing and prevention of relative movements by appropriate measures. The load securing of single packages can be done correctly for example by using tightening straps on pallets.

[6.4.2.2] (608) The package has no handling devices. Handling is done by drum grip, pallets and fork lift.

[6.4.2.3] (609) There are no features at the outside of the package which can be used for lifting.

[6.4.2.4] (610) The outside of the packaging has with exception of the clamping ring no protruding features. The clamping ring is necessary for the secure closure of the outer container. The packaging is painted with a lacquer which provides easy decontamination properties.

[6.4.2.5] (611) A collection of water is due to the design only possible on the lid of the package. This has no impact on the safe function of the packaging.

[6.4.2.6] (612) The pallets or lashing devices which may be present during transport do not reduce the safety of the package. Other parts are not present.

[6.4.2.7] (613) The closure screws of the outer clamping ring and of the inner lid are fastened according to the handling instructions HA-97-09 Rev. 3 with definite torques which prevent that they get loose during routine transport because of accelerations, vibrations or vibration resonance. Onto the package in general these effects have also no influence, because especially the inner pails containing the radioactive material are centred in the cavity of the container by a distance frame or a distance tube.

[6.4.2.8] (614) The materials of the packaging are physically and chemically compatible with each other and the radioactive content. Because of the nature of the allowable content (non-irradiated uranium) the radiation is so low that an effect onto the used materials can be excluded.

[6.4.2.9] (615) The package has no valves.

[6.4.2.10] (616) The materials of the package are suitable for a temperature range of -40°C to +38°C. Pressure differences caused by inner overpressure or outer negative pressure during routine transport are taken into regard by the design (see chapter 4).

[6.4.2.11] (617) In chapter 2 and chapter 7 it is demonstrated that the surface dose rate under routine conditions of transport will under no circumstances exceed the limit value of 2 mSv/h, even for the largest radioactive inventory that the package is designed for.

[6.4.2.12] (618) According to the definition of the allowable content the impurities which are present in addition to the uranium must not have additional dangerous properties. As mentioned above of the uranium compounds listed in the allowable content only the solid uranylnitrat has additional dangerous properties. However a risk from this can be excluded because on the on hand the package design fulfils the requirements for a package of Type A for fissile materials of class 7 and therefore the package requirements of class 5.1 packaging group III (lightly oxidizing) are covered and on the other hand during loading and transport no additional materials are added which may have an oxidizing effect to the UNH.

[6.4.2.13] This requirement is fulfilled by the delivery of drawings, parts lists and the handling instruction.

10.2 Additional requirements for packages transported by air

(619) The temperature of the package without insolation is because of the negligible heat rate in the region of the ambient temperature of 38°C. The allowable value of 50°C is not exceeded.

(620) The materials of the package are suitable for a temperature range of -40°C to +55°C.

(621) A pressure difference of 95 kPa with internal overpressure was taken into regard for the safety proof (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

10.3 Requirements for type A packages

[6.4.7.1] (635) See for this chapter 10.1 and 10.2 and the following explanations.

[6.4.7.2] (636) The smallest outer dimension is greater than 10 cm.

[6.4.7.3] (637)) The sealing of the package is done over a bore hole in the closing screw of the outer container. An unnoticed opening is therefore not possible.

[6.4.7.4] (638) The package has no special tie-down attachments.

[6.4.7.5] (639) The components of the package are designed for a temperature range of –40°C to +70°C. Water in free form is not present.

[6.4.7.6] (640) The design and manufacture of the already existing packagings was done on the basis of documents, released by the competent authorities, which were in accordance with the quality assurance requirements /9-2/ and /9-6/ at the time of manufacture and which also fulfill the present requirements of the BAM-GGR 011 /9-1/. For the manufacture of new packagings the documents mentioned in chapter 9 are valid.

[6.4.7.7] (641) The containment is built by the inner container with lid, the gasket and the screwing. An unintentional opening and impairment by an occurring inner pressure can be excluded.

[6.4.7.8] (642) There is no radioactive material in special form present.

[6.4.7.9] (643) The containment is part of the package.

[6.4.7.10] (644) The components of the containment are chosen in such a way that an impairment by effects of gas generation by chemical reaction or radiolysis can be excluded. Because of the low radiation radiolysis can be neglected.

[6.4.7.11] (645) In chapter 4 it is demonstrated that the containment is designed for an outer negative pressure of 60 kPa.

[6.4.7.12] (646) There are no valves present.

[6.4.7.13] (647) In chapter 4 it is demonstrated that under the test conditions of para 719 to 724 no release of radioactive material can occur. An assessment shows that the dose rates under accidental conditions (9 m drop) increase by approx. 30 %. This allows the conclusion that after a free drop test from 1.2 m height only an increase of the dose rate of approx. 5 % has to be expected and therefore the allowable value of 20 % is surely kept.

[6.4.7.15] (649) The radioactive material is not in liquid form.

[6.4.6.16] (650) The radioactive material is not in liquid form.

