orano

Safety Analysis Report
for the
DN30-X Package

0045-BSH-2020-001 Rev. 2

Prepared	Checked	Released
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PART 2 TECHNICAL ANALYSES

List of Revisions

Revision	Date of revision	Modifications
0	June 29, 2021	Original
1	October 7, 2021	• Amended the definition of the permissible content in section 1.3. • Amended the material specification for the interior criticality control system in section 1.4.1.1.3. • Reorganized the description of the 30B-X cylinder in section 1.4.2.1 and added section 1.4.2.1.4, covering additional provisions to ANSI N14.1. • Amended section 1.7.4.1 by also discussing potential impacts on the filling, emptying, and washing operations of the 30B-X cylinder because of the presence of the interior criticality control system. • Update of results of dose rate analysis in section 2.5 for permissible content weights of final cylinder designs.
2	September 09, 2022	• Addition of responses to the NRC requests for additional information (RAIs) dated June 10th 2022 • Complete revision to create a standalone and self-contained SAR without references to the SAR for the DN30 package. All necessary information from the DN30 SAR was transferred to this document and its appendices without change.

List of Abbreviations

BAM	**B**undes**a**nstalt für **M**aterialforschung und- prüfung (German Federal Institute for Material Research and Testing)
BPVC	**B**oiler and **P**ressure **V**essel **C**ode
CCR	**C**riticality **C**ontrol **R**od
CCS	**C**riticality **C**ontrol **S**ystem
CSI	**C**riticality **S**afety **I**ndex
HAC	**H**ypothetical **A**ccident **C**onditions
HALEU	**H**igh-**A**ssay **L**ow-**E**nriched **U**ranium
IMS	**I**ntegrated **M**anagement **S**ystem
MAWP	**M**aximum **A**llowable **W**orking **P**ressure
MNOP	**M**aximum **N**ormal **O**perating **P**ressure
MTSP	**M**anufacturing and **T**est **S**equence **P**lan
NCT	**N**ormal **C**onditions of **T**ransport
ONCS	**O**rano **NCS** GmbH
PIR	**P**oly**i**socyanu**r**ate
PSP	**P**rotective **S**tructural **P**ackaging
QA	**Q**uality **A**ssurance
RCT	**R**outine **C**onditions of **T**ransport
SAR	**S**afety **A**nalysis **R**eport
TI	**T**ransport **I**ndex

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Literature

[10 CFR Part 71]	Code of Federal Regulations Title 10 Part 71 “Packaging and Transportation of Radioactive Material”
[49 CFR Part 173]	Code of Federal Regulations Title 49 Part 173 “Shippers - General Requirements for Shipments and Packagings”
[ANSI N14.1]	Uranium Hexafluoride – Packaging for Transport, ANSI N14.1, 2019
[ANSI N14.5]	Radioactive Materials – Leakage Tests on Packages for Shipment, ANSI N14.5, 2014
[ANSYS]	ANSYS®, Release 2021 R1, Help System, ANSYS, Inc
[ASME BPVC]	ASME Boiler and Pressure Vessel Code, 2019 Edition
[ASTM A333]	ASTM A333 / A333M-18, Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness, ASTM International, West Conshohocken, PA, 2018, www.astm.org
[ASTM A516]	ASTM A516 / A516M-17, Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service, ASTM International, West Conshohocken, PA, 2017, www.astm.org
[ASTM C996]	ASTM C996-20, Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 % ^{235}U, ASTM International, West Conshohocken, PA, 2020, www.astm.org
[DIN EN 10028-3]	Flat products made of steels for pressure purposes - Part 3: Weldable fine grain steels, normalized, October 2017
[DIN EN 10088-2]	Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes, December 2014
[DIN EN 10088-3]	Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes, December 2014
[DIN EN 10216-3]	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 3: Alloy fine grain steel tubes, March 2014
[Harris Sn50]	Technical Information Sheet 50/50 Tin Lead Solder - The Harris Products Group, 2017
[ISO 12807]	Safe transport of radioactive materials – Leakage testing on packages, ISO 12807, September 2018
[ISO 7195]	ISO 7195, Nuclear Energy – Packagings for the transport of uranium hexafluoride (UF_6), Third edition, November 2020
[MILIN 2016]	Milin M. et al, Hydration of uranium residues contained in enriched UF_6 cylinders, Proceedings PATRAM 2016, Kobe, September 2016
[NEA 2019]	International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA, July 2019 Edition, NEA/NSC/DOC(95)03

[NUREG 2216]	Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material, U.S. NRC, Office of Nuclear Material Safety and Safeguards, NUREG-2216, August 2020
[SCALE 2011]	SCALE 6.1, Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design ORNL/TM-2005/39, Version 6.1, Oak Ridge National Laboratory, 2011
[SCALE 2020]	SCALE 6.2.4, SCALE Code System, ORNL/TM-2005/39, Version 6.2.4, Oak Ridge National Laboratory, 2020
[SSG-26 2012]	Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), Specific Safety Guide No. SSG-26, IAEA, Vienna, 2014
[SSR-6 2018]	Regulations for the Safe Transport of Radioactive Material, 2018 Edition, SSR-6 Rev. 1, IAEA, Vienna, 2018
[USEC 651]	The UF_6 Manual – Good Handling Practices for Uranium Hexafluoride, Rev. 9, USEC, 2006

PART 1
GENERAL INFORMATION

1.1 List and Status of Documents Pertaining to this SAR

The list of applicable documents and their status pertaining to this safety analysis report (SAR) is included in Appendix 1.1 (List of Applicable Documents).

1.2 Administrative Information

1.2.1 Name of Package

The package is designated **DN30-X** and consists of the DN30 protective structural packaging (PSP) and the 30B-X cylinder. The “X” in DN30-X and 30B-X is either replaced by “10” or by “20” to refer to a specific design for a maximal enrichment of 10 or 20 wt.-% ^{235}U in uranium, respectively.

Since both the 30B-10 and the 30B-20 cylinder are transported in the same DN30 PSP that has been designed for the transport of standard 30B cylinders according to [ANSI N14.1], the following path is taken with respect to licensing of the DN30-X package:

- The designs of the 30B-10 and the 30B-20 cylinder shall be incorporated into a single package approval for the DN30-X package.
- The package approval for the DN30-X package shall incorporate the allowable contents for each cylinder as specified in section 1.3.
- Already existing DN30 PSPs that have been manufactured for the transport of standard 30B cylinders according to [ANSI N14.1] are allowed to be used for the transport of 30B-10 and 30B-20 cylinders as well.

1.2.2 Identification of Package Designer

The designer and license holder of the DN30-X package is:

Orano NCS GmbH
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D-63457 Hanau
Germany

The principal contact is:

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In this report, Orano NCS GmbH is designated “ONCS”.

1.2.3 Type of Package Design

The DN30-X package, loaded with the allowable content as described in section 1.3, fulfills the requirements of [10 CFR Part 71] and [49 CFR Part 173], as well as [SSR-6 2018] for a

Type AF package for uranium hexafluoride (UF_6)

containing UF_6 grade HALEU in less than or equal to A_2 quantities:

- For the DN30-10, the maximal allowed enrichment is 10 wt.-% ^{235}U in uranium.
- For the DN30-20, the maximal allowed enrichment is 20 wt.-% ^{235}U in uranium.

1.2.4 Shipping Name and UN Number

For the DN30-X package containing fissile UF_6, the proper shipping name and UN number

Radioactive material, uranium hexafluoride, fissile, UN 2977

is used as prescribed in [49 CFR Part 173] §420(e).

1.2.5 Criticality Safety Index

For the DN30-X package, the criticality safety index (CSI) is:

$$\text{CSI} = 0$$

1.2.6 Package Design Identification and Restrictions

A unique serial number is assigned to each DN30 PSP valid for its entire operation time. This number is stamped on the nameplate that is used for the already licensed DN30 package under the entry “Serial No.” (cf. Appendix 1.4.1B (Drawings DN30 PSP), drawing 0023-ZFZ-1000-001).

The serial number has the following pattern:

XX-YYYY-ZZZZ

Where:

XX	=	designation of the fabricator (abbreviation assigned by ONCS)
YYYY	=	year of manufacturing
ZZZZ	=	sequential number

The list of all serial numbers is managed and filed by ONCS. All users of the DN30-X packaging will be requested to update the status of the individual packaging after completion of the regular periodical inspections. Packagings with overdue periodical inspections (more than 1-year overdue) will be marked in that list as “not in use”.

Each individual DN30 PSP may be marked with an owner serial number different from the manufacturer serial number. This owner serial number may be marked on the nameplate under the entry “Owner’s Serial No.” or on an additional nameplate attached to the DN30 PSP. The owner serial number may change whenever required by the owner.

1.2.7 Modes of Transport for which the Package is Designed

- The DN30-X package is designed for transport by road, rail, sea, and inland waterways.
- Transport by air is not permitted.
- Hump shunting of wagons transporting the DN30-X packages is not allowed.

1.2.8 Lowest Transport Temperature for which the Package is Designed

The lowest transport temperature allowed for the DN30-X package is -40 °C.

1.2.9 Maximum Normal Operating Pressure

The maximum normal operating pressure (MNOP) for the DN30-X package is defined as the pressure at the triple point of UF_6 (see table 1-1):

$$\mathrm{MNOP} = 152\,\mathrm{kPa}$$

Note: the maximum allowable working pressure (MAWP) of the 30B-X cylinder is specified with regard to the requirements of [ANSI N14.1] as 1.38 MPa. This definition of the MAWP only applies to the use of the 30B-X cylinder in the enrichment and fuel fabrication process and not for its use as part of the DN30-X package.

1.2.10 Maximal Standardized Helium Leakage Rate

With reference to [ANSI N14.1], the maximal standardized helium leakage rate of the 30B-X cylinder is specified as:

$$Q_{\mathrm{N(SLR)}} = 1 \cdot 10^{-4}\,\mathrm{Pa} \cdot \mathrm{m}^3/\mathrm{s}$$

1.2.11 Reference to Applicable Regulations and Standards

The safety proof of the DN30-X package is based on the following regulations and standards:

- [10 CFR Part 71] Code of Federal Regulations Title 10 Part 71, “Packaging and Transportation of Radioactive Material”
- [49 CFR Part 173] Code of Federal Regulations Title 49 Part 173, “Shippers - General Requirements for Shipments and Packagings”
- [ANSI N14.1] American National Standard, “For Nuclear Materials – Uranium Hexafluoride – Packagings for Transport”, ANSI N14, 2019-12-05
- [ISO 7195] Nuclear Energy – Packagings for the transport of uranium hexafluoride (UF_6), Third edition, November 2020
- [SSR-6 2018] “Regulations for the Safe Transport of Radioactive Material”, 2018 Edition, SSR-6, Rev. 1, International Atomic Energy Agency (IAEA), Vienna, 2018

In the remainder of this SAR, reference is only made to [ANSI N14.1]. However, unless stated otherwise, references to [ANSI N14.1] always include [ISO 7195] as well.

1.3 Specification of the Radioactive Contents

The allowable content of the DN30-X packaging is uranium in the chemical composition UF_6 with maximal enrichments of 10 and 20 wt.-% ^{235}U in uranium. In the context of this SAR, the allowable content is designated:

- HALEU 10 for an enrichment of 10 wt.-% ^{235}U in uranium
- HALEU 20 for an enrichment of 20 wt.-% ^{235}U in uranium

A general specification of HALEU 10 and HALEU 20 defining the impurity and uranium isotope limits is provided in section 1.3.1. Based on this general specification, the permissible contents for the DN30-10 and DN30-20 package are specified in section 1.3.2.

1.3.1 General Specification of UF_6 grade HALEU 10 and HALEU 20

This general specification of UF_6 grade HALEU 10 and HALEU 20 covers nuclear grade UF_6 that has been processed through an enrichment plant and that is intended for fuel fabrication. It corresponds to a large extent to [ASTM C996] and the objective of this specification is to define the impurity and uranium isotope limits for HALEU 10 and HALEU 20 that can be transported in the DN30-10 and DN30-20 package, respectively.

1.3.1.1 Terminology

In the following specification of the permissible contents of the DN30-X package, the definitions of terms defined in [ASTM C996], section 3 are used.

1.3.1.2 Origin of Material

HALEU 10 and HALEU 20 shall be enriched from Commercial Natural UF_6. Neither Reprocessed nor Derived Enriched UF_6 shall be used for HALEU 10 and HALEU 20.

1.3.1.3 Safety, Health Physics and Criticality Requirements

The safety, health, and criticality requirements for HALEU 10 and HALEU 20 are identical to the requirements provided in [ASTM C996], section 4 for Enriched Commercial Grade UF_6 with a maximal enrichment of 5 wt.-% ^{235}U in uranium:

(1) The UF_6 concentration shall not be less than 99.5 g UF_6 per 100 g of sample in order to limit the potential hydrogen content for nuclear criticality safety.

(2) The total absolute vapor pressure shall not exceed the following values:

- 380 kPa at 80 °C (55 psia at 176 °F), or
- 517 kPa at 93 °C (75 psia at 200 °F), or
- 862 kPa at 112 °C (125 psia at 235 °F)

Additionally, if a measurement is taken over solid UF_6, the vapor pressure shall not exceed the following values:

- 50 kPa at 20 °C (7 psia at 68 °F), or
- 69 kPa at 35 °C (10 psia at 95 °F)

The purpose of the pressure check is to limit the hydrogen fluoride, air, or other volatile components that might cause overpressure when heating the 30B-10 or 30B-20 cylinder (see [ASTM C996], section 4.2 for further details).

(3) The total hydrocarbon, chlorocarbon, and partially substituted halohydrocarbon content shall not exceed 0.01 mol % of the UF_6. The reason for the exclusion of these materials is to prevent a vigorous reaction with UF_6 upon heating (see [ASTM C996], section 4.3 for further details).

(4) For HALEU 10 and HALEU 20 meeting the requirements of section 1.3.1.4, the gamma activity from fission products and the alpha activity from neptunium and plutonium are expected to be below the detection limits (see [ASTM C996], section 4.4 for further details).

1.3.1.4 Chemical, Physical and Isotopic Requirements

Table 1-1 shows the most relevant properties of UF_6 extracted from [USEC 651].

Table 1-1 UF_6 properties

Property	Metric		Imperial	
	Value	Unit	Value	Unit
Density solid at 20 °C (68 °F)	5.09	g/cm³	317.8	lb/ft³
Density liquid at 64.1 °C (147.3 °F)	3.65	g/cm³	227.7	lb/ft³
Density liquid at 121 °C (250 °F)	3.26	g/cm³	203.3	lb/ft³
Sublimation point at 101 kPa (14.7 psia)	56.6	°C	133.8	°F
Triple point at 152 kPa (22 psia)	64.1	°C	147.3	°F
Heat of sublimation at 64.1 °C (147.3 °F)	135	kJ/kg	58.2	BTU/lb
Heat of fusion at 64.1 °C (147.3 °F)	56	kJ/kg	23.5	BTU/lb
Heat of vaporization at 64.1 °C (147.3 °F)	81	kJ/kg	35.1	BTU/lb
Critical pressure	4610	kPa	668.8	psia
Critical temperature	230.2	°C	446.4	°F
Specific heat, solid at 27 °C (81 °F)	477	J/(kg K)	0.114	BTU/(lb °F)
Specific heat, liquid at 72 °C (162 °F)	544	J/(kg K)	0.130	BTU/(lb °F)

The chemical, physical and isotopic requirements for HALEU 10 and HALEU 20 are based on [ASTM C996], section 5.

(1) Both HALEU 10 and HALEU 20 must meet the specification criteria. Except for the isotopes given in table 1-2, but including artificially created radioactive species, limits are set so as to have no special impact on the use of this material in existing facilities (see [ASTM C996], section 5.1 for further details).

(2) The following impurities shall not exceed these values:

Boron: 4 µg/gU

Silicon: 250 µg/gU

(3) HALEU 10 and HALEU 20 shall comply with the limits given in table 1-2. For purposes of determining conformance with these limits, the observed values shall be rounded to the nearest significant digit indicated as described in [ASTM C996], section 5.5.

Table 1-2 Isotopic limits of UF_6 grade HALEU 10 and HALEU 20

Nuclide	Maximal concentration in wt.-% in uranium		
	Enriched Commercial Grade[1)]	HALEU 10	HALEU 20
^{232}U	$1 \cdot 10^{-8}$	$3 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
^{234}U	$5.5 \cdot 10^{-2}$	$1.2 \cdot 10^{-1}$	$2.6 \cdot 10^{-1}$
^{235}U	5	10	20
^{236}U	$2.5 \cdot 10^{-2}$	$5.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-1}$
^{238}U	rest	rest	rest
^{99}Tc	$1.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$

1) According to [ASTM C996], provided for information purposes only.

(4) Heels of HALEU 10 and HALEU 20 shall also comply with the limits given in table 1-2. Additionally, the activity limits given in table 1-3 apply for heels of HALEU 10 and HALEU 20.

Table 1-3 Activity limits for heels of UF_6 grade HALEU 10 and HALEU 20

Nuclide	Maximal activity in Bq	
	HALEU 10	HALEU 20
^{99}Tc[1)]	$7.6 \cdot 10^{7}$	$6.0 \cdot 10^{7}$

1) Calculated based on the maximal A_2 value for ^{99}Tc after a 5-year refilling cycle and 10 years of storage of a filled cylinder (see table 1-8).

1.3.2 Permissible Contents for the DN30-X Package

1.3.2.1 Permissible Mass of UF_6

The permissible mass of UF_6 and the maximum heel quantities for each package design are listed in table 1-4.

Table 1-4 Permissible mass of UF_6 for each package design

Package design	Enrichment limit in wt.-% ^{235}U in U	Permissible mass of UF_6 in kg	Maximum heel quantities in kg
DN30-10	10	1460	11.3
DN30-20	20	1271	11.3

Note: Today's cleaning processes for standard 30B cylinders achieve heel quantities below 2 kg on a regular basis, which leaves sufficient margins for the increased free surfaces of the 30B-10 and 30B-20 cylinder in comparison to the standard 30B cylinder. Calculating the ratios of the internal free surfaces of the 30B-X and the 30B cylinder given in table 1-13, heel quantities below $2\ kg \cdot 20.01\ m^2 / 4.75\ m^2 = 8.5\ kg$ *and* $2\ kg \cdot 22.89\ m^2 / 4.75\ m^2 = 9.7\ kg$ *are expected for the 30B-10 and the 30B-20 cylinder, respectively. This allows for defining the same maximum heel quantities for the 30B-10 and 30B-20 cylinder as defined in [ANSI N14.1] for the standard 30B cylinder.*

1.3.2.2 Non-Fissile and Fissile Material

The uranium is classified as fissile material enriched from original uranium with natural isotopic composition. The maximal enrichment in ^{235}U for each package design is listed in table 1-4.

1.3.2.3 Mass of Fissile Material and Nuclides

The mass of the fissile material for each package design is calculated from the permissible mass of UF_6 that is given in table 1-4 and the corresponding maximum enrichment in ^{235}U according to the following equation:

$$m_{\mathrm{fiss,X}} = m_{\mathrm{UF_6,X}} \cdot r_{\mathrm{enrich,X}} \cdot \frac{M_{^{235}\mathrm{U}}}{\left(r_{\mathrm{enrich,X}} \cdot M_{^{235}\mathrm{U}} + \left(1 - r_{\mathrm{enrich,X}}\right) \cdot M_{^{238}\mathrm{U}} + 6 \cdot M_{\mathrm{F}}\right)} \quad (1)$$

In equation (1), $M_{^{235}\mathrm{U}}$, $M_{^{238}\mathrm{U}}$, and M_{F} are the atomic masses of ^{235}U, ^{238}U, and fluorine, respectively. The fissile masses calculated with equation (1) are listed in table 1-5.

Table 1-5 Mass of fissile material for each DN30-X package design

Package design	Enrichment limit in wt.-% ^{235}U in U	Mass of UF_6 in kg	Fissile material in kg
DN30-10	10	1460	98
DN30-20	20	1271	170

1.3.2.4 Special Form or Low Dispersible Radioactive Material

The radioactive content in the DN30-X package is neither in special form nor low dispersible.

1.3.2.5 Total Radioactivity

The radioactive contents have a total radioactivity of less than or equal to 1 A_2. For filled cylinders, this is due to the unlimited A_2 value of enriched uranium with natural isotopic composition U (enriched to 20 % or less) according to [10 CFR Part 71] Appendix A. Furthermore, the analysis in section 1.3.2.11 shows that the DN30-X also complies with this limit when the 30B-X cylinders are regularly refilled without intermediate washing before loading.

1.3.2.6 Nature and Characteristics of the Radiation Emitted

The radiation emitted by the content of the DN30-X package is mainly gamma radiation with a very small contribution from neutron radiation.

1.3.2.7 Limitation of the Heat Generation Rate of the Content

The heat generation rate for an enrichment limit of 5 wt.-% ^{235}U in uranium is based on a UF_6 net weight of $m_{\mathrm{UF_6,5}} = 2277\ \mathrm{kg}$. Using the isotopic composition given in table 1-2 and the permissible mass of UF_6 $m_{\mathrm{UF_6,X}}$ for the DN30-X as listed in table 1-4, the heat generation rates for maximum enrichments of "X" wt.-% ^{235}U in uranium are calculated according to equation (2):

$$H_{\mathrm{Gen,X}} = \frac{w_{\mathrm{\%,X}}}{w_{\mathrm{\%,5}}} \cdot \frac{m_{\mathrm{UF_6,X}}}{m_{\mathrm{UF_6,5}}} \cdot H_{\mathrm{Gen,5}} \qquad (2)$$

In equation (2), $w_{\mathrm{\%,X}}$ refers to the content limit of each uranium isotope for an enrichment of "X" wt.-% ^{235}U in uranium. The corresponding content limit for an enrichment of 5 wt.-% is used as the reference. Table 1-6 shows the resulting heat generation rate of UF_6 for maximum enrichments of 5, 10, and 20 wt.-% ^{235}U in uranium.

For each enrichment limit, the most significant contribution is from ^{234}U and the contribution to the thermal power from the traces of fission products and other actinides is negligible. For the thermal analysis in section 2.3, a heat generation rate of 3 W is assumed, safely covering the actual heat generation rate of the content of the DN30-X.

Table 1-6 Heat generation rate of UF_6

Nuclide	Heat generation rate in W		
	5 wt.-% ^{235}U in U[1)]	10 wt.-% ^{235}U in U[1)]	20 wt.-% ^{235}U in U[1)]
^{232}U	$1.0 \cdot 10^{-4}$	$1.92 \cdot 10^{-4}$	$3.91 \cdot 10^{-4}$
^{234}U	$1.52 \cdot 10^{-1}$	$2.13 \cdot 10^{-1}$	$4.01 \cdot 10^{-1}$
^{235}U	$4.56 \cdot 10^{-3}$	$5.85 \cdot 10^{-3}$	$1.02 \cdot 10^{-2}$
^{236}U	$6.73 \cdot 10^{-4}$	$8.63 \cdot 10^{-4}$	$1.50 \cdot 10^{-3}$
^{238}U	$1.24 \cdot 10^{-2}$	$7.52 \cdot 10^{-3}$	$5.81 \cdot 10^{-3}$
Total	$1.70 \cdot 10^{-1}$	$2.27 \cdot 10^{-1}$	$4.19 \cdot 10^{-1}$

1) The underlying isotopic limits are given in table 1-2.

1.3.2.8 Physical and Chemical State

During transport, the UF_6 contained in the DN30-X package is in solid form. UF_6 reacts with most metals (nickel, Monel, copper, and aluminum) to create a fluoride of the metal and other uranium compounds. It heavily reacts with hydrocarbons so that the absence of hydrocarbons in empty 30B-X cylinders is essential before those are filled with UF_6.

UF_6 does not react with nitrogen, oxygen, carbon dioxide or dry air. However, UF_6 reacts strongly with water and water vapor in the air producing HF-H_2O fog. If inhaled, this fog is very harmful.

$$\mathrm{UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF}$$

The UF_6 could contain some impurities that are due to chemical reactions. These impurities, like HF or $UO_2F_2 \cdot 5.5\ H_2O$, are also considered in the criticality safety analysis (see section 2.6).

1.3.2.9 Other Dangerous Properties

In accordance with 49 CFR Subpart F - Placarding, § 172.505 (b), UF_6 is classified as corrosive and poisonous. Consequently, the CORROSIVE and POISON placard must be used alongside the RADIOACTIVE placard (see figure 1-1).

Figure 1-1 CORROSIVE and POISON placard

1.3.2.10 Permissible Conditions for Repeated Use

30B-X cylinders complying with their specification in section 1.4.1.1 and within their valid recertification period as specified in section 1.8 may be refilled with content complying with the definitions in section 1.3.1 and 1.3.2. It is shown in section 1.3.2.11 that the DN30-X complies with the limit of 1 A_2 for a Type AF package when the 30B-X cylinders are regularly refilled without intermediate washing before loading.

1.3.2.11 Refilling of Cylinders Containing Heel Quantities

After emptying of 30B-X cylinders, heel quantities of UF_6 might remain in the cylinder. In table 1-4, the heel quantities of UF_6 are specified as maximal 11.3 kg for the 30B-10 and the 30B-20 cylinder. With reference to [ANSI N14.1], a heel is defined as:

A heel is a residual amount of UF_6 and/or nonvolatile reaction products of uranium

According to [10 CFR Part 71] Appendix A or [SSR-6 2018] Table 2, the A_2 values of natural uranium U(nat), enriched uranium with natural isotopic composition U(enriched to 20 % or less), and depleted uranium U(dep) are unlimited. Hence, all amounts of contents ranging from 0 kg up to the fill limits of the 30B-10 and 30B-20 cylinder specified in table 1-4 that comply with the content specifications in section 1.3 can be transported in the DN30-X package. However, subsequent refilling of 30B-X cylinders without washing before loading may lead to a build-up of decay products that contribute to the radioactivity relevant for the A_2 value. This is investigated in the following.

Table 1-7 illustrates the calculation procedure, which is based on the covering inventories listed in table 1-4 assumed for the contents of the 30B-10 and 30B-20 cylinder.First, a new (or emptied and washed) 30B-X cylinder is filled with UF_6 content. Then, several cycles follow in which the filled cylinder is transported to the destination, emptied, and transported back to the enrichment facility containing the maximum heel quantities of UF_6 (see table 1-4).

During these cycles, decay products build up that contribute to the radioactivity relevant for the A_2 value. For each cycle, it is conservatively assumed that all decay products resulting from the previous filling and emptying cycles remain in the heels. Furthermore, the mass of heels already present in the cylinder is conservatively not taken into account for subsequent fillings.

Hence, with each filling and emptying cycle, the content mass in the 30B-X cylinder is increased by the maximal permissible amount of heel quantities of 11.3 kg. Using the example of the 30B-10 cylinder, this means that after 3 cycles the calculation model actually represents a content mass of $1460\ \mathrm{kg} + 3 \cdot 11.3\ \mathrm{kg} = 1493.9\ \mathrm{kg}$ (using the definition of cycles in table 1-7). The contribution of the decay products in each cycle is therefore based on the contribution of the decay products from all previous cycles as well as a new filling of the cylinder, assuming the maximal permissible content mass specified in table 1-4.

Table 1-7 Calculation scenario of the radioactivity in 30B-X cylinders for contents complying with HALEU 10 and HALEU 20 for a continuous use without washing

Cycle	Time	Cylinder condition	Content mass in kg	
			30B-10	30B-20
Initial	0	New or empty and washed	0	0
1	t_1	Filled and transported to destination	1460	1271
1	t_2	Emptied and returned to enrichment facility	11.3	11.3
2	t_3	Filled and transported to destination	1460	1271
2	t_4	Emptied and returned to enrichment facility	11.3	11.3
3	t_5	Filled and transported to destination	1460	1271
3	t_6	Emptied and returned to enrichment facility	11.3	11.3
...	...	…	…	…
$n/2$	t_{n-1}	Filled and transported to destination	1460	1271
$(n/2)$	(t_n)	(Emptied and returned to enrichment facility)	(11.3)	(11.3)
Final	t_{n+1}	After 5 years refilling is not permissible.[1)]	11.3 or 1460	11.3 or 1271

1) Before next use, the cylinder has to be washed and recertified. Transportation of filled or heeled cylinders to the destination is still possible.

After 5 years, the 30B-X cylinder has to be recertified (see section 1.8), which requires the cylinder to be emptied and washed. However, it is still possible to store a filled or heeled cylinder for a certain time. A final transport to the destination for emptying and/or washing, and recertification is permitted. Since the A_2 value is mainly driven by the accumulating decay products of ^{232}U, the maximum value is reached within 10 years of storage time (at this point, secular equilibrium of ^{232}U and its decay products is reached). A penalizing 3-month filled/heeled cycle is investigated.

Table 1-8 lists the radioactivity of the contributing nuclides for the 3-month filled/heeled cycle in a 30B-10 and 30B-20 cylinder, including a 10-year storage time in filled condition after the 5-year cycle time. A graphical representation of table 1-8 is shown in figure 1-2. This figure also shows the radioactivity of heeled cylinders being stored for 10 years after the 5-year cycle time, and, for comparison purposes, the results for a standard 30B cylinder loaded with Enriched Commercial Grade UF_6 as specified in [ASTM C996].

Table 1-8 Radioactivity in 30B-10 and 30B-20 cylinders for a 3-month filled/heeled cycle followed by a 10-year storage of filled cylinders

Cycle	Cylinder condition	Radioactivity in A_2					
		^{228}Th	^{230}Th	^{231}Pa	^{234}Th	^{99}Tc	Total
		30B-10 cylinder					
1	Filled	$2.09 \cdot 10^{-2}$	$6.27 \cdot 10^{-4}$	$1.08 \cdot 10^{-4}$	$3.80 \cdot 10^{-2}$	$6.94 \cdot 10^{-6}$	0.0597
1	Heeled	$1.93 \cdot 10^{-2}$	$6.32 \cdot 10^{-4}$	$1.09 \cdot 10^{-4}$	$3.05 \cdot 10^{-3}$	$7.00 \cdot 10^{-6}$	0.0231
2	Filled	$3.85 \cdot 10^{-2}$	$1.26 \cdot 10^{-3}$	$2.17 \cdot 10^{-4}$	$3.82 \cdot 10^{-2}$	$1.39 \cdot 10^{-5}$	0.0782
2	Heeled	$3.54 \cdot 10^{-2}$	$1.26 \cdot 10^{-3}$	$2.18 \cdot 10^{-4}$	$3.06 \cdot 10^{-3}$	$1.40 \cdot 10^{-5}$	0.0399
…	…	…	…	…	…	…	…
10	Filled	$1.06 \cdot 10^{-1}$	$6.31 \cdot 10^{-3}$	$1.09 \cdot 10^{-3}$	$3.82 \cdot 10^{-2}$	$6.99 \cdot 10^{-5}$	0.152
10	Heeled	$9.74 \cdot 10^{-2}$	$6.32 \cdot 10^{-3}$	$1.09 \cdot 10^{-3}$	$3.06 \cdot 10^{-3}$	$7.00 \cdot 10^{-5}$	0.108
Final 1)	Filled	$2.20 \cdot 10^{-1}$	$3.39 \cdot 10^{-2}$	$5.75 \cdot 10^{-3}$	$4.09 \cdot 10^{-2}$	$7.69 \cdot 10^{-5}$	0.301
		30B-20 cylinder					
1	Filled	$4.25 \cdot 10^{-2}$	$1.18 \cdot 10^{-3}$	$1.88 \cdot 10^{-4}$	$3.31 \cdot 10^{-2}$	$6.04 \cdot 10^{-6}$	0.077
1	Heeled	$3.92 \cdot 10^{-2}$	$1.19 \cdot 10^{-3}$	$1.90 \cdot 10^{-4}$	$2.69 \cdot 10^{-3}$	$6.10 \cdot 10^{-6}$	0.0433
2	Filled	$7.83 \cdot 10^{-2}$	$2.37 \cdot 10^{-3}$	$3.78 \cdot 10^{-4}$	$3.33 \cdot 10^{-2}$	$1.21 \cdot 10^{-5}$	0.1144
2	Heeled	$7.19 \cdot 10^{-2}$	$2.39 \cdot 10^{-3}$	$3.79 \cdot 10^{-4}$	$2.70 \cdot 10^{-3}$	$1.22 \cdot 10^{-5}$	0.0774
…	…	…	…	…	…	…	…
10	Filled	$2.16 \cdot 10^{-1}$	$1.19 \cdot 10^{-2}$	$1.89 \cdot 10^{-3}$	$3.33 \cdot 10^{-2}$	$6.09 \cdot 10^{-5}$	0.264
10	Heeled	$1.98 \cdot 10^{-1}$	$1.19 \cdot 10^{-2}$	$1.90 \cdot 10^{-3}$	$2.70 \cdot 10^{-3}$	$6.10 \cdot 10^{-5}$	0.215
Final 1)	Filled	$4.47 \cdot 10^{-1}$	$6.39 \cdot 10^{-2}$	$1.00 \cdot 10^{-2}$	$3.56 \cdot 10^{-2}$	$6.70 \cdot 10^{-5}$	0.557

1) After 10 years of storage

The results show that the DN30-X complies by a large margin with the limit of 1 A_2 for a Type AF package, even for the assumption that the 30B-X cylinders are regularly refilled with the contents specified in table 1-2 and without intermediate washing before loading. After a 10-year storage of filled cylinders, a maximal radioactivity of 0.3 A_2 and 0.56 A_2 is present in the 30B-10 and 30B-20 cylinder, respectively.

The calculation procedure above has been used for an additional investigation to determine to what degree the maximal radioactivity is affected by larger amounts of heels remaining in a cylinder. Assuming higher amounts of heels only affects the development of the radioactivity during the filling/emptying cycles and the storage of a filled cylinder. However, the maximal value that is reached at the end is not affected. This is due to the fact that the used calculation procedure assumes that all decay products resulting from all previous cycles completely remain in the heels. The amount of resulting decay products is thereby determined through the maximum permissible content mass, but not by the permissible amount of heel quantities, which is why the actual mass of the heels is irrelevant in the used calculation model.

As an example, the corresponding bounding cases of a filled 30B-10 and 30B-20 cylinder that is continuously stored for 16 years are shown in figure 1-2 as well. The small differences in the maximal radioactivity at the end of the storage time in comparison to the calculations for the filling/emptying cycles are due to the fact that the mass of heels remaining in the cylinders is not accounted for in subsequent filling cycles. As already explained above, the cylinders therefore

effectively contain more and more UF_6 after each filling cycle, which leads to a slightly higher maximal radioactivity at the end of the storage time in comparison to the calculations assuming a continuous storage.

The performed investigations in this section prove:

- The maximal radioactivity that is obtained for the most penalizing 3-month filled/heeled cycle and a 10-year storage of a filled 30B-10 or 30B-20 cylinder is affected by the isotopic limits specified in table 1-2 as well as the maximal permissible mass of UF_6 specified in table 1-4.
- Increasing the amount of heels remaining in a 30B-10 or 30B-20 cylinder does not further increase the resulting maximal radioactivity.

Accordingly, compliance with the limit of 1 A_2 for a Type AF package is proven without taking any credit for the maximal mass of heels contents specified in table 1-4.

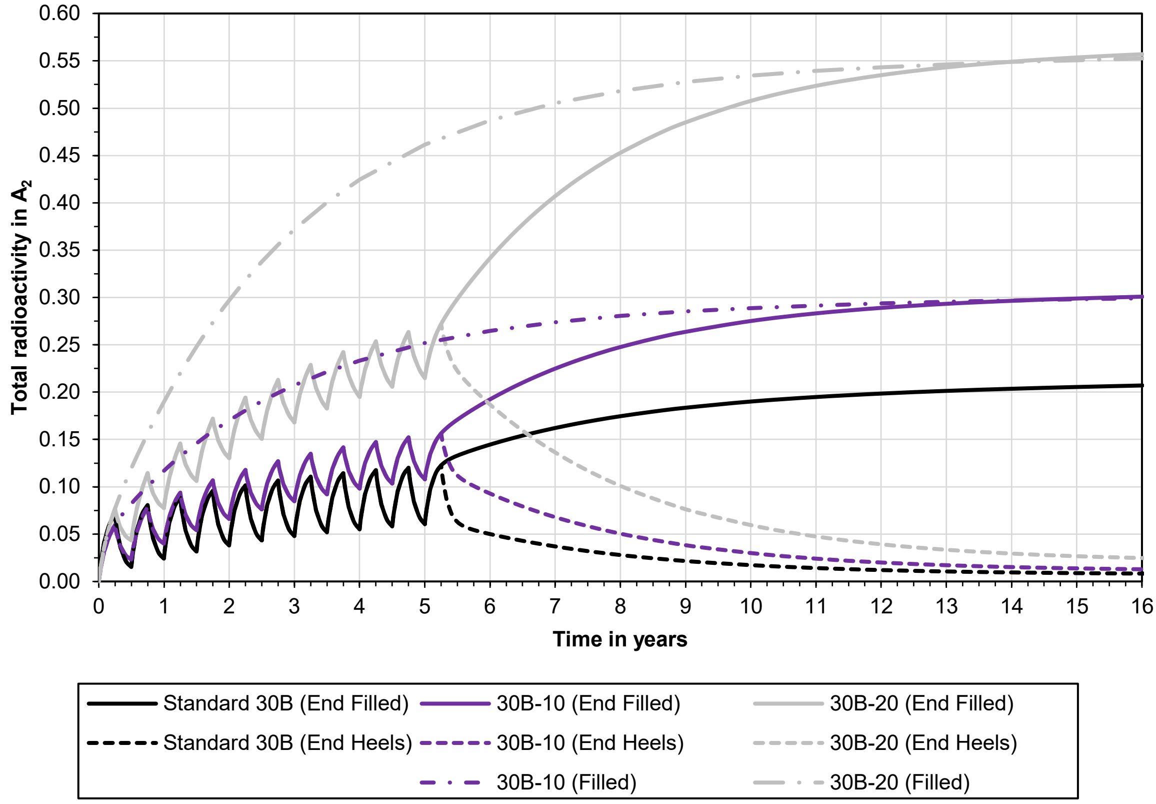

Figure 1-2 Radioactivity in 30B-10 and 30B-20 cylinders in comparison to 30B cylinders for a 3-month filled/heeled cycle followed by a 10-year storage of filled/heeled cylinders

1.4 Specification of the Packaging

1.4.1 List of all Packaging Components and Complete Design Drawings

The DN30-X is a partially new package design, consisting of the new 30B-X cylinder and the DN30 PSP that is already licensed for transport of standard 30B cylinders. The DN30 PSP provides both the mechanical and thermal protection for the 30B-X cylinder including its radioactive content. The DN30-X packaging is designed to meet routine conditions of transport (RCT), normal conditions of transport (NCT), and hypothetical accident conditions (HAC) as required by [10 CFR Part 71] and [49 CFR Part 173], or [SSR-6 2018].

The main packaging components are:

- The 30B-X cylinder consisting of:
  - The cylinder shell with an ellipsoidal head on each end
  - The valve and plug half coupling
  - The cylinder valve and plug
  - Two skirts being attached to each ellipsoidal head, where the skirt on the valve side has two horizontally aligned holes that are used to prevent the rotation of the cylinder inside the DN30 PSP
  - Two criticality control system (CCS) restraints, each consisting of a backing bar and a rotation preventing device, that maintain the position of the interior CCS within the 30B-X cylinder cavity
  - The interior CCS consisting of criticality control rods (CCRs) containing neutron poison material in the form of boron carbide (B_4C), and three lattice holders that keep each CCR in place. The separation of the lattice holders is maintained by 14 longitudinal stiffeners
- The DN30 PSP consisting of:
  - The bottom half with two feet welded to the outer shell for tie-down during transport incorporating four load attachment points to be used for handling the DN30-X package and two forklift pockets for handling the empty and loaded packaging
  - The top half with two load attachment points for handling the top half
  - The valve protecting device that is attached to the bottom half by means of hinges
  - The plug protecting device that is welded to the interior shell of the bottom half
  - The rotation preventing devices consisting of two pins welded to the flange of the bottom half
  - The closure system consisting of six steel blocks welded to the top half and six steel blocks welded to the bottom half forming mortise-and-tenon style joints connected through steel pins
  - Steel blocks welded to the top and bottom half for sealing the DN30-X packaging

Since the DN30-X is only a partially new design, a new set of drawings is only required for the designs of the 30B-10 and the 30B-20 cylinder (see section 1.4.1.1). The specification and drawings of the DN30 PSP are provided in section 1.4.1.2 with the following revised and new drawings:

- Revised to include the 30B-X:
  - Datasheet 0023-ZDB-1000-000 “DN30 PSP”
  - Drawing 0023-ZFZ-1000-000 “DN30 PSP”
- New to include the 30B-X:
  - Drawing 0023-ZFZ-1000-003 “Additional package nameplate”

1.4.1.1 30B-X Cylinder

The DN30 PSP may be loaded with the 30B-10 or the 30B-20 cylinder that both are derived from a standard 30B cylinder as specified in [ANSI N14.1] adding an interior criticality control system (CCS). The CCS consists of criticality control rods (CCRs) containing neutron poison material in the form of boron carbide (B_4C), and lattice holders that keep each CCR in place.

The 30B-10 and the 30B-20 cylinders are defined in the following main drawings:

- 30B-10 Cylinder:
  - Parts list 0045-STL-1000-000 “30B-10 Cylinder”
  - Drawing 0045-ZFZ-1000-000 “30B-10 Cylinder”
  - Drawing 0045-ZFZ-1100-000 “30B Cylinder modified”
  - Drawing 0045-ZFZ-1200-000 “CCS”
- 0045-ZFZ-2000-000 “30B-20 Cylinder”
  - Parts list 0045-STL-2000-000 “30B-20 Cylinder”
  - Drawing 0045-ZFZ-2000-000 “30B-20 Cylinder”
  - Drawing 0045-ZFZ-1100-000 “30B Cylinder modified”
  - Drawing 0045-ZFZ-2200-000 “CCS”

Appendix 1.4.1A (Drawings 30B-X Cylinder) contains proprietary drawings and parts lists of the individual parts of the 30B-10 and the 30B-20 cylinder, respectively. The following material specifications for the 30B-X cylinder pressure envelope in section 1.4.1.1.1 as well as the valve and plug in section 1.4.1.1.2 are identical to the material specifications for a standard 30B cylinder and, thus, are adopted from [ANSI N14.1] as they stand. However, additional material specifications are required in case of the CCS, which are given in section 1.4.1.1.3.

1.4.1.1.1 Pressure Envelope and Skirts

The materials of the 30B-X cylinder are specified in table 1-9. They are identical to the material specifications of a standard 30B cylinder and, thus, are adopted from [ANSI N14.1] as they stand.

Table 1-9 Material specification of the 30B-X cylinder

Item	Material specification
Cylinder	Cylinder shell, heads, backing bars, and skirts shall conform to [ASTM A516], steel, grade 65 or 70 and shall be normalized. a) All steel shall be Charpy V-notch impact tested and shall meet the Charpy V-notch impact requirements as stated in ASTM A20. b) Steel may be plate or coil form.
Couplings	Modified half-coupling per [ANSI N14.1], Figure 14, Forged ASTM A105. *Note: ASTM A106 Grade C may be used in lieu of ASTM A105.*
Nameplate	Sheet, ASTM A240, UNS S30400 or S30403.
Valve protector (optional)	Plate, weldable carbon steel with a minimum tensile strength of 45000 Psi and a maximum carbon content of 0.26 %, such as ASTM A36.
Seal loop(s)	Rod, ASTM A36.

