Safety Analyses Report

Dry Storage System CASTOR® geo69

Docket No.: 72-1052

Non-Proprietary Version

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0 General and Organisation

0.1 Document Organisation

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This design document is organised in a series of chapters. Each chapter is identified by the chapter number.

A section within a chapter is identified by a sequential numeric after the chapter number; thus Section 2 in Chapter 1 is denoted by 1.2. Subsections to a section are identified by the numeric after the section number, e.g. 1.2.3 for Subsection 3 of Section 2 in Chapter 1. Figures and tables are numbered sequentially in each section e.g. Figure 1.2-4 for Figure 4 in section 1.2. Revisions to this document will be controlled at the section level, as indicated in the bottom of each page. Both, document revision and independent revision of a section are separately indicated by the respective revision status in section 0.2 and 0.3. In the head of each page of the document the document ID is indicated and the respective revision status, whereas the bottom line shows the section and the revision and page number of the section, respectively.

References are identified at the section level in square brackets. References are numbered for each chapter or section individually.

0.2 Revision Status of this Document

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Revision	Date	Author	Revised section
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Changes in later revisions will be marked with a vertical bar on the left side

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0.3 Revision Status of Sections

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0.4 Table of Contents

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0.5 Glossary

	Name, Function	Date	Signature
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10 CFR 71	Title 10, Code of Federal Regulations Part 71: Packaging and transportation of radioactive material
10 CFR 72	Title 10, Code of Federal Regulations Part 72: Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste
ACS	Accident Conditions of Storage
ASME	American Society of Mechanical Engineers
BPVC	2017 Edition of the ASME Boiler & Pressure Vessel Code
BWR	Boiling Water Reactor
CASTOR®	Registered trade mark for a dual purpose cask providing sufficient neutron and gamma shielding, heat dissipation, activity retention, criticality safety and mechanical integrity for transport and storage of spent nuclear fuel and radioactive waste
CASTOR® geo69	Manufacturer's designation for the specified storage cask design
CLU	Cask Loading Unit
CoC	Certificate of Compliance
CoG	Centre of Gravity
Confinement	Assembly of fissile material and packaging components intended to preserve criticality safety
Containment	Assembly of components of the packaging intended to retain the radioactive material during transport
DCI	Ductile Cast Iron
Design Drawing	Engineering drawing as required by the NRC Regulatory Guide 7.9
Design Parts List	Supporting design document containing further information as e.g. references on materials, codes and standards or applicable design drawings
Division 3	Applicable division of the BPVC Section III for containment systems for transportation and storage of spent nuclear fuel and high-level radioactive material
DPC	Dual Purpose Cask
DSS	Dry Storage System, CASTOR® geo69 storage configuration comprising the storage cask (consisting of DCI cask, inner canister, basket and shielding elements for the dry storage of SNF) together with the protection cover and a storage frame (as applicable)
FA	Fuel Assembly
FEA, FEM	Finite Element Analysis, Finite Element Method
GNS	GNS Gesellschaft für Nuklear-Service mbH - Headquarters: Frohnhauser Straße 67, D-45127 Essen - Shop: Kranbahnallee 3, D-45473 Mülheim / Ruhr
[redacted]	Product name of UHMW PE

HAC	Hypothetical Accident Conditions
HLW	High Level Radioactive Waste
HM	Heavy Metal
Intact Fuel Assembly	A fuel assembly without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. Partial fuel assemblies, that is fuel assemblies from which fuel rods are missing, shall not be classified as intact fuel assemblies unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the original fuel rod(s).
ISFSI	Independent Spent Fuel Storage Installation
Item	Parts, components or subcomponents of the overall package system, especially when used in context with the parts list
LAP	Load Attachment Point
LT	Leak Testing
MMC	Metal Matrix Composite
MNOP	Maximum Normal Operating Pressure
MT	Magnetic Particle Testing
NCS	Normal Conditions of Storage
NDE	Non-Destructive Examination or Evaluation, respectively
NPP	Nuclear Power Plant
NRC	U. S. Nuclear Regulatory Commission
Package	The packaging together with its radioactive contents as presented in the SAR (transport)
Packaging	The assembly of components necessary to ensure compliance with the packaging requirements of 10 CFR Part 71
PE	Polyethylene
PT	Penetrant Testing
PU	Polyurethane
QA	Quality Assurance
QAP	Quality Assurance Program
RG	U.S. NRC Regulatory Guide
RT	Radiographic Testing
SAR	Safety Analysis Report for the approval application of the CASTOR® geo69 DSS according to 10 CFR 72
SAR (transport)	Safety Analysis Report for the package approval application of the CASTOR® geo69 transport cask as Type B(U)-F package according to 10 CFR 71
Section III	Applicable Section of the BPVC containing rules for construction of nuclear facility components

SNF	Spent Nuclear Fuel
SSC	Structure, System and Components
Storage Cask	CASTOR® geo69 cask as part of the DSS according to 10 CFR 72 providing containment, radiological shielding, sub-criticality control, structural support, and passive cooling of the radioactive content during normal, off-normal, and accident conditions of storage.
UHMW PE	Ultra-High Molecular Weight Polyethylene
UT	Ultrasonic Testing
VT	Visual Testing
ZPA	Zero Period Acceleration

1 GENERAL Description

1.0 Overview

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Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

This Safety Analyses Report (SAR) of the CASTOR® geo69 Dry Storage System (DSS) provides all relevant information of the design analyses and confirmation of the respective safety objectives to conform to the requirements according to 10 CFR 72.

The contents and structure of this SAR follows the guidance according to Regulatory Guide 3.61 [1] taking into account the NRC periodic review conducted in July 2019, as well as the guidance provided in NURGEG 2215 [2].

1.0.1 Summary of Compliance with 10 CFR 72 Requirements

The safety evaluation provided in this SAR complies with 10 CFR 72 and shows that the CASTOR® geo69 DSS fulfils all requirements for a spent nuclear fuel (SNF) DSS acc. to 10 CFR 72. The DSS design considers all design requirements specified in Subpart F of 10 CFR 72.

The CASTOR® geo69 DSS complies with the requirements of 10 CFR 72.122. Structures, systems, and components (SSCs) of the DSS important to safety are designed to withstand the effects of natural phenomena, as demonstrated in Chapter 3, without impairing their capability to perform safety functions. The DSS has the capability for continuous monitoring and allows ready retrieval of the loaded SNF. The materials and constructive arrangement considered in the DSS design do not lead to significant chemical, galvanic or other reactions between the DSS components or the components and the content as demonstrated in Chapter 8.

The CASTOR® geo69 DSS is designed to provide adequate heat removal capacity without active cooling systems. Chapter 4 demonstrates that the maximum spent fuel cladding temperature is maintained below 400 °C during all conditions of storage. The DSS is designed for a maximum heat load specified in Subsection 1.2.3.

As demonstrated in Chapters 5 and 7, the radiation shielding and containment features of the CASTOR® geo69 DSS are sufficient to meet the requirements of 10 CFR 72.104 and 10 CFR 72.106.

The DSS is designed to maintain subcriticality under all conditions, as demonstrated in Chapter 6. The DSS meets the design criteria for nuclear criticality safety specified in 10 CFR 124.

The evaluations through Chapters 3 to 8 demonstrate that the DSS design is adequate to meet all structural, thermal, shielding, criticality containing and material requirements of 10 CFR 72. The operation and acceptance test and maintenance program provided in Chapter 9 and 10 ensure the compliance of the DSS condition with requirements of 10 CFR 72 at any time of the DSS operation.

List of References

[1] Regulatory Guide 3,61 (February 1989)
Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask
U.A. Nuclear Regulatory Commission

[2] NUREG-2215 (April 2020)
Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities
U.A. Nuclear Regulatory Commission

1.1 Introduction

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The DSS and its components are specified by the documents listed in Table 1.1-1. The same is for the cask loading unit (CLU) and its components in Table 1.1-2. The documents are included in Section 1.5.

Table 1.1-1: Documents for dry storage system specification

Document	*Contents*	*Component*	*Reference*
Design Parts list	Design relevant information on each item, e.g. item no., quantity, designation, material, safety classification	Cask	1014-DPL-30934
		Canister	1014-DPL-36855
		Fuel basket	1014-DPL-30984
		Shielding elements	1014-DPL-33604
		Protection cover	1014-DPL-38556
Design Drawing	Design and dimensions of the DSS and its components	Cask	1014-DD-30934
		Canister	1014-DD-36855
		Fuel basket	1014-DD-30984
		Shielding elements	1014-DD-33604
		Protection cover	1014-DD-38556

Table 1.1-2: Documents for CLU specification

Document	*Contents*	*Component*	*Reference*
Design Parts list	Design relevant information on each item, e.g. item no., quantity, designation, material, safety classification	Transfer cask	1015-DPL-37509
		Transfer lock	1015-DPL-38148
Design Drawing	Design and dimensions of the CLU and its components	Transfer cask	1015-DD-37509
		Transfer lock	1015-DD-38148

The design and dimensions of DSS and CLU are defined by the sets of parts lists and drawings. The documents for DSS and CLU specification according to Table 1.1-1 and Table 1.1-2 provide all design related information required for the safety assessment. Furthermore, the design drawings contain the dimensions of the interfaces needed for cask assembly and operation.

1.2 General Description of the Dry Storage System

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The dry storage system (see Figure 1.2-1) consists of the storage cask with the cask body, the cask lid and further attachments enclosing the canister and the fuel basket for accommodation of up to 69 BWR-FAs. Furthermore, the DSS includes the protection cover fastened to the lid end of the cask to protect the cask lid against dust and humidity. The DSS is stored in vertical orientation.

[redacted]

Figure 1.2-1: Main components of the dry storage system

Hereinafter the main components of the DSS are described in detail, using the item numbers according to the respective design parts lists cited in Table 1.1-1.

1.2.1 Dry Storage System Characteristics

The storage cask consists of cask body and cask lid system according to the design parts list [1].

1.2.1.1 Cask Body

The basic structure of the cask body (Item 2) made of DCI is a hollow cylinder with a closed bottom end, cast in one piece. Subsequently to the casting process, every surface of the cask body is machined. This process includes machining of the radial cooling fins into the outer cask surface and the axial drilling of two circumferential rows of each [redacted] deep-holes from the bottom side into the cask wall. Each borehole houses a column of moderator rods (Item 4, 54, 141) made of ultra-high molecular weight polyethylene (UHMW PE) completed by steel bars (Item 8, 53), which are kept in place by compression springs (Item 6, 31) and the stainless steel closure plate (Item 7) bolted to the cask bottom. At the two angular positions of the trunnions, each three outer boreholes and the six moderator rods (Item 54) are slightly shortened. A bottom moderator plate (Item 5) also made of polyethylene is placed in a recess at the bottom end and screwed to the bottom of the cask body via three cap screws (Item 52) and bushes (Item 57).

The closure plate covers the bottom moderator plate (Item 5), closes the deep-boreholes and serves as a seating for the compression springs (Item 6, 31). An elastomer sealing ring (Item 47) is inserted into a groove in the closure plate and each of the 28 hexagon head screw (Item 9) is equipped with a bonded seal (Item 49). Eight circular openings close to the edge of the closure plate give access to threaded blind holes [redacted] in the cask body for fastening the bottom impact limiter. The openings are sealed by O-rings (Item 66). During loading or storage the bottom impact limiter is not assembled and the threaded blind holes are closed by seal plugs (Item 93) equipped with an O-ring (Item 94). For leak-testing of the complete closure plate a test port is added. Channels in the closure plate connect all seals with the test port. During underwater loading, the test port is closed leak-tight by a sealing screw (Item 26) and an O-ring (Item 74). After loading, the sealing screw is replaced by a sealing screw with valve (Item 155) (with a factory-fitted seal). The sealing screw with valve limits the gas overpressure in the volume enclosed by the closure plate, which is generated as a result of the thermal expansion of the UHMW PE moderator material, to a maximum of [redacted]. Accordingly, the channel system of the closure plate also interconnects the deep boreholes for the moderator rods and the recess for the bottom moderator disc.

For handling, the cask is equipped with one pair of lid side trunnions (Item 12) and one pair of tilting studs at the bottom end. The stainless steel trunnions are form-fitted in recesses that are machined into the cask body and are each fastened by 16 stainless steel cap screws (Item 13). The cap screws may be applied in a way [redacted]. The trunnions are intended as load attachment points and allow vertical handling as well as tilting of the cask. The tilting studs [redacted] to support the cask during tilting operations but are not intended for the attachment of load lifting devices. They are covered against wear and corrosion by corresponding wear protections (Item 183) made of stainless steel, which are sealed with an O-ring (Item 184). The wear protections are shrink fitted on the tilting studs and additionally secured against twisting by two hexagon screws (Item 185) with bonded seals (Item 49) each.

The storage cask is marked with a type plate (Item 105), which is mounted on the cooling fin area of the cask body (see Figure 1.2-1). The type plate is mounted via grooved pins with round head (Item 107), distance bolts (Item 108) and discs (Item 87).

1.2.1.2 Cask Lid System

The cask lid (Item 55) closes the cask body (Item 2) and thus the outer containment for the nuclear content. The cask lid has two service orifices that are separately covered by the blind flange (Item 89) or a pressure switch, respectively, and the protection cap (Item 113), which are each sealed via metal gaskets (Item 44, 71). The two service orifices are used for vacuum drying of the cask interior, if necessary, and helium backfilling. Their centres are located above the circumferential gap between moderator plate (Item 56) and retention ring (Item 21). One service orifice is equipped with a quick-connect (Item 60) and a bonded seal (Item 77), which provides pressure-resistant access to the free gas volume in the cask cavity. Both service orifice lids are fastened via cap screws (Item 37). The cask lid is fastened by 72 hexagon head screws [redacted] (Item 62, 63) and sealed via a metal gasket (Item 69) that is fixed within its groove via VMQ clips (Item 30). The three hexagon head screws for sealing (Item 63) enable attaching of a protection seal to be attached by the corresponding authority against unauthorised opening. The bolting system of the cask lid is fit for ultrasonic tightening control. The main components of the cask lid system are shown in Figure 1.2-2.

The pressure switch replaces the blind flange during the long-term storage at a storage facility and monitors the pressure conditions within the storage cask. It is connected to the monitoring system of the storage facility. In case of leakage of the canister or cask containment boundary, the pressure switch gives response to the monitoring system, alerting for human intervention.

[redacted]

Figure 1.2-2: Lid system of the CASTOR® geo69 cask

On the bottom side of the cask lid, a moderator plate (Item 56) is mounted via six cap screws (Item 52) and bushes (Item 57). Below the cask lid, the retention ring (Item 21) is [redacted] to enable adjustment of the gap at the top of the canister e.g. for thermal expansion and to protect the cask lid with the moderator plate from contact with the canister.

1.2.1.3 Canister

The canister consists of the canister body and the canister lid system according to the corresponding design parts list [2]. The welded canister body (Item 2) consist of bottom (Item 2-2), liner (Item 2-3, 2-4) and head ring (Item 2-5). Canister body and canister lid (Item 3) made of stainless steel form the inner containment for the nuclear content.

[redacted]

[redacted]

Figure 1.2-3: Closure system of the CASTOR® geo69 canister

[redacted]

The canister lid has two service orifices. One is connected to the interspace between the metal gasket and the sealing ring to test the leak-tightness of the metal gasket and is closed with a sealing screw (Item 26) and an O-ring (Item 74). The second service orifice (see Figure 1.2-4) is used for dewatering, vacuum drying and helium backfilling of the canister cavity.

[redacted]

Figure 1.2-4: Service orifice and parts for canister dewatering, drying and helium filling

A blind plug (Item 9) with an O-ring (Item 15) is mounted in the service orifice. The quick connect (Item 12) is screwed into the thread in the blind plug with a bonded seal (Item 77). After the canister cavity is dried and filled with Helium, the space above the quick-connect is closed with the tightening plug (Item 10) and sealed with the metal gasket (Item 13). The supporting O-ring (Item 14) limits the test space for leak-tightness testing of the sealing via an orifice in the tightening plug, which is closed by the sealing screw (Item 26) with O-ring (Item 74). The pressure nut (Item 11) is mounted in the canister lid to fasten the tightening plug compressing the metal gasket.

1.2.1.4 Fuel Basket

The fuel basket is designed to ensure criticality safety by accommodation of up to 69 BWR-FA in a secure arrangement inside the canister cavity, as well as the removal of the decay heat released by the loaded FA. The parts of the fuel basket along with their respective item numbers in the corresponding design parts list [3] are described below.

The fuel basket mainly consists of a grid of stacked sheets, building the separation of the FA receptacles as shown in Figure 1.2-5. Single structural sheets of borated aluminium (Item 10 – 27) are stacked, serving both for criticality safety and heat dissipation. The stacks are kept together over the total height by the outer sheets (Item 30, 31) made of stainless steel. Round segments (Item 50) for heat transmission, mechanical support and shielding fill the gap between the outer sheets and the canister wall. FA shoes (Item 2) at the bottom of each FA receptacle serve for positioning of the FAs.

[redacted]

Figure 1.2-5: Fuel basket with structural sheets (main grid), outer sheets and round segments

1.2.1.5 Shielding Elements

The circumferential gaps between the four round segments in the corners of the structural skeleton of the basket are filled with four shielding elements (Item 3, 4) according to the design parts list [4]. The shielding elements are made of solid aluminium profiles, which may consist of several parts. They provide additional shielding, mechanical support and improve the heat conduction. In order to facilitate the draining of the canister cavity after underwater loading, the geometry of one corresponding element (Item 4) provides space for the permanent or temporary dewatering lance. The shielding elements are shown in Figure 1.2-6.

[redacted]

Figure 1.2-6: Shielding elements for the gaps in the corners of the fuel basket

1.2.1.6 Protection Cover

To protect the cask lid from dust and humidity during long-term interim dry storage, the DSS comprises a protection cover (see Figure 1.2-7) according to the respective parts list [5]. The main body (Item 2) of the protection cover consists of a plate (Item 2-2) and a ring (Item 2-3), both made of carbon steel. Plate and ring are attached to each other via a circumferential weld. The plate is equipped with a hole for a cable conduit, guiding the cable connected to the pressure switch. The protection cover is mounted on the cask lid side via centering devices (Item 3), which are attached to the ring via socket head cap screws (Item 9) and washers (Item 7).

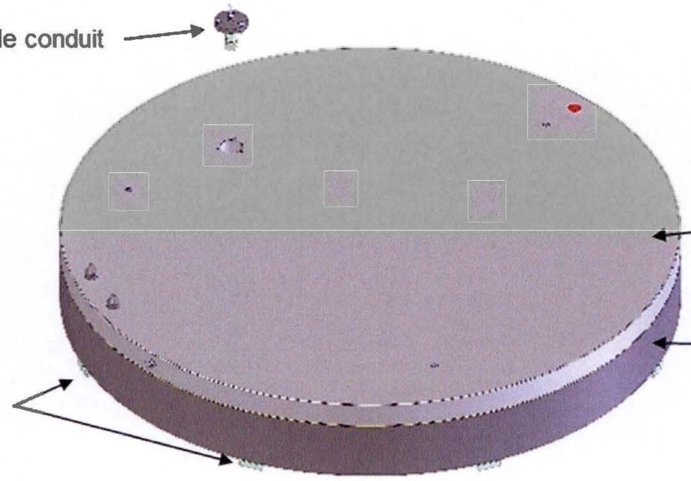

Figure 1.2-7: Protection cover for the lid system of the CASTOR® geo69

The protection cover is not important to safety and hence not regarded in the safety evaluations (especially structural and shielding evaluations), but the thermal evaluations consider a protection cover with a plate of [redacted] thickness. However, comparative thermal calculations without protection plate have shown that thinner plates (minimum thickness of [redacted] are suitable.

A rubber surface protection (tem 6) is glued (Item 220) underneath the plate to protect the surface of the cask lid from scratches. A filling (item 4) is attached to the inner face of the ring via cap screws (Item 8) to fill the lateral interspace between protection cover and cask. Headless screws (Item 10) are mounted in the LAPs of the protection cover plate.

1.2.1.7 Dimensions, Masses and Volumes

The following tables summarise the most important properties of the CASTOR® geo69 DSS components, including dimensions, masses and volumes.

Table 1.2-1: Dimensions of the CASTOR® geo69 DSS components

[redacted]

[redacted]

Table 1.2-2: Masses of the CASTOR® geo69 DSS components

[redacted]

Table 1.2-3: Volumes in the CASTOR® geo69 DSS

[redacted]

1.2.1.8 Components of the Containment System

The containment system consists of all components that prevent the release of radioactive material. The CASTOR® geo69 DSS features a double-containment system with the outer containment formed by the DCI cask body and the cask lid system and the inner containment formed by the canister body and the canister lid system. The function of the outer and inner containment is maintained under all conditions of storage. Table 1.2-4 and Table 1.2-5 summarize the components of the inner and outer containment system. The item no. refer to the respective parts list cited above. The properties of the metal gaskets are further specified in Section 8.2.

Table 1.2-4: Components of the inner containment system of the CASTOR® geo69

Component	*Quantity*	*Item*	*Material*
Canister body	1	2	Stainless steel
Canister lid	1	3	Stainless steel
[redacted]			

Component	Quantity	Item	Material
Tightening plug	1	10	Stainless steel
- Pressure nut	1	11	Alloy steel
- Metal gasket	1	16	Ni-alloy, stainless steel, Ag

Table 1.2-5: Components of the outer containment system of the CASTOR® geo69

Component	Quantity	Item	Material
Cask body	1	2	DCI
Cask lid	1	55	Stainless steel
- Hexagonal screws	69	62	Alloy steel
- Hexagon head screws for sealing	3	63	Alloy steel
- Metal gasket	1	69	Ni-alloy, stainless steel, Ag
Protection cap	1	113	Stainless steel
- Cap screw	6	37	Stainless steel
- Metal gasket	1	44	Ni-alloy, stainless steel, Ag
Blind flange	1	89	Stainless steel
- Cap screw	12	37	Stainless steel
- Metal gasket	1	71	Ni-alloy, stainless steel, Ag

1.2.1.9 Components Required for Shielding

The major components of the CASTOR® geo69 DSS contributing to shielding are presented in Table 1.2-6, Table 1.2-7 and Table 1.2-8. The item no. refer to the respective parts list cited above. Not explicitly mentioned components does only have a subordinate contribution to shielding. Shielding materials are discussed in Subsection 8.2.3. Dimensions refer to the most relevant shielding contribution and are conservative, if a larger range is permitted.