[6.4.7.17] (651) The radioactive material is not in gaseous form.

10.4 Requirements for packages containing fissile material

[6.4.11.1] (673) The proof of criticality safety takes in regard the following boundary conditions:

- The penetration of water into the package is assumed.
- Neutron absorbers or moderator, which may loose their efficiency are not present.
- A rearrangement of the content within the package or an escape from the package has not to be assumed as demonstrated in the drop and fire tests. However as a conservative limiting case the situation is looked at that the fuel pail which contains the radioactive content is not present.

[6.4.11.2] (674) Not applicable because none of the exceptions is fulfilled.

[6.4.11.3] (675) Not applicable because the exception is not fulfilled.

[6.4.11.4] (676) Not applicable because the radioactive content is clearly specified.

[6.4.11.5] (677) Not applicable because the material is non-irradiated.

[6.4.11.6] (678) As shown in chapter 4 under the test conditions according to section 6.4.15 respectively para 719 to 724 the entry of a 10 cm cube can be excluded.

[6.4.11.7] (679) The package is designed for an ambient temperature range of -40°C to +38°C.

[6.4.11.8] (680) For the proof of criticality safety of the package in isolation the penetration of water into all voids including the containment system is assumed.

[6.4.11.9] (681) For the proof of criticality safety of the package in isolation the presence of a water reflector of at least 20 cm thickness is taken into regard.

[6.4.11.10] (682) The criticality safety is demonstrated for an array of packages for the conditions specified in the sub-sections 6.4.11.8 and 6.4.11.9 respectively the paras 680 and 681 in /8-1/ to /8-3/.

[6.4.11.11] (remains open)

(683) The criticality safety for the allowable content is demonstrated under the conditions of para. 683 in chapter 8 (/8-2/ and /8-3/)..

[6.4.11.12] (684) The proof that for an allowable number of 5 N = 355 packages (CSI = 0.71) after the tests for normal conditions of transport the criticality safety is guaranteed under the conditions mentioned in this sub-section (this para) is made in /8-1/ to /8-3/. For this always an optimum moderation of the content is assumed.

[6.4.11.13] (685) For an array of 2 N = 142 packages after the tests for accidental conditions the proof of criticality safety is made in /8-1/ to /8-3/ under the conditions mentioned in this sub-section (this para).

[6.4.11.14] (686) The smallest number N from the two previous paras is 71. Therefore the Criticality Safety Index is CSI = 0.71.

11 References

/1-1/ Regulations for the Safe Transport of Radioactive Material
2009 Edition No. TS-R-1, IAEA, Vienna, 2009

/1-2/ European Agreement for International Transports of Dangerous Goods by Road (ADR), Enclosures A and B, Version dated 31.08.2012

/2-1/ Technical Report No. 3
Chemische und physikalische Eigenschaften der Uranverbindungen UO_3, U_3O_8, UO_2, UF_4, UF_6, ADU, AUC, UO_2F_2, $UO_4 \cdot 2H_2O$ und $UO_2(NO_3)_2 \cdot 6H_2O$
Reaktor Brennelement Union GmbH, Hanau, 24.11.1980

/4-1/ Versuchsbericht Nr. 22040
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Annex 1 Certificate of Approval D/4305/AF-96

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Annex 2 Data Sheet 001-068-00 (Container BU-D)

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Annex 3 Drawings of Container BU-D and Samples of Fuel Pails

Stückliste Behälter BU-D 001-068 Rev. C and drawings indicated therein

Annex 4 BAM Test Certificate for Decontamination Properties

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Annex 6 1. Addendum to BAM Test Report No. 22040

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Annex 7 Test Protocol 88-BP-5
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Annex 8 Test Protocol 88-BP-4 Fire Test

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Annex 9 Input and Output Files HEATING 7.2

CD-ROM with input- and output files

Annex 10 Working Report KWU BT33/94/029 and Supplements

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Annex 13 Specification SB-02-02 Rev. 2

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Annex 14 Handling Instructions HA-97-09

Handling Instructions HA-97-09 Rev. 4, Handling of the Container BU-D

Annex 15 Inspection Instruction PA-03-04 Rev. 1

Inspection Instruction PA-03-04 Rev.1, Inspection of the BU-D Package within the Scope of Maintenance, of Regular and Periodic Inspections

Annex 16 Testing Instruction PA-03-05 Rev. 0

Testing Instruction PA-03-05 Rev. 0, Contamination Control and Dose Rate Measurement of the BU-D Packages

Annex 17 Testing Instruction PA-00-01 Rev. 3

Testing Instruction PA-00-01 Rev. 3, Periodic Inspection of the BU-D Package

Annex 18 Report NCS 0810 Rev. 1

Report NCS 0810 Rev.1, Evaluation of the Effect of the Dynamic Crush Test onto the Package BU-D

Annex 19 Report 0007-BBR-2018-001 Rev. 0

Calculation Report 0007-BBR-2018-001 Rev. 0, Container BU-D: Supplementary criticality calculations for hypothetical arrangements of fuel