1.4.1.1.2 Valve and Plug

The materials of the valve and the plug are specified in table 1-10. They are identical to the material specifications of a standard 30B cylinder and, thus, are adopted from [ANSI N14.1] as they stand.

Table 1-10 Material specification of valve and plug of the 30B-X cylinder

Item	Material specification
Body	Forging, aluminum bronze (UNS C63600), conforming to [ANSI N14.1], section 7.1.2 and 7.1.4.
Stem	Bar, cold drawn, nickel-copper alloy (UNS N04400) ASTM B164 and stress-relieved per [ANSI N14.1], section 7.1.5-2. Certification to include results of testing in accordance with ASTM E2375 over 100 % of stock material. Testing to be per Class AA with straight beam.
Packing nut	*Note: Packing nuts require stress-relieving after final machining. Surface hardness measurements of packing nuts after final stress-relieving may be made on the top of the nut.* a) Bar, aluminum bronze (UNS C61300) ASTM B150, stress-relieved per [ANSI N14.1], section 7.1.5-3 or, b) Bar, nickel-copper alloy (UNS N04400) ASTM B164, stress-relieved per [ANSI N14.1], section 7.1.5-2.
Port cap	a) Bar, aluminum bronze (UNS C61300) ASTM B150, stress-relieved per [ANSI N14.1], section 7.1.5-3 or, b) Bar, nickel-copper alloy (UNS N04400) ASTM B164, stress-relieved per [ANSI N14.1], section 7.1.5-2, or c) Bar, aluminum bronze (UNS C63600), stress-relieved per [ANSI N14.1], section 7.1.5-1.
Packing follower, packing ring	a) Bar, aluminum bronze (UNS C61300) ASTM B150, stress-relieved per [ANSI N14.1], section 7.1.5-3 or, b) Bar, aluminum bronze (UNS C63600), stress-relieved per [ANSI N14.1], section 7.1.5-1.
Packing, cap gasket	PTFE
Fluorinated lubricant	Compatible for UF_6 service.

Item	Material specification
Solder	Tin-lead alloy, with a minimum tin content of 45 % such as alloy SN50 ASTM B32.
Solder flux	Phosphoric acid or approved equivalent.
Hex head plug	Bar, upset forged, extruded, or extruded and drawn, aluminum bronze (UNS C61300) ASTM B150.
Socket head plug	*Note: These plugs may be used in lieu of hex head plugs.* a) Bar, upset forged, extruded, or extruded and drawn, aluminum bronze (UNS C61300) ASTM B150 or b) Bar, upset forged, extruded, or extruded and drawn, aluminum bronze D (UNS C61400, with a tin content restricted to 0.2-0.5 %) ASTM B150 or c) Plate, chemical composition as specified in a) or b) and conforming to ASTM B171.

1.4.1.1.3 Criticality Control System

The materials of the interior CCS of the 30B-X cylinder are specified in table 1-11. Except for the neutron poison material in the form of boron carbide (B_4C), the same materials as for the pressure-envelope of a standard 30B cylinder are used for the CCS. Consequently, the same standards according to [ANSI N14.1] are applied for these parts.

Table 1-11 Material specification of interior CCS of the 30B-X cylinder

Item	Applicable standards
Lattice holders, longitudinal stiffeners, and CCR lids	a) The CCR lids, longitudinal stiffeners, and lattice holders shall conform to [ASTM A516], steel, grade 65 or 70 and shall be normalized. b) All steel shall be Charpy V-notch impact tested per ASTM A20. The test temperature and acceptance criteria shall be as specified in ASTM A20, Table A1.15. Alternatively, the maximum test temperature is specified as -40 °C and the minimum average energy absorption for 3 full-size specimen shall be 27 J. None of the specimen shall have an energy absorption below 22 J. c) Steel may be plate or coil form. *Note: Steel confirming to [DIN EN 10028-3] grade P355NL1 or P355NL2 may be used in lieu of [ASTM A516] grade 65 or 70. In this case, the minimum impact energy requirements of [DIN EN 10028-3] apply.*
CCR pipes	a) The CCR pipes shall conform to [ASTM A333] grade 9 b) All steel shall be Charpy V-notch impact tested. The impact test temperature and impact requirements shall be as specified in [ASTM A333]. Alternatively, the impact test temperature is specified as -40 °C and the minimum average notched bar impact value of each set of 3 full-size specimen shall be 27 J. None of the specimen shall have a minimum average notched bar impact value below 22 J. *Note: Seamless steel pipes confirming to [DIN EN 10216-3] grade P355NL1 or P355NL2 may be used in lieu of [ASTM A333] grade 9. In this case, the minimum impact energy requirements of [DIN EN 10216-3] apply.*
Neutron poison material	Boron carbide (B_4C) as specified in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder)

1.4.1.2 DN30 PSP

The design of the DN30 PSP is defined in the following main drawings:

- 0023-ZFZ-1000-000 "DN30 PSP"
- 0023-ZFZ-1000-100 "Closure device"
- 0023-ZFZ-1100-000 "Bottom half"
- 0023-ZFZ-1200-000 "Top half"
- 0023-ZFZ-1140-000 "Rotation Preventing Device"
- 0023-ZFZ-1140-000 "Valve Protecting Device"
- 0023-STL-1000-000 "Part list DN30 PSP"

Appendix 1.4.1B (Drawings DN30 PSP) contains proprietary drawings and parts lists of the individual parts of the DN30 PSP. The materials of these parts are specified in table 1-12.

Table 1-12 Material specification of the DN30 PSP

Item	Applicable EU standards	Applicable US standards
Inner / outer steel shells	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Inner structure	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Feet	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Lifting lugs (feet)	[DIN EN 10088-2], Grade 1.4462	ASME SA-240, Type 2205 (UNS S31803)
Steel shells of valve protecting device	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Rotation preventing device	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Plug protecting device	[DIN EN 10088-2], Grade 1.4301, 1.4307, or 1.4541	ASME SA-240, Type 304 (UNS S30400) or Type 321 (UNS S32100)
Closure device	[DIN EN 10088-3] / [DIN EN 10088-2], Grade 1.4541 [DIN EN 10088-3] / [DIN EN 10088-2], Grade 1.4571	ASME SA-479 / ASME SA-240, Type 321 (UNS S32100) ASME SA-479 / ASME SA-240, Type 316Ti (UNS S31635)
Body of pin	[DIN EN 10088-3], Grade 1.4542	ASME SA-564, Type 630 (Alloy 17-4 PH, UNS S17400)
Head of pin	[DIN EN 10088-3], Grade 1.4541 or 1.4571	ASME SA-479, Type 321 (UNS S32100) or Type 316Ti (UNS S31635)
Securing bolt	Nitronic 50	ASME SA-193, Type XM-19 (UNS S20910)
Washers	NL16-254SMO ([DIN EN 10088-2], Grade 1.4547)	ASME SA-240M, Alloy 254 (UNS S31254)
Gaskets	EPDM	

Item	Applicable EU standards	Applicable US standards
Foam	Polyisocyanurate (PIR) foam conforming to the specifications RTS 120 and RTS 320 (see Appendix 1.4.2 (Material Properties))	
Intumescent material	Intumescent material, e.g., conforming to the specifications Promaseal-PL® (see Appendix 1.4.2 (Material Properties))	
Thermal insulation	Microporous material, e.g., conforming to the specifications MICROTHERM® OVERSTITCHED 1000R HY or WDS® Multiflex® ST 2D50 HY (see Appendix 1.4.2 (Material Properties))	
Thermal plugs	Polyamide	
Pads	Silicone	

1.4.2 Description of the DN30-X Packaging

The DN30 packaging consists of:

- The 30B-X cylinder
- The DN30 PSP

1.4.2.1 30B-X Cylinder

The 30B-X cylinder is identical to a standard 30B cylinder as specified in [ANSI N14.1], except that an interior criticality control system (CCS) is built into the 30B-X cylinder (see figure 1-3). In the following sections 1.4.2.1.1 to 1.4.2.1.3, a detailed description of 30B-X cylinder is provided. Furthermore, additional provisions to [ANSI N14.1] and their implications on the safety features of the 30B-X cylinder are discussed in section 1.4.2.1.4.

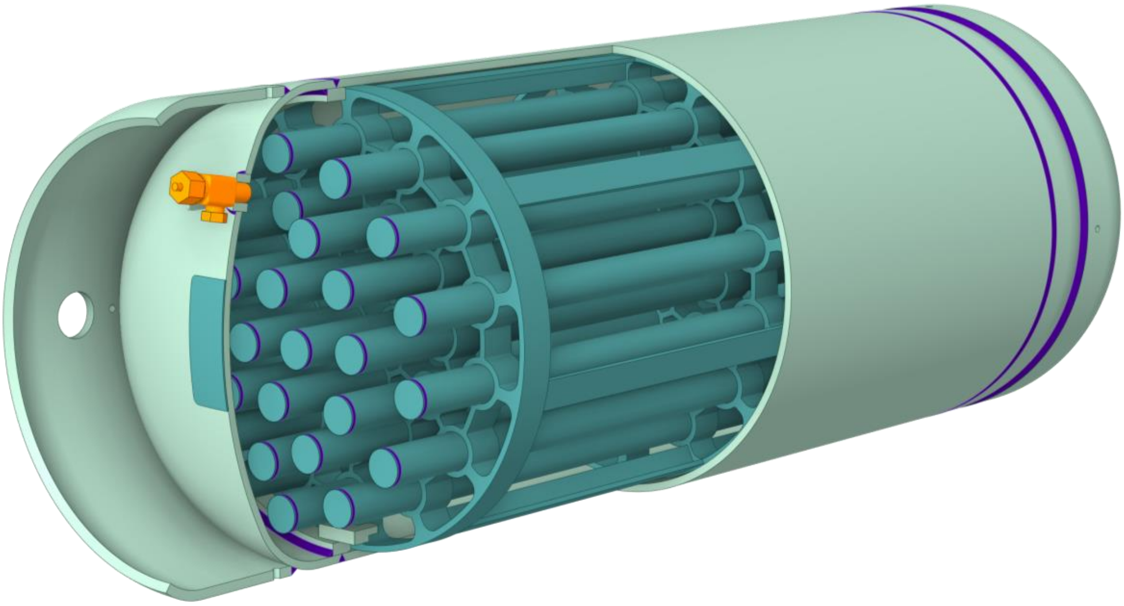

Figure 1-3 30B-X cylinder – Outside view

1.4.2.1.1 Criticality Control System

The CCS consists of criticality control rods (CCRs) filled with neutron poison material and lattice holders that retain the CCR positionings. Longitudinal stiffeners between the lattice holders help to keep the lattice holders separated from each other. The interior CCS of the 30B-X cylinder is shown in figure 1-4.

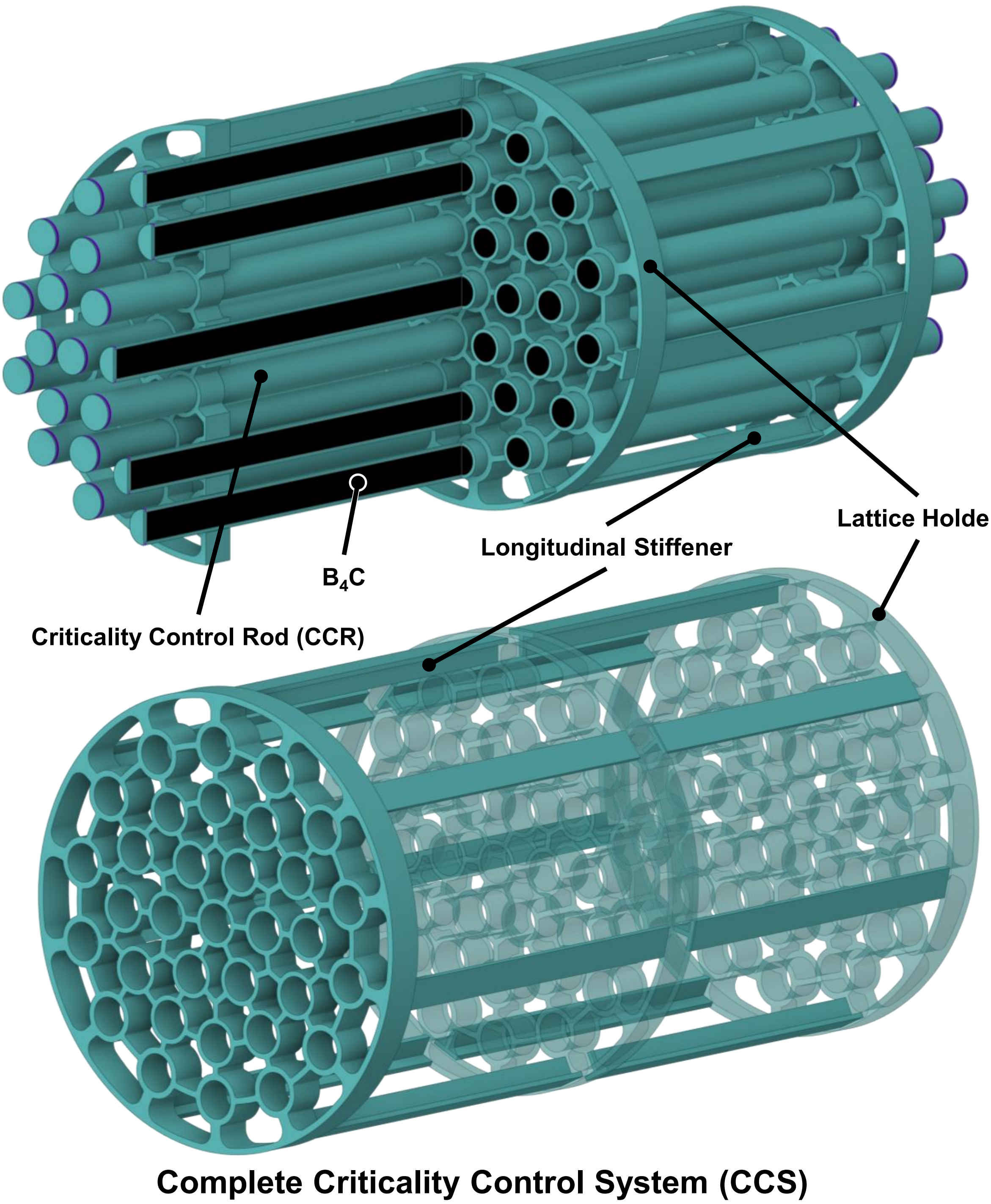

Figure 1-4 30B-X cylinder – Interior criticality control system

The CCRs are seamless steel pipes that are filled with boron carbide (B_4C) as a neutron absorbing material for criticality control and that are sealed by a welded lid on each end. For the CCRs,

standardized seamless pipes are used having an outer diameter of 60.3 mm and a wall thickness of 5.54 mm. Their proper placement, which is crucial for criticality control, is ensured by the three lattice holders. According to the specification in table 1-11, only materials that are already specified in [ANSI N14.1] are used for the steel pipes and the lattice holders. Hence, compatibility is ensured between the interior CCS, the cylinder material and the UF_6 contents.

The cross section through the 30B-X cylinder in figure 1-5 displays the CCS within the cylinder. The length of the CCRs is fitted to the ellipsoidal heads of the 30B-X cylinder. Of special note are the CCRs that end directly in front of the valve and plug – these are shortened by 60 mm to avoid interference with filling and emptying of the cylinder. Shortening these CCRs also helps to ensure that there will be no impact of the CCS on the valve or plug, even under HAC.

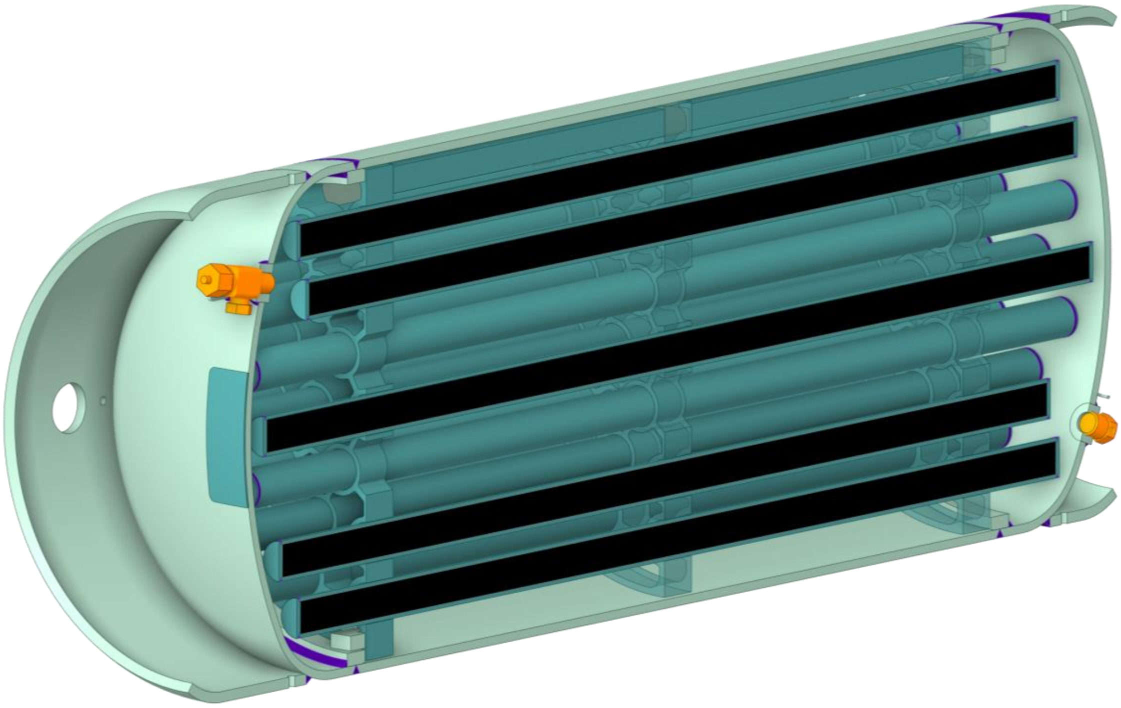

Figure 1-5 30B-X cylinder – Cross sectional view

1.4.2.1.2 Pressure Envelope

The pressure envelope of the 30B-X cylinder is identical to the standard 30B cylinder, except for CCS restraints welded to the straight portion of each cylinder head. These inhibit the longitudinal movement and axial rotation of the interior CCS within the 30B-X cylinder, but no fixed connection exists between the CCS and the pressure envelope of the 30B-X cylinder. The CCS restraints also serve as backing bars for the circumferential head welds of the 30B-X cylinder.

The specification of the outer dimensions, the materials as well as the valve and plug of the 30B-X cylinder are identical to the standard 30B cylinder. However, deviating from [ANSI N14.1], a minimal wall thickness of 11 mm is specified for the 30B-X cylinder shell and heads.

1.4.2.1.3 Main Characteristics of the 30B-X Cylinder

The main characteristics of the 30B-10 and the 30B-20 cylinder in comparison to the standard 30B cylinder are listed in table 1-13. Only the enrichment limit, nominal tare weight, maximum net weight, minimum volume and minimum ullage differ from a standard 30B cylinder.

Table 1-13 Main data of the 30B-X cylinder

Item	Value			Unit
	Standard 30B	30B-10	30B-20	
Enrichment limit ^{235}U in U	5	10	20	wt.-%
Nominal diameter	762	762	762	mm
Nominal length	2070	2070	2070	mm
Nominal wall thickness	13	13	13	mm
Minimum wall thickness	7.94	11	11	mm
Nominal tare weight	635	1452	1641	kg
Maximum net weight	2277	1460	1271	kg
Maximum gross weight	2912	2912	2912	kg
Minimum volume	0.736	0.544	0.493	m^3
Nominal filling ratio at 20 °C	60.8	52.8	50.7	%
Minimum ullage at 121 °C	5	17.6	20.8	%
Nominal internal free surface	4.75	20.01	22.89	m^2
Effective cross section of cavity				
At lattice holders (minimal)	0.426	0.205	0.171	m^2
At CCRs	0.426	0.328	0.298	m^2

In the determination of the maximum net weight (permissible mass of UF_6) listed in table 1-13, two limiting factors are considered. On the one hand, the nominal gross weight of the 30B-10 and 30B-20 cylinder shall be identical to the standard 30B cylinder and, on the other hand, the minimum ullage of 5 % at 121 °C required by [ANSI N14.1] must be complied with. Beside the nominal gross weight, the outer dimensions, the wall thickness and, thus, also the volume of the inner cavity excluding the interior CCS are identical for all cylinder designs. Hence, comparing the density of liquid UF_6 at 121 °C and the average density of the interior CCS of the 30B-X cylinder suffices to determine the limiting case.

The lattice holders are entirely made of steel and, for the CCRs consisting of steel rods filled with boron carbide, an average density of about 4.2 g/cm³ is calculated. Consequently, the average density of the CCS is always higher than the density of liquid UF_6 at 121 °C of 3.26 g/cm³ (see table 1-1). The limiting case in the determination of the maximum net weight is therefore the gross weight, leading to a minimum ullage for the 30B-10 and the 30B-20 cylinder at 121 °C that is significantly larger than the minimally required 5 % per [ANSI N14.1], respectively.

1.4.2.1.4 Additional provisions to ANSI N14.1

In this section, it is discussed how the safety aspects of the 30B-X cylinder, namely its containment function (see section 1.4.2.3.1), continue to be maintained with the additional provisions to [ANSI N14.1] that are required for the 30B-X cylinder. According to the description of the 30B-X cylinder in the previous sections, these additional provisions and their impact on the safety aspects of the 30B-X cylinder are:

1. Addition of the interior CCS
   - Under normal operating conditions for the 30B-X cylinder (see section 2.1.1.1.1), the presence of the CCS has no impact on the containment function of the 30B-X cylinder. Due to the absence of a fixed connection between the CCS and the 30B-X cylinder pressure envelope, the deformation behavior under internal and external pressure loads is identical to the behavior of a standard 30B cylinder.
   - The interior CCS increases the nominal tare weight of the 30B-10 and 30B-20 cylinder compared to a standard 30B cylinder. Since the maximum gross weight of the 30B-X and standard 30B cylinder are required to be identical (see table 1-13), handling of filled cylinders is not affected. Accordingly, the increased tare weight only needs to be considered with regard to the handling of empty 30B-X cylinders.
   - Another consequence of requiring identical maximum gross weights for the 30B-X and standard 30B cylinder is an increase in the minimum ullages at 121 °C for the 30B-10 and 30B-20 cylinder (see table 1-13). Hence, the risk of a fatal pressure build-up caused by melted UF_6 contents is significantly lower for the 30B-X cylinder than for the standard 30B cylinder (see section 2.3.2).
2. Incorporation of stronger backing bars in the design of the 30B-X cylinder that also serve as a CCS restraint
   - The incorporation of stronger backing bars has a positive impact on the resulting stresses at the junction of the cylinder shell and heads under normal operating conditions for the 30B-X cylinder.

This shows that all safety aspects of the standard 30B cylinder are at least maintained or even improved with the above-mentioned additional provisions to [ANSI N14.1] that apply to the 30B-X cylinder.

1.4.2.2 DN30 PSP

The DN30 PSP consists of:

- The bottom half with integrated feet, load attachment points for handling the loaded package, valve protecting device, plug protecting device, rotation preventing devices and bottom half of the closure devices
- The top half with integrated load attachment points for handling the top half and the top half of the closure devices

The main data of the DN30 PSP are listed in table 1-14.

Table 1-14 Main data of the DN30 PSP

Item	Value	Unit
Nominal diameter	1216	mm
Nominal height	1329	mm
Nominal length	2437	mm
Nominal tare weight	1100	kg
Nominal gross weight	4012	kg
Maximum gross weight	4100	kg

1.4.2.2.1 Bottom Half of the DN30 PSP

The body of the bottom half is made of an inner and outer shell of stainless steel, both in the form of a tub that are connected at the top by a flange. The cavity between the inner and outer shell and flange is filled with the PIR foams RTS 120 and RTS 320. Between the inner shell and the RTS 120 foam, there is also a layer of 10 mm microporous material as thermal insulation. At the side the thickness of the inner shell is 2 mm and of the outer shell 3 mm. At the ends the thickness of the inner shell is 10 mm and of the outer shell 4 mm. All surfaces of the inner shell of the bottom half are covered with a layer of 2.6 mm intumescent material.

At the bottom side there are two feet of stainless-steel welded to the outer shell at each end of the DN30 PSP. The feet have a base plate, made of two 10 mm thick stainless-steel plates welded on top of each other, which contains at each side two holes for tie-down to an adapted flatrack (the arrangement and size of these holes is compatible with existing PSP designs).

At the side of each of the feet there is an eyelet welded to the side plate of the foot. These eyelets are designed to be used for lifting the loaded DN30-X package.

At the top side of the bottom half of the DN30 PSP, the lower halves of the mortise-and-tenon closure system are welded to the outer shell, three per side. Adjacent to one of these parts of the closure system, the sealing block is welded to the outer shell.

At the inside of the bottom half, the valve protecting device is attached to the flange by hinges at one end. The valve protecting device consists of a stainless-steel casing filled with PIR foam RTS 320 and a protecting housing that has its interior surfaces covered with intumescent material.

On the opposite end, there is the plug protecting device in the form of a pot that is welded to the inner shell and that has its interior surfaces covered with intumescent material.

At the inner sides of the flange there are two rotation preventing devices welded to the flange. These devices consist of a pin, which is withdrawn into the flange during loading and inserted during transport into the two holes in the skirt of the 30B-X cylinder.

1.4.2.2.2 Top Half of the DN30 PSP

The body of the top half is similar to the bottom half. It is made of an inner and outer shell of stainless-steel, both in the form of a tub that are connected at the bottom by a flange. The cavity between the inner and outer shell and flange is filled with the PIR foams RTS 120 and RTS 320. Between the inner shell and the RTS 120 foam, there is also a layer of 10 mm microporous material as thermal insulation. At the side, the thickness of the inner shell is 2 mm and of the outer shell 3 mm. At the ends the thickness of the inner shell is 10 mm and of the outer shell 4 mm. All surfaces of the inner shell of the top half are covered with a layer of 2.6 mm intumescent material.

At the top, there are two eyelets welded to the outer shell, one on each side. These eyelets are designed to be used for lifting the top half only.

At the bottom side of the top half of the DN30 PSP, the upper halves of the mortise-and-tenon closure system are welded to the outer shell, three per side. Adjacent to one of these parts of the closure system, the sealing block is welded to the outer shell.

At the inside of the top half there is a recess to accommodate the valve protecting device.

In the flange of the top half, there is an elastomeric gasket to prevent water inleakage under RCT.

1.4.2.3 Design Safety Features of the DN30-X Packaging

1.4.2.3.1 Pressure Containment of the DN30-X Packaging

The pressure containment consists of:

- The 30B-X cylinder including its valve and plug

Note: the DN30 PSP is not designed as a pressure retaining component. Because of its design, a pressure difference between the ambient and the DN30 PSP can be excluded. For pressure release during the thermal test under HAC, the DN30 PSP is equipped with fusible plugs that release any pressure that may be induced by the decomposition of the foam parts.

1.4.2.3.2 Mechanical Protection System

The mechanical protection system prevents excessive mechanical impacts on the 30B-X cylinder under RCT, NCT and HAC. It consists of:

- The stainless steel and foam structure of the bottom and top half of the DN30 PSP

1.4.2.3.3 Thermal Protection System

The thermal protection system prevents excessive thermal loads on the 30B-X cylinder including its valve and plug under RCT, NCT and HAC. It consists of:

- The stainless steel / foam structure of the bottom and top half of the DN30 PSP (each fitted with nine thermal plugs/valves, screwed into the outer steel shells)
- The microporous thermal insulation layer between the RTS 120 foam and the inner steel shell
- The intumescent material at the inner surfaces of the DN30 PSP

1.4.2.3.4 Closure System

The top and bottom half of the DN30 PSP are connected by the closure system consisting of 6 robust mortise-and-tenon like devices and the flange.

The two parts of each mortise-and-tenon system have four teeth each with a hole in its center. When closed, the two halves are connected by a pin inserted into these holes. This pin is secured by a bolt. The design of the mortise-and-tenon system is such that neither the connecting pin nor the securing bolt are exposed to mechanical impacts but are protected by the massive body of the system. The system prevents excessive relative movements of top and bottom half in vertical direction under RCT, NCT and HAC.

The flange is shaped like an upside-down "U". It prevents excessive relative movements of the top and bottom half in all horizontal directions under RCT, NCT and HAC. Furthermore, in flat drop orientations the flange will be deformed in such a way that the top and bottom half are clamped together.

1.4.2.3.5 Valve Protecting Device

The valve protecting device consists of a stainless-steel housing filled with PIR foam. It is shaped like a U and encloses the valve of the 30B-X cylinder during transport. It is connected to the bottom half of the DN30 PSP through two hinges. In open condition, it is turned to horizontal position to allow loading and unloading of the cylinder. When the filled cylinder is loaded into the PSP, the device is turned by 90° to vertical orientation so that it is in contact with the cylinder head. The valve protecting device prevents contact of the valve with any part of the DN30 PSP or any other part the 30B-X cylinder except for its original point of contact (thread) under RCT, NCT and HAC.

A protecting housing is placed inside the U-shape of the valve protecting device. This housing is made of thin stainless-steel sheets and its inside is covered with intumescent material.

1.4.2.3.6 Plug Protecting Device

The plug protecting device consists of a pot made of stainless steel welded to the inner shell of the bottom half of the DN30 PSP. This device allows the plug of the 30B-X cylinder to move in axial direction without getting in contact with any part of the DN30 PSP under RCT, NCT and HAC. The inside of the pot is covered with intumescent material.

1.4.2.3.7 Rotation Preventing System

The rotation preventing system consists of two rotation preventing devices installed at the sides of the inner flange of the bottom half of the DN30 PSP. The device consists of a stainless-steel pin accommodated in two sleeves, an internal sleeve in contact with the pin and an external sleeve that is welded to the flange. A lever is welded onto the steel pin to allow turning and lateral movements.

In open condition, the steel pin is withdrawn into the flange so that the cylinder can be loaded or unloaded. In this condition, the top half of the DN30 PSP cannot be put on the bottom half as the position of the lever prevents the correct placement of the top flange onto the bottom flange. The connection of top and bottom half is only possible when the rotation preventing system is properly engaged. This excludes the possibility of the pin being withdrawn while the packaging is closed.

1.4.2.3.8 Sealing System

For sealing of the DN30-X package there are two sealing blocks welded to the top and bottom half adjacent to a closure device. These blocks allow the use of high security seals compliant with ISO 17712 / C-TPAT.

1.4.2.4 Handling Features of the DN30-X Packaging

1.4.2.4.1 Lifting of the DN30-X Package, DN30-X Packaging and Empty DN30 PSP

The DN30-X package can be lifted by using:

- The 4 lifting lugs welded to the upper part of the feet
- A forklift
- Handling slings

Handling of the DN30 PSP or empty DN30-X packaging is carried out in the same manner as for the DN30-X package.

1.4.2.4.1.1 Lifting by Using the 4 Lifting Lugs at the Feet

For lifting the DN30-X package by using the 4 lifting lugs welded to the upper part of the feet, shackles must be used and fixed to the lifting lugs. It is preferable to use lifting slings made from Polyester or Nylon. The angle between the vertical axis of the lifting lugs and the slings/chains must not be greater than 30° (see figure 1-6).

Figure 1-6 Lifting of the DN30-X package by using the 4 lifting lugs

1.4.2.4.1.2 Lifting by Using a Forklift

The loaded DN30-X package may be handled and lifted by using a forklift. For this purpose, two forklift pockets are welded to the bottom half of the DN30 PSP (see figure 1-7).

Figure 1-7 Lifting of the DN30-X package by using a forklift

1.4.2.4.1.3 Lifting by Using Slings (Empty DN30 PSP)

Only the empty DN30 PSP may be handled by slings attached to the bottom half of the DN30 PSP as shown in figure 1-8.

Figure 1-8 Lifting of the empty DN30 PSP by using slings

1.4.2.4.2 Lifting of the Top Half of the DN30 PSP

When transported, the loaded DN30-X package or the empty DN30 PSP is usually mounted on dedicated flatracks. At the destination, only the top half of the DN30 PSP needs to be removed for loading or unloading the 30B-X cylinders into or from the DN30 PSPs.

For handling of the top half, there are two lifting lugs welded to each end of the outer shell of the DN30 PSP (see figure 1-9). These lifting lugs are designed for lifting the top half of the DN30 PSP only. During transport, they have to be rendered inoperable for lifting to prevent inadvertent use of these attachment points (e.g., for lifting the loaded package). Rendering the lifting lugs at the top half inoperable can be done by inserting bolts.

Figure 1-9 Lifting of the top half of the DN30-X packaging

1.4.2.5 Tie-Down Features of the DN30-X Packaging

For tie-down, the DN30 PSP is equipped with two feet. The base plates of the feet consist of 2 x 10 mm thick stainless-steel sheets which incorporate two holes at each end. The dimension and position of these holes are compatible with other PSP designs currently in use. During transport, the DN30 PSP is bolted to a dedicated flatrack (see figure 1-10).

According to international practice, tie-down of the DN30-X package on flatracks by bolts is performed taking into account accelerations of 2 g in axial, 2 g in lateral and 2 g in vertical direction of travel. However, the tie-down features of the DN30-X package are designed to withstand an acceleration of 10 g in axial, 5 g in lateral and 1 g ± 2 g in vertical direction of travel (see section 2.2.5). For application of such tie-down parameters, additional shocks or bumpers must be foreseen in the tie-down plan. However, this tie-down plan is not part of the application.

Only for the transport of DN30 PSP not loaded with a 30B-X cylinder and in case a dedicated flatrack cannot be made available, tie-down by using straps according to figure 1-11 is allowed. In that case, a tie-down plan has to be drawn up based on a tie-down calculation.

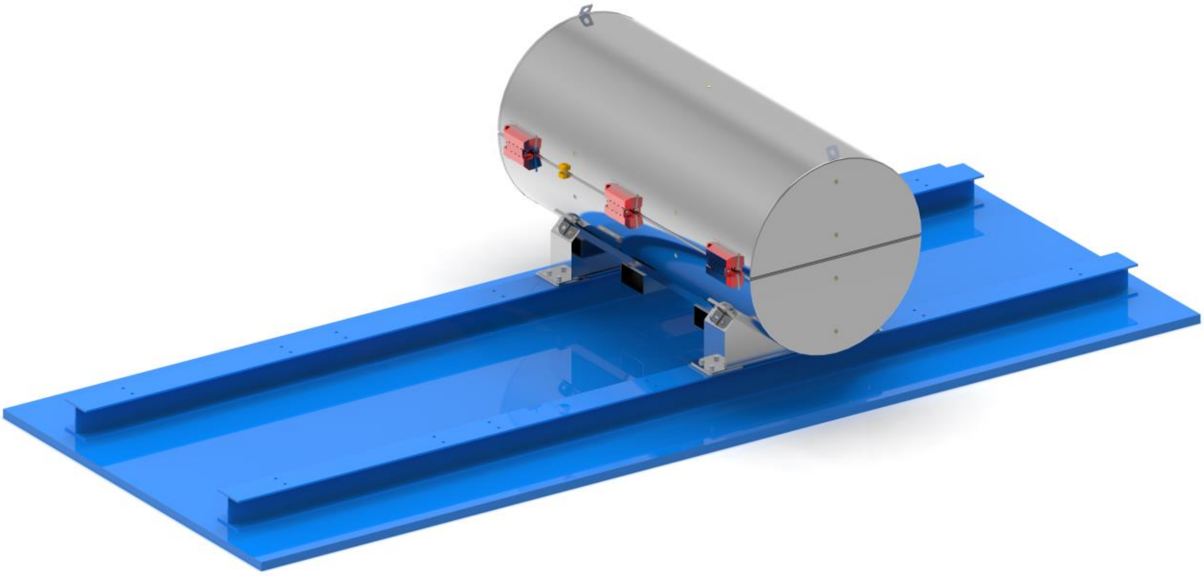

Figure 1-10 General tie-down method for the DN30-X package / DN30 PSP

Figure 1-11 Tie-down of the empty DN30 PSP using straps

1.4.3 Components of the Packaging Relevant for the Containment System

The containment system consists of:

- The 30B-X cylinder shell and heads together with the welding seams forming the pressure envelope
- The valve body and the stem including the threaded connection between the valve and the 30B-X cylinder body
- The plug including its threaded connection between the 30B-X cylinder body

1.4.4 Components of the Packaging Relevant for Shielding

The DN30-X packaging has no components primarily intended for shielding. However, some level of shielding is provided by the 30B-X cylinder shell as well as the inner and outer shells of the DN30 PSP.

1.4.5 Components of the Packaging Relevant for the Confinement System

The confinement system consists of:

- The components of the containment system (see section 1.4.3)
- The interior CCS of the 30B-X cylinder
- The inner and outer shells of the DN30 PSP

1.4.6 Components of the Packaging Relevant for Thermal Protection

The following components of the DN30 PSP are relevant for thermal protection:

- The inner and outer shells
- The RTS 120 and RTS 320 foam
- The microporous thermal insulation layer between the inner shell and RTS 120 foam
- The intumescent material attached to the inside of the inner shell

1.4.7 Components of the Packaging Relevant for Heat Dissipation

Because of the very low level of thermal power, there is no dedicated component for heat dissipation.

1.4.8 Protection against Corrosion

All outer and interior surfaces of the DN30 PSP are made of austenitic stainless steel and, thus, are resistant to corrosion. There is no corrosion due to the interaction of the intumescent material or its glue, since the material is certified halogen-free (see Appendix 1.4.2 (Material Properties)).

Like standard 30B cylinders, the 30B-X cylinder is coated with high quality paint that prevents excessive corrosion on all outer surfaces. Corrosion at the interior surfaces of the 30B-X cylinder is negligible, which is proven by the long term and world-wide experience with standard 30B cylinders. Within the 5-year recertification period or when these cylinders are appropriately stored while loaded with UF_6 or heels, there is no excessive corrosion, which could impair the safety functions of these cylinders. Since the same operation and maintenance procedures apply to the 30B-X cylinder, the corrosion behavior of standard 30B cylinders can be directly transferred to the 30B-X cylinder.

1.4.9 Protection Against Contamination

All outer and interior surfaces of the DN30 PSP are made of austenitic stainless steel and, thus, are easy to decontaminate. Furthermore, the intumescent material is protected by an easy to decontaminate coating.

The 30B-X cylinder is coated with paint that can be easily decontaminated. In transport configuration, the surface of the 30B-X cylinder is not accessible from the outside.

1.4.10 Shock Absorbing Components of the Packaging

The following components of the DN30 PSP are relevant for shock absorption:

- The inner and outer shells
- The RTS 120 and RTS 320 foam
- The valve protecting device

1.4.11 Evaluation of the Impact of Aging Mechanisms

To take into account ageing mechanisms in the design of the DN30-X package, care has been taken to use materials with a long usage history.

1.4.11.1 DN30 PSP

The DN30 PSP consists of an inner and outer shell of austenitic stainless steel enclosing a shock absorbing structure made of PIR foam and a thermal protection made of inorganic materials.

- There is no tensile stress during RCT (except during handling) in any of the steel parts of the DN30 PSP, hence for the austenitic stainless steel aging is not a topic. Fatigue analysis of all parts used during handling and tie-down is described in Appendix 2.2 (Structural Analysis), section 4.3 and 5.1.
- Interaction of the austenitic stainless steel with the shock absorbing material and the thermal protection materials has been thoroughly investigated. It was concluded that due to the properties of the shock absorbing material (closed cell structure, free of acids and halogens) and of the thermal protection materials (inorganic materials, free of acids and halogens) no negative effects are to be considered.
- Aging of the shock absorbing material is taken into account by the testing of samples as described in section 1.9.2.4.
- The inorganic materials used as thermal protection do not show any deterioration of their thermal properties during long term use. Aging is for these materials not a topic.

1.4.11.2 30B-X cylinder

The design of the 30B-X cylinder is based on the 30B cylinder as standardized in [ANSI N14.1], which has been in world-wide use for decades. The 30B-X cylinder (including the CCS except for the B_4C filling of the CCRs) is made of the same materials as the 30B cylinder. Hence, it can be safely assumed that aging mechanisms will have no significant impact on the 30B-X cylinder.

Regarding the B_4C filling of the CCRs, the material is extremely heat resistant, and since it is in powder form, it is not vulnerable to mechanical pressure. There is no concern of long-term loss of efficacy from neutron absorption due to the low neutron fluxes that the material is exposed to.

1.4.12 Transport Concept

Generally, the DN30-X package is transported on dedicated flatracks. A maximum of four DN30-X packages can be mounted onto a 20' flatrack using the holes in the feet and suitable bolts.

- The components of the DN30-X packaging relevant for lifting the package or packaging are described in section 1.4.2.4.
- The components of the DN30-X packaging relevant for tie-down are described in section 1.4.2.5.

1.5 Package Performance Characteristics

1.5.1 Main Design Principles

The DN30-X packaging consists of the DN30 PSP that accommodates the 30B-X cylinder. Both the DN30 PSP and the 30B-X cylinder are designed by ONCS, where the 30B-X cylinder is specifically designed with regard to [ANSI N14.1], fulfilling the same requirements as a standard 30B cylinder.

The 30B-X cylinder is primarily designed to be used as a pressure vessel in enrichment and fuel manufacturing plants to accept UF_6 from the enrichment process and to feed enriched UF_6 into the process at the fuel manufacturer's site. UF_6 contents with enrichments up to 10 or 20 wt.-% ^{235}U in uranium are permissible for the 30B-10 or 30B-20 cylinder, respectively. The 30B-X cylinder provides the containment and the main confinement function of the DN30-X package.

For public transportation, the 30B-X cylinder is protected by the DN30 PSP against mechanical and thermal impacts as defined in [10 CFR Part 71] and [49 CFR Part 173] or [SSR-6 2018], so that the containment and confinement function of the 30B-X cylinder are maintained under RCT, NCT and HAC.

1.5.2 Performance Characteristics

1.5.2.1 Performance Characteristics under RCT

Under RCT, the main performance characteristics are:

- Safe handling of the DN30-X package
- Safe tie-down of the DN30-X package
- Adequate design for accelerations and vibrations to be routinely expected
- Easy handling operations under the environmental conditions to be routinely expected
- Resistance against corrosion
- Long term usability by considering temperatures and ambient conditions to be routinely expected

1.5.2.2 Performance Characteristics under NCT

Under NCT, the main performance characteristics are:

- Protection of the 30B-X cylinder against the mechanical loads to be expected under NCT
- Limitation of deformations to fulfill the requirement regarding dose rate increase

1.5.2.3 Performance Characteristics under HAC

Under HAC, the main performance characteristics are:

- Protection of the 30B-X cylinder against mechanical loads to be expected under HAC
- Protection of the 30B-X cylinder against the thermal loads to be expected under HAC

1.5.3 Assumptions Used for the Safety Analysis

1.5.3.1 Containment Function

The containment function is provided by the 30B-X cylinder and its installed valve and plug. It is assumed that the containment function is preserved if:

- Following the tests prescribed in [10 CFR Part 71] §59(a)(2) or [SSR-6 2018] para. 685(b), there is no physical contact between the valve or plug and any other component of the packaging other than their original points of attachment.
- Following the test prescribed in [10 CFR Part 71] §73(c)(4) or [SSR-6 2018] para. 728, the valve and the plug remain leak-tight.

1.5.3.2 Dose Rates

The shielding function is provided by the shell of the 30B-X cylinder and the inner and outer shells of the DN30 PSP. For RCT and NCT, the foam between the inner and outer shell of the DN30 PSP is credited as well.