Table 1.2-6: Storage cask components required for shielding

Component	Material	Gamma	Neutron
Cask body (Item 2) - Wall: D = [redacted] - Bottom: D = [redacted]	DCI	Major contribution (radial/wall, axial/bottom)	Contribution due to carbon content (minimum 3%)
Cask lid (Item 55) - Thickness: D = [redacted]	Stainless steel	Major contribution (axial)	Minor contribution
Trunnions (Item 12) - Axial: L = [redacted]	Stainless steel	Major contribution (local)	Minor contribution

Component	Material	Gamma	Neutron
Closure plate (Item 7) - Thickness: D = [redacted]	Stainless steel	Major contribution (axial)	Minor contribution
Steel bar (Item 53, 8) - Inner row: Ø = [redacted] - Outer row: Ø = [redacted]	Carbon steel	Major contribution (radial), only bottom end (for activated FA foot piece)	Minor contribution
Moderator rod (Item 141, 4, 54) - Inner row: Ø = [redacted] - Outer row: Ø = [redacted]	UHMW-PE	Minor contribution	Major contribution (radial)
Moderator plate (Item 56, 5) - Lid side: D = [redacted] - Bottom side: D = [redacted]	UHMW-PE	Minor contribution	Major contribution (axial)

Table 1.2-7: Canister components required for shielding

Component	Material	Gamma	Neutron
Canister body (Item 2) - Shell: D = [redacted] - Bottom: D = [redacted]	Stainless steel	Major contribution (radial/wall, axial/bottom)	Minor contribution
Canister lid (Item 3) - Thickness: D = [redacted]	Stainless steel	Major contribution (axial)	Minor contribution

Table 1.2-8: Components of fuel basket and shielding elements required for shielding

Component	Material	Gamma	Neutron
Structure sheets (Item 10 ~ 27) - Thickness: D = [redacted]	Al-B_4C-MMC	Major contribution (radial and diagonal)	Major contribution due to boron-carbide content (10.5% nom)
Outer sheets (Item 30, 31) - Thickness: D = [redacted]	Stainless steel	Major contribution (radial)	Minor contribution
Round segments (Item 50) - Thickness: D = [redacted]	Al	Major contribution (radial)	Minor contribution
FA shoe (Item 2) - Axial: L = [redacted]	Stainless steel	Major contribution (axial)	Minor contribution
Shielding elements (Item 2, 3) - Thickness: = [redacted]	Al	Major contribution (radial)	Minor contribution

Besides the basket components and the shielding elements, the content itself has a major contribution on the gamma shielding.

1.2.1.10 Components of the Confinement System

The components of the confinement system are intended to preserve criticality safety of the fissile material (SNF) apart from the confinement function of the FA itself. This does not only include neutron absorbing materials but also any part of the DSS that is responsible for maintaining the sub-critical arrangement of the FA, as well as components that enclose the FA and prevent in-leakage of water under conditions of storage.

1.2.1.10.1 Canister

The canister forms the boundary of the inner confinement system that encloses the basket with the FA. Consequently, all components of the inner containment system (as described in Subsection 1.2.1.8) are also confinement components. Under all conditions of storage, the canister forms an independent confinement that prevents in-leakage of water.

1.2.1.10.2 Fuel Basket

Sub-criticality is maintained by the arrangement of the FA within the fuel basket. As a consequence, all components of the basket that preserve its structural integrity and thus keep the FA and the neutron absorbing materials in the intended configuration are part of the confinement system. The structural skeleton of the fuel basket comprises 69 FA shoes (Item 2) as a base for the loaded FA. The centre, bottom and top sheets (Item 10-27) made of Al-B_4C-MMC are all part of the confinement system, as the boron carbide is required as neutron absorbing material for criticality control. The outer steel sheets (Item 30 and Item 31) and the round segments (item 50) preserve the integrity of the structural skeleton of the fuel basket.

1.2.1.11 Components for Heat Dissipation

The maximum acceptable heat load of the CASTOR® geo69 DSS is [redacted], which is completely passively dissipated. In the following, the components specifically designed for the heat transfer from the FA within the fuel basket to the atmosphere are summarised. The item no. refer to the respective parts list cited above.

1.2.1.11.1 Fuel Basket

The components of fuel basket play a central role in the heat transfer. The decay heat generated in the SNF is first transferred to the centre, bottom and top sheets (Item 10 to 27) made of Al-B_4C-MMC and the outer steel sheets (Item 30, 31). This heat transfer takes place mainly by radiation and partly by conduction through the helium atmosphere in the canister. Inside the structural skeleton of the fuel basket, the heat is distributed radially and axially by conduction. The heat is radially transferred to the round segments (Item 50) and the shielding elements, both made of aluminium, which transfer the heat further to the canister body.

1.2.1.11.2 Canister

The canister body consists of a welded stainless steel construction, which allows heat conduction without any gap to its surface, where it is transferred to the cask body by radiation and conduction through the helium atmosphere in the cask cavity.

1.2.1.11.3 Cask body

The inner surface of the cask body is coated to improve heat absorption. Without any gap, the heat is conducted around the moderator boreholes through the monolithic DCI cask body to its surface, where it is dissipated to the atmosphere by convection and radiation. Cooling fins machined into the base material significantly increase the effective surface of the outer cask wall and improve the convective heat transfer. The external surface of the cask body is coated to improve heat transfer via thermal radiation, to enable easy decontamination and to protect the material from corrosion.

1.2.2 Operational Features

Due to the limited maximal crane capacity in typical BWR NPPs, it is assumed that it is neither feasible to transfer the CASTOR® geo69 storage cask into and out of the control area nor to transfer it into or out of the SNF pool. The handling masses listed in Table 1.2-2 exceed the maximum capacity of typical gantry cranes installed in NPP. Therefore, the CASTOR® geo69 storage cask is loaded by means of a Cask Loading Unit (CLU). The CLU is designed for loading, handling and transfer of the canister loaded with SNF into the CASTOR® geo69 storage cask. The CLU comprises a transfer cask and a transfer lock, which are shown in Figure 1.2-8. The transfer cask carrying the loaded canister is positioned on top of the CASTOR® geo69 storage cask. The transfer lock in between enables the transhipment of the canister in both directions. Chapter 9 includes a detailed description of the operating procedures for loading, handling and transfer. The following subsections include a description of the CLU and its operational features.

1.2.2.1 Description of the Cask Loading Unit

The CLU comprises the two major components transfer cask and transfer lock as well as further equipment like the lifting gear for the transhipment of the canister from the transfer cask into the CASTOR® geo69 storage cask via the transfer lock, as depicted in Figure 1.2-8.

[redacted]

Figure 1.2-8: Schematic overview of the CASTOR® geo69 CLU

1.2.2.1.1 Transfer Cask

The parts of the transfer cask along with their respective item numbers are listed in the corresponding design parts list [6]. The transfer cask design is based on the onion-shell principle as shown in Figure 1.2-9. It consists (inner towards outer shell) of a rugged inner liner providing the main structural function, followed by a lead and two water chambers, where each of the three is enclosed be [redacted] stainless steel. The inner liner (Item 2-3) is a cylindrical barrel with an inner cavity diameter of [redacted] and a wall thickness of [redacted]. It is made of stainless steel and provides sufficient size for housing the canister. The inner liner as well as the lead and water enclosures (Item 2-6, 2-8 and 2-9), are welded to a head (Item 2-2) and a bottom ring (Item 2-4), both made of stainless steel. Two trunnions (Item 12) also made of stainless steel diametrically opposed are each screwed to the head ring by [redacted] cap screws (Item 13). They serve as LAP for the vertical handling of the transfer cask.

The [redacted] thick lead shield serves as primary gamma radiation protection, whereas the inner ([redacted]) and outer ([redacted]) water chambers moderate the neutron radiation, if flooded with demineralized water.

At the lid-end, the transfer cask can but does not have to be closed by a lid (Item 10) using [redacted] hexagon head screws (Item 60). It has a centric opening with a diameter of [redacted] to attach the canister to the lifting gear to allow the lowering/raising of the canister between the transfer cask and the CASTOR® geo69 storage cask (see Figure 1.2-8).

To close the bottom-end of the transfer cask the bottom ring is equipped with guide rails, so that the bottom lid (Item 7) can be inserted like a drawer. To protect it from unintentional, autonomous loosening [redacted] (Item 42) are used.

In order to prevent clean demineralized water from leaking out of the cavity, an [redacted] seal (Item 56) is foreseen to be placed in a [redacted] groove on the underneath of the bottom ring sealing against the bottom lid. A bore through the bottom ring creates a connection to the transfer cask cavity. [redacted]

Two manual ball valves (Item 51) leading into the inner or outer water chamber provide their flooding and/or dewatering. [redacted] On top of the outer chamber two quick connection plugs (Item 52) allow for several service connections, e.g. a pressure relief device to protect the water chambers from unacceptable overpressure.

[redacted]

Figure 1.2-9: Schematic view (left) and cross section (right) of the transfer cask

1.2.2.1.2 Transfer Lock

The parts of the transfer lock along with their respective item numbers are listed in the corresponding design parts list [7]. The design of the transfer lock comprises a sandwich structure consisting of a structural steel frame (Item 2), which is circumferential enclosed by polyethylene (PE) shielding material (Item 8, 9, 10, 11 and 29) encapsulated by steel sheets (Item 3, 4, 5, 6 and 19) as shown in Figure 1.2-10. The structural frame is made of at least [redacted] thick carbon steel plates and, on the one hand, ensures the mechanical integrity of the transfer lock for its intended tasks. On the other hand, it provides sufficient gamma radiation shielding. The frame is enclosed by PE to at least [redacted], serving as neutron radiation shield. [redacted] sheets of carbon steel function as housing for the PE and further gamma radiation protection. The entire metallic construction is screwed together except for four weld joint connections of the cylinder console to the frame. The PE blocks are inlays. All carbon steel components are varnished.

The inner dimensions of the left part of the transfer lock are in consistence with outer dimension of the bottom ring of the transfer cask. Tow centre bolts (Item 50) provide for adjusting. The right part of the transfer lock serves to accept the bottom lid of the transfer cask. It is equipped with guide rails, which seamlessly couple to those of the transfer cask. A tension bold (Item 17) mounted at the head of the electrical cylinder (Item 31) positively fits into a borehole in the bottom lid. The electrical cylinder, operated automatically by remote control, enables to open and close the bottom lid.

For crane handling, there are four blind holes on the upper side of the right and left base plates and the rear right and left base plates (Item 2-3, 2-4, 2-7 and 2-9) that serve as LAP.

[redacted]

Figure 1.2-10: Schematic view of the transfer lock

1.2.2.1.3 Equipment

Additional equipment (e.g. lifting gear) and services (e.g. flooding with water) are necessary for the operation of the CLU. As it is not important to safety regarding the safety functions of the CASTOR® geo69 DSS a detailed discussion of equipment is not included in this SAR. However, respective interfaces to transfer cask and transfer lock are discussed.

1.2.2.1.4 Dimensions and Masses

Table 1.2-9 to Table 1.2-11 summarise the most important properties of the CLU components, including dimensions and masses. The masses of the CLU and its components in Table 1.2-11 are nominal masses. Masses of actual manufactured components of CLU and canister with basket and shielding elements may differ due to tolerances also affecting the tabulated handling masses (c.f. Section 10.1.4.3). When the handling masses in Table 1.2-11 are compared to the handling masses in Table 1.2-2, it is obvious that the application of the transfer cask in the SNF pool area considerably reduces the required crane capacity. Volumes are not listed since the transfer cask is not capable of retaining internal pressures inside the cavity due to its open design.

Table 1.2-9: Dimensions of the transfer cask components

[redacted]

[redacted]

Table 1.2-10: Dimensions of the transfer lock components

[redacted]

Table 1.2-11: Masses of the CLU components

[redacted]

1.2.2.1.5 Components required for Shielding

The major components of the CLU contributing to shielding are presented in Table 1.2-12 and Table 1.2-13. The item no. refer to the respective parts list cited above. Not explicitly mentioned components does only have a subordinate contribution to shielding. Dimensions refer to the most relevant shielding contribution and are conservative, if a larger range is permitted.

Table 1.2-12: Transfer cask components required for shielding

Component	***Material***	***Gamma***	***Neutron***
Transfer cask body - Liner: D = [redacted] - Sheets: D = [redacted]	Stainless steel	Major contribution (axial)	Minor contribution
- Lead shield: D = [redacted]	Lead	Major contribution (radial)	Minor contribution
- Inner water chamber: [redacted] - Outer water chamber: [redacted]	Water	Minor contribution	Major contribution (radial)
Trunnions (Item 12) - Axial: L = [redacted]	Stainless steel	Major contribution (local)	Minor contribution
Head ring (Item 2-2) - Axial: D = [redacted] - Radial: L = [redacted]	Stainless steel	Major contribution (local)	Minor contribution

Component	Material	Gamma	Neutron
Bottom ring (Item 2-2) - Axial: D = [redacted] - Radial: L = [redacted]	Stainless steel	Major contribution (local)	Minor contribution
Bottom lid (Item 7) - Thickness: [redacted]	Stainless steel	Major contribution (axial)	Minor contribution

Table 1.2-13: Transfer lock components required for shielding

Component	Material	Gamma	Neutron
Frame (Item 2) - Base plates: [redacted]	Carbon steel	Major contribution	Minor contribution
Housing (Item 3, 4, 5, 6) - Thickness: D = [redacted]	Carbon steel	Major contribution	Minor contribution
PE-Shielding (Item 8, 9, 10, 11) - Thickness: D = [redacted] D = [redacted]	Polyethylene	Minor contribution	Major contribution

1.2.2.1.6 Components for Heat Dissipation

The maximum acceptable heat load of the canister is [redacted]. During handling of the canister via CLU, this heat is released from the transfer cask through passive means. In the following, the components are summarised that are specifically designed for the heat transfer from the canister within the transfer cask to the atmosphere.

The chosen materials in the transfer cask ensures a high heat conductivity and a good convective heat transmission from the transfer cask to the environment. The transfer cask body consists of a welded stainless steel construction, which contributes to the heat transfer from the canister to the environment. The inner surface of the transfer cask is coated to improve heat absorption. The interspaces between the steel liner and the steel sheets in the lateral area of the transfer cask are filled either with lead shielding material or with deionized water (inner and outer water chamber). The absence of air gaps in the transfer cask body improves the heat transfer in radial direction. The outer surface of the transfer cask is coated to improve heat transfer via thermal radiation and to enable easy decontamination.

1.2.2.2 Operating Procedures of the Cask Loading Unit

During all operation sequences of the complete loading campaign the transfer cask shall be in vertical orientation. Tilting (by usage of a special tilting device) and horizontal operations shall be permitted only for the transport of the empty transfer cask on an appropriate transport vehicle.

The following operation sequences specifying the functions and boundaries are considered for the design of the components transfer cask and transfer lock of the CLU, including loading, unloading, handling, transfer, transhipment, etc. of transfer cask and canister, respectively. Figure 1.2-11 schematically shows the sequences of SNF loading in the spent fuel pool, handling of the canister by the transfer cask and transfer of the canister into the CASTOR® geo69 storage cask via the transfer lock. A detailed description of these operating procedures is included in Chapter 9.

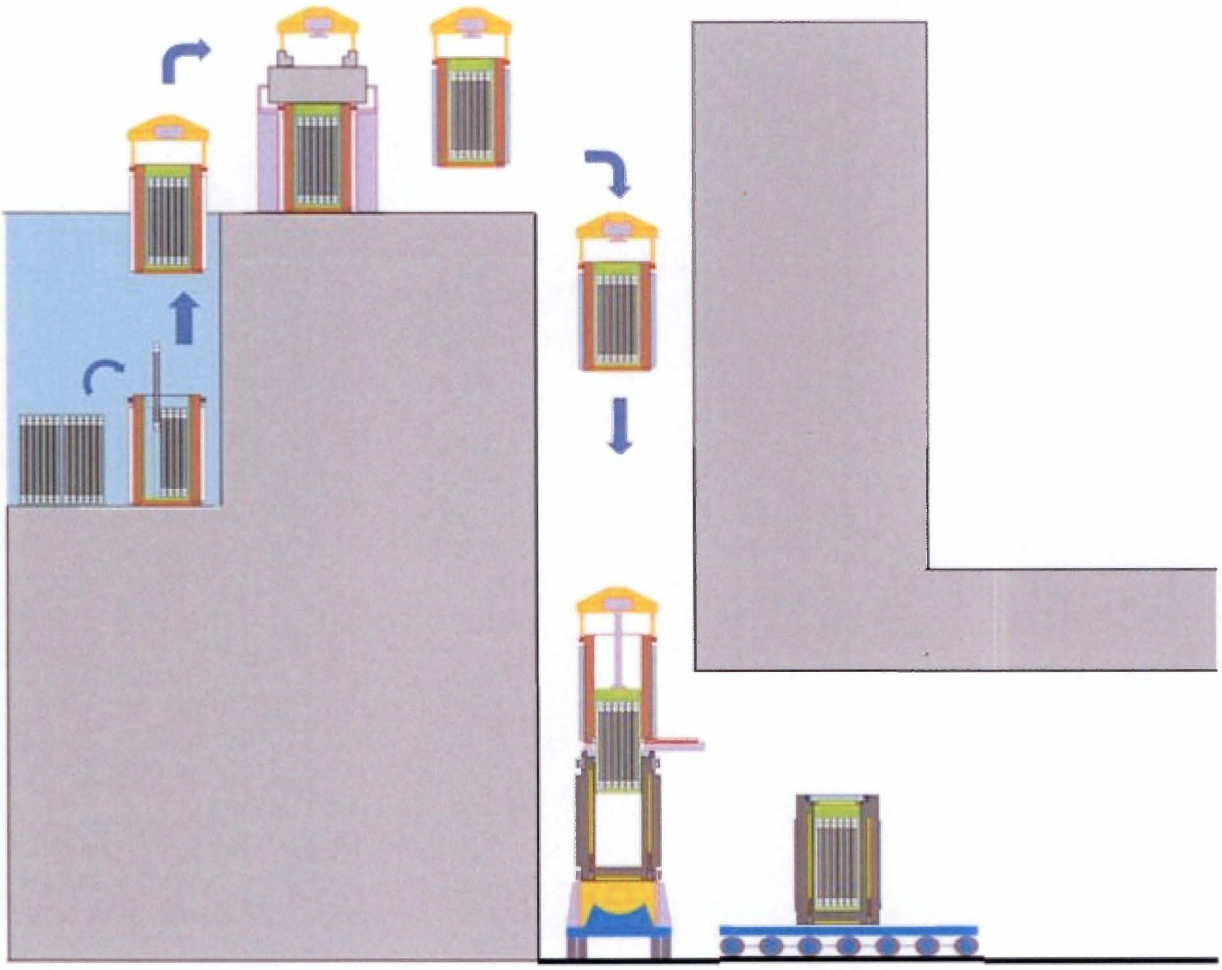

Figure 1.2-11: Sequence for SNF loading and canister transfer via cask loading unit

1.2.2.2.1 Reception of the CLU and Transfer into the Reactor Building

The components of the CLU are prepared and inspected prior to handling. The first handling step involves the load attachment at the trunnions of the transfer cask and, if necessary tilting into vertical orientation, using a special tilting device at the bottom side of the transfer cask. The empty transfer cask is vertically transfer by crane to the service position near the SNF pool. The transfer lock (and further equipment) is transferred into the reactor building as well.

1.2.2.2.2 Transfer of the Canister Next to the Pool via the CLU-system

The components of the CASTOR® geo69 storage cask are prepared and inspected prior to handling. The CASTOR® geo69 storage cask (containing the empty canister) is vertically positioned at the bottom of the truck lock via the transfer vehicle. Cask lid and retention ring are removed from the storage cask. The canister and the CASTOR® geo69 storage cask are prepared for accepting the transfer lock, e.g. by mounting the lifting pintle (mushroom-shaped LAP) onto the canister lid.

The transfer lock (closed) is positioned on top of the CASTOR® geo69 storage cask. Then the empty transfer cask is vertically transferred to the truck lock by crane and positioned on top of the transfer lock. The trunnions of the transfer cask remain attached to the crane. The bottom lid of the transfer cask is remotely opened via the transfer lock. The lifting gear for the canister is attached to the lifting pintle on the canister lid. The canister is lifted into the transfer cask and the transfer lock is closed. Then the vertical crane transfer of the transfer cask (containing the empty canister) to the service position near the SNF pool is performed.

1.2.2.2.3 Underwater Loading

Canister, equipment and the components of the transfer cask are prepared and inspected prior to their usage for SNF handling. The canister lid system is opened and the canister lid is removed. The cavities of canister and transfer cask as well as the inner and outer water chambers of the transfer cask are flooded with deionized water. The transfer cask (containing the empty canister, water and equipment) is vertically transferred to the underwater loading position in the SNF pool via crane. The FA are inserted into the fuel basket according to an approved loading plan.

After underwater loading is completed, the canister lid, equipped with a new metal gasket, is placed on the canister underwater via load attachment at the lifting pintle. Then the loaded transfer cask (containing canister, FAs, water and equipment) is vertically lifted via crane until the head ring is completely above the water surface. The dewatering equipment is mounted and dewatering is performed. After complete dewatering, the transfer cask is lifted entirely above the water surface and its surface is decontaminated. The loaded transfer cask is then transferred to the service station next to the SNF pool for the dispatch of the canister and transfer cask (closure, drying, helium backfilling, etc.).