For the proof that the increase of the dose rate after the mechanical tests simulating NCT does not exceed the limits specified in the regulations, the reduction of the wall thickness of the DN30 PSP due to deformation is considered.

1.5.3.3 Criticality Safety

The following assumptions are made for the proof of criticality safety:

- There are no requirements on the content, neither on its arrangement within the 30B-X cylinder nor regarding the distribution of impurities.
- Based on section 1.5.3.1, the containment function of the 30B-X cylinder is maintained. The maximal amount of water ingress under HAC is less than 3 g (see section 2.6.2.4).
- When taking impacts from HAC into account, the steel shells of the DN30 PSP will maintain a total thickness of at least 10 cm in radial direction (around the mantle) and at least 8 cm in axial direction (on the valve/plug ends).
- The closure system has to ensure that the top and bottom half of the DN30 PSP remain connected during RCT, NCT and HAC.

1.6 Compliance with Regulatory Requirements

1.6.1 Compliance with 10 CFR Part 71

In this section, the compliance of the Type AF package design DN30-X with the regulatory requirements [10 CFR Part 71] for the packaging and transportation of radioactive material is shown. The order of the paragraphs in column 1 of the tables follows [10 CFR Part 71]. Whenever possible, reference to the corresponding paragraphs from the IAEA regulations [SSR-6 2018] is provided in column 2 because some of the supplemental documentation frequently refers to the IAEA regulations [SSR-6 2018].

1.6.1.1 10 CFR Part 71 – Subpart A to D – General Provisions, Exemptions and Application for Package Approval

10 CFR §71	IAEA SSR-6	Remarks
4 *(fissile)*	222	There is only the fissile nuclide ^{235}U present in the content (see section 1.3).
4 *(Type A)*	428	The DN30-X package complies with the DOT regulations in [49 CFR Part 173] (see section 1.6.2).
15	417	There are no exceptions by one of the provisions specified in this paragraph (see specification of contents in section 1.3).
31	-	The application for approval under [10 CFR Part 71] includes the following information: (a) A package description in section 1.4 as required. (b) A package evaluation in part 2 as required. (c) A reference to a previously approved quality assurance program (see section 1.9).
33(a)	-	A detailed description of the DN30-X packaging is provided in section 1.4.
33(b)	-	A detailed description of the contents of the DN30-X package is provided in section 1.3.
35(a)	-	A demonstration that the DN30-X package satisfies the standards specified in subparts E and F of [10 CFR Part 71] is given in part 2 of this SAR.
35(b)	-	The criticality safety index for the DN30-X package is defined in section 1.2.4.
35(c)	-	Special controls and precautions for the DN30-X regarding transport, loading, unloading, and handling are specified in section 1.7. For the DN30-X, there are no special controls required in case of an accident or delay.

10 CFR §71	IAEA SSR-6	Remarks
37	306	The management system of ONCS for the design, fabrication, assembly, testing, maintenance, repair, modification, and use of the DN30-X package is audited and certified by the German competent authority (see section 1.9). Appendix 1.9.3 (Quality Assurance Program) shows compliance of this system with the requirements of [10 CFR Part 71] – Subpart H and contains the corresponding NRC approval.
41	701	The effects on the DN30-X package of the tests specified in 10 CFR §71.71 and the tests specified in 10 CFR §71.73 are evaluated by (a) subjecting specimens to a specific test (see Appendix 2.2 (Structural Analysis) and Appendix 2.3 (Thermal Analysis)) and (b) analysis and calculations (see part 2 of this SAR).

1.6.1.2 10 CFR Part 71 – Subpart E – Package Approval Standards

General standards for all packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
43(a)	636	The smallest overall dimension of the DN30-X package is not less than 10 cm (see section 1.4).
43(b)	637	The outside of the DN30-X package incorporates a seal, that is not readily breakable and that, while intact, is evidence that the package has not been opened by unauthorized persons (see section 1.4.2.3.8).
43(c)	641	The containment system of the DN30-X package is defined in section 1.4.3. The containment system cannot be opened unintentionally as it is enclosed by the DN30 PSP, which in turn is securely closed by a positive fastening device during transport (see section 1.4.2.3.4). The containment system cannot be opened by a pressure that may arise within the package, as it withstands a hydraulic strength test at a pressure of 2.76 MPa, which is much higher than the internal pressure under RCT and NCT (see section 2.2.3.3).
43(d)	614	The design of the 30B cylinder is standardized in [ANSI N14.1]. This design is world-wide in use since decades. The 30B-X cylinder is made of the same kind of materials as the 30B cylinder. Hence, it can be assumed that there will be no significant chemical, galvanic, or other reaction among the packaging components and the package contents.
43(e)	615, 646	The 30B-X cylinder with its valve is enclosed by the DN30 PSP during transport and, thus, is also protected against unauthorized operation.

General standards for all packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
43(f)	648	The DN30-X package is designed, constructed, and prepared for shipment so that under the tests simulating NCT specified in 10 CFR §71.71 there is: (a) No loss or dispersal of the radioactive UF_6 content (see section 2.4). (b) No significant increase (not greater than 20 %) in external surface radiation levels (see section 2.5.6.4). (c) No substantial reduction in the effectiveness of the packaging.
43(g)	(654)	The DN30-X package is designed, constructed, and prepared for transport so that in still air at 38 °C and in the shade, no accessible surface of the package has a temperature exceeding 50 °C so that a nonexclusive use shipment is possible (see section 2.3).
43(h)	-	The DN30-X package does not incorporate a feature intended to allow continuous venting during transport.

Lifting and tie-down standards for all packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
45(a)	608, 609	(a) The lifting attachments, that are a structural part of the DN30-X package, are designed with a minimum safety factor of 3 against yielding when used to lift the package in the intended manner (see section 2.2.4.3). (b) They are designed so that failure of any lifting device under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71]. (c) Any other structural part of the DN30-X package that could be used to lift the package is rendered inoperable for lifting the package during transport (see section 1.4.2.4.2).
45(b)(1)	613	Each tie-down device that is a structural part of the DN30-X package withstands the acceleration forces required by 10 CFR §71.45(b) without generating stresses in any material of the package in excess of its yield strength (see section 2.2.5.1).
45(b)(2)	-	There are no other structural parts of the DN30-X package that could be used for tie-down of the package.
45(b)(3)	638	Each tie-down device that is a structural part of the DN30-X package is designed so that failure of this device under excessive load does not impair the ability of the package to meet other requirements of [10 CFR Part 71] (see section 2.2.5.1).

External radiation standards for all packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
47(a)	526, 527	For all permissible contents in section 1.3, the transport index (TI) of the DN30-X package is below 10 (see section 2.5.6.1). Furthermore, the radiation level at the surface of each DN30-X package does not exceed 2 mSv/h under conditions normally incident to transportation (see section 2.5.6.2).
47(b)	528, 573	The DN30-X package does not exceed the radiation level limits specified in 10 CFR §71.47(a). Hence, the radiation level limits in this paragraph do not apply to the DN30-X package.

General requirements for fissile material packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
55(a)	673	The DN30-X package is designed and constructed in accordance with 10 CFR §71.41 through 71.47. As a Type AF package design, 10 CFR §71.51 does not apply.
55(b)	676, 677, 679-682	The DN30-X package is so designed and constructed and its contents so limited that even if water were to leak into the containment system, it remains subcritical. Under the following conditions, maximum reactivity of the fissile material is attained: (1) The chemical form of UF_6 is well known. For the isotopic compositions, maximal values of the fissile nuclide ^{235}U are assumed. Physical form, mass, concentration of impurities, moderation ratio or density and geometrical configuration are varied to determine the maximum neutron multiplication factor. The variation calculations are documented in section 2.6.5 and Appendix 2.2.5 (Criticality Safety Analysis). (2) For the individual DN30-X package in isolation, it is assumed that water can leak into the containment system and optimal moderation is assumed (see section 2.6.2.2). (3) The analysis for an individual package in isolation assumes a layer of 30 cm water surrounding the DN30-X package (see section 2.6.2.2).
55(c)	-	Does not apply to the DN30-X package.

General requirements for fissile material packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
55(d)	678	The DN30-X package is so designed and constructed, and its contents so limited that after being subjected to the tests simulating NCT: (1) The content is subcritical (see section 2.6.6). (2) The geometric form of the package content is not substantially altered (see section 2.2.6). (3) In the evaluation of the undamaged package, optimal moderation is assumed (see section 2.6.2.2). (4) There is no substantial reduction in the effectiveness of the DN30-X packaging (see section 2.2.6), including: i. No more than 5 % reduction in the total effective volume of the packaging on which nuclear safety is assessed. ii. No more than 5 % reduction in the effective spacing between the fissile content and outer surface of the packaging. iii. No occurrence of an aperture in the outer surface of the packaging large enough to permit the entry of a 10 cm cube.
55(e)	676, 677, 679-682	The DN30-X package is so designed and constructed, and its contents so limited that after being subjected to the tests simulating HAC the package remains subcritical. For this determination, it is assumed in section 2.6 that: (1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the content. (2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the content. (3) There is full reflection by water on all sides, as close as is consistent with the damaged condition of the package.
55(f)	683	The DN30-X package shall not be transported by air.
55(g)	680(b)	The exception for packages containing uranium hexafluoride with a maximum enrichment of 5 wt.-% ^{235}U in cannot be credited for the DN30-X package.

Standards for arrays of fissile material packages		
10 CFR §71	**IAEA SSR-6**	**Remarks**
59(a)(1)	684	The number N derived for the DN30-X package is infinite. The proof of subcriticality under NCT is provided in section 2.6.5.3.
59(a)(2)	685	The number N derived for the DN30-X package is infinite. The proof of subcriticality under HAC is provided in section 2.6.5.3.
59(b)	686	For the DN30-X package, the following applies: CSI = 0 (see section 1.2.4).
59(c)	-	For the DN30-X package, the CSI = 0 so that package may be shipped by a carrier in a nonexclusive use conveyance.

1.6.1.3 10 CFR Part 71 – Subpart F – Package, Special Form, and LSA-III Tests

Normal Conditions of Transport		
10 CFR §71	**IAEA SSR-6**	**Remarks**
71(a)	719	See remarks to 10 CFR §71.71(c)(7)-(10) below.
-	720	The time interval between the water spray test and the subsequent tests has no impact on the performance of the subsequent tests (see remark to 10 CFR §71.71(c)(6)).
71(b)	-	During the mechanical tests with DN30 PSP prototypes documented in Appendix 2.2 (Structural Analysis), the ambient temperature was about 20 °C and there was no internal pressure within the containment (the 30B cylinder) as this is the more unfavorable condition. In the structural analysis of the DN30-X package, ambient temperatures between -40°C and +38°C including insolation are considered (see section 2.2).
71(c)(1)-(2)	-	The design of the DN30-X package considers ambient temperatures ranging from -40 °C to +38 °C including insolation (see section 2.2).
71(c)(3)-(4)	-	The internal pressure in the 30B-X cylinder during transport is below atmospheric. As the 30B-X cylinder withstands the hydraulic strength test at a test pressure of 2.76 MPa, the containment is not affected by a reduction of ambient pressure to 25 kPa (see section 2.2.6.5). Furthermore, the 30B-X cylinder is designed for an external pressure of 172 kPa so that the containment is not affected by an increased external pressure of 140 kPa absolute (see section 2.2.6.5).
71(c)(5)	-	The package is designed to withstand effects of any acceleration, vibration or vibration resonance that may arise under NCT (see section 2.2.5).
71(c)(6)	721	The DN30 PSP is a fully closed and welded structure of stainless steel. Any influence of the water spray test on the properties of the DN30-X package can be excluded (see section 2.2.6.1).
71(c)(7)	722, 717	The free drop test is analyzed in sections 2.2.6.2 and 2.2.7. It was also carried out with DN30 PSP prototypes as documented in Appendix 2.2 (Structural Analysis). The target for the experimental drop tests and the drop test analyses complies with the requirements of [SSG-26 2012] para. 717.2.
71(c)(8)	-	The corner drop from a height of 0.3 m is not applicable as the mass of the DN30-X package exceeds 100 kg.
71(c)(9)	723	The shape of the packaging effectively prevents stacking. Nevertheless, the DN30-X successfully passes the compression test as demonstrated in section 2.2.6.3.
71(c)(10)	724	The DN30-X package is designed to withstand HAC. The puncture test specified in 10 CFR §71.73(c)(3) is much more severe than the penetration test specified in this paragraph (see also section 2.2.6.4).

Hypothetical Accident Conditions		
10 CFR §71	**IAEA SSR-6**	**Remarks**
73(a)	726	DN30 PSP prototypes used for testing were subject to the cumulative effects of twice the mechanical tests specified in 10 CFR §71.71(c)(7), followed by twice the tests specified in 10 CFR §71.73(c)(1)-(3), and finally followed by the thermal test specified in 10 CFR §71.73(c)(4) (see Appendix 2.2 (Structural Analysis) and Appendix 2.3 (Thermal Analysis)).
73(b)	-	During the mechanical tests with DN30 PSP prototypes the ambient temperature was about 20 °C and there was no internal pressure within the containment (the 30B cylinder) as this is the more unfavorable condition (see Appendix 2.2 (Structural Analysis), appendix B). In the structural analysis of the DN30-X package in section 2.2, ambient temperatures between -40°C and +38°C including insolation are considered.
73(c)(1)	727(a), 717	The performance of the DN30-X package subject to the free drop test from a height of 9 m is analyzed in section 2.2.7. It is based on the analyses for the DN30 package in Appendix 2.2 (Structural Analysis), appendix A and B where several free drop tests with DN30 PSP prototypes from a height of 9 m onto a flat, essentially unyielding, and horizontal surface were performed, striking the surface in different orientations for which maximum damage is expected. The target for drop tests complied with the requirements of [SSG-26 2012] para. 717.2.
73(c)(2)	727 (c)	The dynamic crush test is not applicable as the mass of the DN30-X package exceeds 500 kg.
73(c)(3)	727 (b)	The performance of the DN30-X package subject to the puncture test is analyzed in section 2.2.7. It is based on the analyses for the DN30 package in Appendix 2.2 (Structural Analysis), appendix A and B. The requirements for the bar and the drop target were fulfilled in these tests.
73(c)(4)	728	The analysis of the DN30-X package subject to the thermal test is based on thermal tests that were carried out using DN30 PSP prototypes that suffered the cumulative effects of twice the mechanical tests specified in 10 CFR §71.71(c)(7) followed by twice the tests specified in 10 CFR §71.73(c)(1)-(3). The test results are documented in Appendix 2.3 (Thermal Analysis), appendix 1 and analyzed in section 2.3.
73(c)(5)	731-733	The immersion test for fissile material is not applicable to the DN30-X package as optimal moderation and full flooding is assumed in the criticality safety analysis. Furthermore, the test conditions defined in 10 CFR §71.73(c)(6) are more demanding for the DN30-X package.
73(c)(6)	729	The water immersion test is analyzed in section 2.2.7.2. Inleakage of water during this test is taken into account in the criticality safety analysis (see section 2.6 and Appendix 2.6 (Criticality Safety Analysis)). The test conditions before the water immersion test still comply with the test conditions required by 10 CFR §71.55.

1.6.1.4 10 CFR Part 71 – Subpart G – Operating Controls and Procedures

10 CFR §71	IAEA SSR-6	Remarks
83	-	The chemical form of UF_6 is well known. For the isotopic compositions, maximal values of the fissile nuclide ^{235}U are assumed. Physical form, mass, concentration of impurities, moderation ratio or density, and geometrical configuration are varied to determine the maximum neutron multiplication factor.
85(a)	501(b)-(c)	The manufacturing specifications Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and Appendix 1.9.2B (Manufacturing Specification DN30 PSP) as well as the testing requirements and controls before first use in section 1.7.1 ensure that there are no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the DN30-X packaging: (a) The effectiveness of the containment is within the limits specified for the DN30-X package as the 30B-X cylinder is manufactured and tested before its first use to prove its compliance with [ANSI N14.1]. (b) The effectiveness of the confinement is within the limits specified for the DN30-X package as the applied measures ensure that the CCS of the 30B-X cylinder is present and in proper condition. (c) The effectiveness of the shielding, structural and thermal protection are within the limits specified for the package as the applied measures ensure that the 30B-X cylinder and the DN30 PSP are in proper condition.
85(b)	501(a)	The MNOP for the DN30-X package is defined in section 1.2.9 with 152 kPa. Consequently, the requirements of this paragraph are fulfilled, as a hydraulic strength test at a test pressure of 2.76 MPa is performed for the 30B-X cylinder, which is the containment system of the DN30-X package (see section 2.2.3.3).
85(c)	501, 533	The DN30-X packaging is conspicuously and durably marked on the nameplate with its model number, serial number, gross weight, and the package identification number assigned by the NRC (see section 1.4). Before the model number is applied to a DN30-X packaging, it is determined whether the packaging has been fabricated in accordance with the design approved by the Commission (see section 1.7.1).
87(a)	502	The analyses in part 2 of this SAR prove that the DN30-X package is properly designed for the contents specified in section 1.3. Furthermore, administrative controls ensure that only the contents as specified in the certificate of package approval are loaded into the DN30 PSP (see section 1.7.2).
87(b)	-	The testing requirements and controls before each transport in section 1.7.2 ensure that the DN30-X package is in unimpaired physical condition except for superficial defects such as marks or dents.
87(c)	-	The testing requirements and controls before each transport in section 1.7.2 ensure that the closure devices of the DN30-X package (including any required gasket) are properly installed and secured and free of defects.
87(d)	-	The testing requirements and controls before each transport in section 1.7.2 ensure that during transport the UF_6 is in solid form. However, to make provisions for filling effects, the 30B-X cylinder is always filled to less than 60 % taking care of the significant expansion of UF_6 during its solid to liquid phase change in case the UF_6 is liquefied during filling or emptying.

10 CFR §71	IAEA SSR-6	Remarks
87(e)	-	Does not apply to the DN30-X package as no specific pressure relief devices are present in the package design.
87(f)	503(c)	The handling instructions defined in section 1.7.4 ensure that the DN30-X package is loaded and closed in accordance with written procedures.
87(g)	501(c)	The manufacturing specifications in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and the testing requirements and controls before first use in section 1.7.1 ensure that the CCS of the 30B-X cylinder is present and in proper condition. The handling instructions defined in sections 1.7.3 and 1.7.4, the testing requirements and controls before each transport in section 1.7.2 and the prescribed inspections in section 1.8 ensure that the proper condition of the CCS is maintained throughout the life-time of a 30B-X cylinder.
87(h)	503(a)	The handling instructions defined in sections 1.7.3 and 1.7.4 take into account the respective measures.
-	507	Other dangerous properties of UF_6 are taken into account (see section 1.7.6).
87(i)	508	Contamination checks defined in section 1.7.2 take the specified limits specified in DOT regulations in 49 CFR §173.443 into account.
87(j)	-	The external radiation levels around the DN30-X package and around the vehicle do not exceed the limits specified in 10 CFR §71.47 at any time during transportation (see section 1.6.1.2).
87(k)	503(b)	The accessible DN30-X package surface temperatures do not exceed the limits specified in 10 CFR §71.43(g) at any time during transportation (see section 1.6.1.2).
89	-	Special instructions needed to safely open the DN30-X package are documented in the handling instruction in Appendix 1.7.1 (Handling Instruction). The handling instruction will be made available to all users of the DN30-X package (see section 1.9.3).

1.6.1.5 10 CFR Part 71 – Subpart H – Quality Assurance

10 CFR §71	IAEA SSR-6	Remarks
Subpart H (101 – 137)	306	The management system of ONCS is audited and certified by the German competent authority (see section 1.9). Appendix 1.9.3 (Quality Assurance Program) shows compliance of this system with the requirements of this subpart and contains the corresponding NRC approval.

1.6.2 Compliance with 49 CFR Part 173

In this section, the compliance of the Type AF package design DN30-X with the regulatory requirements [49 CFR Part 173] for the transport of radioactive material is shown. The order of the paragraphs in column 1 of the tables follows [49 CFR Part 173]. Whenever possible, reference to the corresponding paragraphs from the IAEA regulations [SSR-6 2018] is provided in column 2 because some of the supplemental documentation frequently refers to the IAEA regulations [SSR-6 2018].

1.6.2.1 Definitions and General Design Requirements

General design requirements		
49 CFR §173	**IAEA SSR-6**	**Remarks**
2(a)	507, 618	Other dangerous properties of UF_6 are taken into account (see section 1.7.6).
403 (fissile)	222	There is only the fissile nuclide ^{235}U present in the content (see section 1.3).
410(a)	607	The DN30-X package can be easily handled and properly secured during transport (see sections 1.4.2.4 and 1.4.2.5).
410(b)	608, 609	(a) The lifting attachments, that are a structural part of the DN30-X package, are designed with a minimum safety factor of 3 against yielding when used to lift the package in the intended manner (see section 2.2.4.3). (b) They are designed so that failure of any lifting device under excessive load does not impair the ability of the DN30-X package to meet other requirements of 49 CFR Subpart I. (c) Any other structural part of the DN30-X package that could be used to lift the package is rendered inoperable for lifting the package during transport (see section 1.4.2.4.2).
410(c)	610	The external surfaces of the DN30-X package, as far as practicable, are free from protruding features and consist of stainless steel. Therefore, they are easily decontaminated (see section 1.4.2).
410(d)	611	The outer layer of the package prevents the collection and retention of water (see section 1.4.2).
410(e)	612	There are no features added to the package at the time of transport that could reduce its safety (see section 1.4.2.5).
410(f)	613	The DN30-X package is designed to withstand the effects of any acceleration, vibration or vibration resonance that may arise under RCT or NCT without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the DN30-X package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use (see section 2.2.5).
410(g)	614	The DN30-X packaging consists mainly of the materials stainless steel and foam. Those are physically and chemically compatible with each other. Any part in contact with the radioactive UF_6 content has been designed for this purpose (see section 1.4.2).

General design requirements		
49 CFR §173	**IAEA SSR-6**	**Remarks**
410(h)	615	The valve and the plug of the 30B-X cylinder are protected by the DN30 PSP during transport and cannot be operated unauthorized (see section 1.4.2).
-	616	The DN30-X package is designed to comply with the requirements for fissile material packages. It takes into account ambient temperatures and pressures that are likely to be encountered under RCT.
-	617	The radiation level at the surface of the DN30-X package does not exceed 2 mSv/h under conditions normally incident to transportation (see section 2.5.6.2).
410(i)	619-621	The DN30-X package shall not be transported by air.

1.6.2.2 Additional Design Requirements for Type A Packages

Additional design requirements for Type A packages		
49 CFR §173	**IAEA SSR-6**	**Remarks**
412	635	The DN30-X package meets the general design requirements prescribed in 49 CFR §173.410 and is also designed to meet the requirements prescribed in 49 CFR §173.412(a)-(l).
412(a)	637	The outside of the DN30-X package incorporates a seal, that is not readily breakable and that, while intact, is evidence that the package has not been opened by unauthorized persons (see section 1.4.2.3.8).
412(b)	636	The smallest overall dimension of the DN30-X package is not less than 10 cm (see section 1.4).
412(c)	639	The design of the DN30-X packaging takes into account temperatures ranging from -40 °C to +70 °C (see section 1.4.1). Special attention is given to the potential degradation of the packaging materials within the temperature range.
-	640	The design and manufacturing techniques for the 30B-X cylinder are in accordance with ASME and ANSI standards. The design and manufacturing techniques for the DN30 PSP are in accordance with ISO and EN standards.
412(d)	641, 642, 643	The containment system of the DN30-X package is defined in section 1.4.3. The containment system cannot be opened unintentionally as it is enclosed in the DN30 PSP, which in turn is securely closed by a positive fastening device during transport (see section 1.4.2.3.4). The containment system cannot be opened by a pressure that may arise within the package, as it withstands a hydraulic strength test at a pressure of 2.76 MPa, which is much higher than the internal pressure under RCT and NCT (see section 2.2.3.3).

Additional design requirements for Type A packages		
49 CFR §173	**IAEA SSR-6**	**Remarks**
412(e)	644	The design of the 30B cylinder is standardized in [ANSI N14.1]. This design is world-wide in use since decades. The 30B-X cylinder is made of the same kind of materials as the 30B cylinder. Hence, it can be assumed that there will be no significant radiolytic decomposition of materials or generation of gas by chemical reaction and radiolysis.
412(f)	645	The pressure in the 30B-X cylinder during transport is below atmospheric pressure. As the 30B-X cylinder withstands a test pressure of 2.76 MPa, the containment is not affected by a reduction of ambient pressure to 60 kPa.
412(g)	646	The 30B-X cylinder with its valve is enclosed by the DN30 PSP during transport.
412(h)	647	The 30B-X cylinder is enclosed in the DN30 PSP, which is securely closed by a positive fastening device (see section 1.4.2).
412(i)	638	Each tie-down device that is a structural part of the DN30-X package is designed so that failure of this device under excessive load does not impair the ability of the package to meet other requirements of 49 CFR Subpart I (see section 2.2.5.1).
412(j)	648	When evaluated against the performance requirements of this section and the tests specified in 49 CFR §173.465, the DN30-X packaging prevents: (1) Loss or dispersal of the radioactive UF_6 contents (see section 2.4). (2) A significant increase (more than 20 %) in the radiation levels recorded or calculated at the external surfaces for the condition before the test (see section 2.5.6.4).
412(k)(1)	649	During transport the UF_6 is in solid form. However, to make provisions for filling effects, the 30B-X cylinder is always filled to less than 60 % taking care of the significant expansion of UF_6 during its solid to liquid phase change in case the UF_6 is liquefied during filling or emptying.
412(k)(2)	650	Not applicable to the DN30-X package as during transport the UF_6 is in solid form.
412(l)	651	Not applicable to the DN30-X package as during transport the UF_6 is in solid form.

1.6.2.3 Authorized Type A and Fissile Material Packages

49 CFR §173	IAEA SSR-6	Remarks
415	-	The DN30-X is a Type AF packaging that meets the applicable standards for fissile materials in 10 CFR Part 71 and is used in accordance with 49 CFR §173.471.
417	-	The DN30-X is a Type AF packaging that meets the applicable standards for fissile material packages in 10 CFR Part 71.

1.6.2.4 Uranium Hexafluoride

49 CFR §173	IAEA SSR-6	Remarks
-	420	The contents of the DN30-X package comply with the following requirements: (a) The permissible mass of UF_6 is specified for the 30B-X cylinder in section 1.3.2.1. (b) The permissible mass of UF_6 considers a minimal ullage of 5 % at the maximum temperature of the DN30-X package. (c) When presented for transport, the UF_6 is in solid form and the internal pressure is below atmospheric pressure.
420(a)	420, 631, 632, 718	In addition to the other applicable requirements of 49 CFR Subpart I, the following is considered for the DN30-X package with regard to its UF_6 content: (1) Before initial filling and during periodic inspection and test, the 30B-X cylinder is cleaned in following the requirements of [ANSI N14.1] for standard 30B cylinders. (2) The 30B-X cylinder is designed, fabricated, inspected, tested and marked with regard to the requirements for standard 30B cylinders in [ANSI N14.1]. A formal inclusion of the 30B-X cylinder in [ANSI N14.1] is in preparation. (3) The DN30-X package is designed so that it will: (i) Withstand a hydraulic strength test at an internal pressure of 2.76 MPa without leakage (see section 2.2.3.3). (ii) Withstand the test specified in 49 CFR §173.465(c) without loss or dispersal of the UF_6 (see section 2.2.6). (iii) Withstand the test specified in 10 CFR §71.73(c)(4) without rupture of the containment system (see section 2.2.7). (4) The testing requirements and controls before each transport in section 1.7.2 ensure that during transport, the UF_6 is in solid form. (5) The volume of the solid UF_6 content does not exceed 61 % of the certified volumetric capacity of the 30B-X cylinder at 20 °C to take care of the significant expansion of UF_6 during its solid to liquid phase change in case the UF_6 is liquefied during filling or emptying. (6) The testing requirements and controls before each transport in section 1.7.2 ensure that during transport, the internal pressure in the 30B-X cylinder is below atmospheric pressure (less than 101.3 kPa at 20 °C).
-	633	The DN30-X package has no pressure relief valves.
-	634	Does not apply to the DN30-X package.
420(b)	-	The inspections prescribed in section 1.8 ensure that the DN30-X package is periodically inspected, tested, marked and otherwise conforms with the requirements of [ANSI N14.1].
420(c)	-	Each repair to a 30B-X cylinder is performed with regard to the requirements of [ANSI N14.1] (see section 1.9.4).
420(d)-(e)	401, 419	For the DN30-X package, the proper shipping name and UN number “Radioactive material, uranium hexafluoride, fissile, UN 2977” must be used (see section 1.2.4).

1.6.2.5 Activity Limits, Radiation Level and Thermal Limitations, Contamination Control and Transportation

49 CFR §173	IAEA SSR-6	Remarks
431(a)	429	The activity in a DN30-X package licensed as Type AF package is limited to $1A_2$ (see section 1.3.2.5).
433(d)	430	For mixtures of radionuclides, the respective formula is applied.
441	527, 617	For all permissible contents in section 1.3, the transport index (TI) of the DN30-X package is below 10 (see section 2.5.6.1). Furthermore, the radiation level at the surface of each DN30-X package does not exceed 2 mSv/h under conditions normally incident to transportation (see section 2.5.6.2).
442	(654), 679	The DN30-X package is designed, constructed, and prepared for transport so that in still air at 38 °C and in the shade, no accessible surface of the package has a temperature exceeding 50 °C so that a nonexclusive use shipment is possible (see section 2.3).
447	568	For the DN30-X package, the CSI = 0 in all cases and, thus, also for groups of DN30-X packages the sum of the CSIs is 0.
-	569	Not applicable to the DN30-X package as the CSI = 0 in all cases.
-	570	Not applicable as the material defined in section 1.3 does not meet any of the provisions in 49 CFR §173.453.
448(a)	564	The DN30-X package is transported by road, rail or sea on dedicated flat racks. The tie-down features of the package are designed such that shifting of the package during normal transportation conditions is prevented.
448(b)	565	Not applicable to the DN30-X package.
448(c)	563	Not applicable to the DN30-X package.
448(d)-(g)	-	Not applicable to the DN30-X package.
-	566(b)	The radiation level of a conveyance of several packages is below 2 mSv/h at any point of the external surface and below 0.1 mSv/h at 2 m distance from the external surface (see section 2.5.6.3).
453	417	There are no exceptions by one of the provisions specified in this paragraph (see specification of contents in section 1.3).

49 CFR §173	IAEA SSR-6	Remarks
457	525-528	(a) A CSI and a TI in accordance with 49 CFR §173.403 will be assigned to the DN30-X package. (b) The DN30-X package satisfies the radiation level restrictions of 49 CFR §173.441(a). (c) For the DN30-X package, the CSI = 0 so that package may be shipped by a carrier in a nonexclusive use conveyance. (d) For the DN30-X package, the CSI = 0 in all cases and, thus, also for groups of DN30-X packages the sum of the CSIs is 0. (e) See (c). (f) See (b). (g) See 49 CFR §173.447. (h) See section 1.6.2.7.
459	-	Not applicable to the DN30-X package.

1.6.2.6 Test Procedures

General test procedures		
49 CFR §173	**IAEA SSR-6**	**Remarks**
461	701	For the demonstration of compliance, the following methods are used: (1) Performance of tests with DN30 PSP prototypes (see Appendix 2.2 (Structural Analysis), appendix A and B, and Appendix 2.3 (Thermal Analysis), appendix 1). (2) Analysis and calculations for the DN30-X package in part 2 of this SAR.
-	702	The DN30 PSP prototypes used for the tests were assessed before and after the tests according to written procedures (see Appendix 2.2 (Structural Analysis), appendix B and Appendix 2.3 (Thermal Analysis), appendix 1).
462(a)	713	The DN30 PSP prototypes used for the tests were inspected before each test according to a written procedure. The results of the inspection were documented. The inspection comprised at least: (a) Divergence from the design (b) Defects in manufacture (c) Corrosion and deterioration (d) Distortion of features The inspection procedures are specified in Appendix 2.2 (Structural Analysis), appendix A and B, and Appendix 2.3 (Thermal Analysis), appendix 1.

General test procedures		
49 CFR §173	**IAEA SSR-6**	**Remarks**
462(b)	-	The deviations from the specified design for the DN30 PSP were taken into account in the subsequent evaluation of the DN30-X package.
462(c)	714	The containment system of the DN30-X package is defined in section 1.4.3.
462(d)	715	The DN30 PSP prototypes used for the tests were marked with a serial No. and, therefore, could be easily referenced (see Appendix 2.2 (Structural Analysis), appendix A and B, and Appendix 2.3 (Thermal Analysis), appendix 1).
-	716	After each test or group of tests or sequence of the applicable tests, as appropriate: (a) Faults and damage are identified and recorded (see Appendix 2.2 (Structural Analysis). (b) It is determined whether the integrity of the containment system and shielding has been retained to the extent required (see Appendix 2.2 (Structural Analysis). (c) It is determined whether the assumptions and conditions used in the criticality safety analysis for one or more packages are valid (see Appendix 2.2 (Structural Analysis).

Type A packing tests and tests for demonstrating the ability of fissile materials packagings to withstand accident conditions in transportation		
49 CFR §173	**IAEA SSR-6**	**Remarks**
465(a)	719	See 49 CFR §173.465(b)-(e).
465(b)	720,721	The DN30 PSP is a fully closed and welded structure of stainless steel. Any influence of the water spray test on the properties of the DN30-X package can be excluded (see section 2.2.6.1).
465(c)	722	The free drop test is analyzed in sections 2.2.6.2 and 2.2.7. It was also carried out with DN30 PSP prototypes as documented in Appendix 2.2 (Structural Analysis), appendix B. The target for the experimental drop tests and the drop test analyses complies with the requirements of [SSG-26 2012] para. 717.2.
465(c)(2)	-	The impact from preceding 0.3 m corner drops is estimated to be negligible for the DN30-X package (see section 2.2.6.2).
465(c)(5)	717	The target for drop tests complies with the requirements of [SSG-26 2012] para. 718.2.
465(d)	723	The shape of the packaging effectively prevents stacking. Nevertheless, the DN30-X successfully passes the compression test as demonstrated in section 2.2.6.3.
465(e)	724	The DN30-X package is designed to withstand HAC. The puncture test (drop onto a bar) specified in 10 CFR §71.73(c)(3) is much more severe than the penetration test specified in this paragraph (see also section 2.2.6.4).

Type A packing tests and tests for demonstrating the ability of fissile materials packagings to withstand accident conditions in transportation		
49 CFR §173	**IAEA SSR-6**	**Remarks**
466	725	Not applicable as during transport, the UF_6 content is in solid form.
467	726-733	The DN30-X package meets the test requirements prescribed in 10 CFR Part 71 for the ability to withstand accident conditions in transportation (see section 1.6.1.3).

Quality control for constructing of packaging and quality control requirements prior to each shipment		
49 CFR §173	**IAEA SSR-6**	**Remarks**
474	501, 501(b)	The manufacturing specifications in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and Appendix 1.9.2B (Manufacturing Specification DN30 PSP) as well as the testing requirements and controls before first use in section 1.7.1 ensure that: (a) The DN30-X packaging meets the design and construction requirements as specified in 49 CFR Subpart I. (b) The effectiveness of the shielding and containment are within the limits specified for the package. The DN30-X packaging has no dedicated component for heat dissipation because of the very low level of thermal power.
475(a)	502	The administrative controls before shipment in section 1.7.2 ensure that only the contents as specified in the certificate of package approval are loaded into the DN30-X packaging.
475(b)	-	The DN30-X packaging is in unimpaired physical condition, except for superficial marks.
475(c)	-	Each closure device of the DN30-X packaging, including any required gasket, is properly installed, secured, and free of defects.
475(d)	501(c)	The manufacturing specification in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and the testing requirements and controls before first use in section 1.7.1 ensure that the CCS of the 30B-X cylinder is present and in proper condition. The handling instructions defined in sections 1.7.3 and 1.7.4, the testing requirements and controls before each transport in section 1.7.2 and the prescribed inspections in section 1.8 ensure that the proper condition of the CCS is maintained throughout the life-time of a DN30-X package.
475(e)		Each special instruction for filling, closing, and preparation of the packaging for shipment has been followed.
475(f)	503(c)	Each closure, valve, or other opening of the containment system through which the radioactive content might escape is properly closed and sealed.
475(g)	-	Not applicable to the DN30-X package.
475(h)	-	The internal pressure of the containment system will not exceed the design pressure during transportation.
475(i)	-	External radiation and contamination levels are within the allowable limits specified in 49 CFR Subpart I.

Quality control for constructing of packaging and quality control requirements prior to each shipment		
49 CFR §173	**IAEA SSR-6**	**Remarks**
476	803	Not applicable to the DN30-X package.

1.6.2.7 Additional Requirements Relating to Transport by Vessel

49 CFR §176	IAEA SSR-6	Remarks
704(a)	566 (b)	The radiation level of a conveyance of several packages is below 2 mSv/h at any point of the external surface and below 0.1 mSv/h at 2 m distance from the external surface (see section 2.5.6.3).
704(b)	575	The radiation level at the surface of each package is below 2 mSv/h (see section 2.5.6.3).

1.7 Operation

Operation of the DN30-X packaging is subdivided into four lifetime phases of the DN30-X packaging:

1. Testing and controls before its first use,
2. Regular usage and testing and controls before each transport,
3. Periodical inspection in defined intervals,
4. Repairs to return the DN30-X packaging to service.

All these phases are regulated in manufacturing specifications, handling and test instructions as specified below. At the time of application of these specifications and instructions, the user must make sure that valid revisions of these specifications and instructions are available.

Operation of the 30B-X cylinder in facilities, especially with regard to filling, emptying and washing, is described in Appendix 1.7.3 (30B-X Cylinder Facility Operations), along with the demonstration that these processes have no impact on the safe transport of the DN30-X package.

1.7.1 Testing Requirements and Controls before first Use

The testing requirements and controls before the first use of the packaging are specified in:

- The specification for the 30B-X cylinder in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder)
- The specification for the DN30 PSP in Appendix 1.9.2B (Manufacturing Specification DN30 PSP)

1.7.2 Testing Requirements and Controls before each Transport

The testing requirements and controls before each transport are described in:

- Section 1.7.2.1 for the 30B-X cylinder
- Section 1.7.2.2 for the DN30 PSP
- For annual and 5-year inspection requirements as well as treatment of non-conformances and deviations see section 1.8.

1.7.2.1 Inspection of the 30B-X Cylinder

Before filling the 30B-X cylinder, inspections in accordance with [ANSI N14.1] and at least as described in [USEC 651] (or in equivalent plant specific instructions) shall be carried out:

- The 30B-X cylinder shall be handled and filled in accordance with [ANSI N14.1] and at least as described in [USEC 651].
- The 30B-X cylinder has a valid maintenance certificate (valid date on the 30B-X cylinder's nameplate).

- 30B-X cylinders that have not been inspected and tested within the required 5-year period shall not be refilled until they are properly reinspected and retested. Prior to shipment, 30B-X cylinders that have not been recertified within the 5-year requirement shall be visually inspected for degradation of the cylinder wall. Any questionable conditions should be investigated. Details on the visual inspection are provided in the test instruction in Appendix 1.8.1 (Inspections of 30B-X Cylinders).
- Any defective condition must be corrected before filling according to the requirements of [ANSI N14.1]:
  - The 30B-X cylinder shall be routinely examined as received and prior to sampling, withdrawal, filling, or shipping to ensure that it remains in a safe and usable condition.
  - Leakage, cracks, excessive distortion, bent or broken valves or plugs, broken or torn skirts, or other conditions that may affect the safe use of the cylinder shall warrant appropriate precautions, including removing the cylinder from service until the defective condition is satisfactorily corrected.
  - Questionable conditions should be referred to a qualified inspector for evaluation and for recommendations concerning use, repair, or condemnation of the cylinder in question.
  - Conditions of the 30B-X cylinder that might indicate excessive damage of the CCS, such as severe outer damages of the cylinder shell or skirts, should be referred to a qualified inspector. Reuse of such cylinders is only allowed after internal inspection of such cylinders and proof that the CCS is undamaged.
- Before filling, the cylinder is weighted to establish the net weight of the heels to ensure the fill limit will not be exceeded.
- To avoid overfilling, the 30B-X cylinder shall be weighted after being filled.

Before loading into the DN30 PSP, the inspection of the 30B-X cylinder should be carried out in accordance with [ANSI N14.1], and at least as described in [USEC 651] (or in equivalent plant specific instructions):

- The content of the 30B-X cylinder has to comply with the certificate of approval of the DN30-X package.
- Before shipping, the 30B-X cylinder shall be inspected for leak-tightness, damage, as well as other unacceptable conditions.
- UF_6 shall be shipped only in solid form and when the vapor pressure within the 30B-X cylinder is below atmospheric.
- The safe state of the 30B-X cylinder shall be recorded by the UF_6 supplier and the record shall be provided to the shipper.

Special care has to be taken to ensure that the filled cylinder fulfills the leak-tightness criteria of [ANSI N14.1] and the following requirements:

- The leak tightness of the valve seat of a filled cylinder shall be verified by leakage rate testing of the pigtail before disconnection and after closing the cylinder valve seat.
- A standardized leakage rate larger than $L_{\mathrm{N}} = 1 \cdot 10^{-4}\ \mathrm{Pa} \cdot \mathrm{m}^3/s$ specified in section 1.2.10 shall not be permitted.

- If air is used for a pressure drop test, the air supply should be clean, dry and free from oil. If it is not, or if the quality of the air supply is uncertain, the test should be performed with nitrogen to ensure reliable results.
  - The leakage test method shall comply to [ANSI N14.5] or [ISO 12807].
  - The test shall be performed using a pressure gauge, accurate within 1 %, or less, of full scale.
  - After the test pressure of 100 psig (690 kPa gauge) prescribed in [ANSI N14.1] has been applied, the pressure supply shall be removed. A drop in pressure within a test period of at least 15 minutes that is greater than the minimum detectable amount shall be cause for test failure.
  - Corrective measures shall be taken to remedy the leak as prescribed by the facility's operating procedures.
- Alternatively, a vacuum test may be performed on the cylinder by attaching a pigtail to the closed cylinder valve and drawing a vacuum for at least 15 minutes.
  - The continued presence of UF_6 in the pigtail is an indication that the valve is not fully closed or is defective.
  - Corrective measures shall be taken to remedy the leak as prescribed by the facility's operating procedures.

  Note: the cylinder's outer surface shall be approximately at ambient temperature and its vapor pressure below atmospheric pressure.

1.7.2.2 Inspection of the DN30 PSP

The DN30 PSP shall be inspected prior to loading according to the handling instruction in Appendix 1.7.1 (Handling Instruction). The inspection comprises:

- A visual inspection
- A functional test of all movable parts

Following observations shall be cause for further investigation, replacement of parts, or rejection of the DN30 PSP as specified in detail in the test instruction in Appendix 1.8.2 (Inspections of DN30 PSPs):

- Structural changes of exterior or interior shells like excessive deformations, cracks, holes, etc.
- Excessive damage of flange areas
- Missing or damaged marking of the DN30 PSP
- Missing or damaged thermal plugs
- Missing or damaged gasket
- Damage of the mortise-and-tenon closure system
- Missing or damaged seals
- Damage of the valve protecting device as well as functional issues
- Damage of the rotation preventing device as well as functional issues

- Excessive wear and tear of the intumescent material
- Damage to any welding seams like cracks, holes, excessive corrosion
- Excessive damage of handling devices
- Excessive damage of the silicon pads

The test instruction in Appendix 1.8.2 (Inspections of DN30 PSPs) contains in detail the criteria and measures in case of deviations during the visual inspections and functional tests. Measures could comprise cleaning, replacement of parts, minor repairs (on site) and major repairs (to be carried out by the license holder or an authorized repair shop qualified for such repair).

1.7.3 Handling and Tie-down Requirements

Handling of the DN30-X package, the DN30-X packaging and also its parts is described in section 1.4.2.4. For the handling operations, adequate means as described in the handling instruction in Appendix 1.7.1 (Handling Instruction) have to be used.

Tie-down of the DN30-X package and packaging is described in section 1.4.2.5. The procedures to be applied to ensure proper tie-down are specified in the handling instruction in Appendix 1.7.1 (Handling Instruction).

1.7.4 Loading Procedures for the 30B-X Cylinder and the DN30 PSP

Before each use, the 30B-X cylinder and the DN30 PSP shall be inspected as described in section 1.7.2.1 and section 1.7.2.2, respectively.

1.7.4.1 Loading and unloading of UF_6 content into the 30B-X Cylinder

Filling with UF_6, and emptying and washing of 30B-X cylinders is described in site-specific operating handbooks that are not part of this SAR. General aspects of these processes are described in Appendix 1.7.3 (30B-X Cylinder Facility Operations), along with the demonstration that these processes have no impact on the safe transport of the DN30-X package.

Before transport, it must be assured that the 30B-X cylinder was given ample time for cooling down such that the UF_6 is in solid form.

The testing and controls described in section 1.7.2 shall be performed and documented prior to loading a 30B-X cylinder into the DN30 PSP.

Any 30B-X cylinder filled with either UF_6 or heels from UF_6 shall comply with the transport regulatory requirements for UF_6.

1.7.4.2 Loading of the 30B-X Cylinder into the DN30 PSP

Loading of a 30B-X cylinder into the DN30 PSP is identical to loading a standard 30B cylinder into the DN30 PSP. An overview of the safety related loading steps during loading of a 30B-X cylinder into the DN30 PSP is listed in the following:

1. The lever of the rotation preventing devices are in position “open”.
2. The valve protecting device and its housing are in position “open”.

3. Lower the 30B-X cylinder in horizontal orientation with the valve in 12°o'clock position into the bottom half of the DN30 PSP.
4. When the lower rim of the cylinder skirt has passed the valve protecting device, rotate the valve protecting device towards the cylinder head by about 90° until it gets in contact with the cylinder head. Then lower the cylinder until it rests on the inner shell of the bottom half of the DN30 PSP. Then push the housing in position "closed".
5. Move the lever of the rotation preventing devices to position "closed".
6. Lower the top half of the DN30 PSP onto the bottom half.
7. Insert the pins into the six mortise-and-tenon closure devices and fix the pins with the securing bolts.
8. Install the seals.

Details on each loading step are specified in the handling instruction in Appendix 1.7.1 (Handling Instruction).

1.7.4.3 Unloading of the 30B-X Cylinder from the DN30 PSP

Unloading of a 30B-X cylinder from the DN30 PSP is identical to unloading a standard 30B cylinder from the DN30 PSP. In order to prevent damage of any safety related feature during unloading, the following general steps are required:

1. Check and remove the seals.
2. Loosen the securing bolts and remove the pins of the six mortise-and-tenon closure devices.
3. Lift off the top half of the DN30 PSP.
4. Move the lever of the rotation preventing devices to position "open".
5. Pull the housing from the valve protecting device in position "open".
6. Lift the 30B-X cylinder and rotate the valve protecting device by about 90° until it rests on the flange of the bottom half.
7. Lift the 30B-X cylinder out of the bottom half of the DN30 PSP.

Details on each unloading step are given in the handling instruction in Appendix 1.7.1 (Handling Instruction).

1.7.5 Supplementary Equipment and Operational Controls

No supplementary equipment except means for tie-down are used during transport of the DN30-X package in any transport mode.

1.7.6 Precautions and Measures because of the other Dangerous Properties of the Content

No precautions and measures due to the other dangerous properties of the content are required except for the correct labeling according to the respective transport mode.

1.8 Inspection

1.8.1 Annual Inspection Requirements for the DN30 PSP

The annual inspections of the DN30 PSP were already established in the safety analysis of the DN30 package and are described in the test instruction in Appendix 1.8.2 (Inspections of DN30 PSPs), in which the criteria for the checks and measures in case of non-conformances or deviations are specified as well.

In the case that non-conformances or deviations might affect the safety of the DN30-X packaging the user of the packaging has to inform the owner of the certificate of package approval in writing about the non-conformance or deviation. It is then the decision of the owner of the certificate of package approval to undertake suitable measures to return the packaging to service in full compliance with the SAR and the certificate of package approval.

1.8.2 5-year Inspection Requirements for the 30B-X Cylinder and the DN30 PSP

The 5-year periodical inspections of the DN30-X packaging are subdivided into the periodical recertification of the 30B-X cylinder and the periodical inspection of the DN30 PSP.

The 5-year inspection of the 30B-X cylinder shall be performed conforming to the requirements of [ANSI N14.1] and at least as described in [USEC 651] (or in equivalent plant specific instructions). This inspection includes, but is not limited to, the following:

- 30B-X cylinders, except those already filled at the 5-year expiration date, are to be periodically inspected and tested throughout their service life.
- 30B-X cylinders that have not been inspected and tested within the required 5-year period shall not be refilled until they are properly reinspected and retested. Prior to shipment, 30B-X cylinders that have not been recertified within the 5-year requirement shall be visually inspected for degradation of the cylinder wall. Any questionable conditions should be investigated. Details on the visual inspection are provided in the test instruction in Appendix 1.8.1 (Inspections of 30B-X Cylinders).
- The 5-year periodic inspections and tests consist of the following:
  - An internal and external examination of the 30B-X cylinder by a qualified inspector, including a visual inspection of the interior CCS as far as accessible.
  - A hydraulic strength test as described in [ANSI N14.1].
  - When a valve or plug change has occurred, a 100 psig pneumatic leak-test as described in [ANSI N14.1] is required.
- After a 30B-X cylinder is tested, its outer shell may be cleaned and repainted. At each 5-year periodic inspection, the cylinder shall have the tare weight re-established.
- A 30B-X cylinder shall be removed from service (for repair or replacement) when it is found to contain leaks, corrosion, cracks, bulges, dents, gouges, defective valves, damaged skirts, or other conditions that, in the opinion of a qualified inspector, render it unsafe or unserviceable in its existing condition.
- A 30B-X cylinder shall no longer be used in UF_6 service when the shell thickness has decreased below 11 mm.

The periodical inspections of the DN30 PSP were already established in the safety analysis of the DN30 package and are described in the test instruction in Appendix 1.8.2 (Inspections of DN30 PSPs), in which the criteria for the checks and measures in case of non-conformances or deviations are specified as well.

In case non-conformances or deviations might affect the safety of the DN30-X packaging, the user of the packaging has to inform the owner of the certificate of package approval in writing about the non-conformance or deviation. It is then the decision of the owner of the certificate of package approval to undertake suitable measures to return the packaging to service in full compliance with the SAR and the certificate of package approval.

1.9 Management System

The management system of company Orano NCS GmbH (ONCS) is laid down in the Integrated Management Handbook (see Appendix 1.9.1 (IMS)). The integrated management system (IMS) is certified according to:

- DIN EN ISO 9001
- DIN EN ISO 14001
- OSHAS 18001
- KTA 1401
- BAM GGR 011
- 10 CFR Part 71 – Subpart H

The IMS covers the design and development, manufacturing and operation of packagings for packages requiring approval by the competent authorities for the transport of radioactive material. Appendix 1.9.3 (Quality Assurance Program) provides a description of the ONCS quality assurance (QA) program that demonstrates compliance with the requirements of [10 CFR Part 71] – Subpart H. It also includes the NRC approval of this program.

1.9.1 Design, SAR, Documentation and Records

1.9.1.1 General

ONCS is responsible for the design, development, safety analyses, manufacturer planning and surveillance, inspection, and controls before first use of DN30 PSPs and 30B-X cylinders. ONCS is also responsible for the operation of DN30 PSPs and 30B-X cylinders including maintenance and periodical recertification.

All documents like drawings, calculations, specifications etc. are written, checked and released in accordance with the IMS of ONCS. The author and the examiner must be experienced in the respective field of technology whereas the person releasing the document must be authorized according to the organizational structure of ONCS. For each field of technology, the different roles of the employees of ONCS are described in the IMS.

Any design modifications including any revisions of specifications, drawings and instructions are carried out according to the processes laid down in the IMS and documented accordingly. In case there are documents from suppliers, ONCS will check these documents according to the process laid down in the IMS.

1.9.1.2 Design

ONCS is responsible for the whole design process from establishing the requirements based on the applicable regulations and standards up to the completion of the drawings, safety analyses, and the manufacturing specification. All individual steps necessary for the design process are stipulated in the IMS of ONCS.

Design modifications required due to the progress in carrying out the safety analyses or resulting from the outcome of physical tests with specimens or prototypes are introduced into the design process in compliance with the respective process described in the IMS of ONCS.

1.9.1.3 Documents and Records

Traceability of each document and record relevant during the design process is assured by the requirements of the IMS of ONCS with respect to a unique numbering and filing system. During the design process the documents listed in Appendix 1.1 (List of Applicable Documents) are produced and filed.

For each document written and released by ONCS, the original workable document is stored together with the signed document as image. For documents and records of suppliers, only an image of the document might be made available and stored.

1.9.2 Manufacturing and Testing

1.9.2.1 Manufacturing of 30B-X Cylinders

For the 30B-X cylinder, qualification and selection of the manufacturer as well as the requirements towards QA during material procurement, manufacturing, and final inspection before first use are specified in the manufacturing specification in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder). This specification details among others the following requirements:

- Qualification of manufacturer
- Scope of services and responsibilities of manufacturer
- Responsibilities of ONCS
- Requirements for materials including certification
- Requirements concerning fabrication including welding
- Requirements concerning final acceptance test
- Treatment of non-conformances
- Manufacturing test sequence plan (MTSP)

1.9.2.2 Manufacturing of Serial DN30 PSPs

The manufacturing of serial DN30 PSPs has already been established for the DN30 package. Therefore, qualification and selection of the manufacturer as well as the requirements towards QA during material procurement, manufacturing, and final inspection before first use are specified in the manufacturing specification in Appendix 1.9.2B (Manufacturing Specification DN30 PSP). This specification details the same requirements as listed for the 30B-X cylinder in section 1.9.2.1

1.9.2.3 Testing of Samples and Prototypes

Manufacturing and testing of samples and prototypes is managed comparably to the standards specified for the 30B-X cylinders and the serial DN30 PSPs.

Samples for mechanical and thermal testing of the foam used as shock absorbing material and thermal insulation in the DN30 PSP are manufactured, certified, and documented identically to the foam used in the DN30 PSP prototypes and serial DN30 PSPs.

Samples for thermal testing of the thermal intumescent material are manufactured, certified, and documented identically to the intumescent material used in the DN30 PSP prototypes and serial DN30 PSPs.

The tests to determine the properties of the foam and intumescent material are documented in the summary reports that are part of Appendix 1.4.2 (Material Properties). For these tests qualified institutes were involved:

- The Material Testing Institute, University of Stuttgart (MPA), for the mechanical tests with foam specimen.
- The institute for combustion and gas dynamics, University of Duisburg-Essen, for the analysis of the chemical composition of the foam under different thermal conditions.
- Company Influtherm, an independent society specialized in thermal measurements and services, for the measurement of the thermal properties of the foam and the intumescent material.
- Company Thermoconcept, an independent society specialized in thermal measurements and services, for the measurement of the thermal conductivity of the expanded intumescent material.
- Company Mecanium, an independent society specialized in mechanical measurements and services, for the measurement of the expansion forces of the intumescent material.
- Experimental drop tests with DN30 PSP prototypes were carried out by the BAM. For package approvals originating in Germany, BAM is one part of the German competent authorities and responsible for the structural, thermal, and containment analysis as well as QA.

1.9.2.4 Storage of Batch Samples

During the manufacturing of the serial DN30 PSPs, several samples are taken from each batch of foam, intumescent material and thermal insulation and stored at DAHER's site for the lifetime of the DN30 PSP (estimated between 30 and 50 years), for the following reasons:

- Monitoring and analyzing of the aging process of these materials, since most of them are not visible or easily accessible during the maintenance of the DN30 PSP.
- Being able to perform tests on the aged samples on request by any competent authority.

This is also mentioned in Appendix 1.4.2 (Material Properties).

1.9.3 Operation

The quality management requirements for operation are specified in the handling instruction in Appendix 1.7.1 (Handling Instruction).

In case the DN30 PSP is leased to a customer for transports, the handling instruction is provided to this customer who has to confirm in writing that he will comply with the requirements stipulated there.

In case the DN30-X packaging is sold to a customer, the handling instruction and the test instruction regulating regular and periodical inspections are provided to this customer who has to confirm in writing that he will comply with the requirements stipulated there.

1.9.4 Maintenance and Repair

The quality management requirements for the recertification of 30B-X cylinders are described in the test instruction in Appendix 1.8.1 (Inspections of 30B-X Cylinders) and a description of the non-conformances and deviations for which repair is required is included in this test instruction as well. Since, the same non-conformances and deviations apply to the visual inspection of the 30B-X cylinder, this test instruction is also referenced in the handling instruction in Appendix 1.7.1 (Handling Instruction). In addition, the following applies to repairs other than replacement of parts:

- For repair of 30B-X cylinders other than replacement of parts, the specification in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) must be complied with.

The quality management requirements for periodical inspections of DN30 PSPs were already established in the safety analysis of the DN30 package and are described in Appendix 1.8.2 (Inspections of DN30 PSPs). This test instruction also contains the non-conformances and deviations for which repair of a DN30 PSP is required. In addition, the following applies to repairs other than replacement of parts:

- For repair of DN30 PSPs other than replacement of parts, the specification in Appendix 1.9.2B (Manufacturing Specification DN30 PSP) must be complied with.

In all cases in which repair of a 30B-X cylinder or a DN30 PSP is required, ONCS must be involved in the planning, authorization, and execution of the repair measures.

1.9.5 Compliance of any Activity with the SAR

The specifications in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and Appendix 1.9.2B (Manufacturing Specification DN30 PSP) ensure that during manufacturing and final acceptance tests before first use, the requirements of this SAR towards the design of the 30B-X cylinder and the DN30 PSP are met. In detail the following requirements are considered:

- Specification of the material properties in material data sheets to comply with the properties used throughout this SAR
- Requirements for welders and welding to ensure the structural properties of the 30B-X cylinder and the DN30 PSP as defined in this SAR
- Specification of tests and documentation during manufacturing and before first use ensuring the design of the 30B-X cylinder and the DN30 PSP comply with the drawings

The handling instruction in Appendix 1.7.1 (Handling Instruction) and test instruction in Appendix 1.8.1 (Inspections of 30B-X Cylinders) ensure that during operation, the 30B-X cylinder is kept compliant with this SAR. For the DN30 PSP, this is ensured by the application of the test instruction in Appendix 1.8.2 (Inspections of DN30 PSPs).

1.9.6 Deviations

Deviations concerning the safety elements listed in table 1-15 and the corrective actions implemented are to be reported to the competent authority.

1.9.7 Safety Elements

The safety elements of the DN30-X package are summarized in table 1-15.

Table 1-15 Safety elements

Element of the package	Safety function	Parameters
Closure system	Mechanical protection	• Welds • Absence of structural defects • Completeness
Outer shell	Mechanical protection	• Welds • Absence of structural defects in the steel sheets
Foam	Mechanical protection	• Thickness • Density
Microporous material	Thermal protection	• Thickness • Thermal conductivity
Intumescent material	Thermal protection	• Thickness • Completeness • Thermal conductivity
Inner shell	Mechanical protection	• Welds • Absence of structural defects in the steel sheets
Valve protecting device	Mechanical protection	• Welds • Absence of structural defects in the steel sheets • No unacceptable deformation of the housing • Completeness
Plug protecting device	Mechanical protection	• Welds • Absence of structural defects
Rotation preventing devices	Mechanical protection	• Welds • Absence of structural defects of the bolts • Completeness
30B-X cylinder	Containment	• Welds • Absence of structural defects • Thickness
	Confinement	• Absence of structural defects • Presence of neutron absorbing material

1.10 Package Illustration

Figure 1-12 to figure 1-14 show illustrations of the DN30-X package including the DN30 PSP and the 30B-X cylinder. More detailed illustrations of the 30B-X cylinder are presented in section 1.4.2.1. Appendix 1.4.1A (Drawings 30B-X Cylinder) and Appendix 1.4.1B (Drawings DN30 PSP) contain the set of drawings for the DN30 PSP and the 30B-X cylinder, respectively.

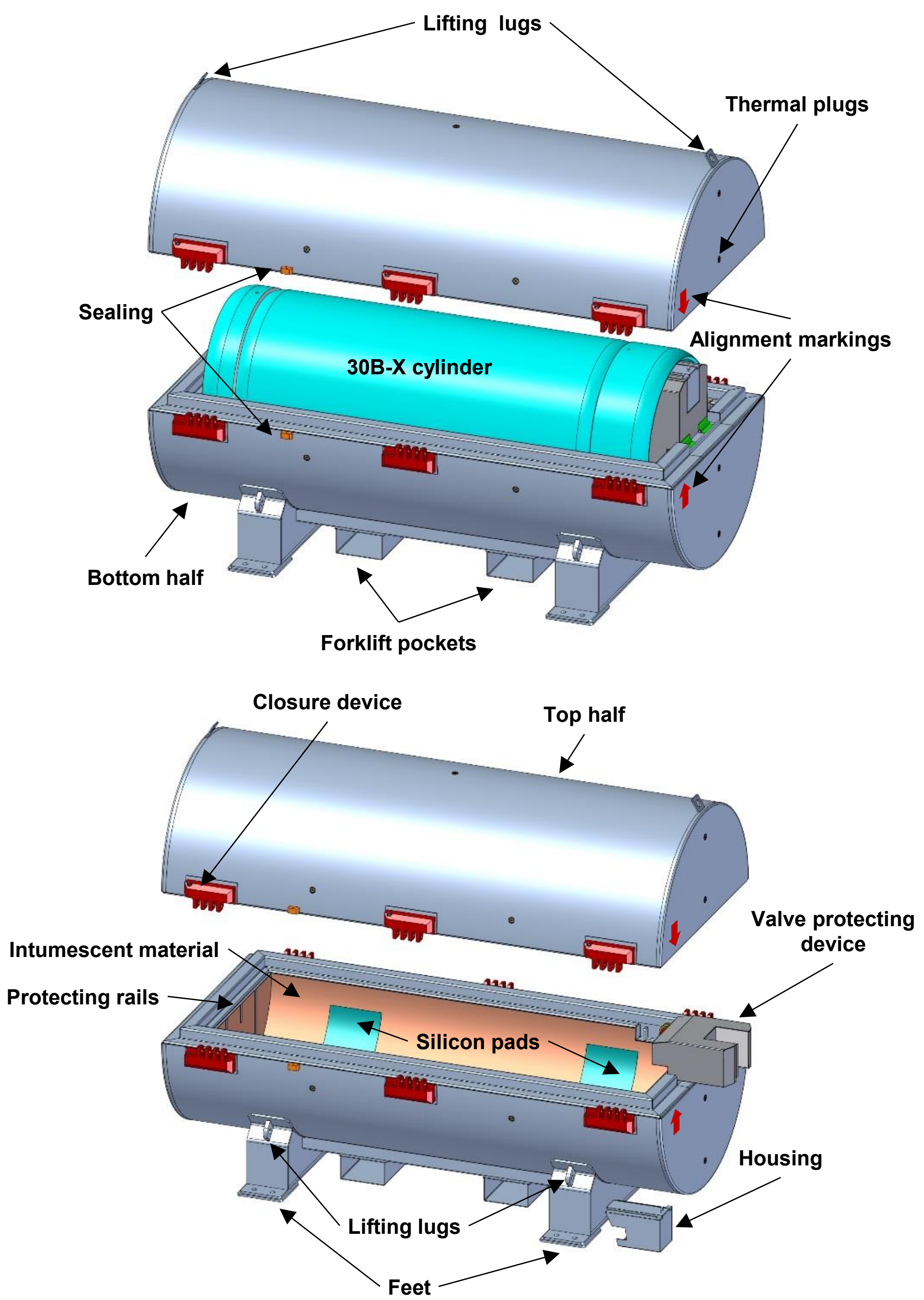

Figure 1-12 DN30-X Package Overview

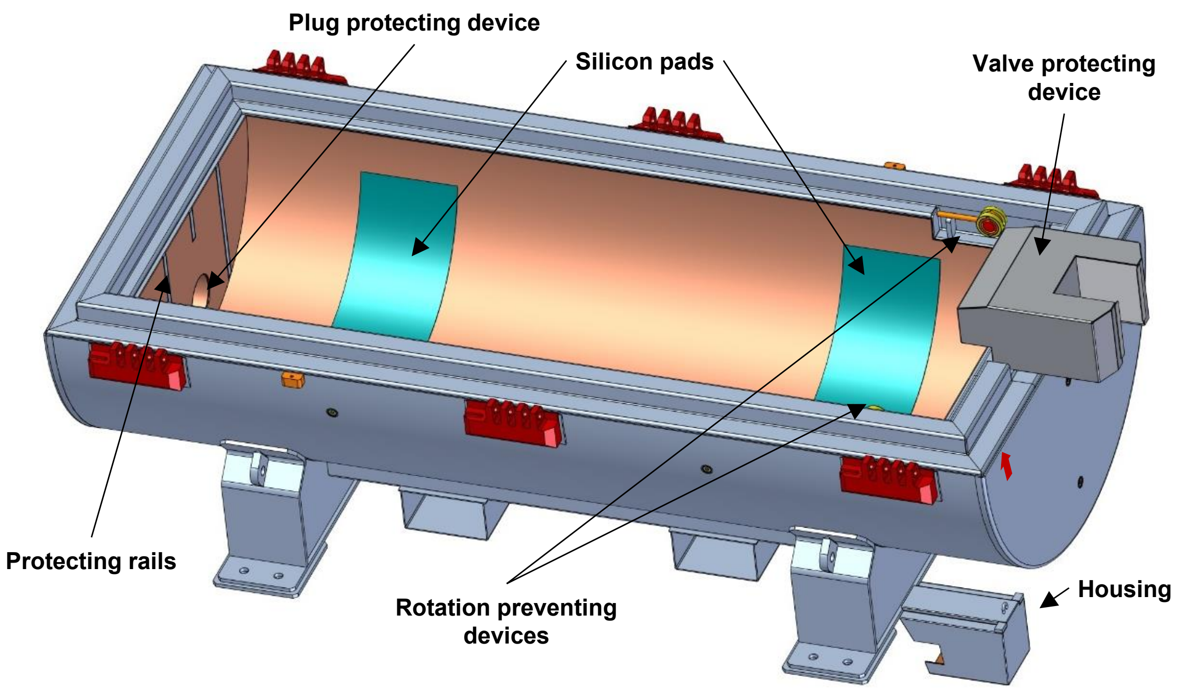

Figure 1-13 DN30 PSP bottom half

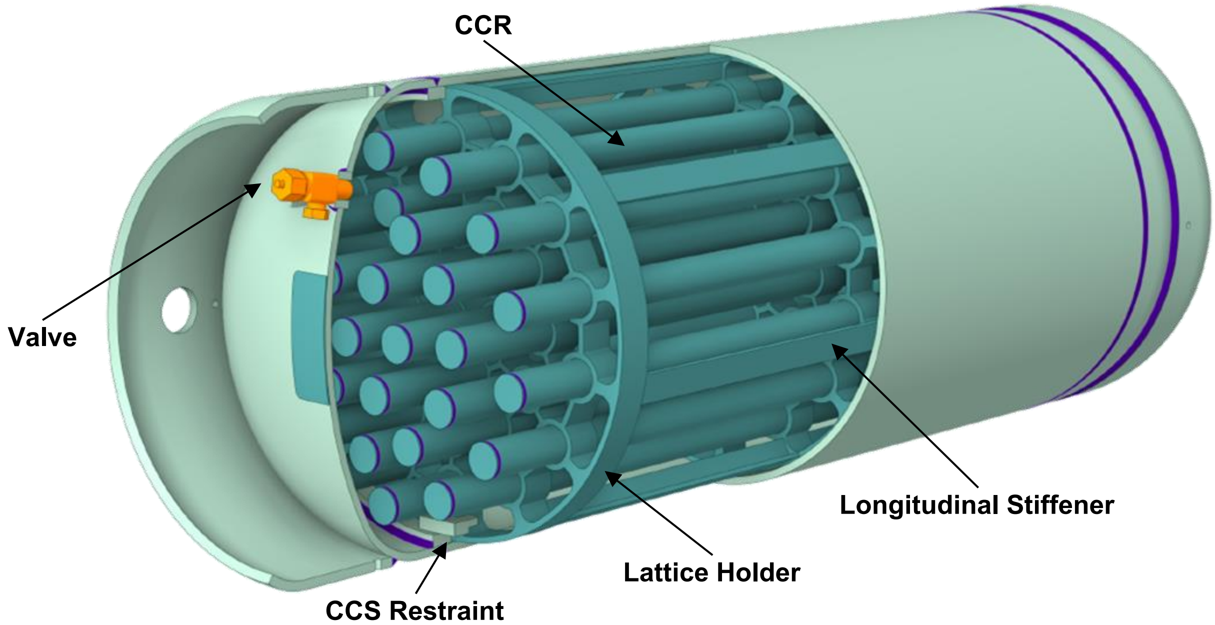

Figure 1-14 30B-X cylinder – Outside view

PART 2
TECHNICAL ANALYSES

2.1 Introduction

This introductory section provides a general outline of the technical analyses presented in the following sections, especially regarding the use of results from tests performed with the DN30 package that uses the same DN30 PSP design. It also contains an overview of the provisions and central assumptions that each technical analysis is based upon.

Section 2.1.1 provides a general guideline through the entire technical analysis of the DN30-X package. This includes the description and justification of the analysis methods for each part of the technical analysis. For the structural and the thermal analysis, this also includes the reasons why the results from drop and fire tests carried out for the DN30 package can be transferred to the DN30-X package.

The guideline through the technical analysis is followed by the common provisions for all technical analyses in section 2.1.2. For each technical analysis, a summary of the package design forming the basis for the technical analyses and a description of the required content properties, fundamental properties of the specification of the 30B-X cylinder and the DN30 PSP as well as the material characteristics are provided in section 2.1.2.1. With this at hand, the acceptance criteria and design assumptions for the 30B-X cylinder and the DN30-X package are defined in section 2.1.2.2.

2.1.1 Guideline through Technical Analyses

2.1.1.1 Structural Analysis

The structural analysis of the DN30-X package consists of two main parts:

1. The proof that the design requirements for normal operating conditions and recertification of the 30B-X cylinder are fulfilled (see section 2.1.1.1.1).
2. The proof that the requirements for Type AF packages for the transport of UF_6 from [10 CFR Part 71] and [49 CFR Part 173], resp. [SSR-6 2018] are fulfilled. This covers the structural analysis of the DN30-X for handling as well as under RCT, NCT, and HAC (see section 2.1.1.1.2.). Additional analyses regarding the the interaction between the 30B-X cylinder and the DN30 PSP are discussed in section 2.1.1.1.3.

The complete structural analysis of the DN30-X package is found in Appendix 2.2 (Structural Analysis) and summarized in section 2.2.

2.1.1.1.1 Structural Analysis of the 30B-X Cylinder for Normal Operating Conditions

The structural analysis of the 30B-X cylinder for normal operating conditions in section 2.2.3 shows that the requirements towards design, fabrication, inspection, and testing stipulated for the 30B-X cylinder in Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) are fulfilled. The analysis for normal operating conditions comprises:

- The analysis of the 30B-X cylinder for an internal and external maximum allowable working pressure (MAWP) at the design temperature of 121 °C.
- The analysis of the 30B-X cylinder with regard to the minimum design metal temperature (MDMT) of -29 °C and the minimal transport temperature of -40 °C.

- The analysis of the 30B-X cylinder for a hydraulic strength test at twice the MAWP.

These analyses are carried out by argumentation and, as required, by additional hand calculations using well established formulas for stress and strain provided by the ASME boiler and pressure vessel code (BPVC) [ASME BPVC].

2.1.1.1.2 Structural Analysis of the DN30-X for Handling and under RCT

The structural analysis of the DN30-X package for handling in section 2.2.4 and under RCT in section 2.2.5 comprises:

- Analysis of the lifting attachment points of the DN30 PSP
- Analysis of the features of the DN30 PSP used for tie-down
- Analysis of vibrations during transport
- Analysis of stresses caused by temperature influences

These analyses are carried out using hand calculations and well-established formulas for stress and strain.

2.1.1.1.3 Structural Analysis of the DN30-X under NCT and HAC

The structural analysis of the DN30-X under NCT in section 2.2.6 comprises the analysis of the following:

- Water spray test
- Free drop test
- Compression test
- Penetration test
- Reduced and increased external pressure

As explained in section 2.2.6.2, the free drop test is analyzed in sequence with the drop tests under HAC. Compliance with the other requirements is demonstrated by argument or calculations.

The structural analysis of the DN30-X under NCT and HAC in section 2.2.7 comprises the analysis of the sequence of the following drop tests:

Test 1: 1.2 m free drop test

Test 2: 9 m free drop test

Test 3: Puncture test

The calculation model for these analyses is validated via the simulation of results from the experimental drop test program for the DN30 package.

This validation is part of the structural analysis of the DN30 package under NCT and HAC (described in detail in appendix A of Appendix 2.2 (Structural Analysis)), carried out in three major steps:

1. Pre-analysis of the behavior of the DN30 package by using proven simulation tools and selection of benchmarks for real drop tests with prototypes.
2. Real testing of prototypes of the DN30 package by applying the selected benchmark test sequences.

3. Refinement of the simulation model for the DN30 package based on the results of the tests and complete analysis of the behavior of the DN30 package under NCT and HAC for the operating temperature range of -40 °C to +60 °C.

The structural analysis of the DN30 package in conjunction with the experimental drop tests proved that the following major requirements of [10 CFR Part 71] or [SSR-6 2018] are fulfilled:

- The DN30 package withstands the free drop test from a height of 1.2 m under NCT without loss or dispersal of the UF_6 content.
- The DN30 package withstands the free drop test from a height of 9 m and the puncture test under HAC without damage to the containment system.

The structural analysis of the DN30-X package under NCT and HAC assumes that the impact of the 30B-X cylinder on the DN30 PSP is comparable to the impact of the 30B cylinder on the DN30 PSP. This approach allows to use the results from prototype tests for the DN30 package and is admissible because of the following:

1. The 30B-X cylinder has the same gross weight as the standard 30B cylinder while also having the same outer dimensions, shell thicknesses and material specifications of the pressure envelope and the cylinder skirts (see Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and table 1-13).
2. The 30B-X and the standard 30B cylinder are equipped with the same valve and plug.
3. The 30B-X and the standard 30B cylinder are both transported in the same DN30 PSP.

With regard to the structural analysis, the only difference between the DN30 and the DN30-X package is the slightly different distribution of the content mass within the 30B-X cylinder, which is due to the addition of the interior CCS. Furthermore, the combination of the CCS and the UF_6 content might interact slightly differently with the cylinder shells than the UF_6 content on its own. However, when the UF_6 is in solid form during transport, the CCS is essentially stuck in the content. The possibilities of CCS to move around within the 30B-X cylinder are therefore very limited. Consequently, the interaction of the content with the 30B cylinder and the interaction of the CCS stuck in the content with the 30B-X cylinder is comparable.

Based on this argumentation, the experimental drop tests performed for the DN30 package and the complete analysis of the behavior of the DN30 package under NCT and HAC for the operating temperature range of -40 °C to +60 °C are also covering for the DN30-X package. To complete the structural analysis of the DN30-X package under NCT and HAC, only a few additional analyses are required to account for the differences between the two packages. Consequently, the structural analysis of the DN30-X package under NCT and HAC consists of two fundamental parts:

1. The first part, described in detailed in section 2.1.1.1.3.1, demonstrates that the interaction between the 30B-X cylinder and the DN30 PSP is comparable to the interaction between the 30B cylinder and the DN30 PSP. These analyses prove that the initially made assumptions are correct.
2. In the second part, described in detailed in section 2.1.1.1.3.2, analyses are performed that specifically consider the acceptance criteria established for the CCS of the 30B-X cylinder.

In the following, further details on each aspect of the structural analysis are given.

2.1.1.1.3.1 Comparison of Drop Test Analyses for the DN30-X and DN30 Package

For the structural analysis under NCT and HAC, the interaction between the DN30 PSP and the 30B-X cylinder must be considered to show that the 30B-X cylinder withstands these tests in a similar condition as the standard 30B cylinder. This is shown in section 2.2.7.1.3 by comparing the simulation results of drop tests performed at room temperature for the DN30-X package to the corresponding results for the DN30 package. Specifically, the deformations at the outer shells of the DN30 PSP as well as the plastic deformations and decelerations at the cylinders are compared. The results of the analyses together with the experimental drop tests performed with DN30 PSP prototypes prove that the requirements of [10 CFR Part 71] or [SSR-6 2018] are also fulfilled for the DN30-X package.

Because of the fissile properties of the UF_6 content, the structural analysis of the DN30-X must also demonstrate that the CCS retains its properties relevant to criticality control after the tests simulating NCT and HAC. This part of the structural analysis of the DN30-X represents the only major difference compared to the DN30 package. The criteria for the CCS of the 30B-X cylinder to ensure safe subcriticality after the tests simulating NCT and HAC are given in section 2.1.2.2.1.

2.1.1.1.3.2 Additional Analyses for the DN30-X Package

The acceptance criteria for the CCS of the 30B-X cylinder that are established in section 2.1.2.2.1 require the investigation of additional drop test scenarios for the DN30-X package that were not part of the structural analysis of the DN30 package. These are included in section 2.2.7.1.4. To complete the structural analysis of the DN30-X package, this part also contains a discussion of the remaining drop test scenarios that are not investigated in detail by analysis for the DN30-X package, but which were considered in the safety analysis of the DN30 package.

2.1.1.2 Thermal Analysis

The thermal analysis of the DN30-X package is investigated for NCT and HAC with steady-state and transient calculations using FEM. The basis for benchmarking and validation of the used calculations models are two prototype fire tests that were carried out with DN30 PSP prototypes and empty 30B cylinders complying with [ANSI N14.1]. These two real world fire tests were initially performed for the thermal analysis of the already licensed DN30 package, but the results are valid for the DN30-X package as well, as both packages share the same DN30 PSP and only parameters of the PSP are benchmarked.

Using empty cylinders minimizes the heat sink provided by the content and, thus, not only maximizes the thermal load acting on the cylinder shells and the valve/plug during the thermal test under HAC but also in the subsequent cooling phase. The thermal analysis in conjunction with the prototype tests demonstrated that the requirements of [10 CFR Part 71] or [SSR-6 2018] with respect to the thermal behavior of the DN30-X package are fulfilled, especially regarding containment and safety against rupture of the pressure envelope of the 30B-X cylinder.

The thermal analysis is described in detail in Appendix 2.3 (Thermal Analysis) and summarized in section 2.3.

2.1.1.2.1 Thermal Analysis for NCT

The thermal analysis for NCT covers the conditions according to [10 CFR Part 71] §71.71(c)(1) or [SSR-6 2018] para. 657 for different filling ratios of the 30B-X cylinder for 12-hour solar insolation / 12-hour no insolation cycles.

2.1.1.2.2 Thermal Analysis for HAC

The thermal analysis for HAC covers the conditions according to [10 CFR Part 71] §71.73(c)(4) or [SSR-6 2018] para. 728 for different filling ratios of the 30B-X cylinder.

- The thermal analysis considers a thermal test with an ambient temperature of 800 °C and an exposure time of 30 min, followed by a subsequent cooling phase at an ambient temperature of 38 °C and solar insulation.
- The thermal analysis is carried out for an empty 30B-X cylinder and for 30B-X cylinders with filling ratios of 50% and 100%.
- A possible pressure build-up by melting UF_6 contents is investigated beforehand in the determination of the admissible temperatures for the DN30-X package.
- Additional sensitivity analyses are carried out to investigate the influence of certain parameters like contact modelling, mesh size or time step size.

2.1.1.3 Containment Design Analysis

The containment design analysis of the DN30-X package is described in detail in Appendix 2.4 (Containment Analysis) and summarized in section 2.4. It covers UF_6 of grade HALEU 10 and HALEU 20 for all filling ratios ranging from 0 kg up to the specific fill limits of the 30B-10 and 30B-20 cylinder listed in table 1-4.

Only RCT and NCT are considered, as the DN30-X is a Type AF package with no restriction on the radioactivity release under HAC due to the 1 A_2 limit on the radioactivity of the contents.

2.1.1.4 External Dose Rate Analysis

The external dose rate analysis is documented in detail in Appendix 2.5 (External Dose Rate Analysis) and summarized in section 2.5. The analysis covers the DN30 package loaded with filled cylinders as well as cylinders containing heels under RCT and NCT. It is valid for UF_6 contents of type HALEU 10 and HALEU 20 as specified in section 1.3 and considers the following assumptions:

- The internal CSS of the 30B-X cylinder is considered in the dose rates analysis.
- The analysis covers UF_6 grade HALEU 10 and HALEU 20.
- For the 30B-X cylinder, the minimal wall thickness of 1.1 cm as specified in table 1-13 is applied.

2.1.1.4.1 External Dose Rate Analysis under RCT

The external dose rate analysis of the DN30-X package under RCT consists of:

- The analysis of the external dose rates at the surface of the DN30-X package and at a distance of 2 m from the external surface of the DN30-X package.
- The analysis of the external dose rates at a distance of 1 m from the external surface of the DN30-X package to provide an estimate for the TI to be expected. Nevertheless, the TI will always be determined by measurement before each transport.

- The analysis of the external dose rates at the surface of a standard vehicle routinely used for transportation of the DN30-X package and in a distance of 2 m from the external surface of the vehicle:
  - Two possible transport configurations for the DN30-X package are considered.
  - For the analysis of the external dose rates in 2 m distance from the vehicle, the influence of all transported DN30-X packages is taken into account.

2.1.1.4.2 External Dose Rate Analysis under NCT

The external dose rate analysis under NCT consists of the comparison of the maximal dose rates for a non-damaged DN30-X package complying with the manufacturing drawings and for a damaged DN30-X package under NCT to prove that the increase in the maximal dose rates is not significant (not greater than 20 %).

2.1.1.5 Criticality Safety Analysis

The criticality safety analysis for the DN30-X package takes into account the maximal enrichments of 10 wt.-% ^{235}U for the DN30-10 and 20 wt.-% ^{235}U for the DN30-20. It is based on the following assumptions:

- For the single package in isolation, optimal water moderation of the UF_6 content is assumed.
- For the array of packages, flooding with water is excluded because of the results of analyses and experimental drop tests described in the structural analysis in section 2.2.
- For all contents, the most reactive arrangement in the packaging is determined in all cases. All credible rearrangements of contents in the package are taken into account in the analyses. Based on the results of the structural and thermal analysis, release of contents from the package does not need to be assumed.
- Water around the package is considered in different layer thicknesses in the analysis of the array of packages.
- Temperature changes are taken into account by assuming a conservatively high density for UF_6 and the theoretical maximal density of 1 g/cm³ for water. A decrease of water density caused by a temperature rise or freezing will lead to lower moderation that is less reactive.

2.1.2 Common Provisions for all Technical Analyses

2.1.2.1 Package Design

Details of the DN30-X package design are described in section 1.3 for the content and in section 1.4 for the 30B-X cylinder and the DN30 PSP. In the following, the provisions for the content and the DN30-X packaging are given with respect to each part of the technical analysis. In addition, an overview of the materials used in the structural and thermal analysis is included. The material properties for all other technical analysis are given in the corresponding sections of those analyses.

2.1.2.1.1 Content

As defined in section 1.3, the content is UF_6 for all technical analyses. However, referring to a specific analysis, only certain properties of the content may be relevant and, thus, are considered in the corresponding analysis. Further details on each of technical analysis are provided in table 2-1.

Table 2-1 Provisions for the UF_6 content of the DN30-X package used in the technical analyses

Technical analysis	Provisions made for the DN30-X
Structural	• The relevant physical property is the density. • Potential deformations of the content and, thus, energy absorption by the content is neglected in the analysis.
Thermal	• The relevant physical properties are the density, thermal conductivity, and specific heat capacity. • Scenarios under HAC are investigated for an empty, partially filled (50 %), and a completely filled cylinder. • For the partially filled and completely filled cylinder, an evenly distributed air/UF_6-mixture is considered, which completely fills the cylinder cavity.
Containment design	• The relevant physical property is the viscosity of gaseous UF_6. For the containment analysis, the content configuration has no impact on results. • The radioactivity of the contents is conservatively assumed to be 1 A_2.
External dose rate	• The relevant physical properties are the density and the shielding properties of the UF_6 contents. • Conservatively, a 100 % filled 30B-X cylinder is considered, which exceeds the permissible mass of UF_6 for the 30B-10 and 30B-20 cylinder listed in table 1-4. • For cylinders containing heels, a covering configuration with heels forming a puddle at the lower side of the 30B-X cylinder is investigated. • The source terms are derived from the UF_6 contents specified in section 1.3.
Criticality safety	• The relevant physical properties are the density, the purity (hydrogen impurities) and the ^{235}U enrichment of the UF_6. • Conservatively, a 100 % filled 30B-X cylinder is considered which exceeds the permissible mass of UF_6 for the 30B-10 and 30B-20 cylinder listed in table 1-4. • For the single package in isolation, optimal moderation of the UF_6 contents with water is assumed.

2.1.2.1.2 30B-X Cylinder

The design of the 30B-X cylinder is defined in the drawings in Appendix 1.4.1A (Drawings 30B-X Cylinder). A detailed description of the 30B-X cylinder is provided in sections 1.4.1.1 and 1.4.2.1. Provisions made for each technical analysis with regard to the 30B-X cylinder are given in table 2-2.

Table 2-2 Provisions for the 30B-X cylinder used in the technical analyses

Technical analysis	Provisions made for the 30B-X cylinder
Structural	• Nominal dimensions of the 30B-X cylinder are assumed. • The influence of temperature on the mechanical behavior of the package is analyzed in variation calculations: – The maximum package temperature is evaluated in the thermal analysis. – The minimum temperature of -40 °C is required by the transport regulations.
Thermal	• Nominal dimensions of the 30B-X cylinder and standard physical properties of the materials of the 30B-X cylinder are assumed. • The cylinder including the CCS is modeled in a simplified geometry for the 2D-environment.
Containment design	• The minimum free volume inside the 30B-X cylinder volume is assumed.
External dose rate	• A simplified 30B-X cylinder without skirts and with flat ends is assumed. • The minimum wall thickness of the 30B-X cylinder is assumed to be 1.1 cm.
Criticality safety	• The skirts and domed heads of the cylinder are represented in the calculation model, while valve, plug and nameplate are neglected. • For the CCS, only the CCRs are taken into account, the lattice holders and all other structural parts of the CCS are conservatively neglected. • The geometry of the cylinder and CCS are varied to assess the most reactive values within the range of the manufacturing tolerances and HAC deformations.