1.2.2.2.4 Transfer of the Canister into the Storage Cask

Prior to further operation, the preparation and inspection of the transfer cask incl. the loaded and completely dispatched canister and the preparation and inspection of the CASTOR® geo69 storage cask and the transfer lock on top of it for accepting the transfer cask is performed.

The transfer cask incl. the loaded and completely dispatched canister is vertically transferred from the service station to the truck lock and positioned onto the transfer lock on top of the CASTOR® geo69 storage cask. The trunnions of the transfer cask remain attached to the crane. The lifting gear is attached to the lifting pintle on the canister lid. The transfer lock is opened by remote control and the canister is lowered into the CASTOR® geo69 storage cask. After removal of the lifting gear, the transfer lock is closed and transfer cask and transfer lock are subsequently removed by crane.

1.2.2.3 Dispatch of the CASTOR® geo69 storage cask

After the canister transfer is completed, the cask lid, equipped with a new metal gasket, is placed on the cask via load attachment at the lifting pintle. The storage cask is dispatched (including drying, if necessary, evacuation and helium backfilling) and the service orifices are closed by blind flange and protection cap including new metal gaskets. Finally the storage cask is ready for transport to the storage facility.

1.2.2.4 Operation of the DSS during Long-term Interim Dry Storage

During long-term interim dry storage, the DSS is placed in a storage building in vertical orientation. The protection cover is mounted on top of the storage cask. The cable conduit in the protection cover is used to connect the pressure switch in the cask lid to the pressure monitoring system of the storage facility. The pressure switch replaces the blind flange in the cask lid during long-term interim dry storage. Multiple storage casks are arranged in arrays as further described in Section 1.4. Figure 1.2-12 shows a possible arrangement of CASTOR® geo69 DSS with the cable connection to the pressure monitoring system. The internal pressure of all DSS is continuously monitored during long-term interim dry storage.

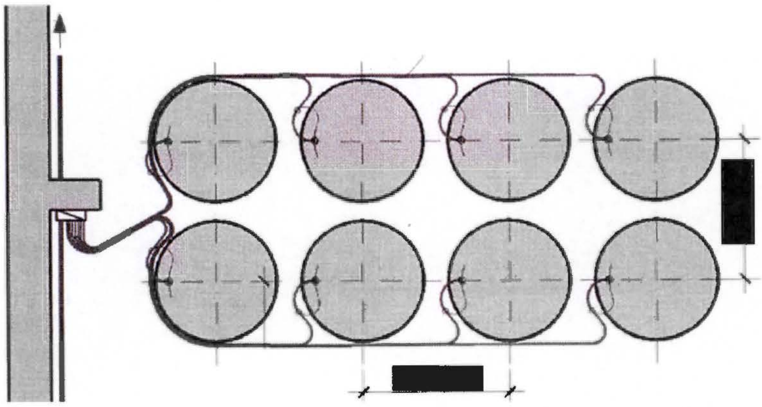

Figure 1.2-12: Pressure monitoring of the DSS during long-term interim dry storage

Depending on the design basis earthquake of the ISFSI where the CASTOR® geo69 DSS is used, the application of a storage frame can be necessary to prevent tipping of the cask during long-term interim dry storage. Figure 1.2-13 shows the generic design of a storage frame for the CASTOR® geo69 DSS. The storage frame is anchored in the storage pad of the ISFSI. It encloses the bottom part of the storage cask and is equipped with gaps for the tilting studs of the cask. Therefore, tipping or sliding of the cask during a design basis earthquake is prevented.

Subsection 13.2.2 provides limiting conditions for the use of the CASTOR® geo69 DSS without application of a storage frame. The structural evaluation of the DSS in Chapter 3 does not consider the application of a storage frame. However, the application of a storage frame similar to the one depicted in Figure 1.2-13 is considered in the thermal evaluation in Chapter 4, because a storage frame decreases the heat dissipation at the bottom are of the storage cask. Therefore, the consideration of a storage frame is bounding for the thermal evaluation of the CASTOR® geo69 DSS without storage frame.

[redacted]

Figure 1.2-13: Possible design of a storage frame for the CASTOR geo69 DSS

1.2.3 Contents

The CASTOR® geo69 DSS is designed for dry storage of BWR SNF. The characteristic values of the contents per loading are specified in Table 1.2-14. The detailed characteristics of the FA to be stored in the CASTOR® geo69 DSS are described in Section 2.1.

Table 1.2-14: Characteristic values of the radioactive contents per loading of the CASTOR® geo69 DSS

Maximum number of fuel assemblies	69
Maximum decay heat [kW]	18.5
Maximum total activity [PBq]	500
Maximum FA-averaged burn-up [GWd/Mg_{HM}]	58

Figure 1.2-14 shows the general loading schematic of the CASTOR® geo69 DSS (top view), including fuel basket position numbers 1 to 69 and position groups (PG) A to F. A PG comprises positions in the fuel basket that are treated equivalently in terms of shielding and decay heat limit.

[redacted]

Figure 1.2-14: Loading schematic of the CASTOR® geo69 DSS

The total decay heat of the loading is distributed to the 69 positions in the fuel basket by means of loading patterns. The FA of the six fuel types described in Section 2.1 are to be loaded into one of three different loading patterns, which are defined by overall thermal requirements. The [redacted] admissible loading patterns of the CASTOR® geo69 DSS are presented in Section 4.1. At the time of loading into the canister, the decay heat of every FA has to comply with one of the [redacted] thermal requirements. Only one single thermal requirement is admissible for a single given loading. The thermal requirements comprise decay heat maxima (in Watts) for every position in the fuel basket. Thermal requirements are legit for all FA regardless of their type. In addition to the individual boundaries for decay heat, the overall decay heat of a single loading must not exceed [redacted], as stated in Table 1.2-14. It is possible to combine FA of different types within one single loading. The bounding thermal parameters are discussed and specified in detail in Chapter 4.

List of References

[1] 1014-DPL-30934, Rev. 0
Design Parts List, Cask, CASTOR geo69

[2] 1014-DPL-36855, Rev. 0
Design Parts List, Canister, CASTOR geo69

[3] 1014-DPL-30984, Rev. 0
Design Parts List, Basket, CASTOR® geo69

[4] 1014-DPL-33604, Rev. 0
Design Parts List, Shielding Elements, CASTOR® geo69

[5] 1014-DPL-38556, Rev. 0
Design Parts List, Protection Cover, CASTOR® geo69

[6] 1015-DPL-37509, Rev. 0
Design Parts List, Transfer Cask, CASTOR® geo69

[7] 1015-DPL-38148, Rev. 0
Design Parts List, Transfer Lock, CASTOR® geo69

1.3 Identification of Agents and Contractors

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

This section contains the necessary information to fulfil the requirements pertaining to the qualifications of the applicant pursuant to 10 CFR 72.2(a)(1),(b) and 10 CFR 72.230(a). GNS Gesellschaft für Nuklear-Service mbH, based in Essen, Germany is the system designer and applicant for certification of the CASTOR® geo69 DSS.

With its 40 years of nuclear experience, GNS is a world-leading supplier of casks for SNF. GNS also offers services for management and disposal of SNF and all types of radioactive waste. More than 1700 SNF casks of the CASTOR® and CONSTOR® types are used today in a number of countries on four continents. This makes GNS the world's top supplier of shielded transport and storage casks. As an example, Table 1.3-1 lists the location, type and number of all casks for high-level radioactive waste (HLW) and SNF located in the USA that were developed and manufactured by GNS.

Table 1.3-1: Location, type and number of loaded casks for high-level waste and spent fuel in the USA

Location	***Cask Type***	***Loaded***
Department of Energy, Idaho Falls	CASTOR® V/21	1
Department of Energy, Hanford, Washington	CASTOR® GSF	6
	GNS 12	2
Surry Power Station, Virginia	CASTOR® V/21	25
	CASTOR® X/33	1

Design and supply of treatment facilities and all kinds of engineering support complete the GNS portfolio. Furthermore, GNS offers comprehensive solutions for all phases of decommissioning from defueling to dismantling and packaging of large components such as reactor pressure vessels and their internals.

1.4 Generic Cask Arrays

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The CASTOR® geo69 DSS is stored in a vertical configuration. The required centre-to-centre spacing between neighbouring storage casks (pitch) is guided by operational considerations. Figure 1.4-1 provides the nominal layout pitch, as evaluated by the heat transfer calculations in Chapter 4. The pitch values in Figure 1.4-1 are nominal and may be increased to suit the user's specific needs.

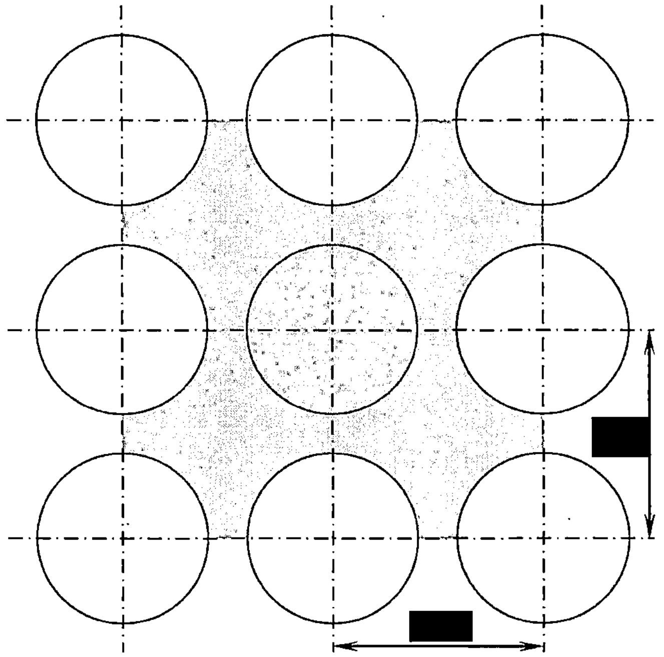

Figure 1.4-1: Nominal layout pitch in a generic CASTOR® geo69 DSS array

For the shielding evaluation in Chapter 5, a bounding array of storage casks is investigated, which comprises [redacted] storage casks in total, grouped in [redacted] rectangular arrangements of [redacted] storage casks. Inside each of the [redacted] arrangements, the storage cask pitch is equal to the one depicted in Figure 1.4-1. The centre-to-centre distance between neighbouring arrangements is [redacted]. The annual dose from the bounding cask array is evaluated at various distances from the centre of the long side of the array.

For the criticality evaluation in Chapter 6, an infinite array of densely packed storage casks is assumed. This evaluation is bounding for every generic array of multiple storage casks.

The CASTOR® geo69 DSS is stored in a vertical configuration. The required centre-to-centre spacing between neighbouring storage casks (pitch) is guided by operational considerations. Figure 1.4-1 provides the nominal layout pitch, as evaluated by the heat transfer calculations in Chapter 4. The pitch values in Figure 1.4-1 are nominal and may be increased to suit the user's specific needs.

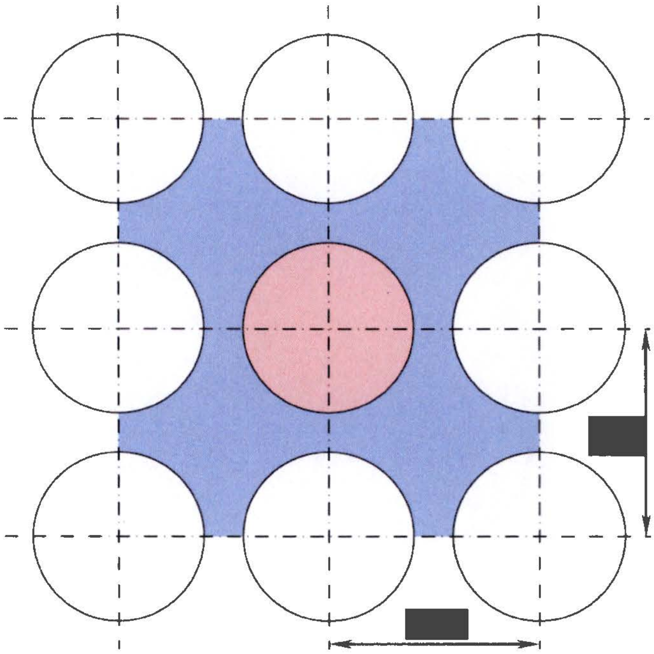

Figure 1.4-1: Nominal layout pitch in a generic CASTOR® geo69 DSS array

For the shielding evaluation in Chapter 5, a bounding array of storage casks is investigated, which comprises [redacted] storage casks in total, grouped in [redacted] rectangular arrangements of [redacted] storage casks. Inside each of the [redacted] arrangements, the storage cask pitch is equal to the one depicted in Figure 1.4-1. The centre-to-centre distance between neighbouring arrangements is [redacted]. The annual dose from the bounding cask array is evaluated at various distances from the centre of the long side of the array.

For the criticality evaluation in Chapter 6, an infinite array of densely packed storage casks is assumed. This evaluation is bounding for every generic array of multiple storage casks.

1.5 Appendix

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

Appendix 1-1: 1014-DD-38566 Rev. 0, Design Drawing, Storage Configuration, CASTOR® geo69

Appendix 1-2: 1014-DPL-38556, Rev. 0, Design Parts List, Protection Cover, CASTOR® geo69 incl. referenced drawings

Appendix 1-3: 1015-DPL-37509 Rev. 0, Design Parts List, Transfer Cask, CASTOR® geo69 incl. referenced drawings

Appendix 1-4: 1015-DPL-38148 Rev. 0, Design Parts List, Transfer Lock, CASTOR® geo69 incl. referenced drawings

APPENDIX 1-1 to 1014-SR-00002

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

Component and maximum weight overview		t
1	Cask (loadad)	[redacted]
2	Protection cover	[redacted]
3	Pressure switch	[redacted]

	Date	Name
Approved DM	14.04.2021	[redacted]
Reviewed DM-AI	09.04.2021	
Reviewed DM-D	08.04.2021	
Prepared DM-D	01.04.2021	

Specification: [redacted]

Projection method 1 acc. to ISO 128-30

Design Drawing

GNS Gesellschaft für Nuklear-Service mbH
Frohnhauser Str. 87, 45127 Essen
Germany

Scale 1:20 | Dimensions in millimeters | Weight approx.

Title: Storage configuration

CASTOR® geo69

Format	Draw.-No	Article No	No. of NOK	Rev
A1	1014-DD-38566	38566		0

The document is stamped with electronic signatures and is valid!

GNS	**PARTS LIST** APPENDIX 1-2 to 1014-SR-00002 Design **Protection cover** **CASTOR® geo69**	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1014-DPL-38556	Rev. 0	Page: 1 of: 3
		Date: 08.04.2021 Reviewed by DM-D: [redacted]	Date: 09.04.2021 Reviewed by QM-AI [redacted]	Date: 14.04.2021 Approved by DM: [redacted]	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]							
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[redacted]		[redacted]							
[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]					[redacted]		

The document is stamped with electronic signatures and is valid!

GNS	**PARTS LIST** Design **Protection cover** **CASTOR® geo69**	APPENDIX 1-2 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1014-DPL-38556	Rev. 0	Page: 2 of: 3
			Date: 08.04.2021 Reviewed by DM-D: [redacted]	Date: 09.04.2021 Reviewed by QM-AI: [redacted]	Date: 14.04.2021 Approved by DM: [redacted]	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]							
[redacted]		[redacted]					[redacted]		

The document is stamped with electronic signatures and is valid!

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

GNS	LEGEND Design Protection cover CASTOR® geo69	APPENDIX 1-2 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1014-DPL-38556	Rev. 0	Page: 3 of: 3
			Date: 08.04.2021 Reviewed by DM-D: [redacted]	Date: 09.04.2021 Reviewed by QM-A [redacted]	Date: 14.04.2021 Approved by DM: [redacted]	

[redacted]

The document is stamped with electronic signatures and is valid!

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

Tolerancing acc. to specification.

Longitudinal dimensions without tolerance							Radii and chamfers without tolerance	
until 6	over 6 to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over [illegible]	until 6	over 6
[redacted]							[redacted]	

	Date	Name
Approved DM	14.04.2021	[redacted]
Reviewed QM-A	09.04.2021	
Reviewed DM-D	08.04.2021	
Prepared DM-D	01.04.2021	

Specification: [redacted]

Projection method 1 acc. to ISO 128-30

Design Drawing

GNS Gesellschaft für Nuklear-Service mbH
Frohnhauser Str. 67, 45127 Essen
Germany

Scale 1:10 | Dimensions in millimeters
Weight approx. [redacted]

Title: Protection cover

CASTOR® geo69

Format	Draw.-No.	Article No	No of NOR	Rev
A1	1014-DD-38556	38556		0

The document is stamped with electronic signatures and is valid!

GNS	**PARTS LIST** Design Transfer cask CASTOR® geo69	APPENDIX 1-3 to 1014-SR-00002	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 1 of: 7
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	PARTS LIST Design Transfer cask CASTOR® geo69	APPENDIX 1-3 to 1014-SR-00002	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 2 of: 7
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** APPENDIX 1-3 to 1014-SR-00002 Design Transfer cask CASTOR® geo69	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 3 of: 7
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]							

GNS	**PARTS LIST** Design Transfer cask CASTOR® geo69	APPENDIX 1-3 to 1014-SR-00002	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 4 of: 7
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** APPENDIX 1-3 to 1014-SR-00002 Design Transfer cask CASTOR® geo69	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 5 of: 7
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]							
[redacted]		[redacted]	[redacted]						

GNS	PARTS LIST Design Transfer cask CASTOR® geo69	APPENDIX 1-3 to 1014-SR-00002	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 6 of: 7
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]							
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[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]					[redacted]		

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

GNS	**LEGEND** Design Transfer cask CASTOR® geo69	APPENDIX 1-3 to 1014-SR-00002	Date: 30.03.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-37509	Rev. 0	Page: 7 of: 7
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

[redacted]

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Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

Tolerancing acc. to specification

Longitudinal dimensions without tolerance							Radii and chamfers without tolerance	
until 6	over 6 to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over 2000	until 6	over 6
[redacted]							[redacted]	

	Date	Name
Approved DM		
Reviewed DM A		
Reviewed DM D		
Prepared DM D	[redacted]	

Specification: [redacted]

Projection method 1 acc. to ISO 128-30

Design Drawing

GNS Gesellschaft für Nuklear-Service mbH
Frohnhauser Str. 67, 45127 Essen
Germany

Scale 1:10 | Dimensions in millimeters

Weight approx. [redacted]

Title
Transfer cask

CASTOR® geo69

Format	Draw.-No.:	Article No.		Rev.
A0	1015-DD-37509	37509		0

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

Tolerancing acc. to specification.

Longitudinal dimensions without tolerance							Radii and chamfers without tolerance	
until 6	over 6 to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over 2000	until 6	over 6
[redacted]							[redacted]	

	Date	Name
Approved DM		
Reviewed DM A		
Reviewed DM D		
Prepared DM-D	[redacted]	

Specification: [redacted]

Projection method 1 acc. to ISO 128-30

Design Drawing

GNS Gesellschaft fur Nuklear-Service mbH
Frohnhauser Str. 67, 45127 Essen
Germany

Scale 1:10 | Dimensions in millimeters | Weight approx.

Title: Transfer cask body

CASTOR® geo69

Format	Draw.-No:	Article No.	No of NCR	Rev.
A0	1015-00-3750912	37509		0

GNS	PARTS LIST Transfer lock CASTOR® geo69	APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 1 of: 11
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

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GNS	PARTS LIST Transfer lock CASTOR® geo69	APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 2 of: 11
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]	[redacted]	Base plate for cylinder [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	Base plate for cylinder [redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
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Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

GNS	**PARTS LIST** APPENDIX 1-4 to 1014-SR-00002 Transfer lock CASTOR® geo69	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 3 of: 11
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** Transfer lock CASTOR® geo69	APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 4 of: 11
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	PARTS LIST APPENDIX 1-4 to 1014-SR-00002 Transfer lock CASTOR® geo69	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 5 of: 11
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** APPENDIX 1-4 to 1014-SR-00002 Transfer lock CASTOR® geo69	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 6 of: 11
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	PARTS LIST Transfer lock CASTOR® geo69	APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 7 of: 11
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]	[redacted]				[redacted]		
[redacted]		[redacted]					[redacted]		
[redacted]		[redacted]					[redacted]		
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[redacted]		[redacted]					[redacted]		

GNS	PARTS LIST APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021	Parts List:	Rev.	Page: 8
	Transfer lock	Prepared by DM-D: [redacted]	1015-DPL-38148	0	of: 11
	CASTOR® geo69	Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** APPENDIX 1-4 to 1014-SR-00002 Transfer lock CASTOR® geo69	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 9 of: 11
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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GNS	**PARTS LIST** Transfer lock CASTOR® geo69	APPENDIX 1-4 to 1014-SR-00002	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 10 of: 11
			Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

Item	Qty.	Description	Article No. Applicable Document	To Item	Legend	Material Requirements	Dimension / Remarks	SC	Rev
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[redacted]		[redacted]					[redacted]		

GNS	**LEGEND** APPENDIX 1-4 to 1014-SR-00002 Transfer lock CASTOR® geo69	Date: 01.04.2021 Prepared by DM-D: [redacted]	Parts List: 1015-DPL-38148	Rev. 0	Page: 11 of: 11
		Date: Reviewed by DM-D:	Date: Reviewed by QM-AI:	Date: Approved by DM:	

[redacted]

APPENDIX 1-4 to 1014-SR-00002

Non-Proprietary Version
Proprietary Information withheld per 10 CFR2.390

Tolerancing acc. to specification

Longitudinal dimensions without tolerance							Radii and champfers without tolerance	
until 6	over 6 to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over 2000	until 6	over 6
[redacted]					[redacted]		[redacted]	

	Date	Name
Approved DM		
Reviewed DM A		
Reviewed DM B		
Prepared DM D	[redacted]	

Specification: [redacted]

Projection method 1 acc. to ISO 128-30

Design Drawing

GNS Gesellschaft für Nuklear-Service mbH
Frohnhauser Str. 67, 45127 Essen
Germany

Scale 1:20 | Dimensions in millimeters

Weight approx. [redacted]

Title: Transfer lock

CASTOR® geo69

Format	Draw.-No.:	Article No.	No of HOR	Rev
A0	1015-DD-38148	38148		0

2 Principal Design Criteria

2.0 Overview

	Name, Function	Date	Signature
[redacted]		[redacted]	
[redacted]			

This chapter contains a compilation of design criteria applicable to both, the CASTOR® geo69 DSS as well as the CLU. Storage cask and canister are designed to comply with both 10 CFR 72 and 10 CFR 71 and therefore certain design criteria are overly conservative for storage. This chapter sets forth the loading conditions and relevant acceptance criteria; it does not provide results of any analyses. The analyses and results carried out to demonstrate compliance with the design criteria are presented in the subsequent chapters of this SAR.