2.1.2.1.3 DN30 PSP

The design of the DN30 PSP is defined in the drawings in Appendix 1.4.1B (Drawings DN30 PSP). A detailed description of the DN30 PSP is provided in sections 1.4.1.2 and 1.4.2.2. Provisions made for each technical analysis with regard to the DN30 PSP are given in table 2-3.

Table 2-3 Provisions for the DN30 PSP used in the technical analyses

Technical analysis	Provisions
Structural	• Nominal dimensions of the DN30 PSP are assumed. • The influence of temperature on the mechanical behavior of the package is analyzed in variation calculations: – The maximum package temperature is evaluated in the thermal analysis. – The minimum temperature of -40 °C is required by the transport regulations.
Thermal	• Under NCT, nominal dimensions of the DN30 PSP and nominal physical properties of the materials of the DN30 PSP are assumed. • Under HAC, nominal dimensions and deteriorated physical properties of the materials of the DN30 PSP are assumed. Damages from free drop tests from a height of 9 m and from drops on a bar from a height of 1 m are included by benchmarking the thermal model using two prototype fire tests with prototypes damaged by these drop tests. Furthermore, a self-sustaining pyrolysis of the foam as experienced in the thermal test under HAC is considered.
Containment design	• The DN30 PSP is not part of the containment system and, thus, is not considered in the containment design analysis.
External dose rate	• Nominal dimensions of the DN30 PSP and standard physical properties of the materials of the DN30 PSP are assumed.
Criticality safety	• The foam material is neglected. • The steel shells of the DN30 PSP are compacted around the 30B-X cylinder to a total thickness of 5 mm in radial direction and 14 mm in axial direction, thereby minimizing the distance between adjacent packages.

2.1.2.2 Acceptance Criteria and Design Assumptions

2.1.2.2.1 Structural Design

The acceptance criteria and design assumptions for the structural design are:

- Lifting attachments that are a structural part of the DN30-X package are designed with a minimum safety factor of 3 against yielding when used to lift the package in the intended manner. Failure of any lifting device under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].
- Tie-down devices that are a structural part of the DN30-X package withstand, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents. Failure of the devices under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].
- No failure of the DN30 PSP closure system.
- No physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.

- No physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- No loss or dispersal of radioactive contents under NCT.
- No rupture of the 30B-X cylinder containment system under HAC.
- No failure of the 30B-X cylinder confinement system:
  - The relative dislocation of the CCRs must remain below 5 mm.
  - The increase in radial movability of the entire CCS out of the center of the 30B-X cylinder must remain below 3 mm.
  - The increase in axial movability of the entire CCS out of the center of the 30B-X cylinder must remain below 7 mm.
  - Failure of the lattice holders must not occur.
  - Rupture of the CCRs must not occur.

The evaluation of these design criteria for the DN30-X package is possible without considering material damage or failure in the simulation model of the DN30-X package, even if local deformations of the DN30 PSP shells above the uniform elongation occur. However, the following must be considered in this case:

- The material models for the steel parts cover the inelastic range up to the uniform elongation. For plastic strains above the uniform elongation, the discrepancy compared to the real material behavior increases successively because of the negligence of a damage and failure model. Thus, failure analysis of certain parts of the DN30 PSP is solely based on the experimental drop tests.
- Locations with plastic strains above the uniform elongation and close to or above the elongation at fracture are compared with the corresponding areas of the prototypes used for the experimental drop tests. If those locations match and failure occurred in the experimental drop tests, the exact value of the plastic strain is of no importance for the safety of the DN30-X package because the thermal test under HAC was passed with fractures in the inner and outer shells of the DN30 PSP.
- An analysis with previously introduced cracks in the inner shell of the DN30 PSP simulation model, exceeding the cracks observed after the drop tests, proves that safety relevant simulation results are not sensitive to failure of the inner steel shells. The results of this sensitivity analysis are documented in Appendix 2.2 (Structural Analysis).

2.1.2.2.2 Thermal Design

The acceptance criteria and design assumptions for the thermal design are:

- The temperatures at the 30B-X cylinder, including valve, plug and shell, should not exceed 131 °C during the thermal test simulating HAC for a package in the condition after the structural tests simulating NCT and HAC (see section 2.3.2). The leakage rate after the thermal test should be less than $1.0 \cdot 10^{-4}\ \text{Pa} \cdot \text{m}^3/\text{s}$.
- Withstand, without rupture of the containment system (the 30B-X cylinder), the thermal test simulating HAC.

The thermal design considers different filling ratios from an empty cylinder up to a cylinder filled with the maximum admissible amount of UF_6.

2.1.2.2.3 Containment System Design

The acceptance criteria and design assumptions for the containment system design are:

- Under NCT, the loss or dispersal of UF_6 must be prevented.
- The containment is the 30B-X cylinder with its valve and plug.
- The DN30 PSP has no containment function.

2.1.2.2.4 External Dose Rate Assessment

The acceptance criteria and design assumptions for the external dose rate assessment are:

- The external dose rate limits for RCT, NCT, and HAC as defined in [49 CFR Part 173] or [SSR-6 2018] must not be exceeded.
- For the assessment of the dose rates, conservative assumptions with respect to the cylinder filling ratio and the shape of the 30B-X cylinder are used.
- For the assessment of the dose rate at the vehicle, two and four packages loaded side-by-side are considered, respectively.
- For the assessment of the dose rate increase after the tests simulating NCT, a covering value of 4 mm for the deformations of the DN30 PSP is taken into account to demonstrate compliance with the limit of 20 % dose rate increase compared to RCT dose rates.

2.1.2.2.5 Criticality Safety Assessment

The acceptance criteria and design assumptions for the criticality safety assessment are:

- Criticality safety is ensured by the confinement system consisting of the 30B-X cylinder with the CCS and the steel shells of the DN30 PSP.
- For RCT, NCT and HAC the criticality safety criterion is $k_{eff} + 3\sigma + \Delta k \leq 0.95$. The systematical deviations Δk are determined from a validation based on critical benchmark experiments applicable to the DN30-X.

2.2 Structural Analysis

The structural analysis of the DN30-X package is described in detail in Appendix 2.2 (Structural Analysis). This section provides a summary of the main points and results.

The analysis of the DN30-X package under NCT and HAC is based on the experimental drop test program for the DN30 package, consisting of the 30B cylinder and the DN30 PSP, that is described in appendix B of Appendix 2.2 (Structural Analysis). This is possible for the following reasons:

- The 30B-X cylinder has the same gross weight as the standard 30B cylinder while also having the same outer dimensions, shell thicknesses and material specifications of the pressure envelope and the cylinder skirts (see Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder) and table 1-13).
- The 30B-X and the standard 30B cylinder are equipped with the same valve and plug.
- The 30B-X and the standard 30B cylinder are both transported in the same DN30 PSP.

Additional analyses are only required to account for the differences between the 30B and 30B-X cylinders, i.e. the interior CCS. The calculation model for these analyses is validated via the simulation of results from the experimental drop test program for the DN30 package, described in detail in appendix A of Appendix 2.2 (Structural Analysis).

The acceptance criteria for the structural analysis are defined in section 2.2.1. A complete list of the basic assumptions for the performed calculations is provided in section 2.2.2. This includes the load assumptions for normal operating conditions of the 30B-X cylinder, handling of the DN30-X package, RCT, NCT, and HAC as well as the material data used in these analyses. In sections 2.2.3 through 2.2.7, only the fundamental results are provided that are required to prove compliance with the transport regulations. The corresponding detailed analyses are found in Appendix 2.2 (Structural Analysis), section 3 through 7.

2.2.1 Objective of Verification

The acceptance criteria for the structural analysis are:

- Lifting attachments that are a structural part of the DN30-X package are designed with a minimum safety factor of 3 against yielding when used to lift the package in the intended manner. Failure of any lifting device under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].
- Tie-down devices that are a structural part of the DN30-X package withstand, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents. Failure of the devices under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].
- No failure of the DN30 PSP closure system.
- No physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.

- No physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- No loss or dispersal of radioactive contents under NCT.
- No rupture of the 30B-X cylinder containment system under HAC.
- No failure of the 30B-X cylinder confinement system:
  - The relative dislocation of the CCRs must remain below 5 mm.
  - The increase in radial movability of the entire CCS out of the center of the 30B-X cylinder must remain below 3 mm.
  - The increase in axial movability of the entire CCS out of the center of the 30B-X cylinder must remain below 7 mm.
  - Failure of the lattice holders must not occur.
  - Rupture of the CCRs must not occur.

2.2.2 Basic Assumptions for the Calculations

Basic assumptions for the calculations are listed in the following. They include load assumptions for different load cases, the definition of calculation methods and material parameters of the materials used for the proof.

2.2.2.1 Load Assumptions

Individual load assumptions are made for normal operating conditions of the 30B-X cylinder as well as for handling, RCT, NCT and HAC for the DN30-X package. They are discussed in detail in the following sections.

2.2.2.1.1 Normal Operating Conditions for the 30B-X Cylinder

With reference to [ANSI N14.1], Table 1, the load assumptions for normal operating conditions of the 30B-X cylinder are adapted from the standard 30B cylinder:

- The 30B-X cylinder is designed for an internal maximum allowable working pressure (MAWP) of 1.38 MPa gauge at a temperature of 121 °C.
- The 30B-X cylinder is designed for an external MAWP of 172 kPa gauge.
- The 30B-X cylinder is designed for a minimum design metal temperature (MDMT) of -29 °C at 1.38 MPa gauge.
- The 30B-X cylinder is designed for a transport temperature of -40 °C.
- The 30B-X cylinder withstands the hydraulic strength test at a test pressure of 2.76 MPa gauge (twice the MAWP) without generating unacceptable stress.

2.2.2.1.2 Handling of the DN30-X Package

Load assumptions for handling include:

- Temperatures at the package corresponding to an ambient temperature of 38 °C and solar insolation (see section 2.3)

- Internal and external pressure
- Hoisting coefficients that are considered for handling operations

Load assumptions as basis for calculations for handling the package are listed in table 2-4.

Table 2-4 Load assumptions for handling

Load assumption	Component	Value	Unit
Temperature	30B-X cylinder	64	°C
	Lifting lugs at feet	70	°C
	Lifting lugs at top half	100	°C
	Feet	70	°C
Internal / external pressure	30B-X cylinder	152 / 100	kPa
Hoisting coefficient	Lifting lugs	2	-
Load cycles for fatigue analysis	Lifting lugs	150000	-

2.2.2.1.3 RCT for the DN30-X Package

Load assumptions for RCT include:

- Temperatures at the package corresponding to an ambient temperature of 38 °C and solar insolation (see section 2.3)
- Maximum transport accelerations according to [10 CFR Part 71] §45(b)(1)
- Vibrations during transport

Load assumptions as basis for calculations under RCT are listed in table 2-5.

Table 2-5 Load assumptions for RCT

Load assumption	Component	Value	Unit
Temperature (ambient temperature of 38 °C and solar insolation)	Outer shell, feet	70	°C
	30B-X cylinder	64	°C
Temperature (ambient temperature of -40 °C in the shade)	Complete packaging	-40	°C
Accelerations	Complete packaging		
axial		10.0	g
lateral		5.0	g
vertical		-1.0 ± 2.0	g
Vibrations	Complete packaging	0.3	g

2.2.2.1.4 NCT for the DN30-X Package

Load assumptions for NCT include:

- Temperatures at the package corresponding to an ambient temperature of 38 °C and solar insolation (see section 2.3)
- Tests for demonstrating the ability to withstand normal conditions of transport according to [10 CFR Part 71] §71 and [49 CFR Part 173] §465 or [SSR-6 2018] para. 719
- Reduction of ambient pressure

Load assumptions as basis for calculations under NCT are listed in table 2-6.

Table 2-6 Load assumptions for NCT

Load assumption	Individual test	Component	Value
Temperature	Drop test, stacking test, penetration test	DN30 PSP	60 °C
		30B-X cylinder	64 °C
Tests according to [10 CFR Part 71] §71(a) and [49 CFR Part 173] §465 or [SSR-6 2018] para. 719	Water spray	Packaging surface	[10 CFR Part 71] §71(c)(6) and [49 CFR Part 173] §465(b) or [SSR-6 2018] para. 721
	Free drop	Complete package	[10 CFR Part 71] §71(c)(7) and [49 CFR Part 173] §465(c) or [SSR-6 2018] para. 722 Free drop height 1.2 m
	Compression	Complete package	[10 CFR Part 71] §71(c)(9) and [49 CFR Part 173] §465(d) or [SSR-6 2018] para. 723
	Penetration	Packaging surface	[10 CFR Part 71] §71(c)(10) and [49 CFR Part 173] §465(e) or [SSR-6 2018] para. 724
Ambient pressure	Reduced	30B-X cylinder	[10 CFR Part 71] §71(c)(3) and [49 CFR Part 173] §412(f) or [SSR-6 2018] para. 645 25 kPa[1)]
	Increased	30B-X cylinder	[10 CFR Part 71] §71(c)(4) 140 kPa

1) Only 60 kPa are required per [49 CFR Part 173] §412(f) or [SSR-6 2018] para. 645.

2.2.2.1.5 HAC for the DN30-X Package

Load assumptions for hypothetical accident conditions of transport include:

- Temperatures at the package corresponding to an ambient temperature of 38 °C and solar insolation (see section 2.3)
- Tests for demonstrating the ability to withstand accident conditions of transport according to [10 CFR Part 71] §73(a) or [SSR-6 2018] para. 726
- Internal and external pressure

Load assumptions for accident conditions of transport are listed in table 2-7.

Table 2-7 Load assumptions for HAC

Load assumption	Individual test	Component	Value
Temperature	Free drop and puncture	Packaging main body outer shell	60 °C
		30B-X cylinder	64 °C
Tests according to [10 CFR Part 71] §73 or [SSR-6 2018] para. 726	Free drop	Complete package	[10 CFR Part 71] §73(c)(1) or [SSR-6 2018] para. 727(a) Free drop height 9 m
	Puncture	Complete package	[10 CFR Part 71] §73(c)(3) or [SSR-6 2018] para. 727 (b) Free drop height 1 m
	Thermal	Complete package	[10 CFR Part 71] §73(c)(4) or [SSR-6 2018] para. 728
	Immersion	30B-X cylinder	[10 CFR Part 71] §73(c)(6) or [SSR-6 2018] para. 729 150 kPa for 8 h
Water pressure	Immersion (fissile material)	30B-X cylinder	[10 CFR Part 71] §73(c)(5) or [SSR-6 2018] para. 731 9 kPa for 8 h
Increase of internal pressure during the thermal test	Thermal	30B-X cylinder	[10 CFR Part 71] §73(c)(4) or [SSR-6 2018] para. 728 106 kPa (see section 2.2.7.3.1)

2.2.2.2 Material Data

2.2.2.2.1 Material Data 30B-X Cylinder

The materials of the 30B-X cylinder are specified in section 1.4.1.1. A complete list of the corresponding material data is provided in Appendix 1.4.2 (Material Properties).

2.2.2.2.2 Material Data DN30 PSP

The materials of the DN30 PSP are specified in section 1.4.1.2. The corresponding material data that is used in the structural analysis of the DN30-X package is provided in Appendix 1.4.2 (Material Properties).

2.2.3 Normal Operating Conditions for the 30B-X Cylinder

This part of the structural analysis covers the normal operating conditions for the 30B-X cylinder as defined in section 2.2.2.1.1. For these analyses, the 30B-X cylinder is assumed to comply with its specification provided in section 1.4.1.1.

2.2.3.1 MDMT and Minimum Transport Temperature

The analysis in Appendix 2.2 (Structural Analysis), section 3.1 shows that the requirements towards the MDMT of -29 °C at 1.38 MPa gauge and the minimum transport temperature of -40 °C are fulfilled for the 30B-X cylinder. Consequently, this also applies to the materials ductility and resistance to brittle failure at low temperatures.

2.2.3.2 MAWP

The analyses in Appendix 2.2 (Structural Analysis), section 3.2 consider the whole design temperature range of -29 °C to 121 °C to prove the structural integrity of the 30B-X cylinder under the design conditions listed section 2.2.2.1.1. The following is shown with regard to a variation of material strength within this temperature range and thermally induced stresses:

1. The 30B-X cylinder and the standard 30B cylinder equally perform under the conditions of the hydraulic strength test at twice the MAWP.
2. The impact of a decrease in material strength of the 30B-X cylinder at the maximum design temperature is always covered by the hydraulic strength test.
3. Thermally induced stresses are effectively prevented by the design of the 30B-X cylinder:
   - The entire CCS has no fixed connection to another component of the 30B-X cylinder.
   - The longitudinal clearances between the lattice holders and the CCS restraints are sufficient to allow for a faster shrinking of the cylinder shells than the interior CCS.
   - The radial clearance between the lattice holders and the cylinder shell is sufficient to allow for a faster shrinking of the cylinder shells than the interior CCS.
   - The radial clearance between the CCRs and the lattice holders is sufficient to allow for a faster shrinking of the lattice holders than the CCRs.
   - The skirts of the 30B-X cylinder impose the same restrictions in the radial direction as for the standard 30B cylinder.

2.2.3.3 Hydraulic Strength Test

The analyses in Appendix 2.2 (Structural Analysis), section 3.3 show that the 30B-X and the standard 30B cylinder equally perform under the conditions of the hydraulic strength test at twice the MAWP, and that the impact of the hydraulic strength test on the interior CCS of the 30B-X cylinder can be analyzed separately:

- The admissible external pressure for the CCRs is significantly higher than the test pressure of twice the MAWP.
- Failure of the CCRs under the test conditions of the hydraulic strength test can be excluded.
- This and the argumentation in section 2.2.3.2 prove that the 30B-X cylinder is well designed to operate over the same design temperature range as a standard 30B cylinder.

2.2.4 Handling of the DN30-X Package

The DN30-X packaging is designed for the transport of UF_6. Specified contents are defined in section 1.3. Strains in the packaging result from the following loads:

- Internal and external pressure (see section 2.2.4.1)
- Assembling loads (see section 2.2.4.2)
- Handling loads (see section 2.2.4.3)
- Temperature gradients in the components (an analysis covering handling and RCT is provided in section 2.2.5.2)

The corresponding load assumptions are listed in table 2-4.

2.2.4.1 Internal and External Pressure

As shown in section 2.2.3.2, the 30B-X cylinder is designed for an external MAWP of 172 kPa and an internal MAWP of 1.38 MPa. Consequently, the requirements concerning the internal and external pressure for the 30B-X cylinder as well as for the DN30-X package are fulfilled. Further details are provided in Appendix 2.2 (Structural Analysis), section 4.1.

2.2.4.2 Assembling

During assembling, the components of the DN30-X packaging are inserted into each other without applying forces. Stresses in the components during assembling are negligible. For tightening the securing bolts of the closure system, tightening torques are defined in the handling instruction provided in Appendix 1.7.1 (Handling Instruction).

2.2.4.3 Handling Loads

The following handling processes are carried out with the DN30-X package:

- Handling of the loaded and empty package by using the lifting lugs at the feet (see figure 1-6)
- Handling of the loaded and empty package using a forklift (see figure 1-7)
- Handling of the empty package by using slings (see figure 1-8)
- Handling of the top half of the DN30 PSP by using the lifting lugs (see figure 1-9)

Based on the package weight, package dimensions, and material properties given in table 1-13 and table 1-14, the DN30-X package fulfills the following acceptance criteria defined in section 2.2.1 referring to [10 CFR Part 71] §45(a):

- All lifting attachments that are a structural part of the DN30-X package are designed with a minimum safety factor of 3 against yielding when used to lift the package in the intended manner.
- Failure of any lifting device under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].

The corresponding proofs are provided in Appendix 2.2 (Structural Analysis), section 4.3.

2.2.5 Ability of the DN30-X Package to Withstand RCT

The DN30-X packaging is designed for the transport of UF_6. Specified contents are defined in section 1.3. Strains in the packaging result from the following loads under RCT:

- Maximum transport accelerations (see section 2.2.5.1)
- Vibrations during transport (see section 2.2.5.1 and 2.2.5.2)
- Temperature gradients in the components (see section 2.2.5.2)

The corresponding load assumptions are listed in table 2-5.

2.2.5.1 Tie-down

The DN30-X package is transported by road, rail, or sea. For the transport, common flat racks or dedicated transport means are used (see figure 1-10). The tie-down features are designed such that relative movement between the vehicle and the DN30-X package is excluded. Thus, only the maximum acceleration values defined in table 2-5 affect the package during transport.

Based on the package weight, package dimensions, and material properties given in table 1-13 and table 1-14, the DN30-X package fulfills the following acceptance criteria defined in section 2.2.1 referring to [10 CFR Part 71] §45(b):

- All tie-down devices that are a structural part of the DN30-X package withstand, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.
- Failure of the devices under excessive load does not impair the ability of the DN30-X package to meet other requirements of [10 CFR Part 71].

The corresponding proofs are provided in Appendix 2.2 (Structural Analysis), section 5.1.

2.2.5.2 Impact of Vibrations During Transport on the Structural Integrity of the 30B-X Cylinder and its interior Criticality Control System

Compliance with [10 CFR Part 71] §71(c)(5) requires the investigation of vibration normally incident to transport. For the tie-down features of the DN30 PSP, this has been investigated in Appendix 2.2 (Structural Analysis), section 5.1.2. What remains for the safety analysis of the DN30-X package is the proof that the interior CCS of the 30B-X cylinder is also not affected by such vibrations. The main concern here is the occurrence of resonances for the interior CCS that could lead to wear of the cylinder shell or fatigue failure of the CCRs.

Appendix 2.2 (Structural Analysis), section 5.2 contains an investigation of the possible impacts of vibration on the integrity of the 30B-X cylinder and possible interactions between the cylinder shell and the interior CCS. Furthermore, possible fatigue failure of the CCRs is investigated. Therefore, a modal analysis is performed for the central CCR to calculate its natural frequencies. Using the results of this modal analysis (the eigenmodes to each natural frequency), maximal stresses are determined at the central CCR, and it is shown that these stresses are insignificant with regard to the fatigue strength of the CCR material. Hence, the CCRs are not susceptible to fatigue failure and there is no impact of the structural analysis under RCT on the integrity of the interior CCS.

2.2.5.3 Analysis of Stresses Caused by Temperature Influences

The analysis of stresses caused by temperature influences for the DN30-X package, provided in Appendix 2.2 (Structural Analysis), section 5.3, shows the following results:

- The possibly different expansions of the top and bottom half of the DN30 PSP, caused by temperature differences that are due to differing insolating conditions on the top and bottom half, are small. The gaps between the flanges of the top and bottom half allow for sufficient relative movement to compensate for different expansions.
- There is sufficient clearance between the DN30 PSP and the 30B-X cylinder to compensate differing thermal expansions of the DN30 PSP and the 30B-X cylinder.
- For the 30B-X cylinder itself, thermally induced stresses because of the expansion of the interior CCS or shrinking of the cylinder shell cannot occur under RCT and NCT.

2.2.6 Ability of the DN30-X Package to Withstand NCT

2.2.6.1 Water Spray Test

The water spray test specified in [10 CFR Part 71] §71(c)(6) and [49 CFR Part 173] §465(b) or [SSR-6 2018] para. 721 has no impact on either the loss or dispersal of the radioactive contents, or on the dose rate at any external surface of the DN30-X package with respect to the requirements in [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j) or [SSR-6 2018] para. 648. Further details are provided in Appendix 2.2 (Structural Analysis), section 6.1.

2.2.6.2 Free Drop Test

The free drop test from a height of 1.2 m is analyzed in sequence with the tests simulating HAC (the 9 m free drop test and the puncture test). For better overview and comparison of the deformations after the 1.2 m free drop test and after the 9 m free drop test, the results of these sequences are both discussed in section 2.2.7. As the DN30-X package is designed to withstand HAC, the proof that the DN30-X package is also designed to withstand NCT is almost always a direct consequence. A more careful examination is only required for the proof of preventing loss or dispersal of the radioactive contents, which is further discussed in section 2.2.6.2.1.

As explained in Appendix 2.2 (Structural Analysis), section 6.2, preceding corner drops from a height of 0.3 m as required by [49 CFR Part 173] §465(c)(2) will not have any adverse effect on the DN30-X package.

In the following, the conditions for the proof of [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j) or [SSR-6 2018] para. 648 are established.

2.2.6.2.1 Conditions to Prevent Loss or Dispersal of the Radioactive Contents

In section 2.2.7, it is shown that even after a 10.2 m free drop test, there is no physical contact between the valve or the plug and any other component of the DN30-X packaging other than its original point of attachment. Hence, structural damaging of the valve or the plug of the 30B-X cylinder during the 1.2 m free drop test can generally be excluded. Further analysis is only necessary for the flat drop onto the valve side because, after the combined 10.2 m drop test investigated in section 2.2.7.1.3.2, small plastic deformations are visible at the cylinder head at the valve half coupling. Accordingly, for the proof of compliance with [10 CFR Part 71] §43(f), a separate

analysis of the 1.2 m free drop test under NCT for the flat drop onto the valve side is performed in section 2.2.7.1.4.1, which shows that the area of the valve half coupling is free of inelastic deformations. Further details are provided in Appendix 2.2 (Structural Analysis), section 6.2.1.

2.2.6.2.2 Conditions to Prevent the Increase of the Maximum External Radiation Level

In section 4.1 of Appendix 2.5 (External Dose Rate Analysis), it is shown that the maximum dose rate at the surface of the DN30-X package is to be expected in radial direction in the center of the side of the package. In section 2.2.7, the deformations to be expected after the 1.2 m free drop tests are analyzed. For the 1.2 m free drop onto the top of the package described in section 2.2.7.1.4.3, a reduction of the distance between the inner and outer shell of the DN30 PSP of 4 mm was determined. Conservatively, a distance reduction of 6 mm is assumed for the dose rate analysis.

2.2.6.3 Compression Test

The outer shape of the DN30 PSP effectively prevents stacking. However, according to [10 CFR Part 71] §71(c)(9), a compression test must be performed for packages weighing up to 5000 kg. The corresponding analysis provided in Appendix 2.2 (Structural Analysis), section 6.3 shows that the DN30-X package fulfills the requirements of [10 CFR Part 71] §71(c)(9).

2.2.6.4 Penetration Test

According to [10 CFR Part 71] §71(c)(10), the impact of the hemispherical end of a vertical steel cylinder of 3.2 cm diameter and 6 kg mass, dropped from a height of 1 m onto the exposed surface of the DN30-X package has to be investigated that is expected to be most vulnerable to puncture. As demonstrated in section 2.2.7, the DN30-X package is designed to withstand the puncture test under HAC, which is much more severe for the DN30-X package weighing about 4100 kg than the penetration test. Hence, the test as defined in [10 CFR Part 71] §71(c)(10) and [49 CFR Part 173] §465(e) or [SSR-6 2018] para. 724 is covered by the test defined in [10 CFR Part 71] §73(c)(3) or [SSR-6 2018] para. 727(b).

There is no impact of this test on the loss or dispersal of the radioactive contents with respect to the requirement stipulated in [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j) or [SSR-6 2018] para. 648(a).

In comparison to the free drop test from a height of 1.2 m, the impact of this test on the dose rate at any external surface of the DN30-X package is negligible with respect to the requirement in [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j), or [SSR-6 2018] para. 648(b).

2.2.6.5 Reduced and Increased External Pressure

The 30B-X cylinder is designed for an external and internal MAWP of 172 kPa and 1.38 MPa, respectively. As defined in section 1.2.9, the MNOP of the DN30-X package during transport is 152 kPa. Hence, a reduction to 25 kPa or an increase to 140 kPa of the ambient pressure as specified in [10 CFR Part 71] §71(c)(3) and (4) will not affect the 30B-X cylinder (the containment system). This argumentation covers the reduction of the ambient pressure to 60 kPa as required by [49 CFR Part 173] §412(f) or [SSR-6 2018] para. 645.

2.2.7 Ability of the DN30-X Package to Withstand NCT and HAC

Based on the argumentation in the beginning of section 2.2, the experimental drop tests and the drop tests analysis under NCT and HAC performed for the DN30 package (described in appendices A and B of Appendix 2.2 (Structural Analysis)) in the operating temperature range of -40 °C to +60 °C are also covering the DN30-X package. They are summarized in section 7.1 of Appendix 2.2 (Structural Analysis). To complete the structural analysis of the DN30-X package under NCT and HAC, only some additional analyses are required to account for the differences between the 30B and the 30B-X cylinder:

1. The first part in Appendix 2.2 (Structural Analysis), section 7.2.5 provides evidence that the interaction between the 30B-X cylinder and the DN30 PSP is comparable to the interaction between the 30B cylinder and the DN30 PSP. These analyses prove that the initially made assumptions are admissible.
2. In the second part in Appendix 2.2 (Structural Analysis), section 7.2.6, analyses are performed that specifically consider the acceptance criteria established for the interior CCS of the 30B-X cylinder in section 2.2.7.1.4 and, therefore, also account for the differences between the DN30-X and the already licensed DN30 package.

Both the comparison between the two packages and the specific analyses for the DN30-X package consider a 30B-X cylinder design with 35 CCRs arranged in a 1 x 6 x 12 x 16 pattern, which deviates from the actual designs of the 30B-10 and 30B-20 cylinder having 33 and 43 CCRs, respectively. The impact of these deviations on the results of the structural analysis of the DN30-X package under NCT and HAC is discussed in in Appendix 2.2 (Structural Analysis), section 7.5. The following sequential application of tests is considered in the analyses:

1. The free drop test under NCT as defined in [10 CFR Part 71] §71(c)(7) and [49 CFR Part 173] §465(c) or [SSR-6 2018] para. 722 (drop height 1.2 m)
2. The free drop test under HAC as defined in [10 CFR Part 71] §73(c)(1) or [SSR-6 2018] para. 727(a) (drop height 9 m)
3. The puncture test under HAC as defined in [10 CFR Part 71] §73(c)(3) or [SSR-6 2018] para. 727(b) (drop height 1 m)

Apart from the two fundamental parts of the structural analysis of the DN30-X under NCT and HAC, the water immersion test for packages containing fissile material is discussed in section 2.2.7.2. Finally, the influence of the thermal test under HAC on the structural integrity of the DN30-X package is evaluated in section 2.2.7.3.

2.2.7.1 Drop Test Analyses for the DN30-X Package under NCT and HAC

As pointed out in the beginning of section 2.2.7, this part of the structural analysis of the DN30-X package provides evidence that the interaction between the 30B-X cylinder and the DN30 PSP is comparable to the interaction between the standard 30B cylinder and the DN30 PSP. This proves that the initially made assumptions are admissible, and that the drop test analyses as well as the experimental drop tests performed for the DN30 package are also covering for the DN30-X package. The comparison of the drop test analyses for the DN30-X and the DN30 package is described in section 2.2.7.1.3.

With this at hand, additional analyses are described in section 2.2.7.1.4 that specifically consider the acceptance criteria in section 2.2.1 that have been established for the interior CCS of the 30B-X cylinder and, therefore, also account for the minor differences between the DN30-X and

the DN30 package. Furthermore, this part contains a discussion of the remaining drop test scenarios that were considered in the safety analysis of the DN30.

The analyses of the drop tests under NCT and HAC are valid for all filling ratios from 30B-X cylinders with heels up to 30B-X cylinders filled with the maximum amount of UF_6 as defined in table 1-4. Further details on the investigated analysis sequences and orientations are provided in section 2.2.7.1.1. A brief introduction to the software being used to perform the simulations is provided in Appendix 2.2 (Structural Analysis), section 7.2.2.

The entire modelling procedure is described in Appendix 2.2 (Structural Analysis), section 7.2.3. Since the same simulation model is used for the DN30 PSP that has already been developed for the structural analysis of drop tests for the DN30 package, the modelling description focuses on the specific design for the 30B-X cylinder. Apart from the deviations between the FEM and the CAD models of the cylinders, the chosen element types, applied initial and boundary conditions as well as contact definitions and material models are described. Finally, a comprehensive description of the content modelling is provided.

2.2.7.1.1 Analysis Sequences and Orientations

In Appendix 2.2 (Structural Analysis), section 7.2, detailed analyses are carried out for three drop test orientations of the DN30-X package:

1. Inclined onto the valve side so that the line between center of gravity and point of impact is perpendicular to the target surface
2. Flat onto the valve side
3. Flat onto the feet

The first two drop test orientations are investigated in Appendix 2.2 (Structural Analysis), section 7.2.5 and are used to provide evidence that the interaction between the 30B-X cylinder and the DN30 PSP is comparable to the interaction between the standard 30B cylinder and the DN30 PSP. The drop test flat onto the feet has not been investigated for the DN30 package, but this orientation is specifically relevant with regard to the acceptance criteria for the CCS inside the 30B-X cylinder defined in section 2.2.1. The flat drop test onto the feet is investigated in Appendix 2.2 (Structural Analysis), section 7.2.6.2.

The following drop test orientations, which have also been investigated for the DN30 package, are considered in the structural analysis of the DN30-X package as well:

- Flat onto the plug side
- Flat onto the closure system
- Flat onto the top side
- Inclined onto the plug side so that the line between center of gravity and point of impact is perpendicular to the target surface
- Inclined onto the closure system so that the line between center of gravity and point of impact is perpendicular to the target surface
- Inclined onto the feet (slap-down)
- Inclined onto the top side (slap-down)

The detailed discussion for each of the above drop test orientation is also provided in Appendix 2.2 (Structural Analysis), section 7.2.6.2.

2.2.7.1.2 FEM Model

The FEM model of the DN30-X package is described in detail in Appendix 2.2 (Structural Analysis), section 7.2.3. Generally, it is identical to that of the DN30 package, except for the model of the standard 30B cylinder and its content being replaced by the model of the 30B-X cylinder. Consequently, the same deviations and simplifications apply to the modelling of the DN30 PSP.

As mentioned in the beginning of section 2.2.7, the model of the 30B-X cylinder used in the structural analysis of the DN30-X package considers 35 CCRs arranged in a 1 x 6 x 12 x 16 pattern. This number of CCRs lies between the actual designs of the 30B-10 and the 30B-20 cylinder having 33 and 43 CCRs. However, the way the content of the 30B-X cylinder is modelled always ensures that the maximal allowable gross weight of a standard 30B cylinder of 2912 kg is achieved for the 30B-X cylinder as well. Consequently, the differences in the number of CCRs in comparison to the actual 30B-10 or 30B-20 cylinder designs has no relevant impact on the simulation results. This aspect of the structural analysis of the DN30-X package is discussed in more detail in Appendix 2.2 (Structural Analysis), section 7.5.

The geometry of the 30B-X cylinder FEM model is discretized with shell and solid elements. Solid elements are used for the valve, plug and their half couplings as well as the CCS restraints, the lattice holders and the neutron absorbing material within the CCRs. The cylinder shells, skirts, and the pipes of the CCRs are modeled using shell elements.

For solid elements, the default solid element formulation is used in nearly all cases. This is an eight-node solid hexahedron element with one-point integration and constant stress within each element. The valve is discretized using the standard tetrahedral element formulation with one-point-integration. Since the valve is solely modelled to detect a contact, it is represented as a rigid body in the FEM model. In this case, the element formulation has no impact on the simulation results, but using tetrahedral elements simplifies the meshing of the complex geometry of the valve body.

Without exception, the default shell element formulation is used for thin parts. It is an extremely effective 4-node element that uses one-point integration and can describe small deformations with large rotations.

The UF_6 content is simulated by increasing the nodal mass of each mesh node of the outer CCR surfaces. This approach is described in detail in Appendix 2.2 (Structural Analysis), section 7.2.3.7, also discussing its conservatism with regard to the acceptance criteria for proving the integrity of the pressure-containment and the integrity of the CCS of the 30B-X cylinder that are established in section 2.2.1.

2.2.7.1.3 Comparison of Drop Test Analyses for the DN30-X and DN30 Package

2.2.7.1.3.1 Corner Drop onto the Valve Side – Drop Test Sequence 1

The structural analysis of the DN30 package showed that the corner drop onto the valve side, part of drop test sequence 1 for the DN30 package, is one of the most critical drop test orientations regarding the magnitude of deformations of the DN30 PSP in the valve area. As the valve is the most vulnerable part of the containment system, this drop test orientation is used in the comparison analysis between the DN30-X and DN30 package.

A detailed presentation of the simulation results a provided in Appendix 2.2 (Structural Analysis), section 7.2.5.1. Here, only a short summary is given, covering the fundamental results with regard to the acceptance criteria defined in section 2.2.1.

2.2.7.1.3.1.1 Deformations

2.2.7.1.3.1.1.1 DN30 PSP and Cylinder Pressure Envelope

The state of maximal deformation for the DN30-X to the DN30 package during the corner drop test onto the valve side is compared in figure 2-1. For both packages, the compression of the foam in the valve area and the deformations of the inner and outer DN30 PSP shell are nearly identical. As for the DN30, no physical contact at the valve is detected for the DN30-X other than its initial point of attachment.

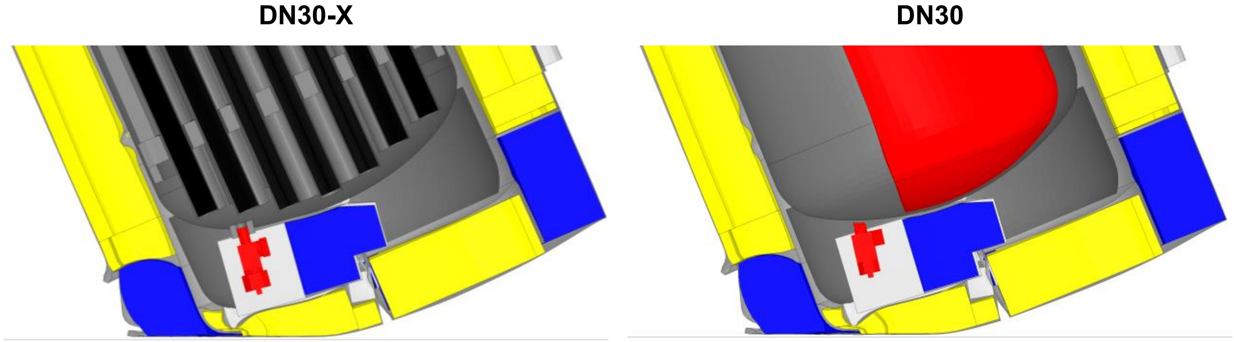

Figure 2-1 Corner drop onto the valve side from a height of 10.2 m – State with the maximal deformation of the DN30-X and DN30 package

At the end of the simulation, the deformations of the DN30 PSP are determined using two measurement locations at the impact zone (see figure 2-2). Table 2-8 lists the resulting values and provides a comparison to the corresponding results for the DN30 package.

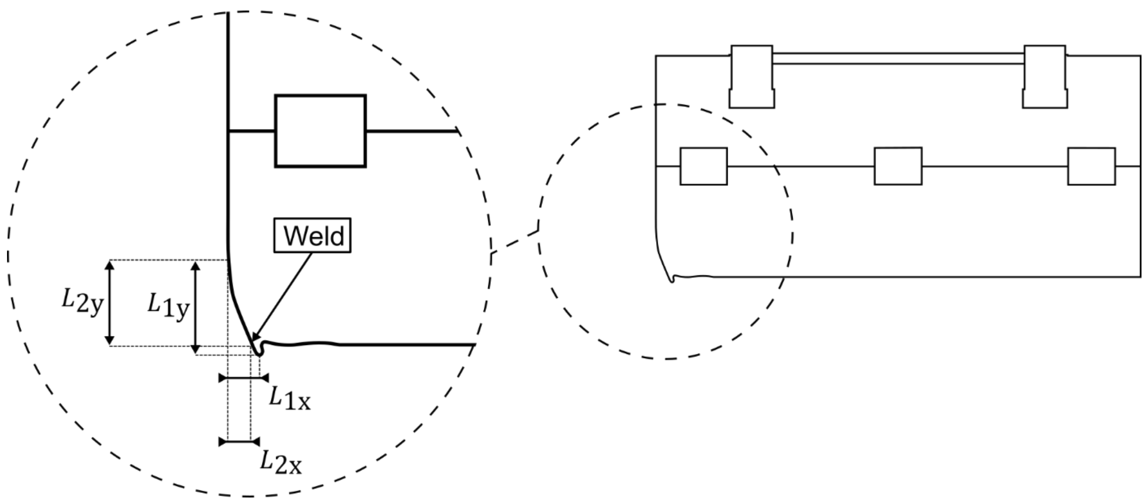

Figure 2-2 Measured distances for the corner drop onto the valve side

The obtained results for the measured distances in table 2-8 correspond well to the very similar deformations visible in figure 2-1. The changes in L_{1x} and L_{2x} are increased by about 5 %, while the changes in L_{1y} and L_{2y} are slightly smaller. However, the extent of the impacted area measured by the Euclidian norm L_1 is nearly identical for both packages, proving that the deformations are comparable.

Table 2-8 Corner drop onto the valve side from a height of 10.2 m – Measured distances at the impact zone after the drop test

Measurement point	Parameter	Deformation in mm		Change in %
		DN30-X	DN30	
Largest Fold	L_{1x}	175	167	5.0
	L_{1y}	392	396	-0.9
	$L_1 = \sqrt{L_{1x}^2 + L_{1y}^2}$	430	429	≈ 0
Weld between head and outer shell	L_{2x}	163	156	4.8
	L_{2y}	368	372	-0.8

In case of the cylinder pressure envelope, the determined maximal plastic deformation slightly increases from 1.1 % for the standard 30B to 4.0 % for the 30B-X cylinder. Despite those differences that solely refer to the content modelling, 4.0 % maximal plastic strain is significantly below the elongation at fracture of the cylinder shell material so that rupture of the containment system can safely be excluded.

2.2.7.1.3.1.1.2 Criticality Control System of the 30B-X Cylinder

Noticeable plastic strains at the CCS occur only in the lower half of the lattice holder on the valve side and near the connection between the lattice holders and the longitudinal stiffeners. The maximal plastic strain in these areas reach 2.1 % and 1.6 %, respectively, which is acceptable for the lattice holders and the longitudinal stiffeners. Safety relevant is only the relative dislocation between the CCRs, which can be expected to be very small as the pipe clamps of the lattice holders hardly experience any plastic deformations.

2.2.7.1.3.1.2 Summary

The DN30-X package design ensures that after the corner drop test onto the valve side simulating HAC, all acceptance criteria as defined in section 2.2.1 are met:

- There is no failure of the DN30 PSP closure system.
- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no loss or dispersal of radioactive contents under NCT.
- There is no rupture of the 30B-X cylinder containment system under HAC.
- There is no failure of the 30B-X cylinder confinement system.

2.2.7.1.3.2 Flat Drop onto the Valve Side – Drop Test Sequence 3

With the corner drop onto the valve side, as described in section 2.2.7.1.3.1, maximal deformations are reached in the valve area. In contrast to that, maximal acceleration and, therefore, maximal forces at the valve are expected for the flat drop onto the valve side. This drop test orientation was part of drop test sequence 3 in the safety analysis of the DN30 package.

As the valve is the most vulnerable part of the containment system, the flat drop onto the valve side is used in the comparison analysis between the DN30-X and DN30 package. Furthermore, this drop test orientation puts the highest demands on the lattice holders and the CCS restraints of the 30B-X cylinder and, therefore, provides additional information on the structural integrity of the interior CCS of the 30B-X cylinder. Accordingly, the results of this drop test analysis are also used as input for the following analyses:

- Static structural analysis of the fillet weld between the CCS restraint and the 30B-X cylinder shell (see Appendix 2.2 (Structural Analysis), section 7.2.7)
- Static structural analysis of the step welds between the CCRs and the lattice holders (see Appendix 2.2 (Structural Analysis), section 7.2.8)

2.2.7.1.3.2.1 Deformations

2.2.7.1.3.2.1.1 DN30 PSP and Cylinder Pressure Envelope

For both packages, the compression of the foam in the valve area and the deformations of the inner and outer DN30 PSP shell are nearly identical. As for the DN30 package, no physical contact at the valve is detected for the DN30-X other than its initial point of attachment.