2.0.1 CASTOR® geo69 DSS Principle Design Criteria

The CASTOR® geo69 DSS is designed for up to [redacted] years of dry storage, while satisfying the requirements of 10 CFR 72. The DSS is designed for long-term interim dry storage in a storage hall, with multiple storage casks arranged in arrays as described in Section 1.4. The postulated storage hall limits the amount of credible environmental phenomena that are to be considered for the DSS design. Thus, neither loadings due to snow and ice nor loadings caused by tornado, wind, flood or mud flow are specified in Subsection 2.2.3. It is assumed that the storage building does not collapse during any of the natural events listed in 10 CFR 122(b)(2), hence burial under debris is also not to be considered.

The following subsections establish the principle design criteria of the DSS and its components.

2.0.1.1 Structural

The CASTOR® geo69 DSS includes both DCI and structural steel components that are classified as important to safety. The DCI and steel components of the storage cask are designed and fabricated in accordance with the requirements of the BPVC, Section III, Division 3.

The storage cask is designed for all normal, off-normal, and design basis accident condition loads, as defined in Section 2.2. At a minimum, the storage cask must protect the loaded canister from deformation, provide continued adequate performance, and allow the retrieval of the canister under all conditions of storage. Structure, system and components (SSCs) of the storage cask are designed to withstand the effects of the natural phenomena specified in Subsection 2.2.3 to meet the requirements of 10 CFR 72.122.

The CASTOR® geo69 DSS is designed for handling via single-failure proof handling devices, which satisfy the enhanced safety criteria given in NUREG-0612 [1] and are designed in accordance with ANSI N14.6 [2]. Drop events resulting from handling accidents during handling operations performed on the storage cask or the canister are considered non-credible events. A maximum allowable handling height for the DSS is thus not specified.

2.0.1.2 Thermal

The allowable temperatures for the CASTOR® geo69 DSS components made of DCI or structural steel are based on the maximum temperature for material properties and allowable stress values provided in Section II of the BPVC. Cask lid, bottom and lateral area of the storage cask incorporates [redacted] shielding material. This ultra-high molecular weight polyethylene (UHMW-PE) moderator material has a maximum allowable temperature in accordance with the manufacturer's data sheet. The thermal stability of the moderator material is further described in Subsection 8.2.3.

The CASTOR® geo69 DSS is designed for the maximum heat load of [redacted] analyzed for storage operations. The thermal characteristics of the SNF, which the storage cask is designed for, are defined in Section 2.1. The maximum fuel cladding design temperature for normal conditions of storage and short-term operations is generally set at 400 °C. In case the canister is loaded exclusively with SNF with burnup < 45GWd/Mg_{HM}, the fuel cladding temperature limit for short-term operations is set at 570 °C. Appropriate analyses have been performed as discussed in Chapter 4 and operating restrictions added to ensure these limits are met. The DSS provides adequate heat removal capacity without an active cooling system as required by 10 CFR 72.236(f).

The canister cavity is dried after loading in the spent fuel pool using either a vacuum drying system or a forced helium dehydration system. Canister and storage cask are filled with pure helium during sealing operations to promote heat transfer and prevent fuel cladding degradation.

2.0.1.3 Shielding

The off-site dose for normal operating conditions to a real individual beyond the controlled area boundary is limited by 10 CFR 72.104(a) to a maximum of 0.25 mSv/year to the whole body, 0.75 mSv/year to the thyroid, and 0.25 mSv/year for other critical organs. Determination and comparison of off-site doses to these limits are necessarily site-specific and depend e.g. on the storage hall design and the number and arrangement of loaded storage casks in the storage hall. Dose rates for a single storage cask and cask arrays are provided in Chapter 5, including dose rates for a cask array stored in a generic storage hall. The determination of site-specific dose rates at the site boundary and demonstration of compliance with regulatory limits shall be performed by the licensee in accordance with 10 CFR 72.212.

2.0.1.4 Containment

The double containment system of the CASTOR® geo69 DSS retains the radioactive SNF content for all design basis normal, off-normal and accident conditions of storage and natural phenomena. The inner containment is provided by the canister comprising an enclosure vessel with containment welds and a sealed lid. The DCI cask body together with the cask lid system represents the outer containment. Both containment boundaries are designed and inspected in accordance with Division 3. The double containment system fulfills the design requirements of 10 CFR 72.236(e).

Helium leakage testing of both containment boundaries is conducted in accordance with ANSI N14.5. The leakage test provides reasonable assurance that the containment boundary is free of defects that could lead to a leakage rate greater than the allowable design basis leakage rate specified in the containment analyses in Chapter 7.

2.0.1.5 Criticality

The CASTOR® geo69 DSS is designed for criticality safety in accordance with 10 CFR 72.124(a). The DSS provides criticality control for all design basis normal, off-normal, and accident conditions of storage, as discussed in Section 6.1. The effective neutron multiplication factor is limited to $k_{eff} < 0.95$ for fresh unirradiated fuel with optimum water moderation and close reflection, including all biases, uncertainties, and manufacturing tolerances.

The geometric spacing of the FA and the fixed borated neutron absorbing material incorporated into the fuel basket assembly maintain criticality control. The minimum specified boron concentration verified during neutron absorber manufacture is further reduced by 10 % for criticality evaluation. No burnup credit is taken into account.

2.0.1.6 Operations

No radioactive effluents result from storage or transfer operations with the CASTOR® geo69 DSS. Effluents generated during loading operations are handled by the NPP's radwaste system and procedures. Effluent systems in accordance with 10 CFR 72.126(c) must not be provided for the CASTOR® geo69 DSS.

Generic operating procedures for the CASTOR® geo69 DSS are provided in Chapter 9. Detailed operating procedures will be developed by the licensee, based on Chapter 9, site-specific requirements that comply with the 10 CFR 50, technical specifications for the NPP and the CASTOR® geo69 CoC.

2.0.2 CLU Principle Design Criteria

The CLU is designed according to 10 CFR 72, if applicable. The CLU comprises the transfer cask, transfer lock and further equipment and is intended for handling and transfer of a loaded canister out of the SNF pool towards and into the CASTOR® geo69 storage cask. The main safety objectives of the CLU are safe loading, dispatch and handling of the canister containing the SNF, dissipation of decay heat power and shielding of the gamma and neutron radiation.

The CLU components responsible for structural integrity, heat dissipation and shielding are designed as passive systems. Loss of power and instrumentation failures are not to expect. The ambient temperatures for normal handling operations are chosen to cover also off-normal conditions. Furthermore, the CLU components are not capable of retaining internal pressures. Therefore, off-normal handling conditions are not credible.

The CLU is exclusively used inside the reactor building, which is expected not to collapse during the natural events listed in 10 CFR 122(b)(2), thus accident conditions and natural phenomena events are not to be assumed.

2.0.2.1 Structural

The structural steel components of the transfer cask classified as important to safety, with the exception of the trunnions used for lifting and handling, are designed and fabricated in accordance with the applicable requirements of Section III, Subsection NF, of the BPVC. The trunnions are designed to be single failure proof in accordance with the requirements of NUREG-0612 and ANSI N14.6 for non-redundant lifting devices. The same requirements shall apply to associated load attachment devices.

Neither transfer cask nor transfer lock have pressure-bearing components, except for the water chambers of the transfer cask. An uncontrollable pressure rise in the water chambers is excluded due to two redundant pressure relief devices.

2.0.2.2 Thermal

The allowable temperatures for the CLU components made of structural steel are based on the maximum temperature for material properties and allowable stress values provided in Section II of the ASME BPVC. The transfer cask incorporates lead shielding material, which has a maximum allowable temperature in accordance with the manufacturer's data sheet. The water in the water chambers of the transfer cask must stay below 100 °C during all operational procedures. The transfer lock incorporates PE shielding material with a maximum allowable temperature in accordance with the manufacturer's data sheet. The main thermal function of the CLU is the dissipation of the heat that is released from the loaded canister to limit the fuel cladding temperature during canister transfer to 400 °C.

2.0.2.3 Shielding

The transfer cask includes both structural and non-structural biological shielding components. The gamma (lead, steel) and neutron shielding (water, PE) of transfer cask and transfer lock is designed to protect workers from radiation exposure in compliance with the admissible dose limits of 10 CFR 20. The maximum dose rate at a distance of 1 m from the transfer cask is limited to [redacted].

2.0.2.4 Containment

Neither transfer cask nor transfer lock fulfil a containment function.

2.0.2.5 Criticality

The CLU is of subordinate importance for the subcriticality of the loaded SNF in the canister. However, subcriticality is evaluated for underwater FA loading in Chapter 6.

2.0.2.6 Handling

Generic operating procedures involving the CLU are provided in Chapter 9. Detailed operating procedures will be developed by the licensee, based on Chapter 9, site-specific requirements that comply with the 10 CFR 50, technical specifications for the NPP and the CoC of the CASTOR® geo69 DSS.

The total mass of the transfer cask carrying a canister loaded with SNF assemblies must not exceed the capacity of gantry cranes installed in NPP, also considering load attachment devices like e.g. traverses. Within this SAR a maximum crane capacity of [redacted] is chosen as upper limit.

List of References

[1] NUREG-0612, July 1980
Control of Heavy Loads at Nuclear Power Plants
U.S. Nuclear Regulatory Commission, Office for Nuclear Reactor Regulation

[2] ANSI N14.6 – 1993
Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10000 Pounds (4500 kg) or More

2.1 Spent Fuel to be stored

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The characteristics of the FA to be stored in the CASTOR® geo69 DSS, which are essential for the safety analyses, are denoted in Table 2.1-1. If not explicitly specified otherwise, the values are related to the nominal conditions before irradiation. Maximum heavy metal (HM) masses correspond to maximum active fuel rod lengths. Thus, HM masses decrease for shorter fuel rod lengths. FA that have been deformed or damaged during reactor operation or which are otherwise defective in their structural integrity are not to be loaded into the DSS. It is only allowed to load undamaged FA with completely filled grids into the DSS. However, it is allowed to load FAs with completely filled grids containing replacement fuel rods and/or replacement rods manufactured from solid material (dummy rods).

Because of the various FA that can be stored in the CASTOR® geo69 DSS, there is no design basis FA that is bounding for each of the evaluations presented in subsequent chapters (thermal evaluation, shielding evaluation, criticality evaluation, containment). The SNF specifications that are bounding for the individual evaluations and the corresponding loading patterns are presented in each chapter.

Table 2.1-1 Characteristics of the SNF to be stored in the CASTOR® geo69 DSS

Internal ID	Footnote	FA No		1	2	3	4	5	6
		Fuel Type		GE 8x8-1	GE 8x8-2	SPC 8x8-2	GE9B 8x8	GE12 LUA	ATRIUM-10A
		Fissile Material		UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
1	1	max. FA mass	kg	[redacted]					
2		max. metallic HM mass	kg						
3	2	max. fuel density	g/cm³						
4		outer size of the assembly (fuel channel, centre)	mm						
5		outer size of the assembly (corner)	mm						
6		thickness of the fuel channel in centre (corner)	mm						
7		total height of FA (bottom to the top of handle)	mm						
8		fuel rod pitch	mm						
9		number of fuel rods	-	63	62	62	60	92	91
10		number of part length fuel rods	-	0	0	0	0	14	8
11	3	number of water rods	-	1	2	2	1 (2x2)	2 (2x2)	1 (3x3)
12		fuel rod length	mm	[redacted]					
13		fuel pellet stack length (active fuel length)	mm						
14		part length pellet stack length	mm						
15		nominal pellet diameter	mm						
16		tolerance of the pellet diameter	mm			[redacted]			[redacted]
17		max. dishing+chamfering, pellet volume fraction	vol.-%						
18	4	max. ^{235}U initial enrichment	wt-%	[redacted]					
19	5	min. ^{235}U initial enrichment	wt-%						
20		max. FA-averaged discharge burn-up	GWd/Mg_{HM}						
21		min. cooling time	d						
22		max. decay heat of a single FA	W						
23		axial burn-up profile (peaking factor) for ID 20	-	1.35					
24		cladding material	-	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy
25		cladding outer diameter	mm	[redacted]					
26		tolerance of cladding diameter	mm						
27		cladding thickness	mm						
28	6	tolerance of cladding thickness	mm						
29		water rod/channel material	-	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy
30		min. water rod/channel outer dimension	mm	[redacted]					
31		min. thickness of the water rod/channel	mm						
32		[redacted]	[redacted]						
33									
34									
35									
36									
37									
38									
39							[redacted]		

All values are given for the cold, non-irradiated state, if not stated otherwise. Tolerances are applied positively and negatively.

[1] the weight of the fuel channel is included

[2] for criticality assessment

[3] FA No 4 to 6 show larger water rods with grid dimensions of 2 by 2 water regular rods or a larger water channel with grid dimensions of 3 by 3 water regular rods

[4] averaged over the cross section of the assembly in the region with highest enrichment including production tolerance

[5] averaged over the cross section of the assembly in the region with lowest enrichment excluding production tolerance

[6] deduced from the tolerances of the inner and outer diameter

2.1.1 Source Specification

The decay heat values, gamma and neutron source terms, nuclide activities, and fissile gas masses are determined with the help of burn-up and depletion calculations. This section briefly describes the approach used for the calculations. Results and details are presented in corresponding chapters of this SAR. The aforementioned physical quantities were calculated using the TRITON [1] and ORIGAMI [2] modules of the SCALE 6.2 system [3].

To enable subsequent ORIGAMI calculations, TRITON is utilized to generate cross-section libraries for all FA types from Table 2.1-1. The two-dimensional TRITON models creating the cross-section libraries for the six types of FA are shown in Figure 2.1-1, Figure 2.1-2 and Figure 2.1-3. Dark blue circles stand for fuel pins, yellow circles for fuel pins with Gd_2O_3 content. Pin cladding is shown in light blue. Red areas denote the position of the water rods/channels and surrounding moderator. Structural materials of the water rods/channels and the outer fuel assembly are pictured in purple.

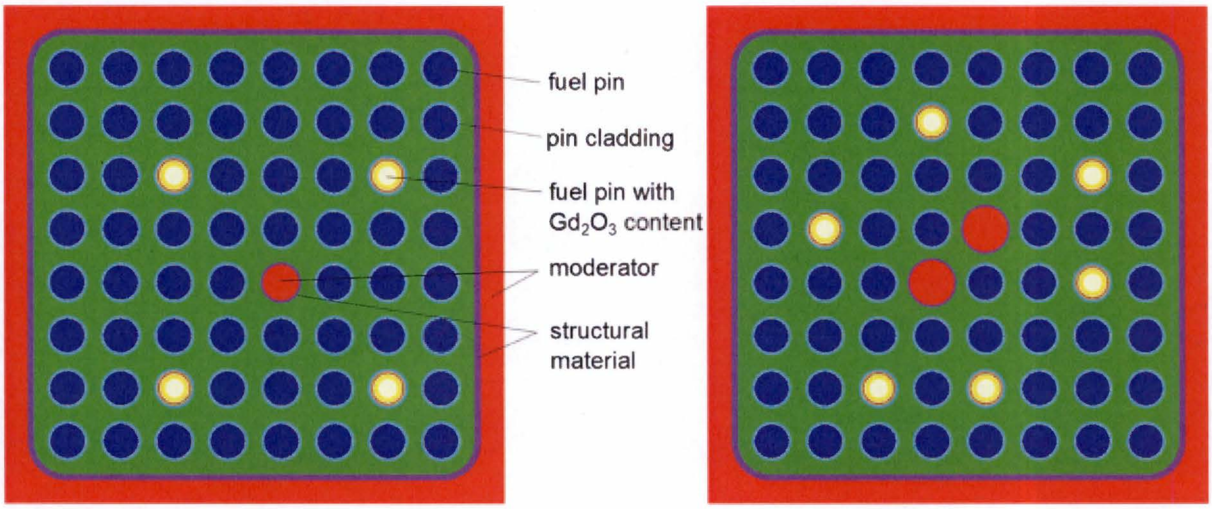

Figure 2.1-1: TRITON models of FA of types GE 8x8-1 (left) and GE 8x8-2

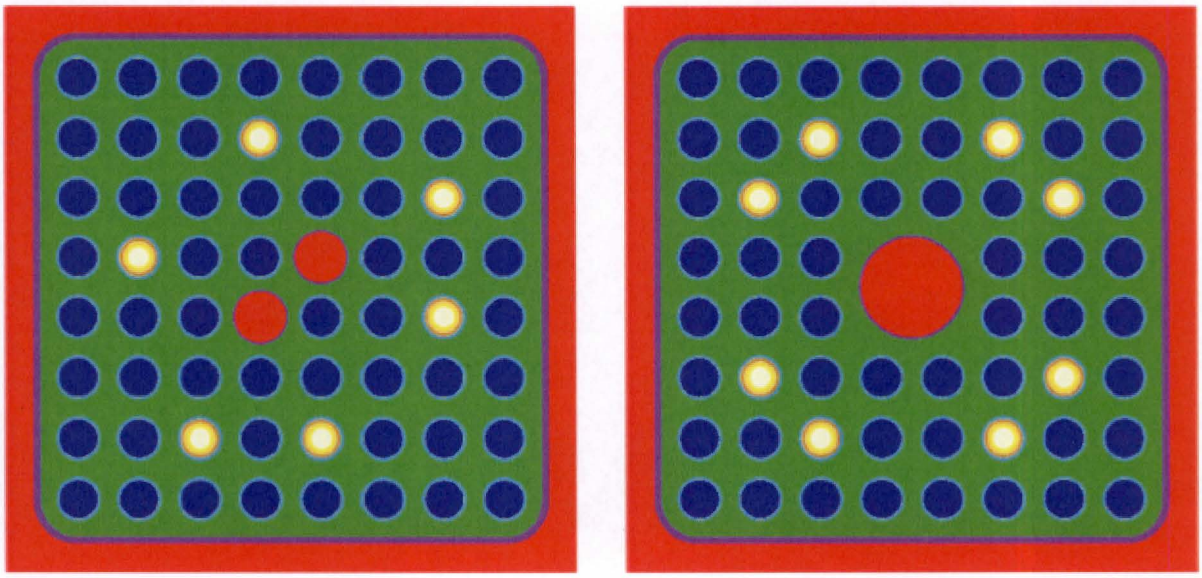

Figure 2.1-2: TRITON model of FA types SPC 8x8-2 (left) and GE9B 8x8 (right)

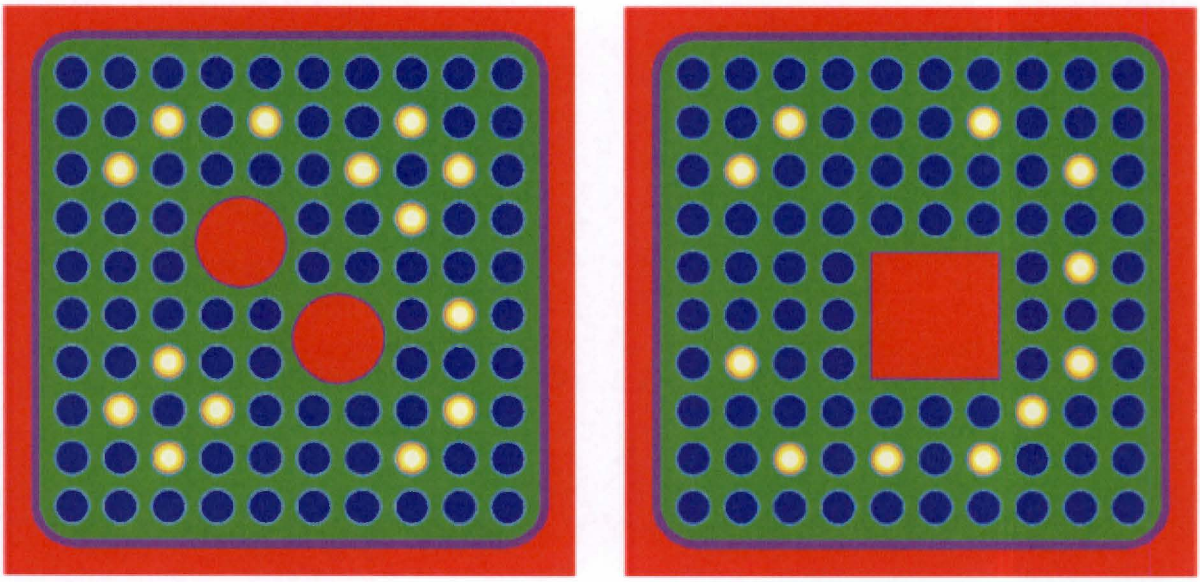

Figure 2.1-3: TRITON model of FA types GE12 LUA (left) and ATRIUM-10A

The libraries have been generated using the following parameters:

- ENDF/B-VII 252-group library,
- enrichment [redacted] wt-% ^{235}U in steps of [redacted] wt-% ^{235}U for FA types excluding [redacted]
- enrichment [redacted] wt-% 235U in steps of [redacted] wt-% 235U for FA type [redacted]
- moderator density [redacted] g/cm³ in steps of [redacted] g/cm³,
- burn-up up to [redacted] GWd/Mg_{HM} in steps of [redacted] GWd/Mg_{HM}.