The flat drop test onto the valve side also provides a good estimate of the closest axial approach of two neighboring DN30-X packages. Therefore, the permanent axial reduction in the wall thickness of the DN30 PSP is evaluated in the valve area, which is required as input for the criticality safety analysis in section 2.6. Including the corresponding sheet thicknesses, a minimal permanent wall thickness of the DN30 PSP of 103 mm is obtained.

With regard to the cylinder pressure envelope, rupture of the containment system can safely be excluded because the maximal plastic strain only increases from 1.8 % for the standard 30B to 4.0 % for the 30B-X cylinder. Such an increase was to be expected because the content is only implicitly incorporated in the FEM model of the DN30-X. However, there is still a very large margin to the elongation at fracture of the cylinder shell material.

2.2.7.1.3.2.1.2 Criticality Control System of the 30B-X Cylinder

Noticeable plastic strains occur only at the most outer spokes of the lattice holders and near the connection between the lattice holders and the longitudinal stiffeners. The maximal plastic strain in these areas reach 2.6 % and 2.1 %, respectively, which is acceptable for the lattice holders and the longitudinal stiffeners.

Regarding the acceptance criteria for the CCS defined in section 2.2.1, the relative dislocations between the CCRs and also the movement of the entire CCS relative to the 30B-X cylinder shell are evaluated. Considering the plastic deformations at the lattice holders are limited to their outermost spokes, there are no permanent relative dislocations between the CCRs.

For the flat drop onto the valve side, there are only negligible deformations that would increase the radial movability of the entire CCS within the 30B-X cylinder. With regard to the axial movability of the entire CCS within the 30B-X cylinder, a detailed analysis provided in Appendix 2.2 (Structural Analysis), section 7.2.5.2.2.2 shows an increase of approximately 2 mm.

2.2.7.1.3.2.2 Summary

The DN30-X package design ensures that after the flat drop test onto the valve side simulating HAC, all acceptance criteria as defined in section 2.2.1 are met:

- There is no failure of the DN30 PSP closure system.
- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no loss or dispersal of radioactive contents under NCT (see additional analyses of the flat drop onto the valve side under NCT in section 2.2.7.1.4.1).
- There is no rupture of the 30B-X cylinder containment system under HAC.
- There is no failure of the 30B-X cylinder confinement system.

2.2.7.1.4 Additional Drop Test Analyses for the DN30-X Package

As mentioned in the beginning of section 2.2.7.1, this part of the drop test analyses for the DN30-X package under NCT and HAC contains additional analyses that specifically consider the acceptance criteria in section 2.2.1 that have been established for the interior CCS of the 30B-X cylinder and, therefore, also account for the minor differences between the DN30-X and the DN30 package. Furthermore, Appendix 2.2 (Structural Analysis), section 7.2.6 contains detailed discussions of the remaining drop test scenarios that were considered in the safety analysis of the DN30 package. Here, only those drop test scenarios are mentioned that are directly relevant for proving compliance with the transport regulations or that are relevant to other safety analyses of the DN30-X package. Appendix 2.2 (Structural Analysis), section 7.2.6 also contains several sensitivity and comparison analyses for the DN30-X package.

2.2.7.1.4.1 Flat Drop onto the Valve Side – Drop Test Sequence 3 – Normal Conditions of Transport

The results of the combined 10.2 m flat drop onto the valve side in section 2.2.7.1.3.2 revealed small plastic deformations close to the valve half coupling, probably largely because of the very conservative modelling approach for the UF_6 contents. For the proof of compliance with [10 CFR Part 71] §43(f) regarding the containment function of the 30B-X cylinder under NCT, inelastic deformations of the containment have to be safely excluded near closure devices like the valve and the plug. Therefore, the safety analysis of the DN30-X package is supplemented by a separate analysis of the flat drop onto the valve side under NCT, considering a free drop height of 1.2 m.

2.2.7.1.4.1.1 Deformations

2.2.7.1.4.1.1.1 DN30 PSP and Cylinder Pressure Envelope

No physical contact at the valve occurs for the DN30-X other than at its initial point of attachment. The maximum plastic strain at the inner shell of the DN30 PSP reaches 24 % in the simulation of the 1.2 m free drop test with the DN30 package. In case of the DN30-X package, 26.2 % are reached showing that the amount of deformation is comparable.

In case of the cylinder pressure envelope, the region where the maximal plastic strain occurs has changed for the 30B-X cylinder in comparison to the standard 30B cylinder. This behavior was to be expected because the content is only implicitly incorporated in the FEM model of the DN30-X. As can be seen in figure 2-3, this leads to some deformations at the 30B-X cylinder head on the valve side that result from a stronger interaction between the valve protecting device of the DN30 PSP and the cylinder head. Nevertheless, the maximal plastic strains at the cylinder pressure envelope are identical for both cylinders and remain below the elastic limit (0.2 % proof stress).

Furthermore, the areas with very small plastic deformations occur far away from the valve and the plug half coupling so that the areas near closure devices of the containment system remain free of inelastic deformations. Based on this observation, there is no risk of loss or dispersal of the radioactive contents of the 30B-X cylinder.

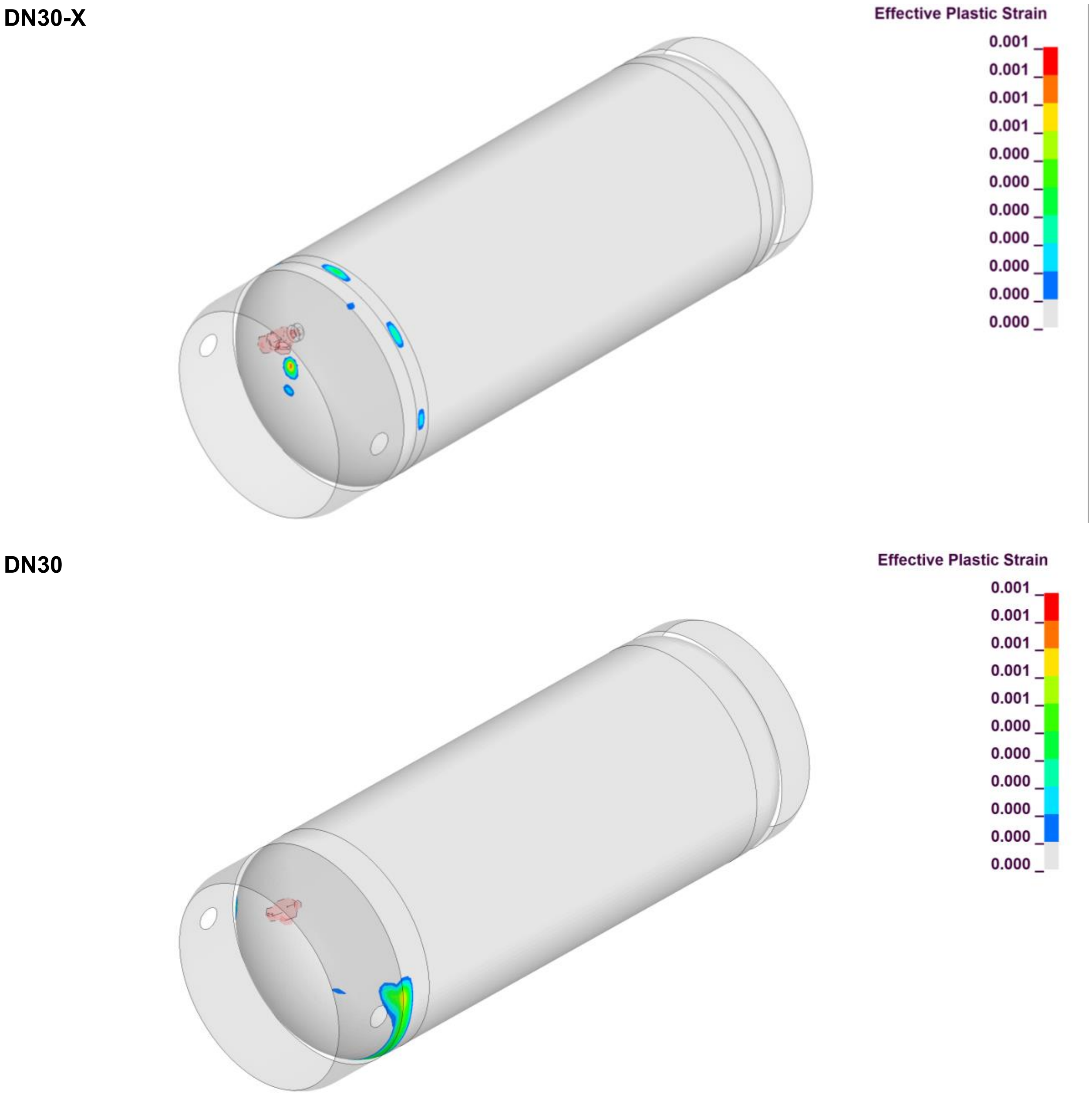

Figure 2-3 Flat drop onto the valve side under NCT – Comparison of equivalent plastic strain at the cylinder pressure envelope

2.2.7.1.4.1.1.2 Criticality Control System of the 30B-X Cylinder

For the flat drop onto the valve side, covering deformations of the interior CCS of the 30B-X cylinder are obtained for the combined 10.2 m drop test investigated in section 2.2.7.1.3.2.1.2. Since the requirements with regard to the parts of the CCS are identical under NCT and HAC, no additional evaluations are required for these parts.

2.2.7.1.4.1.2 Summary

The DN30-X package design ensures that after the flat drop test onto the valve side simulating NCT, all acceptance criteria as defined in section 2.2.1 are met:

- There is no failure of the DN30 PSP closure system.
- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There are no inelastic deformations of the 30B-X cylinder in the proximity of the valve and plug half coupling
- No loss or dispersal of radioactive contents of the 30B-X cylinder.
- There is no failure of the 30B-X cylinder confinement system.

2.2.7.1.4.2 Flat Drop onto the Feet – Drop Test Sequence 9

With the corner drop and the flat drop onto the valve side as described in section 2.2.7.1.3.1 and 2.2.7.1.3.2, two drop test orientations have been investigated for the DN30-X that have also been used to validate the DN30 package FEM model against experimental drop test results. These two drop test scenarios put high stress on the DN30 PSP, but in case of the flat drop onto the valve side, the interior CCS of the 30B-X cylinder also experiences high loads, especially the lattice holders and the CCS restraints. In contrast to this, the investigation of the flat drop onto the feet aims at generating maximal decelerations at the CCRs perpendicular to their axis resulting in maximal bending stresses and, thus, the highest risk of kinking of the CCRs.

2.2.7.1.4.2.1 Deformations

2.2.7.1.4.2.1.1 DN30 PSP and Cylinder Pressure Envelope

The feet of the DN30 PSP undergo severe buckling and are pushed into the outer shell of the DN30 PSP. The largest equivalent plastic strain in the outer shell is 29 % and occurs in the area where the feet are pushed into the outer shell. Because of the very high plastic deformations at the feet, cracks are to be expected. Nevertheless, the occurring plastic deformations of the inner steel parts remain below 10 %. Furthermore, the rotation preventing, valve and plug protecting device are nearly undamaged after the flat drop test onto the feet and no contact at the valve is detected, except for its initial point of attachment.

The flat drop test onto the feet is used to determine the permanent radial reduction in the wall thickness of the DN30 PSP, which is required as input for the criticality safety analysis in section 2.6. Including the sheet thicknesses of the inner and outer shell, a minimal permanent wall thickness of the DN30 PSP of 134 mm is obtained.

In case of the cylinder pressure envelope, the maximal equivalent plastic strain of 2.4 % is reached at the bottom of the cylinder, where the three lattice holders impact the cylinder shell. This value is significantly below the elongation at fracture of the cylinder shell material so that rupture of the containment system can safely be excluded.

2.2.7.1.4.2.1.2 Criticality Control System of the 30B-X Cylinder

Noticeable plastic deformations of the CCS only occur at the lower half of the lattice holders. However, with maximally 3.9 % plastic strains, the relative dislocations between the CCRs is still small as most of the pipe clamps of the lattice holders hardly experience any plastic deformations.

Regarding the acceptance criteria for the CCS defined in section 2.2.1, the relative dislocations between the CCRs and also the movement of the entire CCS relative to the 30B-X cylinder shell are evaluated. A detailed evaluation of the relative dislocations between the inner and middle CCR as well as the middle and outer CCR is provided in Appendix 2.2 (Structural Analysis), section 7.2.6.1.2.2. This evaluation leads to a maximal permanent relative dislocation between the inner and middle ring of -0.31 mm. Applying the same procedure to the middle and outer ring results in a maximal permanent relative dislocation of -0.75 mm.

For the flat drop onto the feet, there are only negligible deformations that would increase the axial movability of the entire CCS within the 30B-X cylinder. The radial movability of the entire CCS within the cylinder is evaluated by measuring the radial gap between the central lattice holder and the cylinder shell as the maximal plastic deformations of the lattice holders and the cylinder shell occur in this area. The detailed evaluation provided in Appendix 2.2 (Structural Analysis), section 7.2.6.1.2.2 shows an increase of the radial movability of the entire CCS within the cylinder of 2.1 mm.

2.2.7.1.4.2.2 Summary

The DN30-X package design ensures that after the flat drop test onto the feet simulating HAC, all acceptance criteria as defined in section 2.2.1 are met:

- There is no failure of the DN30 PSP closure system.
- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no rupture of the 30B-X cylinder containment system.
- There is no failure of the 30B-X cylinder confinement system.

2.2.7.1.4.3 Flat Drop onto the Top Half – Drop Test Sequence 8

The drop test sequence flat onto the top of the DN30 PSP was performed in the safety analysis of the DN30 package because of its relevance with regard to the determination of the increase in the maximal dose rate after the tests simulating NCT. Furthermore, the simulation provided information about the extent of the reduction of the thickness of the DN30 PSP for the thermal analysis. The detailed discussion in Appendix 2.2 (Structural Analysis), section 7.2.6.6 proves that the design of DN30-X package ensures that after the tests simulating HAC:

- There is no failure of the DN30 PSP closure system.

- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment.
- There is no rupture of the 30B-X cylinder containment system.
- There is no failure of the 30B-X cylinder confinement system.
- The extent of the reduction of the wall thickness of the DN30 PSP after NCT amounts to maximally 4 mm and, thus, is such that the increase of the dose rate does not exceed the limit specified in section 2.5.1.
- The extent of the reduction of the thickness of the DN30 PSP after HAC is such that the thermal protection properties of the DN30 PSP are still sufficient to limit the temperature increase in the thermal tests to the limits specified in section 2.3.1.

2.2.7.2 Water Immersion Test for all Packages

The containment (the 30B-X cylinder) is designed to comply with requirements from [ANSI N14.1] for an external MAWP of 172 kPa. The water immersion test for all packages defined in [10 CFR Part 71] §73(c)(6) or [SSR-6 2018] para. 729 requires the immersion of the specimen under a head of water of at least 15 m for a period of not less than 8 hours. This is equal to an external gauge pressure of 150 kPa, which is below the external MAWP. Hence, the DN30-X package is designed to withstand the water immersion test.

2.2.7.3 Influence of the Thermal Test under HAC on the Structural Integrity of the DN30-X Package

2.2.7.3.1 Internal Pressure

The pressure build-up during the thermal test is investigated in the thermal analysis in section 2.3.2. The calculations prove that the maximum pressure in the 30B-X cylinder during the thermal test caused by elevated temperatures and by melted UF_6 contents remains below the admissible pressure. Thus, an influence of the thermal test on the containment system of the DN30-X package can be excluded.

2.2.7.3.2 Pressure Development because of Expansion of Intumescent Material

In case of a fire accident, the expansion of the intumescent material is triggered when its expansion temperature is reached. This may cause the development of a pressure that is acting on the 30B-X cylinder. The analysis for the 30B-X cylinder in Appendix 2.2 (Structural Analysis), section 7.4.2, provesthat neither the 30B-X cylinder shells nor the valve or the plug will be damaged by the expansion of the intumescent material.

2.2.7.3.3 Thermally Induced Stresses

The analysis of thermally induced stresses at the DN30 PSP during the thermal test under HAC for the DN30-X package is provided in Appendix 2.2 (Structural Analysis), section 7.4.3, and shows that no stresses occur in the DN30 PSP shells during or after the thermal test.

Additional considerations are required for the interior CCS of the 30B-X cylinder to investigate potential stresses due to temperature gradients. As pointed out in Appendix 2.2 (Structural Analysis), section 7.4.3, this has already been discussed for normal operating conditions of the 30B-X cylinder. Using these results, and considering that the thermal analysis of the DN30-X package under HAC in section 2.3.4.4.1 proves that the maximum temperature during the thermal test under HAC remains below the maximal design temperature of the 30B-X cylinder of 121 °C in all cases, it follows that no thermally induced stresses in the CCS occur during the HAC thermal test.

2.2.7.4 Conclusion

The analysis of the drop test sequences and the experimental drop tests for the DN30 package provided in Appendix 2.2 (Structural Analysis) in conjunction with the comparing analyses between the DN30-X and the DN30 package in section 2.2.7.1.3 show compliance with the acceptance criteria defined in section 2.2.1:

- There is no failure of the DN30 PSP closure system in any drop test sequence.
- There is no physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment in any drop test sequence.
- There is no physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment in any drop test sequence.
- There is no rupture of the 30B-X cylinder containment system in any drop test sequence.

The additional analyses in section 2.2.7.1.4 performed specifically with regard to the acceptance criteria for the interior CCS of the 30B-X cylinder prove that the deformations of the 30B-X cylinder and its interior CCS are such that there is no failure of the confinement system of the DN30-X package:

- The relative dislocation of the criticality control rods (CCRs) remains below 5 mm.
- The increase in radial movability of the entire CCS out of the center of the 30B-X cylinder remains below 3 mm.
- The increase in axial movability of the entire CCS out of the center of the 30B-X cylinder remains below 7 mm.
- There is no failure of the lattice holders.
- There is no rupture of the CCRs.

Furthermore, the following results from the analysis of the experimental drop tests provided in appendix A of Appendix 2.2 (Structural Analysis) can be applied wholly to the DN30-X package (see section 2.1.1.1):

- The leakage rate after each drop test sequence is less than $1.0 \cdot 10^{-6}\ \mathrm{Pa \cdot m^3/s}$.
- The valve protecting device of the DN30 PSP fulfills its function after each drop test sequence.
- The rotation preventing device of the DN30 PSP fulfills its function after each drop test sequence.
- The plug protecting device of the DN30 PSP fulfills its function after each drop test sequence.

- The intumescent material as well as the housing are still present and undamaged after each of the drop test sequences.
- The deformations of the DN30-X package at +60 °C have to be very similar to the deformations of the DN30 package at 60 °C.
- The deformations of the DN30-X package at -40 °C have to be very similar to the deformations of the DN30 package at -40 °C.
- Neither at -40 °C nor at +60 °C a physical contact between the valve of the 30B-X cylinder and any other component of the packaging other than its original point of attachment is detected.
- Neither at -40 °C nor at +60 °C a physical contact between the plug of the 30B-X cylinder and any other component of the packaging other than its original point of attachment is detected.
- The valve protecting device of the DN30 PSP fulfills its function after each drop test sequence in the whole temperature range.
- The rotation preventing device of the DN30 PSP fulfills its function after each drop test sequence in the whole temperature range.
- The plug protecting device of the DN30 PSP fulfills its function after each drop test sequence in the whole temperature range.

Consequently, the DN30 PSP provides the required mechanical protection of the 30B-X cylinder for the temperature range of -40 °C to +60 °C under RCT, NCT, and HAC.

2.3 Thermal Analysis

The thermal analysis for the DN30-X package, consisting of the DN30 PSP and the 30B-X cylinder, is summarized in this section and evaluated in detail in Appendix 2.3 (Thermal Analysis). The thermal analysis is based a benchmarked and validated FEM model. Benchmarking and validation was done using the results of two prototype fire tests carried out with DN30 prototypes. This is valid, because:

- The standard 30B and 30B-X cylinders are transported in identical overpacks, the DN30 PSP.
- Only parameters of the DN30 PSP are benchmarked.
- The assumed thermal load of 3 W for the UF_6 content is by far covering for all admissible enrichment levels for the DN30-X package (see section 1.3.2.7).

The thermal analysis is detailed in the following structure: after listing the object of verification for the thermal analysis, at first the admissible component temperatures are evaluated and justified, followed by the analysis of the two prototype fire tests. The main part is the thermal analysis of the DN30-X package using transient-thermal FEM calculations. After presenting the calculation model and the boundary conditions, the benchmark calculations are described that demonstrate the validity of the assumptions by recalculating the two prototype fire tests. The following sections are then the thermal analysis of the DN30-X package for NCT, for ACT, and a comprehensive sensitivity analysis. The conclusion is given in the form of a summary demonstrating the proof for the DN30-X package to meet the regulatory requirements.

2.3.1 Objective of Verification

2.3.1.1 Verification for all Types of Packages

It is verified that the design of the DN30-X package considers ambient temperatures and pressures that are likely to be encountered under NCT. Even though such a requirement is neither stipulated in [10 CFR Part 71] nor in [49 CFR Part 173], it is required for [SSR-6 2018] para. 616.

2.3.1.2 Verification for Packages Containing Uranium Hexafluoride

It is verified that the DN30-X package withstands the thermal test specified in [10 CFR Part 71] §73(c)(4) or [SSR-6 2018] para. 728 without rupture of the containment system.

2.3.1.3 Verification for Packages Containing Fissile Material

The consequences of the thermal test specified in [10 CFR Part 71] §73(c)(4) or [SSR-6 2018] para. 728 on the DN30-X package subjected to the mechanical tests specified in [10 CFR Part 71] §73(a), §73(c)(1), §73(c)(3) and §73(c)(6) or [SSR-6 2018] paras. 726, 727(a), 727(b) and 729 are analyzed to verify the requirements of [10 CFR Part 71] §55(d), §55(e) and §59(a)(2) or [SSR-6 2018] para. 682 and 685.

2.3.2 Admissible Component Temperatures of the DN30-X Package

The containment system of the DN30-X package consists of the 30B-X cylinder shells with installed valve and plug. The admissible temperature for these components is defined as 131 °C (267.8 °F).

This admissible temperature is lower than the admissible temperatures of the components of the 30B-X pressure envelope with installed valve and plug:

- 30B-X pressure envelope: the maximum temperature for the cylinder shells defined in [ASME BPVC] for SA516 steel grade 55/60 is 371.11 °C or 700 °F.
- valve/plug body (aluminum bronze UNS C63600): the melting point is 1030 °C, the hot working temperature is 760 – 875 °C.
- valve/plug stem (nickel copper alloy UNS N04400): the melting point is 1300 – 1350 °C, the hot-working temperature is 648 – 1176 °C.
- valve/plug solder (tin-lead alloy): the solidus temperature of a tin lead solder compliant with ASTM B32 alloy grade Sn 50 is 183 °C, the liquidus temperature is 216 °C (cf. [Harris Sn50])

The limiting factor in the determination of this admissible temperature; apart from the solder of valve and plug, is the pressure build-up caused by melted UF_6 contents for temperatures above the triple point of UF_6 (64 °C/147.3 °F). This is investigated in the following, taking into account the increased minimum ullage of the 30B-10 and 30B-20 cylinder in comparison to the standard 30B cylinder. Furthermore, the following conservative assumptions are used:

- The admissible temperature of 131 °C is assumed to be the average temperature of all UF_6 contents in the 30B-X cylinder. Calculations in section 2.3.4.6.2 show that only the outmost region of the UF_6 in contact with the 30B-X cylinder shell will reach the maximum temperature while the core of the UF_6 is well below that temperature.
- For the calculation of the pressure build-up, the pressure in the empty 30B-X cylinder is conservatively assumed to be 5 psi instead of 3 psi (compare [USEC 651], sections 5.3.5 and 8.3).
- The calculations for the pressure build-up are performed with the maximum net weight and minimum volume of the 30B-X cylinder listed in Table 1-13.
- Any beneficial effects on the stability of the 30B-X pressure envelope by the structure of the CCS, lattice holders, and/or stiffeners are conservatively neglected.
- The admissible pressure under HAC is based on the hydraulic test pressure of twice the maximum allowable working pressure MAWP as specified in [ANSI N14.1] for standard 30B cylinders, which is applicable for the 30B-X cylinder as well. To consider the elevated temperature of 131 °C/267.8 °F, which is above the design limit of 121 °C/250 °F according to the [ASME BPVC], this test pressure is modified. The admissible pressure is reduced using the linear interpolated yield strength of [ASTM A516] Grade 55 for 267.8 °F:

$$p_{max} = 2 \cdot MAWP \cdot \frac{S_{y,267.8\,°F}}{S_{y,250\,°F}} = 2 \cdot 200\,psig \cdot \frac{26.82\,ksi}{27.0\,ksi} = 397.36\,psig$$

Therefore, the admissible pressure under HAC is set to 2.74 MPa/397.36 psig for the 30B-X cylinder including its valve and plug.

A calculation of the pressure build-up for filling ratios of 50 % and 100 % for the admissible temperature of 131 °C/267.8 °F (see Appendix 2.3 (Thermal Analysis), chapter 3 for details) results in the safety margins listed in table 2-9.

As these safeties are calculated with the testing pressure specified in [ANSI N14.1] for a standard 30B cylinder, this safety also includes an additional safety margin because the testing pressure only utilizes a maximum of 95 % of the yield strength for primary stresses (cf. [ASME BPVC]). The requirements for the pressure envelope of the 30B-X cylinder are at least equal to those of regular 30B cylinders according to [ANSI N14.1].

Table 2-9 Safety margins for the pressure build-up inside the 30B-X cylinder

Filling Ratio in %	Safety margin	
	30B-10 cylinder	30B-20 cylinder
50	2.93	2.94
100	2.37	2.48

Because of the large minimum ullage of the 30B-10 and 30B-20 cylinder of 17.6 % and 20.8 %, respectively, the maximum pressure at a temperature of 267.8 °F/131 °C of 1.16 MPa is even below the MAWP (1.38 MPa/200 psig) of the 30B-X cylinder.

Additional calculations for the safety margin for the 30B-X cylinder according to ASME Code Section VIII – Division 1 for the maximum internal pressure of 1.16 MPa are listed in Appendix 2.3 (Thermal Analysis), chapter 3. The calculated safety factors according to [ASME BPVC] are summarized in Table 2-10.

Table 2-10 Safety margins for the required wall thickness of the 30B-X cylinder

		Paragraph/ Appendix	Formula	Required wall thickness t_{req}	Safety factor
Cylinder	I	App. 1-1 (1)	$t_{req} = \frac{p_{max} \cdot R_o}{S_y \cdot E + 0.4 \cdot p_{max}}$	2.71 mm	4.05
Cylinder	II	UG-27 (1)	$t_{req} = \frac{p_{max} \cdot R_o}{S_y \cdot E - 0.6 \cdot p_{max}}$	2.73 mm	4.02
Cylinder	III	App. 1-2 (1)	$t_{req} = R_o \left(1 - exp\left(\frac{p_{max}}{-S_y \cdot E}\right)\right)$	2.79 mm	3.94
Cylinder	IV	App. 1-2 (1)	$t_{req} = R\left(exp\left(\frac{p_{max}}{S_y \cdot E}\right) - 1\right)$	2.73 mm	4.03
Dished heads	I	App. 1-4 (1)	$t_{req} = \frac{p_{max} \cdot D_o \cdot K}{2 \cdot S_y \cdot E + p_{max}(K - 0.1)}$	2.78 mm	3.95
Dished heads	II	App. 1-4 (1)	$t_{req} = \frac{p_{max} \cdot D \cdot K}{2 \cdot S_y \cdot E - 0.2 \cdot p_{max}}$	2.72 mm	4.04

A possible pressure build-up caused by melted UF_6 contents is therefore generally unproblematic, because the increased ullage compared to a standard 30B cylinder leads to relatively large safety margins.

The admissible temperature for the 30B-X cylinder is therefore set to 131 °C/267.8 °F. This admissible temperature is below the allowable temperatures defined in standards or the hot-working temperatures and liquidus temperatures/melting points of the materials being part of the pressure-containment of the 30B-X cylinder.

The additional components of a 30B-X cylinder compared to a standard 30B cylinder are the components of the CCS: the lattice holders, the criticality control rods (CCRs), and the neutron absorbing material. The material specifications for the lattice holders and the CCRs are in compliance with a standard 30B cylinder according to [ANSI N14.1] and, therefore, exceed the admissible temperature as well. With 2763 °C/ 5005 °F, the melting point of the neutron absorbing material in the form of B_4C is far above the admissible temperature.

Furthermore, there is no danger of rupture because of a possible pressure build-up caused by melted UF_6 contents for temperatures above the triple point. The admissible component temperatures for the DN30 PSP are derived from Appendix 1.4.2 (Material Properties). The admissible temperatures are summarized in table 2-11 below.

Table 2-11 Admissible component temperatures of the DN30-X package

Component	Material	Admissible temperature [°C]	
		NCT	HAC
DN30 PSP			
Outer shell	Type 304/1.4301	70 / 100 1)	900 6)
Inner shell	Type 304/1.4301	60 1)	900 6)
Foam	PIR foam	60 2)	-
Thermal insulation	Microporous material (see table 1-12)	60 2)	1000
Intumescent material	Intumescent material (see table 1-12)	150 3)	600
30B-X cylinder			
Shells	Pressure vessel steel		
Lattice Holder/CCRs	Pressure vessel steel	64 4)	131 5)
Neutron absorber	Boron carbide		
Valve / plug			
Body	Aluminum bronze		
Stem	Nickel copper alloy	64 4)	131 5)
Solder	Tin lead alloy		

1) Calculation temperature for the handling, for the outer shell: 70 °C in general and 100 °C for the lifting lugs at the top half.
2) Identical to the temperature of the shells.
3) Temperature where the expansion of the intumescent material begins.
4) Triple point temperature of UF_6.
5) Covering maximum temperature for the components of the 30B-X cylinder (see calculations above).
6) The hot forming of material Type 304/1.4301 is carried out at temperatures of 950 to 1200 °C. At 900 °C a sufficient strength remains and, thus, a deformation by own weight is not expected. The strength of the outer shell is neither relevant for the containment system nor for shielding and criticality safety.

2.3.3 Prototype Fire Tests

To support the thermal analyses that is mainly conducted using FEM analyses, prototype fire tests of the DN30 package were carried out for benchmarking and validation of the thermal properties and of the heat transfer mechanisms of the DN30 PSP. Because the DN30 PSP used for the DN30 package is identical to the DN30 PSP used for the DN30-X package, these results are applicable for the DN30-X as well.

The performance and results of the prototype fire tests are described in detail in Appendix 2.3 (Thermal Analysis), chapter 4.

2.3.4 Thermal Analysis of the DN30-X Package

The thermal analysis of the DN30-X package is based on transient-thermal calculations with benchmarked and validated FEM models. The prototype fire tests listed in section 2.3.3 were used for benchmarking and validation. The benchmark calculations are detailed in Appendix 2.3 (Thermal Analysis), section 5.4.

After a description of the calculation model and its material properties and heat transfer mechanisms, this benchmarked and validated calculation model is then used to investigate the behavior of the DN30-X package for NCT and HAC and to show compliance with the requirements defined in section 2.3.1. Sensitivity analyses for different parameters like contact definitions, mesh size, and time-step size are included as well.

2.3.4.1 Software

The thermal analysis is carried out with [ANSYS] Workbench 2022 R2, which is a software environment for performing linear and non-linear structural, thermal, and electromagnetic analyses using the finite element method (FEM). The capabilities of ANSYS Workbench encompass geometry creation and optimization, meshing, preparing the finite element model, solving and post-processing of results. For thermal problems, ANSYS Workbench can solve steady-state as well as transient problems using two- or three-dimensional models.

2.3.4.2 Calculation Model

For the thermal analysis of the DN30-X package, an axisymmetric two-dimensional model is used. The models of the DN30 PSP and of the 30B-X cylinder are simplified for the 2D environment. For example, the steel flange between top half and bottom half is not modelled but accounted for in the thermal properties of the foam used in the analysis; the valve and plug end of the 30B-X cylinder are modeled with straight heads instead of curved heads. All assumptions and a detailed description are listed in Appendix 2.3 (Thermal Analysis), section 5.3.

2.3.4.3 Material Properties

The material properties are listed in Appendix 2.3 (Thermal Analysis), section 5.3.4, for three different conditions: for NCT conditions before the fire, HAC conditions during the fire, and HAC conditions after the fire during cooling down. For the foam parts, the material conditions of the HAC fire phase are used for the first 30 min of the HAC cool-down phase as well to account for the complete duration of the foam pyrolysis as observed during the prototype fire tests.

The material properties are mainly derived from Appendix 1.4.2 (Material Properties).

2.3.4.4 Boundary Conditions and Heat Exchange

2.3.4.4.1 Initial Temperatures

The initial temperatures for the steady-state and transient calculations for NCT are uniformly 38 °C.

The initial temperatures for the transient calculations for HAC are:

- For the HAC fire phase: uniformly 63 °C, a conservative temperature calculated for NCT boundary conditions (see section 2.3.4.5).
- For the HAC cooling down phase: the temperature distribution at the end of the fire phase.

2.3.4.4.2 Thermal Contacts

The thermal contacts for components in physical contact are modelled using standard bonded contacts with an augmented Lagrange formulation. The thermal conductance of these contacts is calculated by the program automatically based on the material properties.

2.3.4.4.3 Heat Generation

Heat generation in form of the thermal power of the UF_6 is considered for filled or partly filled packaged as well as the heat generation caused by the pyrolysis of the foam. Further details are listed in Appendix 2.3 (Thermal Analysis), section 5.3.7.

2.3.4.4.4 Solar Insolation

The solar insolation data are specified in Table 2-12. They comply with [10 CFR Part 71] §71.71(c)(1) and [SSR-6 2018] para. 657. For the calculation for NCT and for the initial temperatures for HAC, several 12-hour insolation / no insolation cycles were investigated.

Table 2-12 Solar insolation

Surface Orientation	NCT	HAC Fire Phase	HAC Cooling Down
	Total insolation for a 12-hour period [W/m²]		
Vertical surfaces (valve and plug end)	200	-	200
Horizontal surfaces (cylindrical surfaces)	400	-	400

2.3.4.4.5 Heat Transfer

Heat transfer to the ambient is considered using radiation and convection. For NCT and the cooling phase of HAC, the ambient temperature is 38 °C/100 °F according to [10 CFR Part 71] §71.71(c)(1) and §71.73(b) or [SSR-6 2018] para. 656. For the fire phase of HAC, the temperature is set to 800 °C/1475 °F according to [10 CFR Part 71] §71.73(c)(4) or [SSR-6 2018] para. 728. Further details are listed in Appendix 2.3 (Thermal Analysis), section 5.3.9.

Heat transfer in gaps is considered using radiation, conduction, and convection. Further details are listed in Appendix 2.3 (Thermal Analysis), section 5.3.10.

2.3.4.5 Thermal Analysis of the DN30-X package for NCT

The conditions for the thermal analysis of the DN30-X package for NCT were determined according to [10 CFR Part 71] §71.71(c)(1) or [SSR-6 2018] para. 657. The DN30-X package with different filling ratios is subject to 12-hour insolation / 12-hour no insolation cycles. The cyclic insolation model is run for 20 days to reach conditions of steady periodic behavior.

The maximum temperature of 52 °C for a partially or completely filled 30B-X cylinder and its components is well below the NCT limit of 64 °C defined in Table 2-11. Hence, it can be assumed that the UF_6 remains solid under NCT conditions. The maximum temperature of the outer shell of 63 °C is below the admissible temperature of 70 °C as well.

The maximum temperature of 63 °C complies with the initial conditions used for pre-heating of the prototype for the prototype fire test. The maximum temperatures for a DN30 package with an empty 30B cylinder are listed as well, as this combination was used for the prototype fire tests (see section 2.3.3). In general, the maximum temperatures at the 30B-X cylinder are nearly the same regardless of filling ratio because of the relative high heat sink of the internal CCS.

Table 2-13 Maximum temperatures for NCT at the DN30-X package for 12-hour insolation / no insolation cycles

Position / Component	Maximum temperature [°C]			
	DN30 package with an empty 30B cylinder	DN30-X package with an empty 30B-X cylinder	DN30-X package with a partially filled (50 %) 30B-X cylinder	DN30-X package with a full (100 %) 30B-X cylinder
Valve	53	52	52	52
Plug	53	52	51	52
Cylinder mantle	53	52	52	52
CCS	-	51	51	51
Cylinder volume (Air/UF_6)	53	52	52	52
Inner shell DN30 PSP	57	56	56	56
Outer shell DN30 PSP	63	63	63	63
Average of complete package	56	54	54	54

The temperature development of an empty 30B-X package for NCT during 12-hours insolation / no insolation cycles is shown in Figure 2-4 for the maximum temperatures of the 30B-X pressure envelope (encompasses valve, plug, and mantle), the volume of the 30B-X cylinder (air filling), the inner shell of the DN30 PSP, and the outer shell of the DN30 PSP.

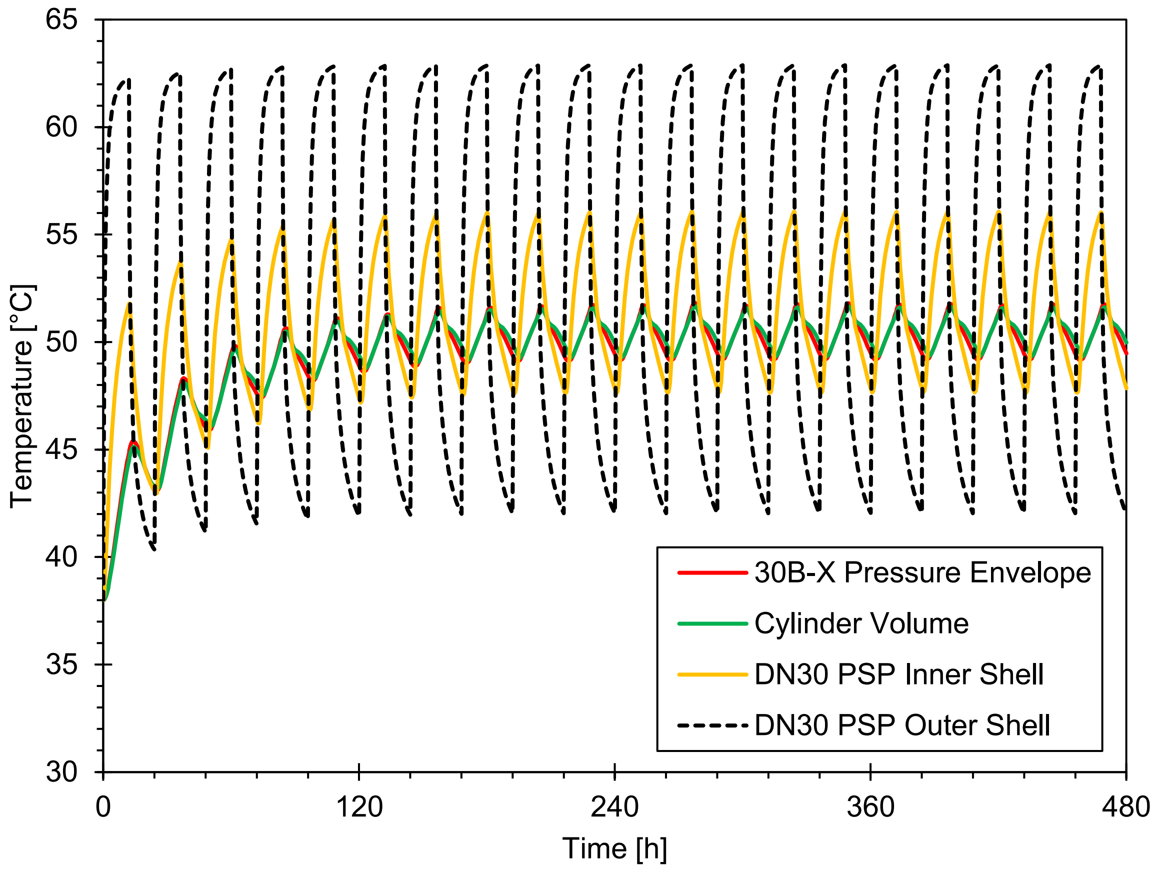

Figure 2-4 Temperature development of an empty DN30-X package for NCT during 12-hours insolation / no insolation cycles

The maximum temperature difference between the 30B-X pressure envelope and interior components like the CCRs and the lattice holder is evaluated for the calculation of thermal stresses (see Appendix 2.2 (Structural Analysis)). The maximum temperature difference for NCT is 3.9 °C for an empty 30B-X cylinder and 3.4 °C for a completely filled 30B-X cylinder (100 %).

2.3.4.6 Thermal Analysis of the DN30-X package for HAC

For the calculations of the DN30-X package for HAC, the ambient temperatures according to [10 CFR Part 71] §71.73(c)(4) or [SSR-6 2018] para. 728 of 800 °C for the fire phase and 38 °C for the cooling down phase are used.

The end time of the calculation is set to 25220 s or 7 hours after the start of the fire and therefore includes 6.5 hours of cooling-down. This end time is chosen so that the temperatures of all components have already reached their maximum and are decreasing.

2.3.4.6.1 Empty 30B-X Cylinder

Figure 2-5 shows an overview of the temperatures at the DN30-X package loaded with an empty 30B-X cylinder. The maximum temperatures are listed in Table 2-14 for relevant components of the DN30-X package. The following can be observed:

- The maximum temperatures for the components of the pressure envelope are for the valve 118 °C, for the plug 114 °C, and for the mantle 118 °C. These temperatures are below the admissible temperature of 131 °C.

- The maximum temperatures for the CCS and the cylinder volume are below the admissible temperature of 131 °C as well with 94 °C and 118 °C.
- The maximum temperatures for the inner and the outer shell are below the admissible temperature of 900 °C with 187°C and 785 °C.
- The maximum temperature difference between the 30B-X pressure envelope and interior components like the CCRs and the lattice holder is 15 °C. For an analysis of the thermal stresses, see Appendix 2.2 (Structural Analysis).