To take axial variations in source term generation into account, axially varying burn-up profiles and moderator densities are employed in the ORIGAMI calculations. [redacted] Every 2D ORIGAMI model is divided into 24 equidistant axial nodes in the active zone, which leads to a virtual third dimension. In the profiles shown in Figure 2.1-4 and Figure 2.1-5 and summarized in Table 2.1-2, node 1 is at the bottom end of the active region and node [redacted] is at the top end. [redacted]

[redacted] Sample input files for TRITON and ORIGAMI are provided in Section 2.5.

[redacted]

Figure 2.1-4: Moderator density used in the ORIGAMI calculations

[redacted]

Figure 2.1-5: Burn-up profiles used in the ORIGAMI calculations

Table 2.1-2: Moderator density und burn-up profile inputs for ORIGAMI calculations

[redacted]

Table 2.1-3 shows the input parameters which are used to generate the ORIGAMI calculation input files resulting in bounding values for decay heat and source terms. Radiation source terms and decay heat increase monotonically with increasing burn-up. Thus, maximum burn-up is a first bounding parameter. Furthermore, it is acknowledged that for decreasing initial fuel enrichments source terms and decay heat are increasing. As a result, minimum initial fuel enrichment is a second bounding parameter. [redacted].

Table 2.1-3: Input parameters for the ORIGAMI calculations of decay heat and source terms

[redacted]

Table 2.1-4 shows the input parameters which are used to generate the ORIGAMI calculation input files resulting in bounding values for nuclide activities and fissile gas masses. As the production of fissile products and actinides differs for varying initial fuel enrichments, a range of this input parameter was taken into account for each fuel assembly type separately. Thus, bounding parameters are determined separately for each nuclide and element, respectively.

Table 2.1-4: Input parameters for the ORIGAMI calculations of nuclide activities and fissile gas masses

[redacted]

Table 2.1-5 contains the calculated values for these quantities. Calculations are performed with respect to 1 Mg_{HM} and for a date at the end of the minimum cooling time stated in Table 2.1-1.

Table 2.1-5: ORIGAMI calculation results for decay heat, nuclide and total activities, and fissile gas masses with regard to 1 Mg_{HM} at the date of minimum cooling time from Table 2.1-1

[redacted]

List of References

[1] M. A. Jessee et al.
TRITON: A Multipurpose Transport, Depletion, and Sensitivity and Uncertainty Analysis Module
in: SCALE Code System
ORNL/TM-2005/39, Version 6.2.2, 2017

[2] M. L. Williams et al.
ORIGAMI: A Code for Computing Assembly Isotopics with ORIGEN
in: SCALE Code System
ORNL/TM-2005/39, Version 6.2.2, 2017

[3] SCALE Code System
ORNL/TM-2005/39, Version 6.2.2, 2017

2.2 Design Criteria for Environmental Conditions and Natural Phenomena

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The CASTOR® geo69 DSS is engineered for the interim storage of SNF as described in Section 2.1 for the duration of its design lifetime. Accordingly, the DSS is designed to withstand normal, off-normal, and design basis accident conditions of storage and natural phenomena events. Normal conditions include the conditions that are expected to occur regularly or frequently in the course of normal operation. Off-normal conditions include those infrequent events that could reasonably be expected to occur during the lifetime of the DSS. Accident conditions of storage and natural phenomena events include events that are postulated because their consideration establishes a conservative design basis.

Loads associated with NCS act in combination with loads due to off-normal conditions of storage, ACS and natural phenomena events. Loads caused by off-normal condition of storage, natural phenomena events and ACS are not applied in combination.

In the following subsections, the design criteria are established for NCS, off-normal conditions of storage, and ACS. Loads that require consideration under each condition are identified and the design criteria are discussed. Based on consideration of the applicable requirements of the system, the following loads are identified:

- *NCS:* Dead weight, handling, temperature, pressure
- *Off-normal conditions of storage:* Temperature, pressure
- *ACS:* Tipover, fire, seismic events

Each of these conditions and the applicable loads are identified and applicable design criteria are established. The design criteria shall be satisfied to prevent an excess of the allowable stress limits.

2.2.1 Normal Conditions of Storage

2.2.1.1 Dead Weight

The CASTOR® geo69 DSS must withstand the static loads due to the weights of each of its components in storage configuration. Additionally, the CASTOR® geo69 storage cask shall withstand the combined dead weight of transfer cask and transfer lock of the CLU, which are placed on top of the storage cask during canister transhipment.

2.2.1.2 Handling

The CASTOR® geo69 must withstand loads experienced during routine handling including:

- Handling of the storage cask (e.g. lifting, lowering, moving) via trunnions
- Tilting of the storage cask via tilting studs
- Handling of the canister (e.g. lifting and lowering during transfer) via LAP located in the canister lid

The loads shall be increased by 15% to include any dynamic effects from the lifting operations as directed by CMAA #70 [1]. Lifting attachments and special lifting devices shall meet the requirements of ANSI N14.6 [2] and NUREG-0612 [3]. Handling operations are assumed to take place at NCS temperatures.

2.2.1.3 Environmental Temperatures

The CASTOR® geo69 DSS is standing inside a storage hall without direct influence by the environmental temperature at the storage facility site and by solar insolation. Multiple storage casks are arrange in arrays as described in Section 1.4. A maximum air temperature between the casks of [redacted] is assumed. This maximum air temperature includes a temperature rise due to the heating of the convective airflow by the storage casks. A maximum temperature of the storage hall walls and ceiling of [redacted] is assumed, considering full insolation according to 10 CFR 71.71 averaged over 24 hours.

A minimum air temperature inside the storage hall of [redacted] is assumed.

2.2.1.4 Pressure

The internal pressure of the canister is dependent on the initial volume of cover gas (helium), the volume of fill gas in the fuel rods, the fraction of fission gas released from the fuel matrix, the number of fuel rods assumed to have ruptured, and temperature.

2.2.2 Off-normal Conditions of Storage

As the CASTOR® geo69 DSS is a passive system, loss of power and instrumentation failures are not defined as off-normal conditions of storage. The off-normal condition design criteria are defined in the following subsections. A discussion of the effects of each off-normal condition is provided in Section 12.1.

2.2.2.1 Off-normal Environmental Temperatures

For NCS, sufficiently high values are chosen as maximum and minimum ambient temperatures inside the storage hall. These ambient temperatures already consider seasonal variations so that off-normal environmental temperatures are bounded by the NCS ambient temperatures.

2.2.2.2 Off-normal Pressure

The CASTOR® geo69 DSS must withstand loads due to off-normal pressure. The internal pressure of the canister bounds the cumulative effects of the maximum fill gas volume, off-normal environmental temperatures, the maximum SNF heat load, and an assumed 10 % of the fuel rods ruptured with 100 % of the fill gas and 15 % of the fission gases released due to a cladding breach in accordance with NUREG-2224 [4].

2.2.3 Accident Conditions of Storage and Environmental Phenomena

ACS and natural phenomena event design criteria are defined in the following subsections. The minimum acceptance criteria for the evaluation of the ACS are that the double containment system of the CASTOR® geo69 DSS retains the radioactive fuel content, the canister and fuel basket structure maintain the fuel contents subcritical, the stored SNF can be retrieved by normal means, and the system provides adequate shielding. In the analyses for conditions resulting from design-basis accidents and natural phenomena events, the amount of radioactive material available for release from the stored SNF shall be in accordance with Table 3-1 in NUREG-2224. The DSS must withstand the pressure arising from the gases released due to fuel cladding breach.

A discussion of the effects of each ACS and natural phenomena event is provided in Section 12.2. The consequences are evaluated against the requirements of 10 CFR 72.106. Section 12.2 also provides the corrective action for each event.

2.2.3.1 Storage Cask Tipping

The free-standing CASTOR® geo69 DSS is demonstrated by analysis to remain kinematically stable under the design basis natural phenomena events. However, the CASTOR® geo69 DSS shall also withstand impacts due to a hypothetical tip-over event. The structural integrity of a loaded DSS after a tip-over onto a reinforced concrete pad from a position of balance with no initial velocity is demonstrated by analysis. The cask tip-over is not postulated as an outcome of any environmental phenomenon or accident condition, but is a non-mechanistic event.

2.2.3.2 Fire

The possibility of a fire accident at or near the storage site is considered to be extremely remote due to the absence of significant combustible materials. The only credible concern is related to a transport vehicle fuel tank fire engulfing the loaded CASTOR® geo69 DSS while moving to the storage hall.

The CASTOR® geo69 DSS must withstand temperatures due to a fire event. [redacted] The DSS surface are considered to receive an incident radiation and forced convection heat flux from the fire. A fire temperature of 800 °C is assumed in accordance with 10 CFR 71.73. Section 4.6 includes the thermal evaluation of the fire accident for storage.

2.2.3.3 Seismic Events

The CASTOR® geo69 DSS must withstand loads arising due to a seismic event and must not tip over during a seismic event. To determine the maximum zero period accelerations (ZPA) that will not cause incipient tipping, the storage cask is considered as a rigid body, subjected to a net horizontal quasi-static inertia force and a vertical quasi-static inertia force. It is conservatively assumed that the peak acceleration values in horizontal and vertical direction occur simultaneously. Representative combinations of the ZPA in horizontal and vertical direction above which static incipient tipping would occur are reported in Chapter 3.

The evaluation of the kinematic stability of the DSS for a design basis earthquake is necessarily site-specific. The use of the DSS without additional safety measures (e.g. anchoring of the DSS in the storage pad using a storage frame) is limited to sites with design-basis earthquakes that are bounded by the incipient tipping analysis reported in Chapter 3. For sites where stronger earthquakes are to be assumed, structural evaluations are to be carried out taking into account, for example, an appropriate storage frame.

2.2.4 Handling Operations using the CLU

Handling operations using the CLU take place in the reactor building. As described in Subsection 2.0.2, ACS and natural phenomena are not assumed for the CLU. The handling operations involving the CLU are apportioned to the NCS specified in Subsection 2.2.1.

2.2.4.1 Dead Weight

The transfer cask must withstand the static loads due to the weights of each of its components, including the weight of the loaded SNF, canister and water fillings in the water cambers. The transfer lock must withstand the static loads due to the weights of each of its components together with the loaded transfer cask (including the weight of the loaded SNF, canister and water fillings in the water cambers) atop of it.

2.2.4.2 Handling

The transfer cask must withstand loads experienced during routine handling including crane transfer of the loaded transfer cask in vertical orientation (e.g. lifting, moving, lowering) on trunnions. The loads shall be increased by 15% to include any dynamic effects from the lifting operations as directed by CMAA #70 [1]. Lifting attachments and special lifting devices shall meet the requirements of ANSI N14.6 [2] and NUREG-0612 [3]. Handling operations are assumed to take place at room temperature.

2.2.4.3 Environmental Temperatures

Since all operations with the CLU take place inside the reactor building, no insolation has to be considered. The initial states (e.g. start temperatures) relevant for the thermal evaluations of the individual handling procedures are specified in each case by the ambient room or pool water temperature. Off-normal environmental temperatures are not assumed for the CLU.

2.2.4.4 Pressure

The transfer cask is not capable of retaining internal pressures inside the cavity due to its open design apart from the ambient and hydrostatic pressures. The pressure in the water chambers is limited by means of redundant pressure relief devices.

2.2.5 Service Limits

Consistent with the terminology in NRC documents, this SAR utilizes the terms normal conditions of storage (NCS), off-normal conditions of storage, and accident conditions of storage (ACS). Subsection NCA of the BPVC defines four service conditions in addition to the design limits for nuclear components. They are referred to as Level A, B, C and D service limits in paragraph NCA-2142.4. These four levels apply to the service limits of the CASTOR® geo69 DSS as follows:

- Level A service limits correspond to NCS load combinations.
- Level B service limits correspond to off-normal condition of storage load combinations.
- Level C service limits are not used.
- Level D service limits correspond to ACS and natural phenomena event load combinations.

The service limits are used in the structural analyses for definition of allowable stresses and allowable stress intensities. The storage cask and canister containment boundaries are required to meet Section III, Division 3, Subsection WC stress intensity limits. The components of the CLU are required to meet Section III, Division 1, Subsection NF stress intensity limits. Allowable stresses and stress intensities for structural analyses are tabulated in Chapter 3. These service limits are matched with NCS, off-normal condition of storage, and ACS loads combinations in the following subsections.

2.2.6 Loads and Load Combinations

Subsection 2.2.1, 2.2.2 and 2.2.3 describe the design criteria for normal, off-normal, and accident conditions of storage and natural phenomena events,. Table 2.2-1 identifies the notation for the individual loads that require consideration. The individual loads listed in Table 2.2-1 are defined from the design criteria. Each load is assigned a symbol for subsequent use in the load combinations.

Table 2.2-1: Notations for design loadings for normal, off-normal and accident conditions

Design loading	*Level A*	*Level B*	*Level D*
Dead weight	D		
Handling loads	H		H^D
Pressure (internal, external)	P_i, P_e	P_i^B, P_e^B	P_i^D, P_e^D
Pressure (water chamber)	P_W		
Temperature	T	T^B	
Earthquake			E
Fire			T^D

Some of the loadings listed in Table 2.2-1 primarily affect the kinematic stability, while others primarily produce significant stresses that must be shown to comply with the stress intensity or stress limits, as applicable. The relevant loading combinations for the storage cask, the canister and the transfer cask are different because of differences in their function.

To demonstrate compliance with the design requirements for normal, off-normal, and accident conditions of storage and natural phenomena events, the individual loads, identified in Table 2.2-1, are combined into load combinations. Table 2.2-2 identifies the combinations of the loads that are required to be considered in order to ensure compliance with the design criteria set forth in this chapter. Table 2.2-2 presents the load combinations in terms of the loads that must be considered together. A number of load combinations are established for each ASME Service Level. Within each loading case, there may be more than one analysis that is required to demonstrate compliance.

Table 2.2-2: Applicable load combinations for each condition and component of the DSS

Condition	*Combination*	*Canister*	*Storage Cask*	*Transfer Cask*
NCS (Level A)	1	$D + T + H + P_i$	-	-
	2	$D + T + H + P_e$	$D + T + H + P_i$	$D + T + H + P_W$
Off-normal condition (Level B)	1	$D + T^B + H + P_i^B$	-	-
	2	$D + T^B + H + P_e^B$	$D + T^B + H + P_i^B$	-
ACS (Level D)	1	$D + T + H^D + P_e^D$	$D + T + H^D + P_i^D$	-
	2	$D + T^D + P_e^D$	$D + T^D + H + P_i^D$	-
	3	-	$D + T + P_i^D + E$	-

List of References

[1] CMAA #70, Edition 2015
Specification for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes

[2] ANSI N14.6 – 1993
Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More

[3] NUREG-0612, July 1980
Control of Heavy Loads at Nuclear Power Plants
U.S. Nuclear Regulatory Commission, Office for Nuclear Reactor Regulation

[4] NUREG-2224, November 2020
Dry Storage and Transportation of High Burnup Spent Nuclear Fuel – Final Report
U.S. Nuclear Regulatory Commission

2.3 Safety Protection Systems

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

2.3.1 General

The CASTOR® geo69 DSS is engineered to provide for the safe long-term storage of SNF while withstanding all normal, off-normal and accident conditions of storage incl. natural phenomena events without any uncontrolled release of radioactive material or excessive radiation exposure to workers or members of the public. The following special considerations in the DSS design have been made to ensure long-term integrity and containment of the stored SNF throughout all operating conditions:

- The containment system of the canister is an enclosure vessel with containment welds and a sealed lid, designed and inspected in accordance with the BPVC.
- The canister containment system is surrounded by the storage cask, also closed by a sealed lid, which ensures the physical protection of the canister and fulfils and additional containment function.
- The decay heat emitted by the SNF is released from the CASTOR® geo69 DSS through passive means. The absence of an active cooling system reduces the number of error sources.
- After initial loading of the SNF into the CASTOR® geo69 dual-purpose cask, reopening of the canister or the storage cask for repackaging to transport or store the SNF is not required.

The CLU is engineered to provide for the safe short-term handling operations of SNF while withstanding all normal handling conditions. Any deformation of the transfer cask during operation resulting either in a rupture of the canister containment and thus an uncontrolled release of radioactive material from the canister or excessive radiation exposure to workers or members of the public or in an obstruction to retrievability of the canister from the transfer cask is excluded by design of the CLU components, equipment and operation procedures. The following special considerations are considered to ensure the integrity of the canister and its retrievability throughout operation:

- Transfer cask and transfer lock are designed and inspected in accordance with the BPVC.
- The transfer cask ensures the physical protection of the canister containment system to a certain degree.
- The decay heat emitted by the SNF is dissipated through passive means. The absence of an active cooling system reduces the possible sources of errors.
- Gamma (lead, steel) and neutron shielding (water chambers, PE) are sufficiently designed to protect workers or members of the public from radiation exposure.

- The components are designed such, that direct human interaction is reduced to a minimum in favour of remote handling.

It is recognized that a design of both, DSS and CLU with large safety margins is essential, but not sufficient to ensure acceptable performance over the complete service life of the DSS and during all handling operations, respectively. A carefully planned oversight and surveillance plan will be developed to be either compatible with the specific conditions of the storage facility where the CASTOR® geo69 DSS is installed or the NPP where the CLU operations a performed. The general requirements for the acceptance testing and maintenance programs are provided in Chapter 10. Surveillance requirements are specified in Subsection 13.2.3.

2.3.2 Protection by Multiple Containment Barriers and Systems

2.3.2.1 Containment Barriers and Systems

The radioactivity, which the CASTOR® geo69 DSS must retain, originates from the SNF and, to a lesser extent, the contaminated water in the fuel pool. The two containment barriers of the canister and the storage cask retain this radioactivity.

Radioactivity from the fuel pool water is minimized by preventing contact, removing the contaminated water, and decontamination. These measures are described further in Chapter 9.

The CASTOR® geo69 DSS containment boundaries have been designed to withstand the postulated normal, off-normal and accident conditions of storage and natural phenomena events with the maximum decay heat loads without loss of containment. Designed in accordance with Division 3 the DSS containment boundaries provides assurance that there will be no release of radioactive materials from the DSS under all postulated load combinations. The containment boundaries are monitored during storage by means of a pressure monitoring system installed at the storage facility.

Containment is discussed further in Chapter 7. Fabrication inspections and tests are performed, as discussed in Chapter 10, to verify leak tightness of the containment boundaries of the CASTOR® geo69 DSS.

The CLU does not participate in the containment barriers.

2.3.2.2 Cask Cooling

To facilitate the passive heat removal capability of the CASTOR® geo69 DSS and CLU, the following thermal design criteria are established:

- The fuel basket consists of a structure of stacked metal sheets, which allows the unimpaired conduction of heat and the internal helium circulation.
- The containment boundary ensures that the helium atmosphere inside the canister and the storage cask is maintained during normal, off-normal, and accident conditions of storage.
- The thermal design of the canister maintains the fuel rod cladding temperatures below 400 °C during the long-term interim storage period, so that fuel cladding is not degraded.
- The cask body consists of a single casted monolithic DCI body with radial cooling fins, which ensures a high heat conductivity of the storage cask and a good convective heat transmission from the storage cask to the environment.
- The design of the transfer cask and chosen materials ensure a high heat conductivity and a good convective heat transmission from the transfer cask to the environment.

The thermal features of the CASTOR® geo69 DSS and the CLU are discussed further in Chapter 4.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.3.1 Equipment

2.3.3.1.1 DSS

Miscellaneous equipment is essential for the operation, handling and dispatch of the DSS as discussed in Chapter 9. The miscellaneous equipment of the DSS includes load attachment devices (e.g. traverses, lifting lugs, lifting pintles), equipment for dewatering, drying, helium backfilling, bolting equipment (torque and preload controlled), temporary additional shielding and protections for sealing surfaces. Load attachment devices shall comply with the guidance provided in NUREG-0612 [1] for single failure proof devices.

2.3.3.1.2 CLU

The components of the CLU (transfer cask, transfer lock) themselves are equipment for handling the canister loaded with SNF. However, further equipment is required for the intended operations with the CLU components discussed in Chapter 9. Load attachment devices shall comply with the guidance provided in NUREG-0612 [1] for single failure proof devices.

2.3.3.2 Instrumentation

2.3.3.2.1 DSS

Because of the passive nature of the CASTOR® geo69 DSS, instrumentation, which is important to safety, is not required. The cask lid is equipped with a pressure switch for continuous monitoring of the internal pressure to fulfill the requirements of 10 CFR 122(h)(4). During long-term interim dry storage, the pressure switch is connected to the pressure monitoring system of the ISFSI. A pressure drop in the storage cask is automatically reported, so that the licensee is able to determine when corrective action needs to be taken to maintain safe storage conditions.

2.3.3.2.2 CLU

Not relevant since no continuous monitoring is intended.

2.3.4 Nuclear Criticality Safety

The criticality safety criteria stipulates that the effective neutron multiplication factor, k_{eff}, including statistical uncertainties and biases, is less than 0.95 for all postulated arrangements of fuel within the cask under all credible conditions.

2.3.4.1 Control Methods for Prevention of Criticality

The control methods and design features used to prevent criticality for all SNF configurations are the following:

- Incorporation of permanent neutron absorbing material in the fuel basket walls
- Favorable geometry provided by the fuel basket

Administrative controls shall be used to ensure that SNF loaded into the CASTOR® geo69 DSS meets the requirements described in Section 2.1 and Section 6.2. The criticality evaluation is presented in Chapter 6.

2.3.4.2 Error Contingency Criteria

Provision for error contingency is included in the criticality evaluation performed in Chapter 6. Because biases and uncertainties are explicitly evaluated in the analysis, there is no need for the introduction of additional error contingency criteria.

2.3.4.3 Verification Analyses

In Chapter 6, critical benchmark experiments are selected which reflect the design configurations. These critical benchmark experiments are evaluated using the same calculation methods, and a suitable bias is incorporated in the reactivity calculation.

2.3.5 Radiological Protection

2.3.5.1 Access Control

As required by 10 CFR 72, uncontrolled access to the storage facility shall be prevented through physical protection means. A peripheral fence with an appropriate locking and monitoring system is a standard approach to limit access to the storage facility. Further access control measures shall be implemented at the storage building accommodating the DSS. The user of the CASTOR® geo69 DSS will develop the details of the access control systems and procedures, including division of the site into radiation protection areas.