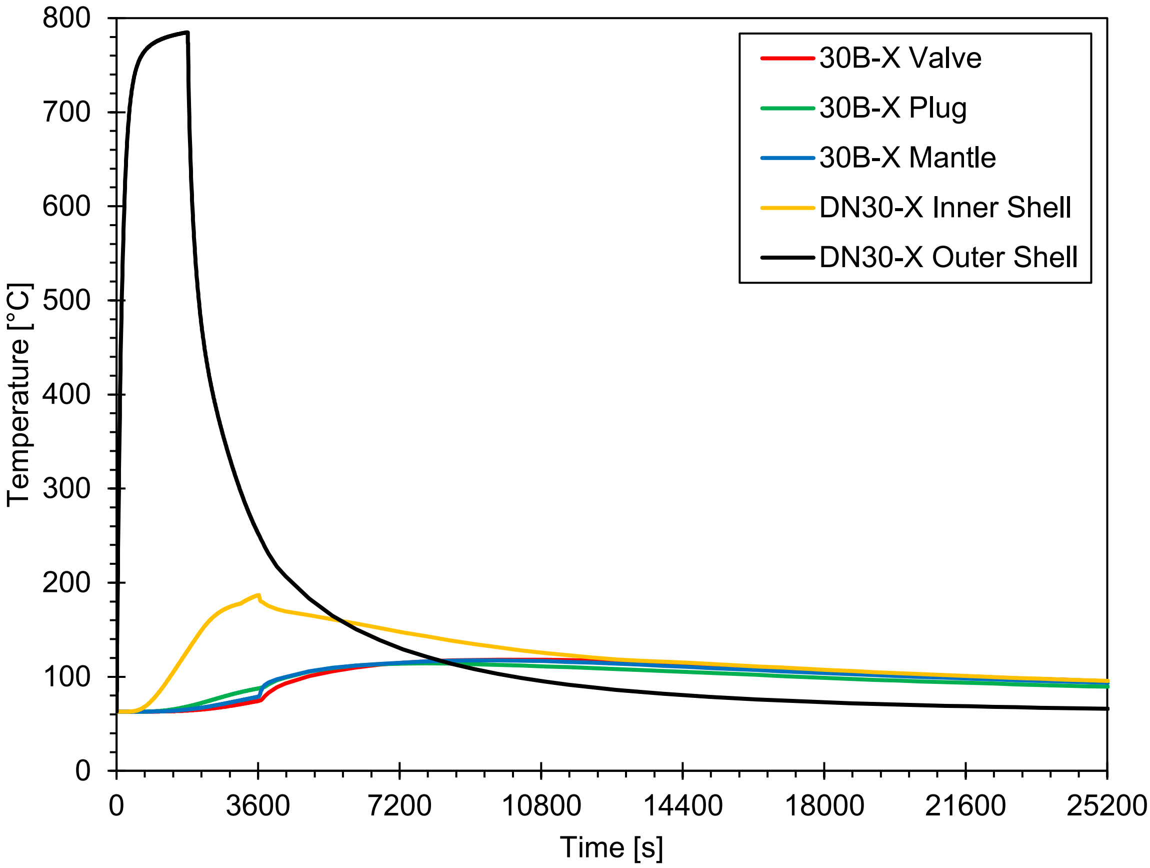

Figure 2-5 Temperatures at the DN30-X package for HAC with an empty 30B-X cylinder

Table 2-14 Maximum temperatures for HAC at the DN30-X package loaded with an empty 30B-X cylinder

Position / Component	Temperature [°C]	Time [s]
Valve	118	10296
Plug	114	7896
Cylinder mantle	118	9096
CCS	94	14496
Cylinder volume (Air/UF_6)	118	10296
Inner shell DN30 PSP	187	3620
Outer shell DN30 PSP	785	1810

Figure 2-6 shows the calculated temperature distribution at the time when the maximum temperature is reached for the valve of the 30B-X cylinder.

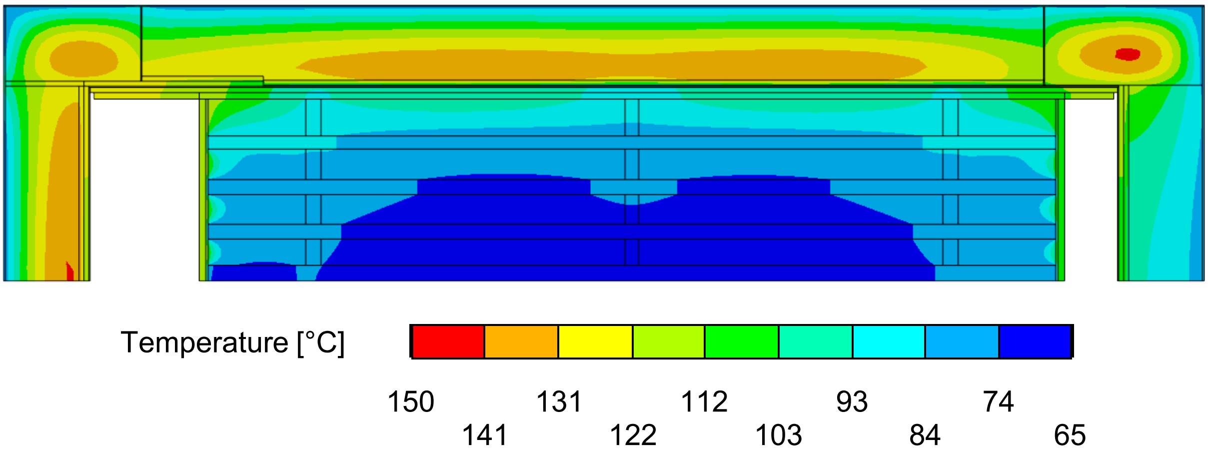

Figure 2-6 Temperature distribution for the empty DN30-X package for HAC at the time when the maximum temperature is reached for the valve (t = 10296 s or ~172 min)

The temperature distribution for the DN30-X package for the time when the maximum temperature difference of 15 °C is calculated between the 30B-X pressure envelope and interior components like the CCRs and the lattice holders is shown in Figure 2-7. Only the temperatures of the components inside the 30B-X cylinder are shown in order to better present the temperature distribution of these components.

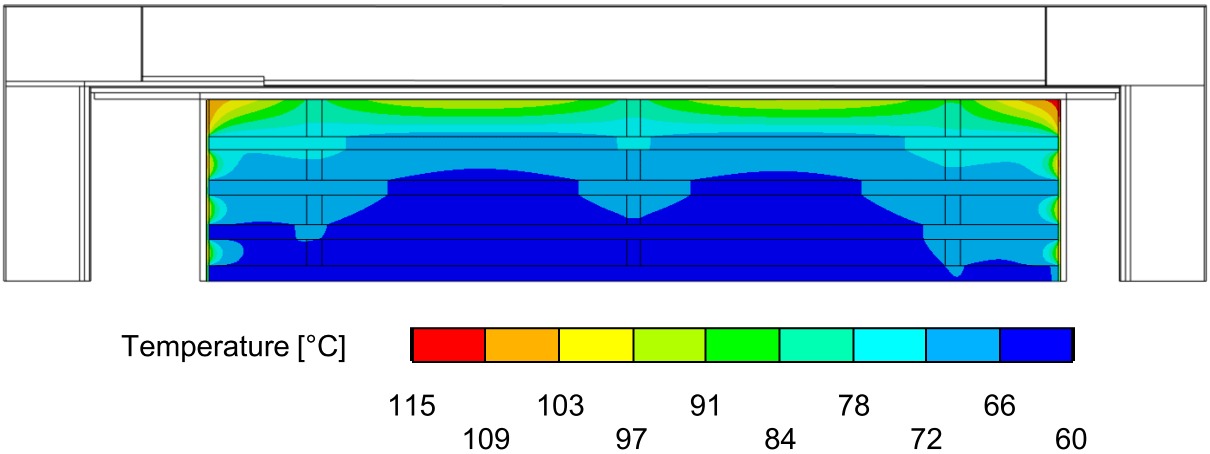

Figure 2-7 Temperature distribution for the empty DN30-X package for HAC at the time when the maximum temperature difference between 30B-X pressure envelope and CCS is reached (t = 6096 s or ~102 min)

Further details are listed in Appendix 2.3 (Thermal Analysis), section 5.6.1.

2.3.4.6.2 Filled 30B-X Cylinder

This calculation is similar to the calculation for an empty cylinder in the section before, but with a full 30B-X cylinder (filling ratio 100 %) instead. The UF_6 is distributed homogeneously in the cavity of the 30B-X cylinder. The material properties are listed in Appendix 2.3 (Thermal Analysis). All other parameters are identical to the parameters used for the analysis of the DN30-X package

loaded with an empty 30B-X cylinder documented in section 2.3.4.6.1. The different thermal conductance of the contacts UF_6 to the 30B-X cylinder pressure envelope or the CCS compared to air are calculated automatically by the calculation program based on the material properties.

Figure 2-8 shows an overview of the temperatures at the DN30-X package loaded with a filled 30B-X cylinder.

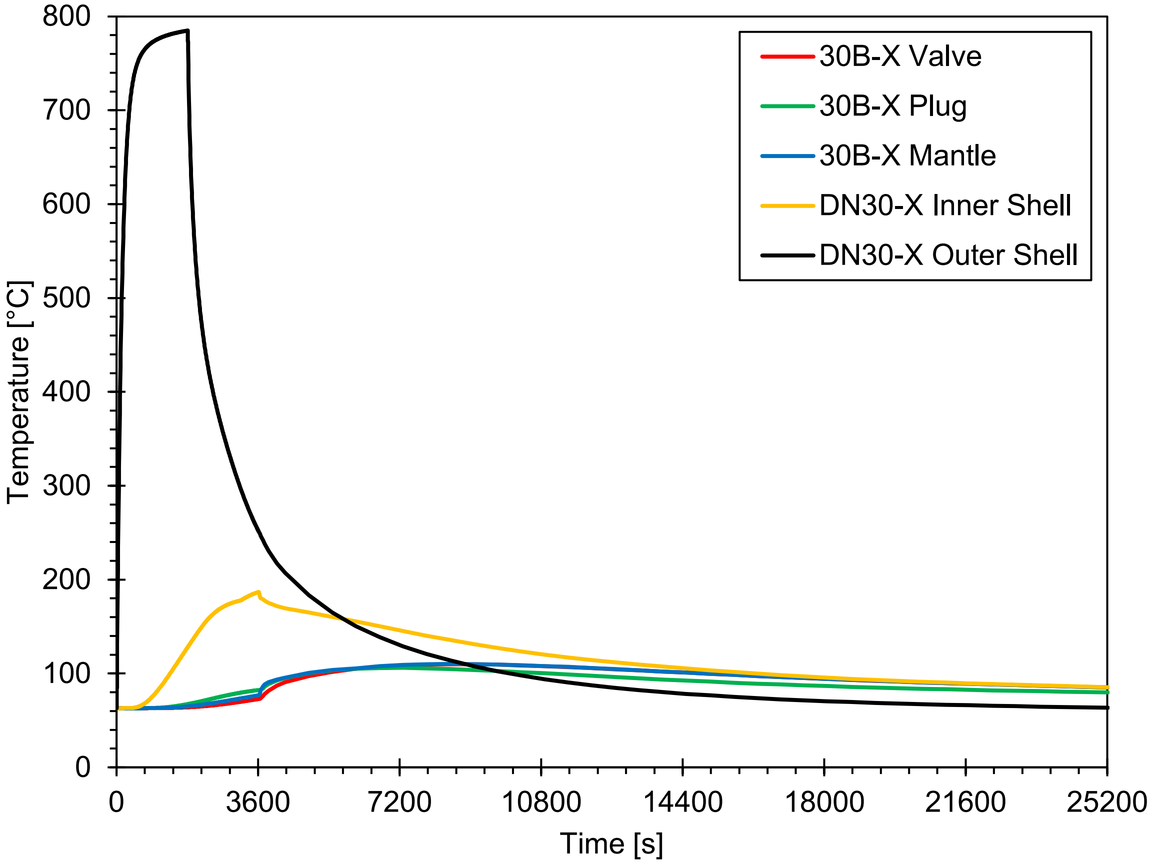

Figure 2-8 Temperatures at the DN30-X package for HAC with a full 30B-X cylinder

The temperatures at relevant positions of the completely filled DN30-X package calculated for the HAC fire test in comparison to the calculation for the empty DN30-X package are listed in Table 2-15. The following can be observed:

- The temperatures at the surface of the DN30 PSP for the completely filled DN30-X package are similar to the temperatures calculated for an empty DN30-X package.
- The temperatures at the 30B-X cylinder are 8 – 10 °C lower for the full cylinder compared to the temperatures calculated for an empty cylinder and the maximum is reached after a shorter time. The additional thermal power of the UF_6 is not even remotely high enough to elevate the temperatures above the ones for an empty cylinder because of the increased heat sink of the UF_6 compared to air.
- The maximum temperatures for the components of the pressure envelope are for the valve 110 °C, for the plug 106 °C, and for the mantle 110 °C. These temperatures are below the admissible temperature of 131 °C.

- The maximum temperature difference between the 30B-X pressure envelope and interior components like the CCRs and the lattice holder is 12 °C. For an analysis of the thermal stresses, see Appendix 2.2 (Structural Analysis).

Table 2-15 Maximum temperatures for HAC at the DN30-X package loaded with a full 30B-X cylinder

Position / Component	DN30-X package loaded with a full 30B-X cylinder		DN30-X package loaded with an empty 30B-X cylinder	
	Temperature [°C]	Time [s]	Temperature [°C]	Time [s]
Valve	110	8489	118	10296
Plug	106	7289	114	7896
Cylinder mantle	110	8489	118	9096
CCS	86	12089	94	14496
Cylinder volume (Air/UF_6)	109	8489	118	10296
Inner shell DN30 PSP	187	3620	187	3620
Outer shell DN30 PSP	785	1810	785	1810

Figure 2-9 shows the temperature distribution at the time of the maximum valve temperature.

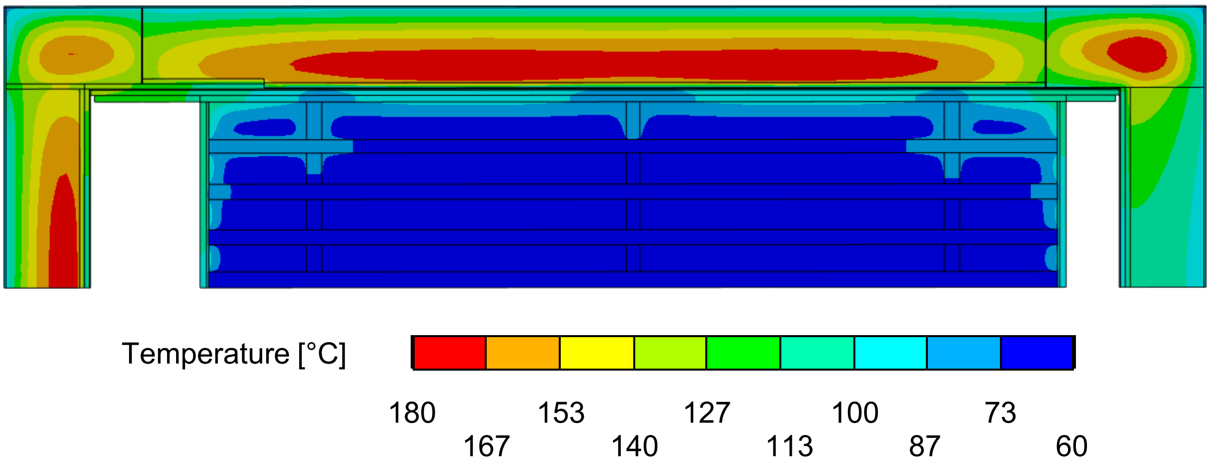

Figure 2-9 Temperature distribution for the full DN30-X package for HAC at the time when the maximum temperature is reached for the valve (t = 8489 s or ~141 min)

To better present the temperature distribution of the 30B-X cylinder and the UF_6 contents, Figure 2-10 shows temperatures for these components only, with a correspondingly smaller temperature scale. The point in time is the same as for Figure 2-9, since this also results in maximal temperatures for the 30B-X cylinder and its contents. Only the outer regions of the UF_6 reach this maximum temperature while the core of the UF_6 is still well below that temperature.

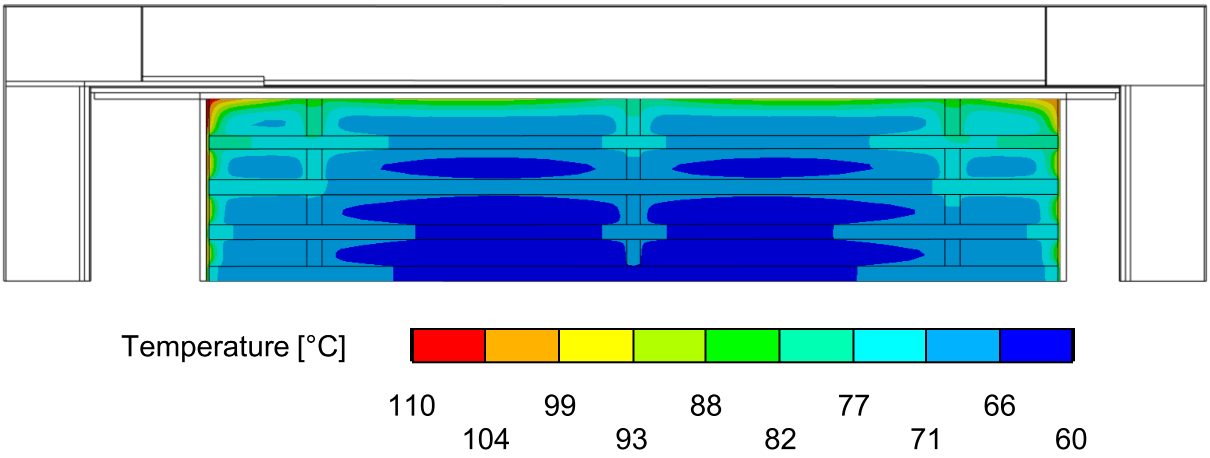

Figure 2-10 Temperature distribution for the full DN30-X package for HAC at the time when the maximum temperature is reached for the UF_6 (t = 8489 s or ~141 min)

Further details are listed in Appendix 2.3 (Thermal Analysis), section 5.6.2.

2.3.4.6.3 Partially Filled 30B-X Cylinder

After the empty and completely filled 30B-X cylinder, a partially filled 30B-X cylinder (filling ratio 50 %) is investigated as well. The UF_6 is distributed homogeneously in the cavity of the 30B-X cylinder. Conservatively, the maximum thermal power for the UF_6 is used for the partially filled 30B-X cylinder, too.

The temperatures at the valve of the 30B-X cylinder are shown in Figure 2-11 for HAC for different filling ratios. The temperatures at relevant positions of the partially filled DN30-X package calculated for the HAC fire test in comparison to the calculation for the empty and completely filled DN30-X package are listed in Table 2-16. The following can be observed:

- The temperatures at the surface of the DN30 PSP for the partially filled DN30-X package are similar to the temperatures calculated for an empty or filled DN30-X package.
- As expected, the temperatures for a partially filled 30B-X cylinder are between the empty and the completely filled 30B-X cylinder, but closer to the completely filled cylinder.
- The temperatures at the 30B-X cylinder are 5 – 7 °C lower for the partially filled cylinder compared to the temperatures calculated for an empty cylinder and the maximum is reached after a shorter time.
- The maximum temperatures for the components of the pressure envelope are for the valve 111 °C, for the plug 108 °C, and for the mantle 112 °C. These temperatures are below the admissible temperature of 131 °C.
- The maximum temperature difference between the 30B-X pressure envelope and interior components like the CCRs and the lattice holder is 13 °C. For an analysis of the thermal stresses, see Appendix 2.2 (Structural Analysis).

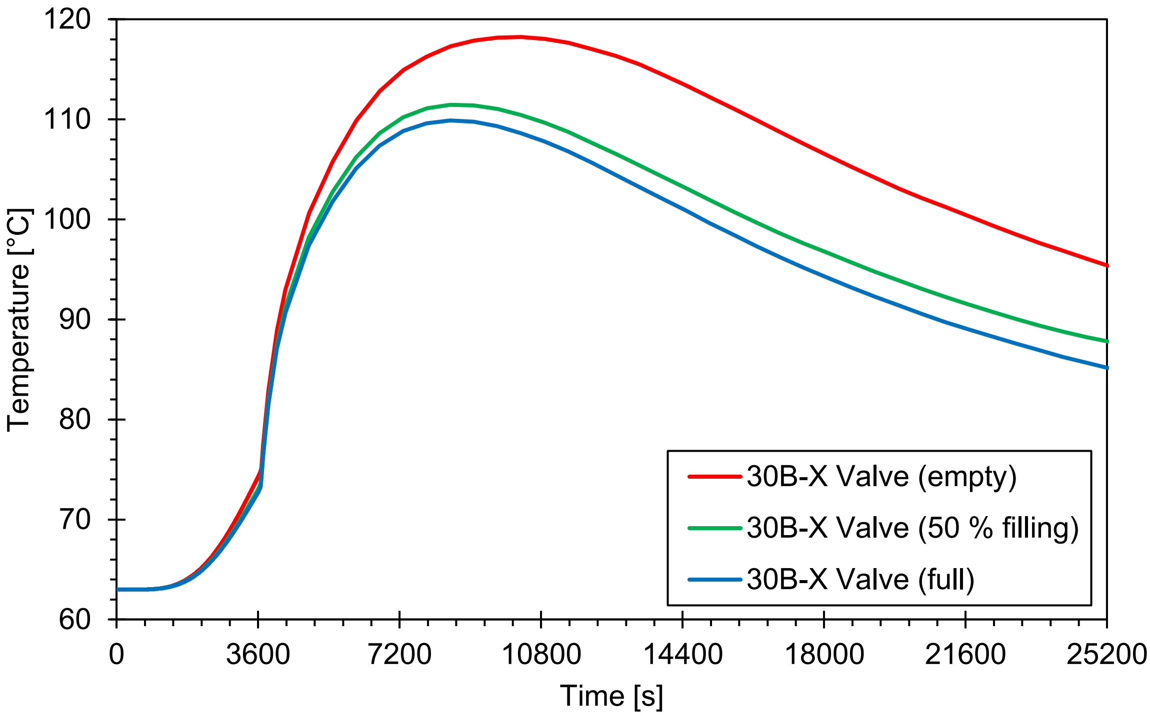

Figure 2-11 Temperatures calculated at the valve of the DN30-X package for HAC for different filling ratios (0, 50, and 100 %)

Table 2-16 Maximum temperatures calculated for HAC at the DN30-X package loaded with a partially filled 30B-X cylinder

Position / Component	Partially filled (50 %) 30B-X cylinder	Empty 30B-X cylinder	Filled (100 %) 30B-X cylinder
		Maximum Temperature [°C]	
Valve	111	118	110
Plug	108	114	106
Cylinder mantle	112	118	110
CCS	89	94	86
Cylinder volume (Air/UF_6)	111	118	109
Inner shell DN30 PSP	187	187	187
Outer shell DN30 PSP	785	785	785

2.3.4.6.4 Sensitivity Analysis

In addition to the calculations for different filling ratios of the 30B-X cylinder, sensitivity analyses are performed to investigate the influence of certain material properties or modelling approaches. These calculations are performed with an empty DN30X package for conservative results, as the temperatures calculated for an empty DN30-X package were higher than for a completely or partially filled DN30-X package due to the lower heat sink. The full account of the conducted sensitivity analyses is listed in Appendix 2.3 (Thermal Analysis), section 5.7; a general overview is

provided in Table 2-17, where the change in the maximum calculated temperature is listed compared to the base model with an empty 30B-X cylinder.

Table 2-17 Overview for the sensitivity analyses

Changed parameters for the sensitivity analysis	Resulting change in maximum temperature compared to base model	
	At the valve	At the plug
Direct contact 30B-X cylinder shell – CCS	-24 °C	-20 °C
Direct contact 30B-X cylinder shell – DN30 PSP	+2 °C	+2 °C
Mesh size +20 %	< 1 °C	< 1 °C
Mesh size -20 %	< 1 °C	< 1 °C
Time step size +20 %	< 1 °C	< 1 °C
Time step size -20 %	< 1 °C	< 1 °C
Extrapolation material properties foam +10 %	+3 °C	+3 °C
Extrapolation material properties foam -10 %	-2 °C	-3 °C
Material properties foam without extrapolation	-12 °C	-13 °C
Parameters for foam pyrolysis +10 %	+1 °C	+1 °C
Parameters for foam pyrolysis -10 %	-1 °C	-1 °C
Thickness reduction of microporous insulation to 9.5 mm	+1 °C	+1 °C
Thickness reduction of microporous insulation to 8.5 mm	+2 °C	+3 °C
Thickness reduction of microporous insulation to 7.0 mm	+4 °C	+6 °C
Thickness reduction of microporous insulation to 5.0 mm	+6 °C	+13 °C
Loss of microporous insulation equal to 1 x $A_{DropBar}$	< 1 °C	+4 °C
Loss of microporous insulation equal to 2 x $A_{DropBar}$	+1 °C	+5 °C
Loss of microporous insulation equal to 4 x $A_{DropBar}$	+1 °C	+8 °C
Loss of microporous insulation and foam equal to 1 x $A_{DropBar}$	+4 °C	+5 °C
Loss of microporous insulation and foam equal to 2 x $A_{DropBar}$	+7 °C	+10 °C

The following can be observed:

- A direct contact between the shell of the 30B-X cylinder and the CCS leads to greatly reduced maximum temperatures because the impact of the CCS acting as a large heat sink is greatly improved by the contact.
- The conservative modelling of the direct contact between the 30B-X cylinder shell and the DN30 PSP only leads to a small increase in maximum temperatures.
- Rather large variations for mesh size, time step size, foam material properties, and foam pyrolysis properties lead to only small changes in the maximum temperatures. Using no extrapolation for the foam parameters leads to a rather large reduction in the maximum temperatures.

- A reduction in the thickness of the microporous insulation layer from nominal to minimal (9.5 mm) leads to only very small changes in the maximum temperature. Even very conservative thickness reductions for HAC do not cause an increase above the admissible temperatures.
- The analyses for losses of microporous insulation and/or foam shows that even very conservative scenarios do not cause an increase of the maximum temperatures above the admissible temperatures.

More details are listed in Appendix 2.3 (Thermal Analysis), section 5.7.

2.3.5 Proof for the DN30-X Package to Meet the Regulatory Requirements

2.3.5.1 Ambient Temperatures and Pressures

For the analysis, an ambient temperature of 38 °C is considered (see section 2.3.4.5). Pressures that are likely to be encountered under RCT and NCT have no effect on the results of the thermal analysis. Consequently, the requirements of [10 CFR Part 71] §71(c)(1)-(4) or [SSR-6 2018] para. 616 are met.

2.3.5.2 Component Temperatures of the DN30-X Package

In the thermal analysis for the DN30-X package for NCT in section 2.3.4.5, the maximal component temperatures are 63 °C for the DN30 PSP and 52 °C for the 30B-X cylinder and its contents. Therefore, the maximal component temperatures of the DN30-X packaging during NCT are lower than the admissible values specified in Table 2-11.

In the thermal analysis of the DN30-X package for HAC in section 2.3.4.6, the maximal component temperatures of the DN30 PSP are close to, but still below, the admissible temperatures defined in Table 2-11. Tests with a prototype of the DN30 package showed that these temperatures do not affect the function of the inner and outer shells of the DN30 PSP with respect to shielding and criticality safety.

The maximum temperature calculated for the 30B-X cylinder shell is below the admissible temperature defined in Table 2-11. The temperatures of the valve and plug thread are below the admissible temperature defined in Table 2-11 as well. The maximum temperatures calculated for the components of the 30B-X cylinder are even below the design limit specified in [ANSI N14.1] of 121 °C/250 °F for regular 30B cylinders. The requirements for the pressure envelope of the 30B-X cylinder are at least equal to those of regular 30B cylinders according to [ANSI N14.1].

With regards to thermal stresses of the 30B-X cylinder, the maximum temperature difference between the pressure envelope of the 30B-X cylinder and interior components like the CCS is less than 4 °C for NCT and maximal 15 °C for HAC. No significant thermal stresses occur for such low temperature differences (see Appendix 2.2 (Structural Analysis)).

2.3.5.3 Rupture of the Containment System

Regarding a rupture of the containment system, an empty and a full cylinder define the two bounding cases. For an empty cylinder, the temperatures during the thermal test under HAC are maximized as the 30B-X cylinder provides the lowest possible heat sink. For a full cylinder, the temperatures are generally lower, but the significant volume expansion of the UF_6 content during its solid-to-liquid phase change potentially causes a pressure build-up with increasing temperatures.

The maximum temperatures reached during the thermal test under HAC required for the evaluations in this section are taken from the thermal analysis of the DN30-X package in 2.3.4.6.

For an empty 30B-X cylinder, a maximum temperature of 118 °C is reached at its components and its cavity during the thermal test under HAC. For a 100 % filled 30B-X cylinder, the maximum temperature reached during the thermal test under HAC are even lower with a maximum of 110 °C. These calculated temperatures are at least 10 °C below the admissible temperature for the containment system of the DN30-X of 131 °C listed in Table 2-11. The maximum temperatures do not exceed the design limit of 121 °C (250 °F) as specified in [ANSI N14.1] for regular 30B cylinders. The requirements for the pressure envelope of the 30B-X cylinder are at least equal to those of regular 30B cylinders according to [ANSI N14.1].

Additionally, the safety ratios calculated for a pressure build-up caused by melted UF_6 contents include an additional safety factor of at least 2 (see Table 2-9). As proven by the above evaluation, all admissible temperatures are met for the containment system of the DN30-X packaging. In the determination of these admissible temperatures, a possible pressure build-up in the 30B-X cylinder due to melted UF_6 contents was considered. As the admissible internal pressure, the hydrostatic test pressure of 2.76 MPa (400 psig) specified in [ANSI N14.1] was assumed, since the requirements for the pressure envelope of the 30B-X cylinder are at least equal to those of regular 30B cylinders according to [ANSI N14.1]. Furthermore, it was shown in section 2.3.2 that the wall thickness of the cylinder shell and of the cylinder heads are above the required wall thicknesses calculated according to [ASME BPVC].

Therefore, all requirements of [49 CFR Part 173] §420(a)(3) or [SSR-6 2018] para. 632(c) are met.

2.3.5.4 Influence of the Thermal Test on the Criticality Safety Analysis

The thermal analysis for the DN30-X package in section 2.3.4.6 proves that the stainless-steel shells of the DN30 PSP as well as the carbon steel shell of the 30B-X cylinder are not affected by the thermal test in such a way that their thickness and density is reduced. The criticality safety is ensured when taking into account these results. In the criticality safety analysis in Appendix 2.6 (Criticality Safety Analysis), a complete loss of the foam is considered.

The requirements of [10 CFR Part 71]§55(d), §55(e) and §59(a)(2) or [SSR-6 2018] para. 682 and 685 with respect to the thermal test under HAC are met.

2.4 Containment Design Analysis

The containment design analysis of the DN30-X package is described in detail in Appendix 2.4 (Containment Analysis). This section provides a summary of the main points and results. The analysis covers UF_6 of grade HALEU 10 and HALEU 20 for all filling ratios ranging from 0 kg up to the specific fill limits of the 30B-10 and 30B-20 cylinder listed in table 1-4.

As applicable to a Type AF package, RCT and NCT are considered, as there is no restriction on the radioactivity release under HAC, which is due to the limit of 1 A_2 for the radioactive content of Type A packages.

2.4.1 Objective of verification

It is verified that the DN30-X package complies with the requirements under NCT according to [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j) or [SSR-6 2018] para. 648(a) when submitted to the tests under NCT according to [10 CFR Part 71] §71(c)(7) and §71(c)(9) and [49 CFR Part 173] §465(c) and §465(d) or [SSR-6 2018] para. 722 and 723:

Prevent loss or dispersal of the radioactive content

It is specified in the Advisory Material for the IAEA Regulations for the Transport of Radioactive Material [SSG-26 2012] para. 648.2, that a maximum allowable leakage rate for NCT has never been defined quantitatively. In [SSG-26 2012] para. 648.3 it is specified that the intention of [SSR-6 2018] para. 648(a) is “to ensure that under NCT the radioactive contents of the package cannot escape in quantities that may create a radiological hazard”.

In this analysis, as a covering criterion the same maximum allowable leakage rate under NCT as for Type B packages (as per [10 CFR Part 71] §71.51 or [SSR-6 2018] para. 659(a) is applied to Type A packages. Hence, the maximum permissible activity release rate under NCT is:

$$R_{\mathrm{N}} \leq 10^{-6} \frac{A_2}{\mathrm{h}}$$

For Type AF packages, there is no restriction on the activity release under HAC due to the limit of 1 A_2 for the whole content.

2.4.2 Calculation Method and Assumptions

The containment design analysis for the DN30-X package is carried out per [ISO 12807] (or the equivalent standard [ANSI N14.5]) in the following steps:

1. Determination of radioactive contents, A
2. Determination of total releasable activity, RI_{T}
3. Determination of maximum permissible activity release rate, R
4. Determination of activity release rate due to permeation, RP
5. Determination of maximum permissible activity release rate due to leakage, $RG = R - RP$
6. Determination of activity per unit volume, C
7. Determination of maximum permissible leakage rate, $Q = L \cdot p$
8. Determination of maximum permissible equivalent capillary leak diameter, D
9. Determination of the permissible standardized leakage rate, Q_{SLR}

These steps and their results are performed for packages with filled 30B-X cylinders and cylinders with heels contents. They are described in detail in Appendix 2.4 (Containment Analysis). A central point of the containment design analysis is the following conservatively covering assumption about the radioactive contents of the DN30-X package:

As proven by the analysis in section 1.3.2.11, the radioactive contents will remain below 1 A_2 even for the pessimistic case of multiple refillings of 30B-X cylinders without intermediate washing. Nevertheless, the containment analysis assumes a radioactive content of 1 A_2 for both filled cylinders and cylinders containing heels and therefore covers all real package contents.

2.4.3 Summary and Evaluation of Results

The permissible standardized helium leakage rates for the 30B-10 and 30B-20 cylinder under NCT resulting from the containment design analysis for a covering radioactive content of 1 A_2 are listed in table 2-18. For comparison, the results for the standard 30B cylinder are listed as well.

Table 2-18 Permissible standardized helium leakage rates under NCT

Item	Condition	Value		
		30B cylinder	30B-10 cylinder	30B-20 cylinder
Required standardized helium leakage rate in $\mathrm{Pa \cdot m^3/s}$	Filled	$1.35 \cdot 10^{-1}$	$0.83 \cdot 10^{-1}$	$0.71 \cdot 10^{-1}$
	Heels	$4.93 \cdot 10^{-4}$	$3.09 \cdot 10^{-4}$	$2.66 \cdot 10^{-4}$

These results show that the objective of verification defined in section 2.4.1 is met for all permitted package contents. The calculated permissible standardized helium leakage rates are less demanding than the maximal standardized helium leakage of 10^{-4} Pa·m³/s that is specified for the 30B-X cylinder in section 1.2.10. For filled cylinders, the calculated results are higher by several orders of magnitude, and for cylinders with heels, they are higher by a factor of at least 2.6.

It should be noted that actual standardized helium leakage rates even after HAC tests, measured after the regulatory tests performed with the DN30 package, were well below 10^{-6} Pa·m³/s (cf. appendix B of Appendix 2.2 (Structural Analysis)).

2.5 External Dose Rate Analysis

The external dose rate analysis covers the DN30 package loaded with filled cylinders as well as cylinders containing heels under RCT and NCT. The analysis is valid for UF_6 contents of type HALEU 10 and HALEU 20 as specified in section 1.3.

This section provides a summary of the main points and results of the external dose rate analysis, which is documented in detail in Appendix 2.5 (External Dose Rate Analysis).

2.5.1 Objective of Verification

2.5.1.1 Verification for all Types of Packages

For DN30-X packages loaded with 30B-X cylinders that are either filled with UF_6 complying with the compositions in table 1-2 or that contain heel quantities of UF_6 complying with the composition in table 1-3, it has to be verified that the limit value for RCT specified in [10 CFR Part 71] §47(a) and [49 CFR Part 173] §441(a) or [SSR-6 2018] para. 526 is not exceeded:

$$\mathrm{TI} \leq 10$$

A transport index $\mathrm{TI} \leq 10$ is equivalent to:

$\mathrm{DL} \leq 0.1\ \frac{\mathrm{mSv}}{\mathrm{h}}$ at a distance of 1 m from the external surface of the package

It has to be verified that the limit value for RCT specified in [10 CFR Part 71] §47(a) and [49 CFR Part 173] §441(a) or [SSR-6 2018] para. 527 is not exceeded:

$\mathrm{DL} \leq 2\ \frac{\mathrm{mSv}}{\mathrm{h}}$ at the surface of the package

It has to be verified that the limit values for RCT specified in [10 CFR Part 71] §47(b) or [SSR-6 2018] para. 566(b) are not exceeded:

$\mathrm{DL} \leq 2\ \frac{\mathrm{mSv}}{\mathrm{h}}$ at any point on the external surface of the vehicle

$\mathrm{DL} \leq 0.1\ \frac{\mathrm{mSv}}{\mathrm{h}}$ at any point 2 m from the vertical planes represented by the outer lateral surfaces of the vehicle, or, if the load is transported in an open vehicle, at any point 2 m from the vertical planes projected from the outer edges of the vehicle

Whenever calculations are performed for the vehicle, it is assumed that the external surface of the package coincides with the external surface of the vehicle. The package might be oriented with its longitudinal axis parallel or perpendicular to the longitudinal axis of the vehicle. In case of parallel orientation, two adjacent packages positioned face-to-face along their symmetry axis are considered. In case of perpendicular orientation four adjacent packages positioned side-by-side are considered.

2.5.1.2 Verification for Type AF Packages

It has to be verified that, the package complies with the requirements according to [10 CFR Part 71] §43(f) and [49 CFR Part 173] §412(j) or [SSR-6 2018] para. 648(b), when submitted to the tests under NCT according to [10 CFR Part 71] §71(a)(6)-(10) and [49 CFR Part 173] §465(a)-(e) or [SSR-6 2018] para. 719-724:

$\Delta \mathrm{DL} \leq 20\ \%$ (no significant increase in external surface radiation)

$\Delta \mathrm{DL}$ is the increase in the maximal radiation level at any external surface of the package.

2.5.2 Assumptions for the Calculations

The calculations of dose rates at the DN30-X package and at the vehicle are based on the assumptions listed in sections 2.5.2.1 to 2.5.2.3.

2.5.2.1 Assumptions Valid for all Calculations

The following assumptions are valid for all calculations carried out throughout this chapter:

- The treated contents comply with the content description in section 1.3.
- The same maximal outer dimensions are used for the calculation model of the 30B-X cylinder as are defined for the standard 30B cylinder in [ANSI N14.1]. Conservatively, a minimal wall thickness of 1.1 cm is assumed (see table 1-13).
- Axial and radial dimensions of the 30B-X cylinder are identical under RCT and NCT.
- The skirts of the 30B-X cylinder are neglected in the considered calculation models and all 30B-X cylinders are assumed to have flat heads.
- The DN30 PSP is taken into account in the calculations.
- The CCS is considered by modelling 37 CCRs, which is an approximation for the 30B-10 and for the 30B-20 cylinder.

2.5.2.2 Assumptions for Routine Conditions of Transport

A conservative density of 0.1 g/cm^3 is assumed for the polyisocyanurate rigid foam (PIR foam). In reality, the PIR foam used in the manufacturing of the DN30 PSP has a higher density than 0.1 g/cm^3.

2.5.2.3 Assumptions for Normal Conditions of Transport

The following assumptions are made with regard to the tests under NCT that are prescribed in [10 CFR Part 71] §71(a)(6)-(10) and [49 CFR Part 173] §465(a)-(e) or [SSR-6 2018] para. 719-724:

- Neither the shape of the UF_6 inside the 30B-X cylinder nor the dimensions of the 30B-X cylinder are affected by the tests.
- A covering maximal deformation of the DN30 PSP of 20 mm is taken into account.

2.5.3 Calculation Method, its Verification and Validation

The calculation of dose rates at the DN30-X package is carried out by means of the program system SCALE 6.2.3/6.2.4 [SCALE 2020]. The gamma and neutron source terms are determined by means of the depletion analysis sequence ORIGEN in the v7-27n-19g energy-group structure. The dose rates are calculated by means of the analysis sequence MAVRIC.

2.5.4 Gamma and Neutron Source Terms

The gamma und neutron source terms used in the external dose rate analysis are determined by considering contributions from the isotopes present in the UF_6 based on Table 1-2, and the contributions from the build-up of their daughter nuclides.

A period of up to 10 years for the build-up of daughter nuclides is used to obtain the maximal source intensities, covering all possible time periods of cylinder storage.

For the analysis of heels contents, it is conservatively assumed that 100% of the amount of all non-uranium nuclides built up from the UF_6 content of the filled cylinder will remain in the heels.

As shown by the analysis, the external dose rates from neutrons are very low compared to the contribution from gamma dose rates, and can be accounted for in a covering way by multiplying the gamma dose rates by a factor of 1.05.

2.5.5 Model Specification

2.5.5.1 Geometrical Model for the DN30-X Packaging

2.5.5.1.1 30B-X Cylinder

The calculation model of the 30B-X cylinder is based on the dimensions of the standard 30B cylinder as specified in [ANSI N14.1]. Throughout the external dose rate analysis of the DN30-X package, the following conservative assumptions are made for the calculation model:

- The 30B-X cylinder is simplified to a cylinder with flat heads.
- The modeled 30B-X cylinder is compliant with the maximal dimensions specified for the standard 30B cylinder in [ANSI N14.1].
- The modeled 30B-X cylinder considers the minimal wall thickness of 1.1 cm as specified in table 1-13.
- The skirts, valve, plug and nameplate of the 30B-X cylinder are neglected.
- The CCS is modelled by 37 CCRs having a diameter of 6.03 cm and a wall thickness of 0.315 cm. The CCRs are arranged in a hexagonal pitch of 5 cm.
- A density of 1.2 g/cm^2 is assumed for the B_4C content of the CCRs.

2.5.5.1.2 DN30 PSP

The calculation model for the DN30 PSP is simplified significantly for the dose rate analysis of the DN30-X package. For this reason, neither the feet nor the six closure devices are modeled, even though they are made up of stainless steel and contribute to the attenuation of gamma radiation. Based on the condition of transport to be modeled, two calculation models of DN30 PSPs are considered throughout the external dose rate analysis of the DN30-X package:

- RCT: In this case, the DN30 PSP is composed of two cylindrical shells of stainless steel with the full thickness of the PIR foam in between.
- NCT: Similar to the calculation model for RCT, but a reduction of the thickness of the PIR foam by 20 mm is assumed so that the outer diameter of the DN30 PSP is also reduced by 20 cm. The density of the PIR foam is conservatively kept unchanged.

2.5.5.2 Geometrical Models for the Content

2.5.5.2.1 Filled Cylinder under RCT and NCT

The calculation model used for the filled 30B-X cylinder under RCT and NCT is a cylinder filled with UF_6 having no ullage. The source is homogeneously distributed within the UF_6.

Figure 2-12 and figure 2-13 show the calculation model. The UF_6 is shown in red, B_4C in blue, carbon steel in green, stainless steel in magenta and foam in yellow.