2.3.5.2 Shielding

The shielding design of the DSS is governed by 10 CFR 72.104 and 10 CFR 72.106, which provide radiation dose, limits for any real individual located at or beyond the nearest boundary of the controlled area.

The objective of shielding is to assure that radiation dose rates at key locations are as low as practical in order to maintain occupational doses to operating personnel as low as reasonably achievable (ALARA) and to meet the requirements of 10 CFR 72.104 and 10 CFR 72.106 for doses at the controlled area boundary. Three locations are of particular interest:

- Immediate vicinity of the transfer cask during short term operations:
    - loading operations in the SNF pool,
    - dispatch at the service position next to the pool
    - transfers e.g. by crane.
- Immediate vicinity of the canister transhipment configuration (transfer cask and transfer lock on top of the storage cask) at the truck lock of the reactor building
- Immediate vicinity of the DSS during long-term storage
- Controlled area boundary

Dose rates in the immediate vicinity of the loaded transfer cask and the loaded DSS are important in consideration of occupational exposure. Section 11.3 includes an evaluation of occupational exposures due to operational and maintenance activities. Because of the passive nature of the CASTOR® geo69 DSS, human activity related to the DSS during storage is infrequent and of short duration.

Conservative evaluations of dose rates are described in Chapter 5 based on the contents specified in Section 2.1. Consistent with 10 CFR 72, there is no single dose rate limit established for the

CASTOR® geo69 DSS. Compliance with the regulatory limits on occupational and controlled area doses is performance-based, as demonstrated by dose monitoring.

2.3.6 Fire and Explosion Protection

There are no combustible or explosive materials associated with the CASTOR® geo69 DSS or the CLU. No such materials would be stored at the reactor building, the storage facility or within the storage building. However, for conservatism we have analyzed a hypothetical fire accident as a bounding condition for the CASTOR® geo69 DSS. An evaluation of the fire accident is discussed in Chapter 12.

2.4 Decommissioning Considerations

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

The DSS design concept utilised by CASTOR® geo69 features an immanent simplicity of decommissioning. At the end of its service lifetime, decommissioning could be accomplished by one of several options described below.

The canister, including the spent fuel stored, could be shipped to a suitable fuel repository for permanent storage. Depending on the licensing requirements at the time of shipment off-site, a placement of the entire storage cask with its contents inside a supplemental shipping container (over-pack) could be considered.

The SNF could be removed from the DSS and shipped to a fuel repository in a special licensed shipping container. The remaining contamination on the interior surfaces of the canister due to the crud from the outside of the fuel pins or the crud left by the spent fuel pool water could be easily removed by using the conventional chemical or mechanical methods. After decontamination, the DSS could be partially or completely cut into pieces and shipped as a low level radioactive waste to a disposal facility.

An activation analysis has been performed to quantify specific activity levels of DSS materials after [redacted] years of storage. It is assumed that the storage cask is fully loaded according to the covering loading pattern TR1. The neutron flux is assumed to be constant for [redacted] years, no cooling of the spent fuel is considered.

The storage cask activation analysis is presented in Section 2.5. The results of the calculations show that the CASTOR® geo69 will be far below the specific activity limits according to 10 CFR 61.55 for Class A waste. Therefore, it is expected that after application of the surface decontamination process as described above, the radiation levels due to the activation products would be negligible, and that the storage cask could be disposed of as Class A waste.

The appropriate method of disposal is to be determined at the time of decommissioning.

Due to the leak tightness of the DSS design and exterior decontamination prior to storage, no residual contamination is expected to be left behind on the regular storage position. The base pad (floor), fence, and peripheral utility structures will require no decontamination or any special handling after removal of the last storage cask. Since the storage cask shields most of the neutron flux from the fuel, the surrounding structure would experience a minimal neutron flux not leading to a significant activation.

The CASTOR® geo69 DSS does not impose any additional decommissioning requirements on the licensee of the storage facility per 10 CFR 72.30.

2.5 Appendix

	Name, Function	Date	Signature
Prepared	[redacted]	[redacted]	
Reviewed	[redacted]		

Appendix 2-1: Sample input file of a TRITON calculation for a FA of type ATRIUM-10A

Appendix 2-2: Sample input file of an ORIGAMI calculation for a FA of type ATRIUM-10A

Appendix 2-3: Activation Analysis

Appendix 2-1: Sample input file of a TRITON calculation for a FA of type ATRIUM-10A

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix 2-2 Sample input file of an ORIGAMI calculation for a FA of type ATRIUM-10A

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix 2-3: Activation Analysis

During storage, all the storage cask components like the body of the cask, the canister, both lids and so on are activated by the neutron flux from the cask contents. Understanding whether the activation could be significant is the task of the actual evaluation.

The evaluation of the activation of the storage cask components is performed in two steps:

- Firstly, the spectral neutron flux densities are calculated based on the storage cask models developed for the shielding analysis (see Chapter 5) using MCNP transport code [1]. The calculation are performed with the maximum source terms for neutrons from spontaneous fission and (α,n)-reactions according to uniform loading pattern TR1 (see Section 5.2). For internal cross-checking purposes – to make sure that the normalisation is done properly when transmitting spectra to step two – the major activation reaction channels are tallied explicitly.
- Secondly, the calculated neutron spectra together with the cask material chemical compositions according to Chapter 8 are transferred to the COUPLE/ORIGEN-S modules [2] of the SCALE 6.2 code system [3]. It is assumed that the cask components are continuously irradiated by constant flux corresponding to the maximum cask contents. The cooling down of the spent fuel is conservatively not taken into account.

The calculations are considered to be conservative, since the chemical compositions of materials from Chapter 8 are interpreted in a way to maximise the elements that would produce the nuclides important for the waste classification. E.g. the contents of such elements as nickel or manganese is maximised. The amount of ^{59}Co is also at its maximum with [redacted] in steel and [redacted] in cast iron and aluminium alloys.

A sample COUPLE/ORIGEN-S input file (for ductile cast iron) is presented in Figure 2.5-1.

The result of the calculation with ORIGEN-S are the specific activities of the irradiated materials taking into account their build-up and decay processes during entire exposure time of 60 years. The time dependence of the activity for the most significant nuclides (normalised to one gram of material) are presented in Figure 2.5-2 to Figure 2.5-5 for the representative materials: [redacted] of structure sheets, aluminium of round segments, steel of outer basket sheets and ductile cask iron of the cask body. These figures are direct outputs generates by ORIGEN-S runs. The curve "Sub-totals" stays for the sum of the shown nuclides, while "Totals" represents the overall sum of the nuclides for which the cross section libraries are available.

The results of the calculations are presented in Table 2.5-1 as nuclide activity concentrations for all parts and components of the storage cask. Only the significant nuclides are presented. The maximum concentrations for specific nuclides are highlighted in bold and displayed at the bottom of the table. The limits of the concentrations according to 10 CFR 61.55 (from both Table 1 and Table 2) are given for comparison. It can be seen that the nuclide activity concentrations after [redacted] of exposure are significantly smaller than the limiting values. Even further, the total maximum activity concentration is some orders of magnitude smaller than the limit for the short-lived nuclides only.

The total activity of the storage cask after [redacted] of irradiation account to [redacted] Thus, the overall activation of the storage cask is very low, even including the very conservative assumption of a constant flux for [redacted] of storage. It means that the CASTOR® DSS would not impose any additional decommissioning requirements on the licensee of the ISFSI facility.

[redacted]

Figure 2.5-1 Sample input file for the calculation of activation

[redacted]

Figure 2.5-2 Activation of the [redacted] structure sheets as a function of time

[redacted]

Figure 2.5-3 Activation of the aluminium round segments as a function of time

[redacted]

Figure 2.5-4 Activation of basket outer sheets as a function of time

[redacted]

Figure 2.5-5 Activation of the cask body as a function of time

Table 2.5-1 Results of activation analysis

[redacted]

List of References

[1] C.J. Werner (ed.), MCNP User's Manual – Code Version 6.2, LA-UR-17-29981, 2017

[2] W. Wieselquist et al.,
ORIGEN: Neutron Activation, Actinide Transmutation, Fission Product Generation, and Radiation Source Term Calculation, Version 6.2.3,
Oak Ridge National Laboratory, Oak Ridge, Tennessee (2018)

[3] B. T. Rearden and M. A. Jessee, Eds.,
SCALE Code System, ORNL/TM-2005/39, Version 6.2.3,
Oak Ridge National Laboratory, Oak Ridge, Tennessee (2018)..

3 Structural Evaluation

3.0 Overview

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

This section presents the evaluation of the integrity of the containment for the DSS according to parts list 1014-DPL-30934 [1], 1014-DPL-36855 [2], 1014-DPL-30984 [3], 1014-DPL-33604 [4] and the transfer cask 1015-DPL-37509 [5] under the following loading conditions:

	Storage Cask [1]	Canister [2]	Basket, Shielding elements [3, 4]	Transfer cask [5]
Normal conditions of storage (NCS)	X	X	X	X
Off - Normal conditions of storage	X	X	-	-
Handling conditions (included in NCS)	X	X	X	X
Accident conditions of storage (ACS)	X	X	X	-
Test Conditions	X	X	-	-

This section demonstrates the compliance of the DSS to the applicable requirements according to 10 CFR 72.

In detail, the following assessments are carried out:

- proof of the sufficient strength for the sealing barrier of the transfer and storage cask and canister according to Division 3 which also ensures the sufficient compression of the metal gaskets during loading.
- proof of the sufficient strength for the cask body, canister body, cask lid and canister lid acc. to Division 3.
- proof of the sufficient strength for the transfer cask acc. to Division 1, Subsection NF [4]

The integrity of the DSS is verified for all stated conditions.

List of References

[1] 1014-DPL-30934, Rev.0
Design Part List Cask, CASTOR® geo69

[2] 1014-DPL-36855, Rev.0
Design Part List Canister, CASTOR® geo69

[3] 1014-DPL-30984, Rev.0
Design Part List Basket, CASTOR® geo69

[4] 1014-DPL-33604, Rev.0
Design Part List Shielding elements, CASTOR® geo69

[5] 1015-DPL-37509, Rev.0
Design Part List Transfer cask, CASTOR® geo69

3.1 Structural Design

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

3.1.1 Discussion

The investigated items are the cask, canister and basket of the DSS and the transfer cask of the CLU. The DSS contains the storage cask with the moderator, closure plate, trunnions, retention ring, storage cask lid, blind flange and the protection cap, as well as the canister. The storage cask is equipped with a protection cover in storage configuration acc. to parts list 1014-DPL-38556 [1]. The canister inside the cask consists of the canister body, canister lid, thread bolts, clamping elements, form pieces, washer and the basket.

The transfer cask is part of the CLU, which is intended for handling and transfer of a loaded canister out of the SNF pool towards and into the CASTOR® geo69 storage cask. The CLU comprises the two major components transfer cask and transfer lock as well as further equipment. This evaluation deals only with the transfer cask.

[redacted]

The following components of the storage cask are assessed in detail:

- Cask body (Items acc. to [1])	Item 2
- Cask lid	Item 55
Cask lid bolting:	
69 Hexagonal screw [redacted]	Item 62
3 Hexagonal head screw for sealing [redacted]	Item 63
gasket:	
metal gasket [redacted]	Item 69
- Blind Flange	Item 89
Blind Flange bolting:	
12 Hexagonal screw M16 x 30	Item 37
gasket:	
metal gasket [redacted]	Item 71
- Protection Cap	Item 113
Protection Cap bolting:	
6 Hexagonal screw M16 x 30	Item 37
gasket:	
metal gasket [redacted]	Item 44
- Trunnion	Item 12
Trunnion bolting:	
32 Cap screw [redacted]	Item 13
- Protection cover (Items acc. to [1])	Item 1

The following components of the canister are assessed in detail:

- Canister body (Items acc. to [2])	Item 2
- canister lid	Item 3
canister lid bolting:	
[redacted]	Item 4
[redacted]	Item 5
[redacted]	Item 6
[redacted]	Item 7
gasket:	
metal gasket Ø1725.9 x 11.8 Silver	Item 16

The following components of the Basket and the shielding elements acc. to [4] are assessed in detail:

- Basket (Items acc. to [3])	Item 1
- Structural sheets	Item 2, 10 to 27
- Outer sheets	Item 30, 31
- Round segment	Item 50
- Shielding elements (Items acc. to [4])	Item 1

The following components of the transfer cask according to [5] are assessed in detail:

- Transfer cask body (Items acc. to [5])	Item 2
- Head ring	Item 2-2
- Liner	Item 2-3
- Bottom Ring	Item 2-4
- Enclosure Lead shield	Item 2-6
- Enclosure inner water chamber	Item 2-8
- Enclosure outer water chamber	Item 2-9
- Bottom lid	Item 7
- Lid	Item 10
- Trunnion	Item 12
- Trunnion bolting (Items acc. to [5])	
- 24 Cap screw [redacted]	Item 13

3.1.2 Design Criteria

This section describes and summarizes the design criteria, which are applied during the verification process according to Division 3. The general process of calculating, resp. extracting the stress states from the results of the structural analysis is described in section 3.1.2.8 to 3.1.2.12.

In general, the assessment criteria are separated into the following different categories:

- Assembly State
- Normal conditions of storage (NCS)
    - Handling conditions, which are a part of the normal conditions of storage
- Off normal conditions of storage
- Accident conditions of storage (ACS)
- Testing Limits
- Fatigue Assessment

The design criteria for the stress assessments of the bolts, the storage cask, canister and transfer cask parts are described in the following.

3.1.2.1 Assembly state

The assessments for assembly state at the bolts are performed analytically. Subsequently the verification is carried out.

The assessment of the stress state of the lid bolting for assembly state is provided according to VDI 2230 [2]. The minimum and maximum preloads of the storage cask lid bolting are calculated for the respective nominal assembly load due to [redacted] at room temperature. A preload tolerance during [redacted]s considered. The minimum and maximum preloads of the blind flange, protection cap, canister lid, trunnion and tilting stud bolts are calculated for the respective nominal tightening torque at room temperature. A tightening torque tolerance of [redacted] is considered. The verification of the required length of engagement of the lid bolting is performed acc. to KTA 3201.2 [3].

3.1.2.2 Normal Conditions of storage (NCS)

Under normal conditions of storage, the admissible elastic analysis stress intensity limits for the storage cask and canister parts are as defined in Division 3, WC-3217 except bolts and gaskets.

General primary membrane stress intensity:	$P_m \leq 1.0 \cdot k \cdot S_m$
Local primary membrane stress intensity:	$P_l \leq 1.5 \cdot k \cdot S_m$
Primary membrane (general or local) plus primary bending stress intensity:	$(P_m \; or \; P_l) + P_b \leq 1.5 \cdot k \cdot S_m$

The base material of the transfer cask is assessed acc. to BPVC Section III, Division 1, Subsection NF-3200 [4] for service level A loads.

General primary membrane stress intensity:	$P_m \leq 1.0 \cdot S_m$
Primary membrane plus primary bending stress intensity:	$P_m + P_b \leq 1.5 \cdot S_m$

The welds at the canister and transfer cask are treated as base material considering the allowable stress values and material properties, which is stated in Division 1, NF-3226.2(a)(1) [4].

Since no stress criteria considering bolts are defined for storage conditions acc. to Division 3, WC-3216, the following stress criteria for bolts acc. to NUREG / CR–6007 [5] and Division 3, WB-3230, already deployed for transport conditions in SAR (transport), are adapted to this condition.

Average stress (Tension):	$\sigma = \frac{F}{A} \leq \frac{2}{3} \cdot S_y$
Average stress (Shear):	$\tau = \frac{Q}{A} \leq 0.4 \cdot S_y$
Stress Ratio (Tension plus shear):	$R_t^2 + R_s^2 < 1$
Maximum stress (Stress intensity S):	$S = \sqrt{(\sigma_m + \sigma_b)^2 + 4 \cdot (\tau + \tau_{res.})^2} \leq 0.9 \cdot S_y$

The evaluation of shear loaded cross sections are performed by assessments considering the shear forces taken from the simulation results. The evaluated shear stress is compared to the pure shear stress criterion (acc. to Division 3, WC-3216.3 (b)):

Pure Shear:	$\tau = \frac{F}{A} \leq 0.60 \cdot S_m$

The admissible stress values are summarized in Appendix 3-2 (Table 3.9-26).

The yield strength S_y of the bolts is summarized in Appendix 3-2 (Table 3.9-27).

The values for the torsional stress $\tau_{res.}$ are taken from the SAR (transport). At assembly state the max. torsional stress is considered. At other load cases, half of the above-mentioned values are considered acc. to [5].

3.1.2.3 Handling conditions

The handling conditions are included in the normal and off normal conditions of storage.

3.1.2.4 Off normal conditions of storage

The off normal conditions are included in the NCS assessment, since the assessment is performed with NCS criteria and the temperature and pressure loads are bounding for both, NCS and ONCS.

3.1.2.5 Accident conditions of storage (ACS)

Under accident conditions of storage, the admissible elastic analysis stress intensity limits for the storage cask and canister parts are as defined in Division 3, WC-3217 and Mandatory Appendix XXVII-3200 [6] except bolts and gaskets:

General primary membrane stress intensity (for austenitic steel, high-nickel alloy, and copper-nickel alloy materials):	$P_m \leq Minimum(2.4 \cdot S_m; 0.7 \cdot S_u)$
General primary membrane stress intensity (for ferritic steel materials):	$P_m \leq (0.7 \cdot S_u)$
Local primary membrane stress intensity (for austenitic steel, high-nickel alloy, and copper-nickel alloy materials)	$P_l \leq Minimum(3.6 \cdot S_m; 1.0 \cdot S_u)$
Local primary membrane stress intensity (for ferritic steel materials):	$P_l \leq (1.0 \cdot S_u)$
Primary membrane (general or local) plus primary bending stress intensity (for austenitic steel, high-nickel alloy, and copper-nickel alloy materials):	$(P_m\ or\ P_l) + P_b \leq Minimum(3.6 \cdot S_m; 1.0 \cdot S_u)$
Primary membrane (general or local) plus primary bending stress intensity (for ferritic steel materials):	$(P_m\ or\ P_l) + P_b \leq (1.0 \cdot S_u)$

The welds at the canister are treated as base material considering the allowable stress values and material properties, which are stated in Division 1, Subsection NF-3226.2(a)(1).

The evaluation of shear loaded cross sections are performed by assessments considering the shear forces taken from the simulation results. The evaluated shear stress is compared to the pure shear stress criterion (acc. to Division 3, WC-3217 and Mandatory Appendix XXVII-3200 [6]):

Pure Shear:	$\tau = \frac{F}{A} \leq 0.42 \cdot S_u$

The admissible stress values are summarized in Appendix 3-2 (Table 3.9-26).

For the bolts, the stress criteria of the normal conditions (Level A) acc. to section 3.1.2.2 are applied for all conditions. According to WB-3234 (Level D Service Limits) the requirement of leak tightness of the closure may be satisfied by using the rules of WB-3232 (Level A service limits). By ensuring that the Level A service limits are satisfied during HAC, the lid systems of both the storage cask and canister remain functional. Thus, by demonstrating that the corresponding acceptance criteria for moderator exclusion, (i.e. confirmation of the cited Level A service limits) are met, it is shown that two independent water-tight boundaries remain intact also under HAC.

The values for the torsional stress are applied as described in section 3.1.2.2.

3.1.2.6 Testing Limits

Under test conditions, the admissible elastic analysis stress limits for the storage cask and canister parts acc. to Division 3 WC-3218 (b) except bolts and gaskets are defined as follows:

General primary membrane stress intensity:	$P_m \leq (0.9 \cdot S_y)$
Primary membrane plus bending stress intensity:	for: $P_m \leq (0.67 \cdot S_y)$ $(P_m + P_b) \leq (1.35 \cdot S_y)$
	for: $(0.67 \cdot S_y) < P_m \leq (0.9 \cdot S_y)$ $(P_m + P_b) \leq (2.15 \cdot S_y - 1.2 \cdot P_m)$

The admissible stress values are summarized in Appendix 3-2 (Table 3.9-28).

Since there are no standards given when considering bolted joints under storage conditions, the following stress criterion acc. to Division 3, WB-3235 is adopted for the assessments of the bolts in the storage cask lid and the canister thread bolts:

Maximum stress (Stress intensity S):	$S = \sqrt{(\sigma_m + \sigma_b)^2 + 4 \cdot (\tau + \tau_{res.})^2} \leq S_y$

The values for the torsional stress are applied as described in section 3.1.2.2.

3.1.2.7 Fatigue Assessment

The fatigue assessment is performed according to the procedure described in Division 3, WC-3219.1.2, which describes the procedure in Sec. III Appendices [6], Mandatory Appendix XIII, XIII-3500 and XIII-3520.

The assessment is based on determining the admissible design life for a given stress intensity amplitude. With the calculation of the usage factor as the quotient of design life target cycles and admissible design life cycles for different load cases, the total usage factor is determined. The total usage factor is the sum of the usage factors of each load case:

$$U = \sum_{k=1}^{n} U_k + \cdots + U_n = \sum_{k=1}^{n} \frac{n_k}{N_k} + \cdots + \frac{n_n}{N_n}$$

where n is the given design life target and N is the admissible number of cycles from the equation established in Division 3.

The admissible number of load cycles is determined with the stress intensity increased by the following factors:

$$S_a = \frac{1}{2} \cdot S \cdot K_F \cdot K_E \; (for\ pulsating\ load)\ and\ S_a = S \cdot K_F \cdot K_E \; (for\ alternating\ load);$$

Where S = stress intensity, Fatigue strength reduction factor $K_F = 4$ and correction factor for modulus of elasticity $K_E = \frac{E_{Al}}{E}$.

3.1.2.8 Performance of FE Calculations

In the following, the general proceeding of the implementation of the FE simulations is described. The boundary conditions described in Appendix 3-1 are applied onto the various models.

In all simulations, the stress states of the bolting for assembly state are calculated in a first load step by applying the preloads of the bolting and the gasket forces. The gasket force is applied by using gasket elements. In the next load steps, the various external forces are applied (the load application).

For the numerical analyses the FEM software ANSYS 2019 R1 [7] is used.

The QA verification of the FEM software is documented in Appendix 3-3. This is done by comparing numerical with analytical results. The verification guarantees that the software produces valid and reliable results for the element types used for the structural analysis.

3.1.2.9 Evaluation of the stress states of the lid bolting

The evaluation of the stress states of the lid bolting is done according to section 3.1.2.2 in accordance with [5]. Therefore, the membrane and bending stresses (nominal stresses) are derived from the equilibrium conditions. The axial force F and the bending moment M in the bolting are determined by integration of the node stresses over a correspondent cutting plane for a reference point on the bolting axis as follows:

$$F = \int_A \sigma \, dA \text{ and } M = \int_A s \cdot \sigma \, dA \,.$$

With:

- A = cross-section area (stress cross-section)
- σ = normal stress
- s = lever arm, respective distance to the reference point

With the stress cross-section A and the section modulus W the nominal stresses (membrane stress σ_m and bending stress σ_b) are calculated:

$$\sigma_m = \frac{F}{A} \text{ and } \sigma_b = \frac{M}{W}$$

The evaluation of the stress states is done in the free loaded shank and thread of the bolting, i. e. in the clamp length of the bolting. Changes of the diameter are considered.

In the FE calculations, the torsional stress resulting from the assembly state is not considered. The torsional stress is considered for the assessments by adding it to the membrane and bending stress. Therefore, a torsional stress of 50 % compared to the assembly state is assumed according to NUREG / CR-6007 [5].

The allowable stress states depending on the design temperature are depicted in Appendix 3-2 (Table 3.9-27).

The evaluation is performed in the load steps in which the external forces are applied (the load application).

3.1.2.10 Evaluation of the stress states of the storage cask, canister components and transfer cask

For the assessment of the stress states of the storage cask, canister parts and transfer cask, the maximum stress intensities are evaluated.

Generally, for the evaluation of the component stress intensities, stress linearizations according to the stress categories established in Division 3 are performed. Wherever local stress intensities satisfy the existing stress limits, those values are used instead of the stress linearization. The evaluated local stress intensities can be identified by the label $S_{Intensity}$. In general, the assessment of local stress intensity values leads to lower safety factors, which is a conservative approach.

The assessed stresses (P_m, P_L, P_b, etc.) are determined from a stress linearization (see Figure 3.1-1), which is a separation of stresses through a section into constant membrane (P_m; P_L) and linear bending (P_b) stresses. This separation is a function of the analysis software and uses predefined paths as exemplarily shown in Figure 3.1-1:

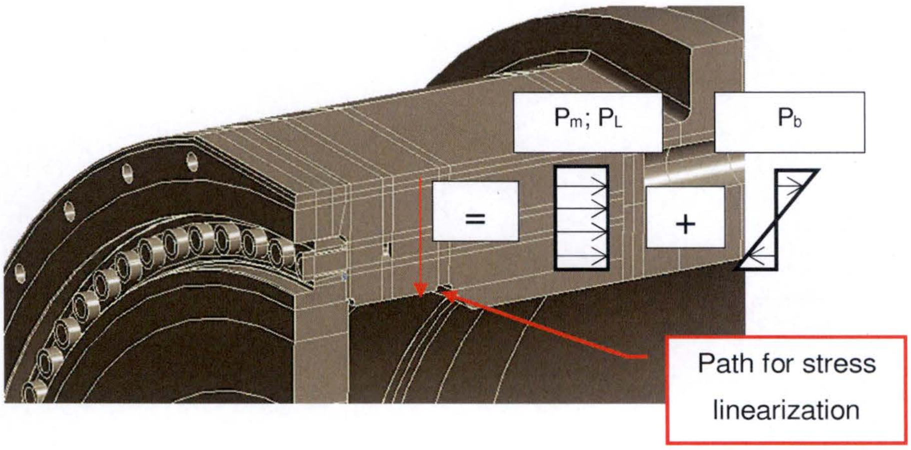

Figure 3.1-1 General stress linearization at arbitrary section

3.1.2.11 Evaluation of the shear sections in the Canister Head Ring and the Canister Clamping Elements

The shear loaded critical sections at the canister are evaluated by extracting the section forces from the simulation model results and by calculating the nominal shear stress with those forces. The following sections in Figure 3.1-2 the head ring and Figure 3.1-3 in the clamping elements are investigated:

Shear section (2x) A_{shear} in Canister Head Ring [mm²]	[redacted]
Shear section A_{shear} in Canister Clamping Element [mm²]	[redacted]

[redacted]

Figure 3.1-2 Shear section for pure shear evaluation in Canister Head Ring Item 2-5

[redacted]

Figure 3.1-3 Shear section for pure shear evaluation in Canister Clamping Element Item 4

3.1.2.12 Evaluation of the functionality of the gaskets

Acc. to Division 3, WB-3234, the gasket is sufficiently compressed under loading conditions as long as the lid bolting assessment criteria are fulfilled, which means that no yielding in the lid bolting occurs. For this reason, the Level A criteria are also applied for accident conditions of storage.

List of References

[1] 1014-DPL-38556, Rev.0
Design Part List Protection Cover, CASTOR® geo69

[2] VDI-Richtlinie 2230, Part 1
Systematic calculation of highly stressed bolted joints, Joints with one cylindrical bolt.
Version 11/2015

[3] KTA 3201.2
Safety Standards of the Nuclear Safety Standards Commission (KTA)
Components of the Reactor Coolant Pressure Boundary of Light Water Reactors Part 2:
Design and Analysis
2017-11

[4] ASME Boiler & Pressure Vessel Code, Sec. III, Div. 1
Subsection NF
2017 Edition

[5] NUREG / CR–6007
UCRL–ID–110637
Stress Analysis of Closure Bolts for Shipping Casks
April 1992

[6] ASME Boiler & Pressure Vessel Code, Sec. III, Appendices
2017 Edition

[7] ANSYS®, Release 2019 R1
ANSYS, Inc., Southpointe
Canonsburg, PA, 11/2018

3.2 Weights

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

Weights of the storage cask, canister and transfer cask assemblies are considered based on drawings acc. to the corresponding parts lists [1, 2, 3, 4, 5]. The masses in Table 3.2-1 are considered in the assessments.

Table 3.2-1 Component masses (rounded)

Component	Part list	mass [Mg]
Cask		
Cask body (w. moderator, bottom closure plate, wear protection)	[1]	[redacted]
Trunnions (2x w. bolts)	[1]	
Cask Lid (w. moderator, seals and bolts)	[1]	
Retention Ring	[1]	
Canister		
Canister (empty w/o lid)	[2]	
Canister lid (with attachments)	[2]	
Fuel basket	[2]	
Shielding elements (4x)	[2]	
Inventory (69 BWR-FA)	[2]	
Protective Cover	[1]	
Cask (storage configuration, loaded)	-	
Transfer Cask		
Lid (incl.bolting)	[5]	
Head ring (incl. Trunnions)	[5]	
Water ballasting outer chamber	-	
Water ballasting inner chamber	-	
Enclosure inner water chamber (sheets)	[5]	
Enclosure outer water chamber (sheets)	[5]	
Enclosure lead shield (sheets)	[5]	
Lead	-	
Liner	[5]	
Bottom ring	[5]	
Bottom lid	[5]	
Small parts (piping, etc.)	-	
Transfer cask	[5]	
Transfer cask incl. loaded Canister	-	

List of References

[1] 1014-DPL-30934, Rev.0
Design Part List Cask, CASTOR® geo69

[2] 1014-DPL-36855, Rev.0
Design Part List Canister, CASTOR® geo69

[3] 1014-DPL-30984, Rev.0
Design Part List Basket, CASTOR® geo69

[4] 1014-DPL-33604, Rev.0
Design Part List Shielding elements, CASTOR® geo69

[5] 1015-DPL-37509, Rev.0
Design Part List Transfer cask, CASTOR® geo69

3.3 Design Temperatures

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

Material properties and allowable stresses are a function of the component temperatures, which are based on actual calculated temperatures (see chapter 4). Table 3.3-1 summarizes the component temperatures dependent on the load case, resp. environmental conditions. The temperature profiles of the load case Fire accident as a result from the transient thermal simulations are compared between transport and storage conditions in Table 3.3-1. These simulations are documented in chapter 4 and are not part of this section. The max. design temperatures from SAR (transport) for storage cask and canister are applied since they cover the temperatures calculated for storage condition.

Table 3.3-1 Design temperatures [°C]

Component name	Parts List	Item	Max. Design Temperatures [°C]	Cold Conditions [°C]	Fire Accident [°C]
Cask					
Cask body	1014-DPL-30934	2	[redacted]	-29°C	Temperature profiles acc. to chapter 4 Max. design temperatures for assessment
Cask lid		55	[redacted]		
Cask lid bolting		62, 63	[redacted]		
Retention Ring		21	[redacted]		
Closure Plate		7	[redacted]		
Closure Plate screws		9	[redacted]		
Canister			[redacted]		
Canister body	1014-DPL-36855	2	[redacted]		
Canister lid		3	[redacted]		
Canister lid bolting		4, 5, 6 ,7	[redacted]		
Basket			[redacted]		
Structure sheet	1014-DPL-30984	10 - 27	[redacted]	-	-
Outer sheet		30, 31	[redacted]		
Round segments		50	[redacted]		
Shielding elements	1014-DPL-33604	1	[redacted]	-	-

Transfer cask					
Head ring, Liner, Lid, Trunnion, Trunnion bolts, Lid bolts	1015-DPL-37509	2-2, 2-3, 10, 12, 13, 60 [61]	[redacted]	-	-
Outer and inner enclosure water chamber sheets, Enclosure lead shield sheets		2-6, 2-8, 2-9			
Bottom Ring Bottom Lid		2-4, 7			

3.4 Mechanical Properties of Materials

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

The material properties of the specific components are specified in Chapter 8.

All components that are part of the assessments are simulated with a linear–elastic material model. For stress assessments, the factors of safety are calculated by the ratio of the allowable stress to the present stress.

Fillet welds and circumferential full penetration groove welds are not modelled explicitly in the simulation models. Full penetration groove welds are treated as base material considering the allowable stress values and material properties, which are stated in BPVC Section III, Division 1, NF-3226.1 and NF-3226.2 [4].

3.5 Normal and Off-normal Conditions of Storage

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed	[redacted]		

The normal and off normal conditions are combined in a single load case with bounding pressure (see Appendix 3-1, Table 3.9-1) and temperature values (see Table 3.3-1). This load case is assessed with criteria designated for the NCS loads Level A acc. to Division 3, WC–3216, which bounds the off normal conditions of storage. The following load situations are considered:

- **Dead weight**: The DSS shall withstand the static loads due to the weights of each of its components, including the weight of the loaded fuel canister and the protection cover. The results are documented in this section.

- **Handling**: The components of the cask and the transfer cask shall be analyzed for handling on lifting devices. For the analysis of the components of the storage and transfer cask excluding lifting devices, the weight of the component times a hoist factor acc. to CMAA specification #70 for slow crane operations is considered. The handling is included in the NCS evaluations. The results are documented in this section.

- **Environmental–, resp. temperatures beyond normal**: The maximum and minimum NCS temperatures are the highest and lowest ambient temperatures recorded at the storage facility location in each year, averaged over the years of record. Since the DSS is also designed for transportation, the temperature requirements in 10 CFR Part 71.7 are used to determine the design basis temperatures for storage. To bound even the temperature beyond normal conditions, temperature conditions for the accident conditions of storage are applied. The results are documented in this section.

- **Pressure**: The DSS is designed to withstand loads due to off normal pressure. The off normal condition internal design pressure in the canister comprises the cumulative effects of the maximum fill gas volume, off normal environmental ambient temperatures, the maximum heat load, and an assumed 10 % of the fuel rods ruptured. The pressure values from the ACS are considered and therefore bound the NCS and off normal pressure values. The results are documented in this section.

3.5.1 Verification - Storage cask trunnion, trunnion bolts, tilting studs, storage cask and canister lid blind holes

The storage cask trunnion bolts, the trunnions and the tilting studs acc. to drawing 1014-DD-30934 2/8, Rev. 0 [1] are assessed for assembly state in the SAR (transport). The assessments include:

- Bolt assembly state for the trunnion bolts
- Length of engagement of the trunnion bolts
- Stress verification for the trunnion and trunnion bolts
- Fatigue analysis of the trunnion and the trunnion bolts
- Stress verification for the tilting studs
- Resistance to stripping of the blind hole threads in the storage cask lid and canister lid
- Handling - Canister on Canister lid
- Resistance to stripping of the blind hole threads in the protection cover
- Handling - Loaded transfer cask with transfer lock on storage cask head

A brief summary of the results is presented in Table 3.5-1 and the following text.

Table 3.5-1 Results summary trunnion and trunnion bolts

		T= -29°C	T = [redacted]
Min. bolt preload [kN]		[redacted]	
Max. bolt preload [kN]			
Effective length of engagement [mm]			
Required length of engagement [mm]			
Stress verification Min. factor of safety S [-]	Trunnion		
	Trunnion Bolts		
Min. number of permissible load cycles N_{min} [-]	Trunnion		
	Trunnion Bolts		

The minimum factor of safety of the tilting stud against stress design factor 3.45 at maximum temperature amounts to $S_{f.3.45.T.max}$ = [redacted] The fatigue analysis of the tilting stud results in N = [redacted] allowable tilting operations.

The covering length of engagement of [redacted] the blind hole threads for the load attachment points of the canister and storage cask lid must be guaranteed (Canister Lid: [redacted], storage cask Lid: [redacted]). With this length of engagement, the sufficient resistance to stripping of the threads is verified. The verification is valid for bolts with a tensile strength of equal or less than [redacted]

The covering length of engagement at the protection cover in the blind holes for the load attachment points of [redacted] must be guaranteed. With this length of engagement, the sufficient resistance to stripping of the threads is verified.

The assessment for the handling load case loaded transfer cask with transfer lock on the storage cask head is performed with nominal stresses in Table 3.5-2. The considered loads are the dead weight of the loaded canister inside the transfer cask and the transfer lock times a hoist factor of 1.15. The resulting forces are related to the storage cask head locating face. The admissible criterion is the yield strength at max. design temperature. The resulting surface pressure is far below the admissible yield strength of the storage cask.

Table 3.5-2 Summary of stress assessment of Storage cask in NCS - Handling Condition Loaded transfer cask with transfer lock on storage cask head [MPa]

Weights			
Configuration Transfer cask	- with loaded canister - without water in canister - with water in both water chambers	[kg]	[redacted]
Transfer Lock		[kg]	[redacted]
Total		**[kg]**	[redacted]
Acceleration		[m/s²]	9.81
Hoist factor		[-]	1.15
Dead Load		**[N]**	[redacted]
Cask head locating surface	depicted from CAD	[mm²]	[redacted]
Surface pressure		**[MPa]**	**1.30**
adm. Yield strength Cask	[redacted] at max. Design Temperature	[MPa]	170

The assessment of the handling condition: Canister on canister lid is performed with nominal stresses. The considered loads are the dead weight of the canister body and inside placed parts and the bolt preload. The resulting forces are related to the section of the clamping elements and the head ring section. The admissible criterion is the pure shear stress criterion. The minimum factor of safety amounts to [redacted] at the head ring section. Table 3.5-3 presents a brief summary of the results. The detailed assessment is presented in Appendix 3-2 (Table 3.9-4 and Table 3.9-5).

Table 3.5-3 Summary of stress assessment of canister components in NCS - Handling condition canister on canister lid; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]
1	Headring (Shear) Item 2-5	[redacted]	τ	[redacted]
2	[redacted] Item 4	[redacted]	τ	[redacted]

3.5.2 Verification - Transfer Cask trunnion, transfer cask trunnion bolts and transfer cask lid bolts

The transfer cask trunnion bolts, the trunnions, and the lid bolts are assessed for assembly state and NCS. The assessments include:

- Bolt assembly state for the transfer cask lid bolts
- Bolt assembly state for the trunnion bolts
- Length of engagement of the trunnion bolts
- Length of engagement of the transfer cask lid bolts
- Stress verification for the trunnion and trunnion bolts
- Fatigue analysis of the trunnion and the trunnion bolts

A brief summary of the results is presented in Table 3.5-4 and Table 3.5-5.

Table 3.5-4 Results summary transfer cask lid bolts

	T= 20°C	T = [redacted]
Min. bolt preload [kN]	[redacted]	
Max. bolt preload [kN]		
Stress utilization against yielding during assembly [%]		
Effective length of engagement [mm]		
Required length of engagement [mm]		

Table 3.5-5 Results summary transfer cask trunnions and trunnion bolts

		T= -29°C	T = [redacted]
Min. bolt preload [kN]		[redacted]	
Max. bolt preload [kN]			
Effective length of engagement [mm]			
Required length of engagement [mm]			
Stress verification Min. factor of safety S [-]	Trunnion		
	Trunnion Bolts		
Min. number of permissible load cycles N_{min} [-]	Trunnion		
	Trunnion Bolts		

3.5.3 Verification - Storage cask, canister and transfer cask - Hot environment

The normal and off normal conditions of storage in hot environment provides for the storage cask and canister components a thermal equilibrium at their respective max. temperature. Containment vessel thermal stresses do occur in this case due to the differential thermal expansion between the steels. Stresses in the assessed components for the high temperature environment for NCS, are obtained by a combination of individual loads as described in Appendix 3-1. Min. and max. lid bolt preload effects (acc. to Appendix 3-1, Table 3.9-2), internal pressure (see Appendix 3-1, Table 3.9-1) and thermal stresses as well as dead weight increased by a hoist factor (see Appendix 3-1) are combined to give the maximum stress intensity in each component for this load combination. The detailed boundary conditions are presented in Appendix 3-1 and chapter 2.

The stress results indicate that the storage cask, canister and transfer cask structure can both withstand the applied impact loadings used in the analysis. The assessment criteria are satisfied.

The stress criteria for the storage cask parts are fulfilled as the following evaluation shows. Table 3.5-6 presents the assessed minimum factors of safety of the critical components of the storage cask parts. The minimum factor of safety amounts to [redacted] for the P_m criterion and occurs at Pos. 2 in the fillet at the storage cask lid. The assessment at this location is performed with the local stress intensity value. A summary is presented in Appendix 3-2 (Table 3.9-3, Figure 3.9-14).

Table 3.5-6 Summary of stress assessment of storage cask components in NCS - Hot environment; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of safety [-]
1	Cask Head Fillet	[redacted]	P_m	[redacted]
			$P_m + P_b$	
2	Cask Lid	[redacted]	$S_{Intensity}$	

The stress criteria for the canister parts are fulfilled as the following evaluation shows. Table 3.5-7 presents the assessed minimum factors of safety of the critical components of the canister parts. The form pieces and washers are not part of the stress assessment, since they are not critical to the structural integrity of the containment. The minimum factor of safety amounts to [redacted] for the $P_m + P_b$ criterion and occurs at Pos. 3 in the canister bottom. The assessment at this location is performed with the linearized stress intensity values. A summary is presented in Appendix 3-2 (Table 3.9-6, Figure 3.9-15).

The fatigue assessment is covered by the assessments in SAR (transport) since the stress amplitudes consider bounding loadings compared to NCS loads.

Table 3.5-7 Summary of stress assessment of canister components in NCS - Hot environment; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]
			$P_m + P_b$	
2	Headring (Shear) Item 2-5		τ	
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4		P_m	
			$P_m + P_b$	
4	Lid [redacted] Item 3		P_m	
			$P_m + P_b$	
5	[redacted] Item 4		τ	

The stress criteria for the transfer cask parts are fulfilled as the following evaluation shows. Table 3.5-8 presents the assessed minimum factors of safety of the critical components of the transfer cask parts. The minimum factor of safety amounts to [redacted] for the P_m criterion and occurs at Pos. 2 in the weld between liner and bottom ring. The assessment at this location is performed with the linearized stress intensity value P_m. A summary is presented in Appendix 3-2 (Table 3.9-7, Figure 3.9-16).

Table 3.5-8 Summary of stress assessment of transfer cask components in NCS; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]
1	Head ring Item 2-2	[redacted]	S_{int}	[redacted]
2	Liner Item 2-3		P_m	
			$P_m + P_b$	
3	Bottom Ring Item 2-4		P_m	
			$P_m + P_b$	
4	Bottom Lid Item 7		P_m	
5	Enclosure inner water chamber Item 2-8		P_m	
			$P_m + P_b$	
6	Enclosure outer water chamber Item 2-9		P_m	
			$P_m + P_b$	
7	Enclosure lead shield Item 2-6		P_m	
			$P_m + P_b$	

The assessment criteria of the storage cask and canister lid bolting are fulfilled. The minimum factor of safety in the storage cask lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.5-9). The minimum factor of safety in the canister lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.5-10). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-8 and Table 3.9-9). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.5-9 NCS - Storage cask lid bolt assessment - Hot environment - Minimum factors of safety [-]

NCS Hot Conditions	Factor of Safety [-]	
	Max. Temp.	
	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

Table 3.5-10 NCS - Canister lid bolt assessment - Hot environment - Minimum factors of safety [-]

NCS Hot Conditions	Factor of Safety [-]	
	Max. Temp.	
	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

3.5.4 Verification - Storage cask and canister - Cold conditions

The normal and off normal conditions of storage in cold condition provides for the storage cask and canister components a thermal equilibrium at −29°C. Containment vessel thermal stresses do occur in this case due to the differential thermal expansion between the parts. The internal pressure at the cold environment condition is assumed [redacted] This results in an external pressure loading for the storage cask and for the canister. Again, min. and max. lid bolt preload effects (acc. to Appendix 3-1, Table 3.9-2), external pressure (see Appendix 3-1, Table 3.9-1) and thermal stresses as well as dead load increased by a hoist factor (see Appendix 3-1) are combined to give the maximum stress intensity in each component for this load combination. A summary is presented in the Appendix 3-1.