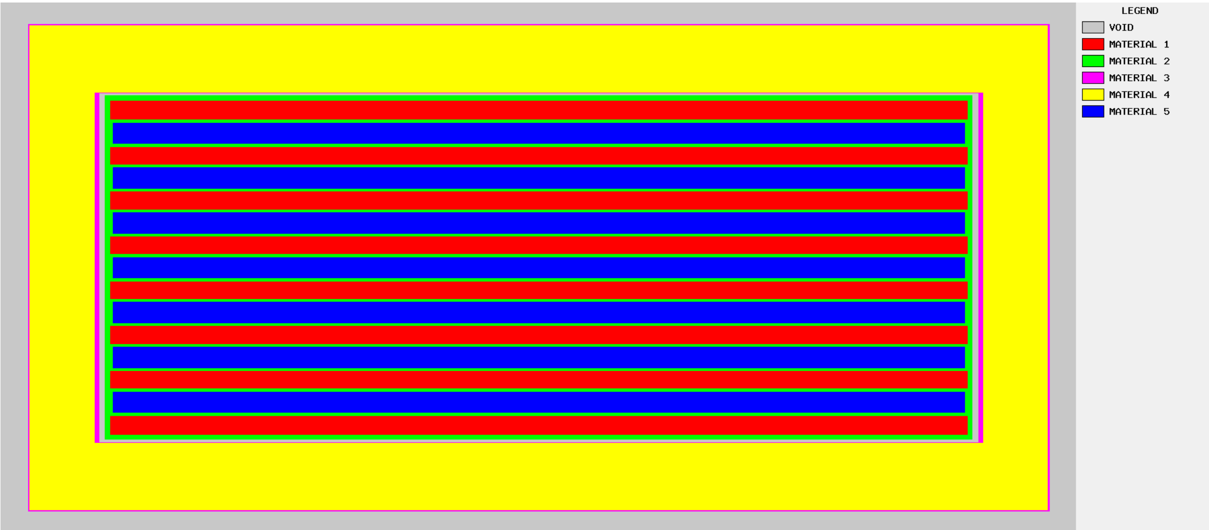

Figure 2-12 Cross section of the calculation model along the longitudinal axis

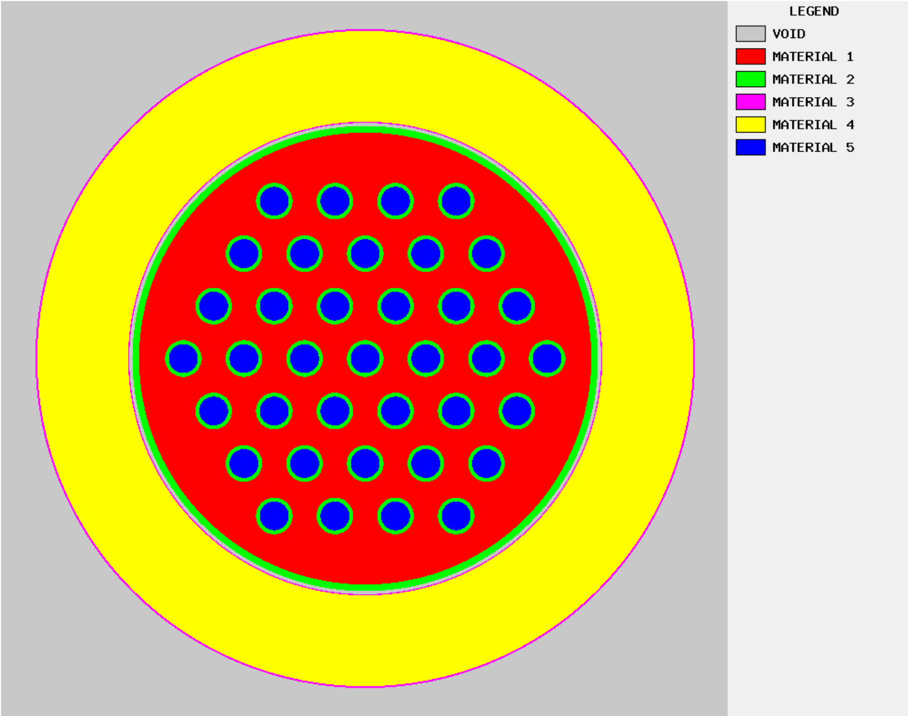

Figure 2-13 Cross section of the calculation model perpendicular to the longitudinal axis

2.5.5.2.2 Cylinder Containing Heel Quantities under RCT and NCT

For 30B-X cylinder containing heel quantities, three different models are investigated:

- The radiation source is a thin layer of UF_6 attached to the inner side of the cylinder wall.
- The radiation source is a pool of UF_6 in form of a puddle at the bottom of the cylinder.
- The radiation source is a thin layer of UF_6 attached to the inner side of one of the cylinder heads.

2.5.6 Verification of Compliance with Dose Rate Limits

2.5.6.1 Verification of the Dose Rates according to 10 CFR §71.47(a) and 49 CFR §173.441(a) or SSR-6 para. 526

The maximal total dose rates at a distance of 1 m from the surface of the DN30-X package loaded with a 30B-X cylinder filled with UF_6 or containing heel quantities of UF_6 complying with table 1-2 and table 1-3, respectively, are listed in table 2-19.

For the DN30-X package loaded with a filled 30B-X cylinder, the transport index is $\mathrm{TI} = 0.8$. Hence, the transport of the DN30-X package loaded with a 30B-X cylinder containing UF_6 complying with the composition in table 1-2 may be carried out under non-exclusive use.

For the DN30-X package loaded with a 30B-X cylinder containing heel quantities, the transport index is $\mathrm{TI} = 5.6$. Hence, the transport of the DN30-X package loaded with a 30B-X cylinder containing heel quantities of UF_6 complying with the composition in table 1-3 may be carried out under non-exclusive use.

Table 2-19 Maximal total dose rates under RCT at a distance of 1 m from the external surface of the package – DN30-X package loaded with a 30B-X cylinder filled with HALEU 10 or HALEU 20 or containing heel quantities of HALEU 10 or HALEU 20

UF_6 composition	Total dose rate in µSv/h
HALEU 10	5
HALEU 20	8
Heels of HALEU 10	45
Heels of HALEU 20	56
Limit value (for non-exclusive use)	100

2.5.6.2 Verification of the Dose Rates according to 10 CFR §71.47(a) and 49 CFR §173.441(a) or SSR-6 para. 527

The maximal total dose rates at the surface of the DN30-X package loaded with a 30B-X cylinder filled with UF_6 or containing heel quantities of UF_6 complying with table 1-2 and table 1-3, respectively, are listed in table 2-20. The calculated dose rates are below the limit value and, thus, the objective of verification is met.

Table 2-20 Maximal total dose rates under RCT at the surface of the package – DN30-X package loaded with a 30B-X cylinder filled with HALEU 10 or HALEU 20 or containing heel quantities of HALEU 10 or HALEU 20

UF_6 composition	Total dose rate in µSv/h
HALEU 10	21
HALEU 20	34
Heels of HALEU 10	374
Heels of HALEU 20	476
Limit value (for non-exclusive use)	2000

2.5.6.3 Verification of the Dose Rates according to 10 CFR §71.47(b) or SSR-6 para. 566(b)

Maximal total dose rates at the external surface of the vehicle (equivalent to the dose rate at the external package surface) loaded with DN30-X packages each loaded with a 30B-X cylinder filled with UF_6 or containing heel quantities of UF_6 are listed in table 2-21. The dose rates are below the limit of 2000 µSv/h and, thus, the objective of verification is met.

Table 2-21 Maximal total dose rates under RCT at the external surface of a vehicle loaded with DN30-X packages each loaded with a 30B-X cylinder filled with HALEU 10 or HALEU 20 or containing heel quantities of HALEU 10 or HALEU 20

UF_6 composition	Total dose rate in µSv/h
HALEU 10	21
HALEU 20	34
Heels of HALEU 10	374
Heels of HALEU 20	476
Limit value	2000

Maximal total dose rates at a distance of 2 m from the external surface of a vehicle transporting four DN30-X packages each loaded with a 30B-X cylinder filled with UF_6 or containing heel quantities of UF_6 are given in table 2-22. The dose rates are below the limit of 100 µSv/h and, thus, the objective of verification is met.

Table 2-22 Maximal total dose rates under RCT at a distance of 2 m from the external surface of a vehicle transporting four DN30-X packages each loaded with a 30B-X cylinder filled with HALEU 10 or HALEU 20 or containing heel quantities of HALEU 10 or HALEU 20

UF_6 composition	Total dose rate in µSv/h
HALEU 10	3
HALEU 20	5
Heels of HALEU 10	23
Heels of HALEU 20	29
Limit value	100

2.5.6.4 Verification according to 10 CFR §71.43(f) and 49 CFR §173.412(j) or SSR-6 para. 648(b)

Even under very pessimistic assumptions, assuming significantly higher deformations of the DN30 PSP than determined in the structural analysis under NCT in section 2.2, an increase of maximally 11.4 % was determined for the dose rate at the surface of the DN30-X package, which is far below the admissible limit of 20 %.

2.5.7 Summary and Evaluation of Results

The dose rate analysis shows that the dose rate limits as listed in section 2.5.1 and prescribed in [10 CFR Part 71] and [49 CFR Part 173] or [SSR-6 2018] are met for the contents specified in table 1-2 and table 1-3.

The calculated dose rates at the DN30-X package containing filled 30B-X cylinders or 30B-X cylinders containing heel quantities are in all cases less than the dose rates limits. The assessment also covers multiple refilling of 30B-X cylinders containing heel quantities with new product.

2.6 Criticality Safety Analysis

The criticality safety analysis for the DN30-X package, documented in full in Appendix 2.6 (Criticality Safety Analysis), covers RCT, NCT and HAC, taking into account the maximal enrichment of 10 wt.-% ^{235}U for the DN30-10 and 20 wt.-% ^{235}U for the DN30-20. It is valid for all filling ratios from UF_6 heels up to the maximum amount of UF_6 defined in section 1.3.2.1, and covers UF_6 containing up to 0.5 wt.-% volatile impurities (HF) and additional hydrogenated uranium residues from accumulated during the time period between recertifications.

Due to maximal UF_6 enrichments above 5 wt.-% ^{235}U, the analysis has to take into account optimal moderation of the UF_6 for the single package. The exclusion of water inleakage allowed in [10 CFR Part 71] §55(g) or [SSR-6 2018], para. 680 (b)(i), is only applicable for packages with UF_6 enriched to a maximum of 5 wt.-% ^{235}U and cannot be credited for higher enrichments.

The drop tests for the mechanical analysis demonstrate that any damage to the cylinder valve and plug can be excluded even under HAC, so that water ingress can be excluded for the package arrays under NCT and HAC.

2.6.1 Objective of Proof

Criticality safety is proven according to the requirements for fissile material packages in [10 CFR Part 71] §55 or [SSR-6 2018], para. 673. For RCT, NCT and HAC the following criticality safety criterion is applied:

$$\mathbf{k_{eff} + 3\sigma + \Delta k \leq 0.95}$$

For the proof, systematical deviations Δk of the calculation method are taken into account to determine an Upper Subcritical Limit (USL) that has to be complied with by the calculation result for $k_{eff} + 3\sigma$. The safety criterion thus becomes:

$$\mathbf{k_{eff} + 3\sigma \leq USL = 0.95 - \Delta k}$$

Systematical deviations are determined via comparison with suitable benchmark experiments. This validation analysis, summarized in section 2.6.3.2, results in the following USL values:

USL = 0.9419 for the DN30-X single package in isolation

USL = 0.9263 for the DN30-X HAC array of packages

It is shown that the DN30-X package fulfills the criticality safety criterion, taking into account all manufacturing tolerances, credible and hypothetical conditions of the arrangement of the UF_6 and inleaked water in the 30B-X cylinder, as well as all deformations of the package and especially the CCS due to RCT, NCT and HAC.

2.6.2 Assumptions for the Proof of Criticality Safety

The proof of criticality safety for the DN30-X package is based on the assumptions detailed in sections 2.6.2.1 through 2.6.2.4.

2.6.2.1 Assumptions Valid for all Calculations

The following assumptions are valid for all calculations:

- The admissible number is N = infinite (CSI = 0).

- The content is enriched UF_6 with an enrichment of 10 wt.-% ^{235}U in uranium for the DN30-10, and 20 wt.-% ^{235}U in uranium for the DN30-20.
- The density of UF_6 is conservatively assumed at a theoretical density of 5.5 g/cm^3 (see section 2.6.4.1).
- Axial and radial dimensions of the 30B cylinder are identical under RCT, NCT and HAC.
- For the representation of the 30B cylinder in the calculation model, the skirts and the shape of the cylinder heads are taken into account.
- The valve and plug as well as the name plate are neglected in all calculation models.
- Water might penetrate arbitrarily into the foam of the PSP.

2.6.2.2 Assumptions for the single package under RCT, NCT and HAC

The proof for the single package under RCT, NCT and HAC is carried out under the assumption of optimal moderation of the contents with water and a full water reflector:

- The DN30 PSP is conservatively neglected
- The 30B-X cylinder is surrounded by a 30 cm water reflector.
- Optimal moderation of the UF_6 contents with water is assumed.
- All deformations of the package and especially the CCS due to HAC are considered.
- Additional calculations are performed for the pessimistic assumption that the UF_6 contents form a heterogeneous lattice with water or transform into the uranium compound UO_2F_2.

2.6.2.3 Assumptions for 5 x N Packages under NCT

The proof for 5 x N = infinite number of packages under NCT is covered by the proof for an infinite number of packages under HAC according to section 2.6.2.4.

2.6.2.4 Assumptions for 2 x N Packages under HAC

The proof is carried out for 2 x N = infinite number of packages under HAC. The proof is based on the conditions of the packages after the tests required to demonstrate their ability to withstand HAC. Ingress of large water volumes into the cavity of the 30B-X cylinder is not assumed as the mechanical analysis shows that the integrity of the cylinder is not compromised under HAC.

- The UF_6 contains the maximum of 0.5 wt.-% volatile impurities (HF), as well as 11.3 kg of hydrogenated uranium residues (HUR) concentrated in a sphere.
- Moderation from water ingress due to the immersion under a head of 15 m water for 8 hours is negligible compared to the hydrogen in HF and HUR (see section 6.5.1 of Appendix 2.6).
- The 30B-X cylinder is completely filled with UF_6. The HUR sphere can be placed anywhere within the cylinder cavity.
- The total thickness of the DN30 PSP around the 30B-X cylinder is reduced to 10 cm in radial direction (around the mantle) and 8 cm in axial direction (on the valve/plug ends), conservatively covering all deformations due to HAC impacts.
- Additional calculations are performed for the hypothetical assumption that the PSP is completely compacted around the cylinder, taking only the steel of the shells into account.

2.6.3 Calculation Method, Verification and Validation

All criticality safety calculations in this document are performed by means of the sequence CSAS6 of the criticality safety code KENO VI from version 6.1.2 of the SCALE package [SCALE 2011].

All calculations use the multi-group cross section library v7-238 based on ENDB/B-VII data.

2.6.3.1 Verification

The verification consists of the installation and functional verification of the SCALE 6.1.2 program system. The functional verification is carried out by the editor of the program system on the basis of the appropriate verification plan. For the individual user, the verification of the program system SCALE 6.1.2 consists of the installation verification on the basis of case studies delivered by the editor. The case studies were calculated successfully and compared with the likewise delivered reference output files. There were no differences in the output files which exceeded the range of admissible deviations mentioned in the installation guide accompanying the code package. Thus, successful installation verification is given.

2.6.3.2 Validation

The calculation method (code and cross-section data) used to establish criticality safety must be validated against measured data (e.g., criticality benchmark experiments) that could be applicable to the package design characteristics. The validation process provides a basis for the reliability of the calculation method and should justify that the calculated k_{eff}, plus bias and uncertainties (if necessary) for the actual package conditions will ensure the compliance with the criticality safety criterion.

The ICSBEP (International Criticality Safety Benchmark Evaluation Project) [NEA 2019] contains a large number of evaluated criticality safety benchmark experiments which can be used for validation purposes. Applicable benchmarks should be selected based on their similarity to the application case. The validation analysis to determine applicability of benchmarks and to determine the calculation bias from the selected set of applicable benchmarks is described in detail in section 5.2 of Appendix 2.6. The most important points and results are summarized below.

For the single DN30-X package with optimal moderation and under covering assumptions (see section 2.6.6) applicable benchmarks are selected via a sensitivity analysis using the TSUNAMI module of the SCALE 6.1.2 package [SCALE 2011]. TSUNAMI provides a quantitative measure of the degree of similarity between an experiment and an application by comparing the sensitivity of k_{eff} to changes in the underlying cross-section data. The degree of similarity is expressed in the correlation coefficient c_k. Applicable benchmarks must have a correlation coefficient of $c_k \geq 0.80$.

Investigation of several benchmark series resulted in a total of 76 applicable benchmarks for the DN30-X. The determination of the calculational bias Δk from these benchmarks, taking into account the bias uncertainty, results in an **USL for the DN30-X single package of 0.9419**.

For the HAC array without water in-leakage and accordingly low moderation of the UF_6 contents, applicability of benchmark experiments is determined via sensitivity studies with the USLSTATS method. The selected benchmark experiments mostly have neutron spectra in the intermediate to fast region. Only benchmark cases with energy of average lethargy causing fission (EALF) between 10 eV to 100000 eV are used for the USLSTATS analysis, to provide a reasonable similarity with the EALF values for the application cases (402 eV for the DN30-10 and 1929 eV for the DN30-20). Based on a total of 31 applicable benchmarks, an EALF fit with USLSTATS is used to derive an **USL for the DN30-X HAC array of 0.9263.**

2.6.4 Material Compositions

2.6.4.1 UF_6

For the UF_6, a maximal density of 5.5 g/cm³ is assumed. This conservative assumption is derived from a linear extrapolation of tabulated UF_6 density values to -40 °C and covers the density of 5.1 g/cm³ at room temperature by a large margin.

2.6.4.1.1 UF_6 impurities

In the proof for the single package, optimal moderation of the UF_6 with water is assumed. Accordingly, the assumption of pure UF_6 is covering and neither HF impurities nor hydrogenated uranium residues (HUR) need to be taken into account in the calculations.

In the proof for arrays of packages, the maximal amount of 0.5 wt.-% volatile impurities is taken into account. These are assumed as HF, using the standard material „hfacid“ in SCALE. The 5.5 g/cm³ density of UF_6 is used for the mixture of UF_6 and HF.

In addition to these volatile impurities, the moderation from hydrogenated uranium residues is taken into account with conservative assumptions based on [MILIN 2016]: The enveloping composition of HUR is UO_2F_2-$2H_2O$-2HF, and the mass of HUR is assumed to be equivalent to the maximal allowable heels mass of 11.3 kg. In the calculations, this compound is replaced by UO_2F_2-$3H_2O$ with the same H/U ratio and a density of 4.317 g/cm³.

2.6.4.2 Carbon steel (30B-X cylinder and CCS)

For the carbon steel of the 30B-X cylinder and the CCS, the standard material „carbonsteel“ of the SCALE library with a density of 7.8212 g/cm^3 is used.

2.6.4.3 Boron carbide (B_4C)

The neutron absorber B_4C in the CCRs is taken into account with a density of 1.2 g/cm³. This is equivalent to 88.9% of the specified B_4C density of 1.35 g/cm³, and thus slightly below the maximal 90% credit applied to solid homogeneous boron-based neutron absorbers (see section 7.4.7.2 of [NUREG 2216]).

2.6.4.4 Stainless steel (DN30 PSP)

For calculations where the stainless steel walls of the DN30 PSP are taken into account, the standard material „ss304“ of SCALE library with a density of 7.94 g/cm^3 is used.

2.6.4.5 Water

For the water used as a reflector and moderator in the proof for the single package, and as interstitial moderation in the proof for package arrays, a covering density of 1.0 g/cm³ is taken into account in the calculations.

2.6.4.6 UO_2F_2

For the single package, a comparison calculation is performed for the pessimistic assumption that UF_6 mixed with water will completely transform into the compound UO_2F_2. For this compound, the maximal theoretical density of 6.37 g/cm³ is taken into account.

2.6.5 Calculation Models

Since the outer cylinder shell is identical for the DN30-10 and DN30-20, and the CCS only differs in the number and distribution of CCRs, the criticality calculation models for both versions of the DN30-X are mostly identical and will be presented here together.

Section 2.6.5.1 presents the calculation model of the 30B-X cylinder itself, including the CCS. The calculation model for the single package in isolation, taking into account unlimited water moderation of the UF_6 content, is described in section 2.6.5.2. The calculation model for the infinite array of packages under HAC, where moderation is provided only by the HF and HUR impurities in the UF_6, is described in section 2.6.5.3.

2.6.5.1 30B-X cylinder

For the outer parts (walls and skirts) of the 30B-X cylinder, the domed heads are modeled in an ellipsoidal shape. Both skirts are modeled straight and without any bends at their ends. The outer diameter is 76.8 cm, and the outer length is 207.5 cm over the skirts and 193.5 cm over the ends of the domed heads. Using maximal values for the diameter and the length is conservative, since it maximizes the amount of UF_6 in general and, more importantly, in regions not directly adjacent to the CCRs.

Valve, plug, and nameplate of the cylinder are completely neglected. The domed head at the plug end is modeled in such a way that its outer surface is in line with the end of the skirt, i.e., moved 1.3 cm outwards. This is conservative since it allows for smaller distances between the fissile contents in adjacent packages.

The wall thickness is assumed at its nominal value of 13 mm. An overview of the dimensions of the walls and skirts of the 30B-X cylinder in the calculation model is shown in Figure 2-14.

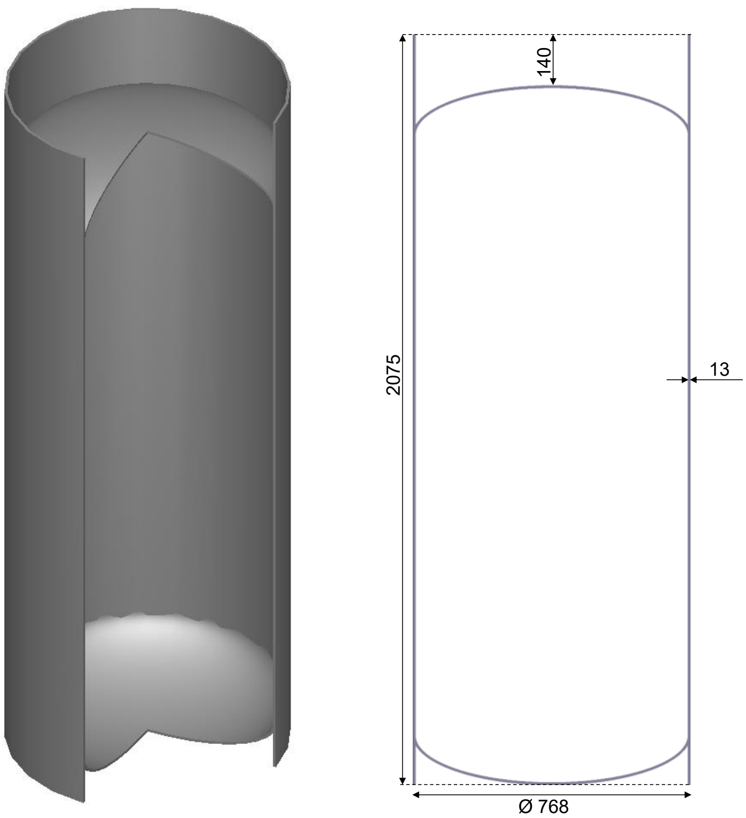

Figure 2-14 Calculation model of the 30B-X cylinder calculation model (without CCS)

For the CCS, the CCRs are modelled with their nominal dimensions (outer Ø 60.3 mm, wall thickness 5.5 mm, lengths see table 2-23) and positions. Manufacturing tolerances and CCS deformations under HAC are evaluated with variational calculations. The lattice holders and all other structural parts of the CCS are conservatively neglected.

The criticality calculation models for the 30B-10 and the 30B-20 are shown in Figure 2-15. The cross section along the cylinder axis shows the shortened CCRs in front of the valve and the plug.

Table 2-23 CCR numbers, ring diameters and lengths for the 30B-10 and the 30B-20

			number of CCRs	
CCR ring	**ring radius**	**CCR length**	**30B-10**	**30B-20**
central CCR	0 cm	185 cm	1	1
1st ring	10 cm	183 cm	6	7
2nd ring	19 cm	178 cm	10	12
2nd ring 1)	19 cm	172 cm	2	2
3rd ring	28 cm	170 cm	14	21

1) shortened CCRs in front of the valve / plug

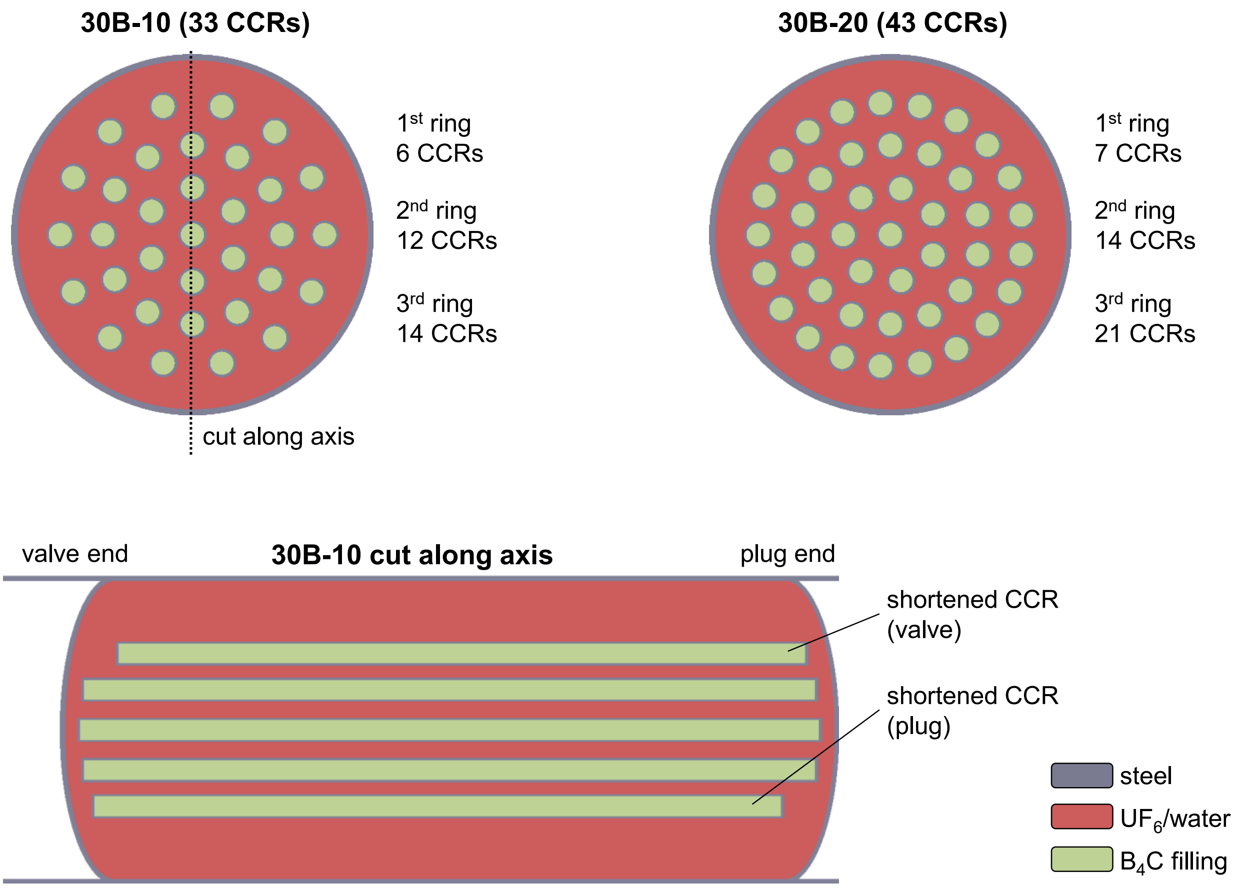

Figure 2-15 Calculation models for the 30B-10 and 30B-20 cylinder

2.6.5.2 Single package in isolation

For the single package with unlimited water moderation of the UF_6 content, the 30B-X cylinder is assumed to be completely filled with a mixture of UF_6 and water. The point of optimal moderation is determined through variation of the water/UF_6 ratio. The UF_6 fill limit is not taken into account, so that there is an overestimation of the fissile content for low amounts of water moderator.

On the outside, the 30B cylinder is surrounded by 30 cm of water reflector on all sides. The basic calculation model for the single package in isolation is shown in Figure 2-16.

Additional calculations are performed with a simplified representation of the DN30 PSP to show that the assumption of a bare 30B-X cylinder is the covering case. In this simplified representation, only the steel walls of the PSP are taken into account and assumed to be compacted around the cylinder, with a total thickness of 5 mm in radial direction and 14 mm in axial direction. The foam insulation as well as the distance between inner and outer shell is completely neglected.

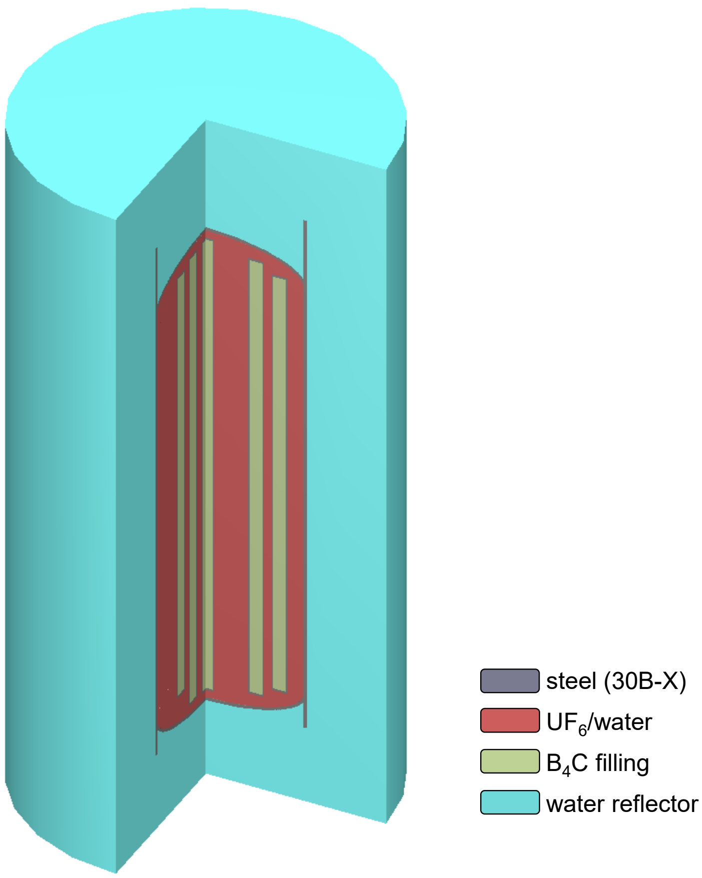

Figure 2-16 Calculation model for the single package in isolation

2.6.5.3 Infinite array of packages

For the array of packages under HAC, an infinite three-dimensional array is achieved by enclosing the DN30-X package in a hexagonal prism with mirror reflection on all surfaces. External water moderation is investigated by adding water layers with varying thickness between packages.

The total thickness of the DN30 PSP around the 30B-X cylinder is assumed to be reduced to 10 cm in radial direction (around the mantle) and 8 cm in axial direction (on the valve/plug ends), conservatively covering all deformations due to HAC impacts. The foam material is neglected.

Moderation of the UF_6 is provided by the maximum of 0.5 wt.-% volatile impurities (HF), and the additional assumption of 11.3 kg HUR. Since the valve and plug retain their function under HAC, the ingressing water due to the immersion under a head of 15 m water for 8 hours only amounts to < 3 g and can be neglected.

The covering assumption for the distribution of these impurities in UF_6 cylinders is given in [MILIN 2016]: the HF is dispersed evenly within the UF_6, but the HUR is assumed to be concentrated in a sphere. To maximize the reactivity, the well-moderated HUR spheres in adjacent packages are brought closely together by placing them at the wall of the domed plug head (where the shorter skirt makes for a small distance to the next cylinder). Furthermore, the sphere is placed close to the CCR that is shortened at the plug end. The covering calculation model for a cylinder within the infinite package array is shown in Figure 2-17.

Additional calculations are performed for the assumption that the PSP is completely compacted around the 30B-X cylinder, taking only the steel material of the inner and outer shell into account.

It should be noted that even with these pessimistic assumptions regarding UF_6 impurities and the deformations of the DN30 PSP, the k_{eff} result for the infinite array is below the result for the optimally moderated single package.

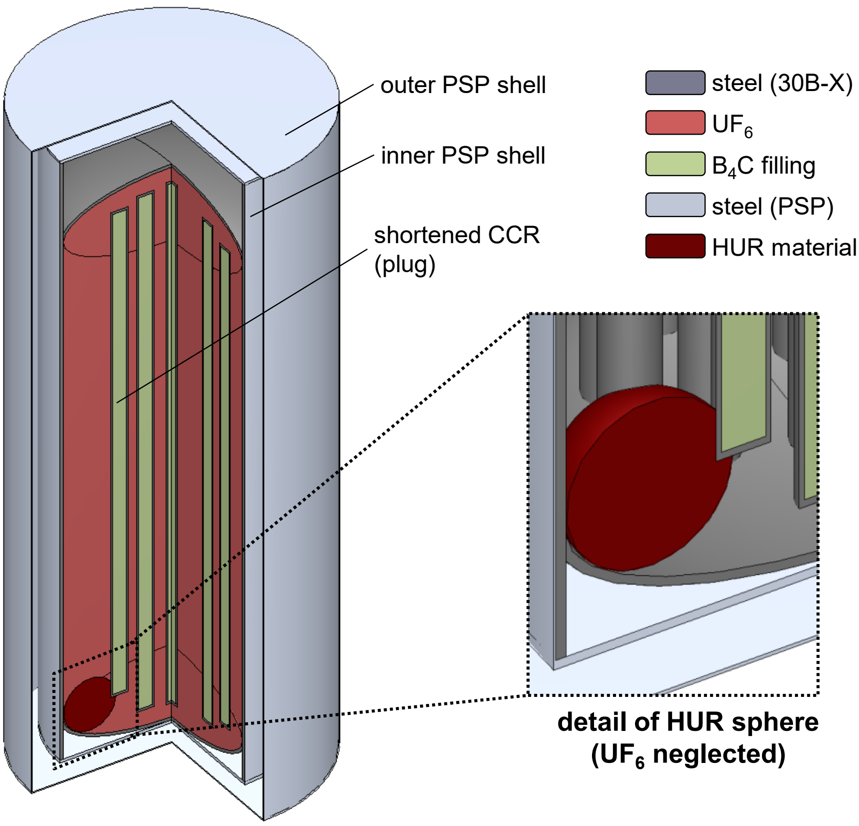

Figure 2-17 Calculation model for the infinite package array

2.6.6 Proof of Criticality Safety for the Single Package in Isolation

Safe subcriticality for the single package under all conditions of transport is proven according to [10 CFR Part 71] §55 or [SSR-6 2018], para. 682.

The covering calculation models for the DN30-10 and the DN30-20 take into account optimal moderation of the UF_6 contents with water, manufacturing tolerances and the deformations of the package under HAC. The most penalizing assumptions for these parameters are derived via variation calculations described in detail in chapter 7 of Appendix 2.6.

As described in section 2.6.1, the safety criterion is expressed as **$k_{eff} + 3\sigma \leq$ USL**, and the USL value for the DN30-X single package in isolation is **USL = 0.9419**.

The results for the covering calculation model are:

$k_{eff} + 3\sigma$ = 0.8981 for the DN30-10

$k_{eff} + 3\sigma$ = 0.9060 for the DN30-20

For the covering calculation model, the criticality safety criterion is met with a large margin to the limit of safe subcriticality.

Comparison calculations with the hypothetical assumption of heterogeneous UF_6/water mixtures with the optimal size of the UF_6 particles give maximal results of:

$k_{eff} + 3\sigma$ = 0.9108 for the DN30-10

$k_{eff} + 3\sigma$ = 0.9122 for the DN30-20

Comparison calculations with the pessimistic assumption that the UF_6 contents will completely transform into the compound UO_2F_2 give maximal results of:

$k_{eff} + 3\sigma$ = 0.9321 for the DN30-10

$k_{eff} + 3\sigma$ = 0.9341 for the DN30-20

The results from these comparison calculations demonstrate that the criticality safety criterion is met even when taking into account additional pessimistic assumptions about the UF_6 contents.

2.6.7 Proof of Criticality Safety for the Infinite Array of Packages

The criticality safety proof for the array of packages under HAC according to [10 CFR Part 71] §59(a)(2) or [SSR-6 2018], para. 685 is carried out for an infinite number of packages in an infinite quadratic and hexagonal lattice with axial infinite stacking.

Since calculation assumptions under HAC are more restrictive than assumptions for NCT, the proof for the package array under NCT according to [10 CFR Part 71] §59(a)(1) or [SSR-6 2018], para. 684 is covered by the proof for the array of packages under HAC.

As described in section 2.6.1, the safety criterion is expressed as **k_{eff} + 3σ ≤ USL**, and the USL value for the HAC array of packages is **USL = 0.9263**.

In addition to the most penalizing assumptions regarding manufacturing tolerances and the deformations of the package under HAC, the covering calculation model for the package array takes into account internal moderation from UF_6 impurities: 0.5 wt.-% volatile impurities (HF), and the additional assumption of 11.3 kg HUR. The HF is dispersed evenly within the UF_6, while the well-moderated HUR impurities are assumed to be concentrated in a sphere.

Optimum interspersed hydrogenous moderation is achieved with a water layer on the 30B-X cylinder with maximal water density. The optimal thickness of this water layer is derived from variation calculations presented in chapter 8 of Appendix 2.6.

With these covering assumptions, the maximal results for the array of packages are:

k_{eff} + 3σ = 0.7130 for the DN30-10

k_{eff} + 3σ = 0.8707 for the DN30-20

For the covering calculation model, the criticality safety criterion is met with a large margin to the limit of safe subcriticality. Especially for the DN30-10, the results are lower than for the single package in isolation.

Comparison calculations with the additional extremely pessimistic assumption of the DN30 PSP being completely compacted around the 30B-X cylinder give maximal results of:

k_{eff} + 3σ = 0.7654 for the DN30-10

k_{eff} + 3σ = 0.9039 for the DN30-20

The results from these comparison calculations demonstrate that the criticality safety criterion is met even when taking into account additional extremely pessimistic assumptions about the deformations of the DN30-X package under HAC.

2.6.8 Summary and Evaluation of Results

The criticality safety for the DN30-10 package loaded with UF_6 with a maximal enrichment of 10 wt.-% ^{235}U in uranium and the DN30-20 package loaded with UF_6 with a maximal enrichment of 20 wt.-% ^{235}U in uranium is proven in accordance with the requirements of [10 CFR Part 71] §55 and §59 or [SSR-6 2018], para. 673 under all credible considerations, including pessimistic or hypothetical assumptions about the packaging and the UF_6 contents:

1. Flooding with water is taken into account for the single package in isolation under all conditions of transport. There is no credit taken from [10 CFR Part 71] §55(g) or [SSR-6 2018] para. 680(b)(i).
2. For the content the most reactive arrangement in the packaging is determined. Any credible rearrangement of contents and the inleaked water in the package is taken into account in the analyses.
3. Based on results of analyses and drop tests described in the mechanical analysis, no release of contents from the package needs to be assumed.
4. Water around the package is considered in the analysis of an array of packages with variation of the water layer thickness at maximal water density.
5. Temperature changes are taken into account by assuming a conservatively high density for UF_6 and a theoretical maximal water density of 1 g/cm^3.
6. For the 30B-X cylinder, the most penalizing assumptions about manufacturing tolerances and deformations under HAC are taken into account in the analysis.
7. The DN30 PSP is completely neglected in the criticality analysis for the single package and assumed to be compacted to a thickness of 10 cm in radial direction (around the mantle) and 8 cm in axial direction (on the valve/plug ends), conservatively covering all deformations due to HAC impacts.
8. The neutron absorber B_4C in the CCRs is taken into account with 88.9 % of its specified density. This is slightly below the maximal 90 % credit applicable to solid homogeneous boron-based neutron absorbers (see section 7.4.7.2 of [NUREG 2216]).

The analysis, described in detail in Appendix 2.6, covers the following arrangements:

- Single package under all conditions of transport
- Arrangement of an infinite number of packages under NCT
- Arrangement of an infinite number of packages under HAC.

The results of the analysis demonstrate that the criticality safety criterion is met with a large safety margin for the covering calculation models for the single package and the infinite array of packages.

For the single package in isolation, the analysis is extended by comparison calculations with pessimistic assumptions about the UF_6 contents, i.e., heterogeneous UF_6/water mixtures and transformation into the denser compound UO_2F_2.

For the infinite array of packages under HAC, the analysis is extended by comparison calculations for the hypothetical assumption of a completely compacted DN30 PSP. The results of these comparison calculations demonstrate safe subcriticality even with these additional pessimistic assumptions.

For both the DN30-10 and the DN30-20 package, the calculated k_{eff}-values are in all cases lower than the value defined as objective of proof in section 2.6.1. The criticality safety requirements for the transport of a package for fissile material according to [10 CFR Part 71] §55 and §59 or [SSR-6 2018], para. 673 are fulfilled.

Appendix 1.1 (List of Applicable Documents)

Applicable Documents
List 0045-LST-2021-001

Proprietary Information

Not to be published

Appendix 1.4.1A (Drawings 30B-X Cylinder)

1) “30B-10 Cylinder”, Parts List 0045-STL-1000-000
2) “30B-20 Cylinder”, Parts List 0045-STL-2000-000

Proprietary Information

Not to be published

Appendix 1.4.1B (Drawings DN30 PSP)

Parts List 0023-STL-1000-000

Proprietary Information

Not to be published

Appendix 1.4.2 (Material Properties)

"Material Properties of the Components of the DN30-X Packaging",

0045-BSH-2020-001-Appendix-1.4.2

Proprietary Information

Not to be published

Appendix 1.7.1 (Handling Instruction)

"Use and handling of the DN30-X package", Handling Instruction 0045-HA-2021-001

Appendix 1.7.2 (Contamination and Dose Rate Measurements)

“Contamination and dose rate measurement at the DN30-X package”, Test Instruction 0045-PA-2021-002

Appendix 1.7.3 (30B-X Cylinder Facility Operations)

“Facility operations with the 30B-X Cylinder”, 0045-BSH-2020-001-Appendix-1.7.3, Rev. 0

Appendix 1.8.1 (Inspections of 30B-X Cylinders)

“Periodic Inspections of the 30B-X Cylinder”, Test Instruction 0045-PA-2021-001

Appendix 1.8.2 (Inspections of DN30 PSPs)

“Periodic Inspections of the DN30 PSP”, Test Instruction 0023-PA-2015-015

Appendix 1.9.1 (IMS)

1) Quality Management Handbook of company Orano NCS GmbH, 2022
2) DIN EN ISO 9001
3) Confirmation on quality assurance according to nuclear standard KTA 1401
4) Confirmation of the Qualification for the development, manufacturing and operation of packagings of packages requiring approval for the transport of radioactive material

Proprietary Information

Not to be published

Appendix 1.9.2A (Manufacturing Specification 30B-X Cylinder)

"Specification 30B-X cylinder", Specification 0045-SPZ-2021-001

Proprietary Information

Not to be published

Appendix 1.9.2B (Manufacturing Specification DN30 PSP)

“Specification DN30 PSP”, Specification 0023-SPZ-2016-001

Manufacturing Test Sequence Plan 0023-BPP-2016-001

Material Test Sheet 0023-WPB-2016-001

Proprietary Information

Not to be published

Appendix 1.9.3 (Quality Assurance Program)

1) U.S. NRC Quality Assurance Program Approval #0951, Rev. 1, July 6, 2018
2) Quality Assurance Program 0023-QAP-2017-001

Proprietary Information

Not to be published

Appendix 2.2 (Structural Analysis)

"Structural Analysis of the DN30-X Package"

Proprietary Information

Not to be published

Appendix 2.3 (Thermal Analysis)

"Thermal Analysis of the DN30-X Package"

Proprietary Information

Not to be published

Appendix 2.4 (Containment Analysis)

"Containment Analysis of the DN30-X Package"

Proprietary Information

Not to be published

Appendix 2.5 (External Dose Rate Analysis)

"External Dose Rate Analysis of the DN30-X Package"

Proprietary Information

Not to be published

Appendix 2.6 (Criticality Safety Analysis)

"Criticality Analysis for the DN30-X Package with 10 wt.-% or 20 wt.-% ^{235}U enrichment"

Proprietary Information

Not to be published