The stress results indicate that the storage cask and canister structure can both withstand the applied impact loadings used in the analysis. The assessment criteria of the storage cask and canister lid bolting are satisfied. The transfer cask is not assessed in cold conditions, since the admissible material values are lower for high temperature conditions.

The stress criteria for the storage cask parts are fulfilled as the following evaluation shows. Table 3.5-11 presents the assessed minimum factors of safety of the critical components of the storage cask parts. The minimum factor of safety amounts to [redacted] for the $S_{Intensity}$ criterion and occurs at Pos. 1 in the fillet at the storage cask head. The assessment at this location is performed with the local stress intensity value. A summary is presented in Appendix 3-2 (Table 3.9-10, Figure 3.9-17).

Table 3.5-11 Summary of stress assessment of Storage cask components in Cold conditions; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of safety [-]
1	Cask Head Fillet	[redacted]	$S_{Intensity}$	[redacted]
2	Cask Bottom	[redacted]	P_m	[redacted]
			$P_m + P_b$	[redacted]
3	Cask Lid	[redacted]	$S_{Intensity}$	[redacted]

The stress criteria for the canister parts are fulfilled as the following evaluation shows. Table 3.5-12 presents the assessed minimum factors of safety of the critical components of the canister parts. The form pieces and washers are not part of the stress assessment, since they are not critical to the structural integrity of the containment. The minimum factor of safety amounts to [redacted] and occurs at Pos. 3 in the canister bottom. The assessment at this location is performed with local stress intensity values. A summary is presented in Appendix 3-2 (Table 3.9-11, Figure 3.9-18).

Table 3.5-12 Summary of stress assessment of Canister Components in Cold conditions; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]
			$P_m + P_b$	
2	Headring (Shear) Item 2-5		τ	
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4		$S_{Intensity}$	
4	Lid [redacted] Item 3		P_m	
			$P_m + P_b$	
5	[redacted] Item 4		τ	

The assessment criteria of the storage cask and canister lid bolting are fulfilled. The minimum factor of safety in the storage cask lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.5-13). The minimum factor of safety in the canister lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.5-14). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-12 and Table 3.9-13). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.5-13 NCS - Cold conditions - Storage cask lid bolt assessment - Minimum factors of safety [-]

	Factor of Safety [-]	
	T= -29°C	
NCS Cold Conditions	**Min. Preload**	**Max. Preload**
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

Table 3.5-14 NCS - Cold conditions - Canister lid bolt assessment - Minimum factors of safety [-]

	Factor of Safety [-]	
	T= -29°C	
NCS Cold Conditions	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

3.5.5 Verification - Basket

The stress assessment is based on the calculated stress values from SAR (transport), while the admissible stresses are calculated based on the temperatures from storage conditions. The stress criteria for the basket under NCS are fulfilled as the evaluation in Table 3.5-15 shows. The minimum factor of safety amounts to [redacted] in the round segments. A covering acceleration of [redacted] is considered in the assessments of the basket parts, while the acceleration for NCS in storage condition amounts to [redacted] The detailed stress calculation is documented in the SAR (transport).

Table 3.5-15: Basket; Evaluated factors of safety under NCT acc. to SAR (transport)

	Membrane stress NCT [MPa] *acc. to SAR transport*	**Allow. membrane stress NCT [MPa]** [Table 3.9-26]	**Factor of safety [-]** $S = \frac{allowable\ stress}{stress\ acc.\ to\ SAR}$
Structure Sheet	[redacted]	[redacted]	[redacted]
Outer Sheets	[redacted]	[redacted]	
Shielding elements	[redacted]	[redacted]	
Round segments	[redacted]	[redacted]	

List of References

[1] 1014-DD-30934 2/8, Rev. 0
Design Drawing Cask body, CASTOR® geo69

3.6 Accident conditions of storage

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

The accident conditions of storage load cases are assessed with criteria designated for the ACS loads Level D acc. to Dicision 3, WC–3216. The accident conditions of storage consider the following conditions:

- **Fire accident:** The DSS shall withstand temperatures due to a fire event. The fire accident for storage is conservatively postulated to be the result of the spillage and ignition of a limited amount of combustible fuel associated with a transport vehicle with a fuel capacity of 200 liters. The storage cask surface is considered to receive an incident radiation and forced convection heat flux from the fire. A fire temperature of 800 °C is assumed in accordance with 10 CFR 71.73. The temperatures are evaluated in a transient thermal analysis documented in chapter 4. The resulting temperature distribution is summarized in section 3.3. The results are documented in section 3.6.5.

- **Seismic event:** The DSS must withstand loads arising due to a seismic event and must not tip over during such an event. A design earthquake is established with a horizontal and a vertical acceleration. It is demonstrated by the calculation that tipping caused by an earthquake is not a credible event. The results are documented in section 3.6.1.

- **Tipping of the storage cask:** Although tipping of the storage cask caused by an earthquake is not a credible event, following analyses are performed acc. to NUREG 2215. The analyses of the storage cask drop with the longitudinal axis horizontal (side drop) and the longitudinal axis vertical (bottom end drop) bound a non-mechanistic tip over analysis acc. to NUREG 2215 section 4.5.3.3.1. Contrary to the analyses in SAR (transport), the side and end drop analyses are performed without the impact limiters. The results are documented in section 3.6.2 and 3.6.3. The decelerations are calculated acc. To Appendix 3-1.

3.6.1 Verification - Seismic event

Tipping analysis

The CASTOR® geo69 DSS in an ISFSI is considered as a rigid body and is subject to a set of quasi-static inertia forces in the horizontal and vertical directions. Subject is to determine a design earthquake that will not cause a tip over of the DSS. The vertical seismic load it assumed to be piecewise proportional to the horizontal seismic load and can be expressed by means of a ratio factor *k*. A conservative static tip over analysis determines the permissible seismic input loads to exclude an incipient tipping of the DSS. The vertical seismic load acts in the assessments in an unfavorable direction against the g-force direction. In the evaluation, the DSS is treated as a rigid, homogenous cylinder with enveloped dimensions. The considered geometric parameters of the DSS are the outer diameter ([redacted]), the height including the protection plate in the ISFSI ([redacted]) and the smallest contact patch diameter ([redacted]). The center of gravity (CoG) on the cask axis is located approximately at half of the height ([redacted]) for a loaded storage cask with the protection plate. The radial location of the CoG is located on the rotational axis. The DSS has a nearby axial symmetric shape. The DSS is stored onto a reinforced concrete pad.

An incipient tipping of the DSS occurs when the overturning static moment reaches the size of the resistive moment around the flattened part of the DSS footprint (smallest inscribed circle, e.g. the smallest distance). The resistive static moment is reduced by the vertical zero period acceleration (ZPA) by reducing the apparent weight of the DSS. The inertia force acting on the DSS can be expressed as a fraction of g, α_h for the horizontal and α_v for the vertical direction. The overturning moment is defined as $M_O = m \cdot \alpha_h \cdot g \cdot H$ and the resistive moment is defined as $M_R = m \cdot g \cdot (1 - \alpha_v) \cdot R$. Performing a static moment balance yield the inequality

$$\propto_h + \frac{R}{H} \cdot \alpha_v \leq \frac{R}{H}$$

Inserting the factor $k = \propto_v / \propto_h$, expressing the ratio of the vertical and horizontal acceleration, in the above equation gives an expression to determine α_h. This expression depends only from *k* and the location of the CoG and can be written in the form

$$a_h \leq \frac{R}{H + k \cdot R}$$

In case of symmetry, α_h represents the resultant horizontal acceleration. It is assumed conservatively in the investigation against incipient tipping that sliding of the DSS is excluded. The DSS is conservatively reduced in the foot print area having double symmetry by using a minimum inscribed circle for both directions. A tip over against the circumferential footprint area is excluded because of the greater diameter. The evaluation of this expression can be done for specified *k*-factors in an appropriate form to determine relevant design base accelerations in horizontal and vertical direction. For the CASTOR® geo69 DSS the factor *k* is chosen as 2/3. This is a good approximation for frequencies with zero period acceleration. The first mode shape of the storage cask has an eigenfrequency of [redacted] (cps) and is clearly away from the 33 Hz (point A) cited in the Regulatory Guide 1.60 for the horizontal and vertical design response spectra. Thus, no modal superposition for the storage cask is necessary. The result of this consideration against incipient tipping is a maximum permissible horizontal, resultant acceleration of $\alpha_h =$ [redacted] with a corresponding vertical acceleration of $\alpha_v =$ [redacted]

In the case of double symmetry, the load values from the actions are linear dependent. The superposition of the actions is therefore equivalent with the superposition of the loads. Applying i.e. the combination rules of KTA 2201.1 for components $1.0\,Ex \oplus 0.3\,Ey \oplus 0.3\,Ez$ respectively $0.3\,Ex \oplus 0.3\,Ey \oplus 1.0\,Ez$ the resultant horizontal acceleration is 1.044 times the acceleration of the two equal horizontal component accelerations. Thus, the components of the acceleration in both horizontal directions is $\alpha_{hc} =$ [redacted]. The proof for the DSS against incipient tipping is done following the principals of KTA 2201.4 using components with superposition rules. The safety against incipient tipping according this procedure is [redacted]

<u>Sliding analysis.</u>

The proof against incipient sliding of the DSS during a postulated seismic event is done using the static horizontal force equilibrium. The horizontal force of the seismic load must overcome the friction force between the storage cask base and the concrete pad before sliding is initiated. The friction force is calculated from the normal force due to gravity and acts at the storage cask to ground interface multiplied with a static coefficient of friction. The normal force onto the storage cask in the contact area is reduced by the vertical seismic force, which acts opposite the direction of the gravity force. Performing a static force balance yields the inequality:

$$\propto_h \leq \mu - \mu \cdot \alpha_v$$

Inserting the factor *k* in this equation results in an expression to determine α_h. This expression depends only from k and the coefficient of friction and can be written in the form

$$a_h \leq \frac{\mu}{1 + k \cdot \mu}$$

The evaluation of this expression can be done for specified *k*-factors in an appropriate form to determine relevant design base accelerations. A minimum coefficient of Coulomb friction $\mu = 0.3$ between concrete and steel is used to determine α_h. In general, a coefficient of friction between concrete and steel is above 0.30 in a range up to 0.50. The same factor *k* is used here as in the equation for the tipping analysis. The result of this consideration against incipient sliding is a maximum permissible horizontal, resultant acceleration of $\alpha_h =$ [redacted] with a corresponding vertical acceleration of $\alpha_h =$ [redacted]. That means incipient sliding occurs before incipient tipping. The horizontal acceleration in the overturning moment is in a static consideration limited by the maximum horizontal sliding force. For rectangular storage cask shapes the calculated horizontal acceleration against incipient sliding is restrictive against the calculated horizontal acceleration against incipient tipping. If sliding occurs, the sliding distance of the DSS is determined. For this scenario conservatively, the higher accelerations from incipient tipping are used to determine the sliding distance.

For the sliding analysis of the CASTOR® geo69 DSS on the concrete pad an assessment is undertaken to determine the sliding distance using the accelerations from incipient tipping. This is done in a dynamic analysis using a single DOF rigid slider model with Coulomb friction in the support surface. No damping effect are taken into the consideration. The slider has the mass of the DSS and is subjected to a sinusoidal acceleration with the amplitude α_h. The normal force of the slider is reduced by the inertia force from the vertical acceleration α_v to obtain the most conservative solution. The dynamic coefficient of friction and static coefficient of friction are assumed to be equal. The equation of motion for the slider block is governed by

$$\ddot{x} = -\mu \cdot g(1 - \alpha_v) \cdot sign(\dot{x}) + \alpha_h \cdot g \cdot \sin(\omega \cdot t)$$

The periodic excitation ω in this equation is the frequency of a sinusoidal acceleration. The evaluation of this DOE is done numerically. The most significant energy of seismic events occurs during the strong motion time period using acceleration time histories of earthquake inputs. For seismic events, the plateau of the design response spectra for accelerations can be used to approximate this frequency domain. For the CASTOR® geo69 DSS the plateau region of the design response spectra from RG 1.60 is considered. A midpoint value in the essentially range from 0.25 Hz (point D) to 9 Hz (point B) in RG 1.60 is considered with $\omega = 28.9$ 1/s and results in a sliding distance below [redacted] For lower values of ω, the sliding distance increases slightly. Using a very conservative low excitation frequency of 1 Hz a maximum sliding distance below [redacted] is obtained.

Due to significant energy dissipation during the sliding phase, it is expected that there is enough space between neighboring storage casks to prevent possible collisions.

3.6.2 Verification - Storage cask; Side and end drop

The accident conditions of storage load case tipping of the storage cask are verified for the storage cask in the following. The considered canister is simplified and included in the analysis model as described in the SAR (transport), but not assessed. Since the analyses of the storage cask drop with the longitudinal axis horizontal (side drop) and the longitudinal axis vertical (bottom end drop) bound a non-mechanistic tip over analysis acc. to NUREG 2215, section 4.5.3.3.1, no tipping of the storage cask is evaluated.

Stresses in the assessed components under ACS are obtained by a combination of individual loads as summarized in Appendix 3-1.

Min. and max. lid bolt preload effects (acc. to Appendix 3-1, Table 3.9-2), internal pressure (see Appendix 3-1, Table 3.9-1) and a deceleration in side drop direction (see Appendix 3-1) are combined to give the maximum stress intensity in each component for this load combination.

The assessment of the maximum temperature condition bounds the range of temperatures since the admissible stress intensities are the lowest. Maximum and minimum bolt preloads are considered for the bolt assessment.

The stress results indicate that the storage cask structure can withstand the applied impact loadings. The assessment criteria are satisfied.

The stress criteria for the storage cask parts under side drop are fulfilled as the following evaluation shows. Table 3.6-1 presents the assessed minimum factors of safety of the critical components of the storage cask under side drop. The minimum factor of safety amounts to [redacted] for the $P_m + P_b$ criterion and occurs at Pos. 2 in the fillet at the upper storage cask ring.

Table 3.6-1 Summary of stress assessment of storage cask components in ACS - Side drop; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of safety [-] Max. design temperature
1	Cask body - center inside	[redacted]	P_m	[redacted]
			$P_m + P_b$	
2	Cask body - Ring		P_m	
			$P_m + P_b$	
3	Cask body - center outside		P_m	
			$P_m + P_b$	
4	Cask Lid		$S_{Intensity}$	

The assessment criteria for the blind flange and the protection cap against lid slipping in side drop are fulfilled as the evaluation in SAR (transport) shows (see Table 3.6-2). The applied horizontal acceleration amounts to [redacted] and therefore bounds the acceleration in storage condition of 35 g. Table 3.6-4 presents a brief summary of the results.

Table 3.6-2 Summary of proof of sufficient lid gasket compression at blind flange and protection cap in HAC - Side drop acc. to SAR (transport); Minimum Factors of Safety [-]

Lid	Minimum factor of safety for lid gasket compression [-]
Blind flange	[redacted]
Protection cap	

The stress criteria for the storage cask parts under end drop are fulfilled as the following evaluation shows. Table 3.6-3 presents the assessed minimum factors of safety of the critical components of the storage cask parts under end drop. The minimum factor of safety amounts to [redacted] for the $P_m + P_b$ criterion and occurs at Pos. 1 in the storage cask bottom. The assessment at this location is performed with the linearized stress intensity.

Table 3.6-3 Summary of stress assessment of Storage cask components in ACS - End drop; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of safety [-] Max. design temperature
1	Cask Bottom Recess	[redacted]	P_m	[redacted]
			$P_m + P_b$	
2	Cask Lid		$S_{Intensity}$	

A summary is presented in Appendix 3-2 (Table 3.9-14 and Table 3.9-18, Figure 3.9-19 and Figure 3.9-21).

The stress criteria for the blind flange and the protection cap under end drop are fulfilled as the following evaluation shows. Table 3.6-4 presents the assessed minimum factors of safety under end drop. The minimum factor of safety amounts to [redacted] for the $P_m + P_b$ criterion and occurs at the protection cap. The assessment at this location is performed with nominal stress intensity. The details of the stress assessments are presented in Appendix 3-2, Table 3.9-19.

Table 3.6-4 Summary of stress assessment of blind flange and protection cap in ACS - End drop; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of safety [-]
1	Blind Flange Item 89	[redacted]	$P_m + P_b$	[redacted]
2	Protection Cap Item 113		$P_m + P_b$	

The assessment criteria of the storage cask lid bolting under side drop are fulfilled. The minimum factor of safety in the storage cask lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.6-5). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-16). The sufficient gasket compression is demonstrated since the bolt assessment criteria are observed.

Table 3.6-5 ACS - Storage cask lid bolt assessment - Side drop - Minimum factors of safety [-]

	Factor of Safety [-]	
	Max. Temp.	
ACS Side Drop	Min. Preload	Max. Preload
Tension	4.3	[redacted]
Shear	16.7	[redacted]
Tension plus Shear	16.7	[redacted]
Maximum Stress S	2.3	[redacted]

The assessment criteria of the storage cask lid bolting under end drop are fulfilled. The minimum factor of safety in the storage cask lid bolting amounts to [redacted] at maximum bolt preload (see Table 3.6-6). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-21). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.6-6 ACS - Storage cask lid bolt assessment - End drop - Minimum factors of safety [-]

	Factor of Safety [-]	
	Max. Temp.	
ACS End Drop	Min. Preload	Max. Preload
Tension	6.3	[redacted]
Shear	100.0	[redacted]
Tension plus Shear	33.3	[redacted]
Maximum Stress S	6.3	[redacted]

The assessment of the blind flange and protection cap bolting is performed by an analytical assessment with a conservative approach. The assessment criteria of the blind flange and protection cap bolting under end drop are both fulfilled. The minimum factor of safety in the lid bolting amounts to [redacted] at maximum bolt preload for the protection cap (see Table 3.6-7 and Table 3.6-8). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-22). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.6-7 ACS - Blind flange lid bolt assessment - End drop - Minimum factors of safety [-]

	Factor of Safety [-]
	Max. Temp.
ACS End Drop Blind Flange Bolting	Max. Preload
Tension	[redacted]
Maximum Stress S	[redacted]

Table 3.6-8 ACS - Protection cap bolt assessment - End drop - Minimum factors of safety [-]

ACS End Drop Protection Cap Bolting	Factor of Safety [-]
	Max. Temp.
	Max. Preload
Tension	[redacted]
Maximum Stress S	[redacted]

3.6.3 Verification - Canister; Side and end drop

The ACS load case tipping of the canister are verified for the storage cask. The considered storage cask is simplified and included in the analysis model as described in SAR (transport), but not assessed.

Stresses in the assessed components under ACS are obtained by a combination of individual loads as summarized in Appendix 3-1.

Min. and max. lid bolt preload effects (acc. to Appendix 3-1), internal pressure (see Appendix 3-1, Table 3.9-1) and impact decelerations in side and end drop direction (see Appendix 3-1) are combined to give the maximum stress intensity in each component for this load combination.

Acc. to Reg. Guide 7.8, the assessments are performed for maximum temperature conditions considering internal overpressure and minimum temperature conditions considering external overpressure. The deceleration values are equal at all temperatures. Maximum and minimum bolt preloads are considered for the bolt assessment.

The stress results indicate that the canister structure can withstand the applied impact loadings. The assessment criteria are satisfied.

The stress criteria for the canister parts under side drop are fulfilled as the following evaluation shows. Table 3.6-9 presents the assessed minimum factors of safety of the critical components of the canister parts under side drop. The minimum factor of safety amounts to [redacted] for the P_m criterion and occurs at Pos. 3 in the canister bottom. The assessment at this location is performed with the linearized stress intensity.

Table 3.6-9 Summary of stress assessment of canister components in ACS - Side drop; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]	
				Min. design temperature	Max. design temperature
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	[redacted]
2	Headring (Shear) Item 2-5	[redacted]	τ	[redacted]	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4	[redacted]	P_m	[redacted]	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	[redacted]
4	Lid [redacted] Item 3	[redacted]	$S_{Intensity}$	[redacted]	[redacted]
5	[redacted] Item 4	[redacted]	τ	[redacted]	[redacted]

The stress criteria for the canister parts under end drop are fulfilled as the following evaluation shows. Table 3.6-10 presents the assessed minimum factors of safety of the critical components of the canister parts under end drop. The minimum factor of safety amounts to [redacted] for the P_m criterion and occurs at Pos. 4 in the pocket of the canister lid. The assessment at this location is performed with the local stress intensity.

Table 3.6-10 Summary of stress assessment of Canister Components in ACS - End drop; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]	
				Min. design temperature	Max. design temperature
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	[redacted]
2	Headring (Shear) Item 2-5	[redacted]	τ	[redacted]	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4	[redacted]	P_m	[redacted]	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	[redacted]
4	Lid [redacted]) Item 3	[redacted]	$S_{Intensity}$	[redacted]	[redacted]
5	[redacted] Item 4	[redacted]	τ	[redacted]	[redacted]

The details of the stress assessments are presented in Appendix 3-2 (Table 3.9-15 and Table 3.9-20, Figure 3.9-20 and Figure 3.9-22).

The assessment criteria of the canister lid bolting under side drop are fulfilled. The minimum factor of safety in the canister lid bolting amounts to [redacted] at maximum bolt preload under maximum temperature (see Table 3.6-11). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-17). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.6-11 ACS - Canister lid bolt assessment - Side drop - Minimum factors of safety [-]

	Factor of Safety [-]			
	Min. Temp.		Max. Temp.	
ACS Side Drop	Min. Preload	Max. Preload	Min. Preload	Max. Preload
Tension	[redacted]	[redacted]	[redacted]	[redacted]
Shear	[redacted]	[redacted]	[redacted]	[redacted]
Tension plus Shear	[redacted]	[redacted]	[redacted]	[redacted]
Maximum Stress S	[redacted]	[redacted]	[redacted]	[redacted]

The assessment criteria of the canister lid bolting under end drop are fulfilled. The minimum factor of safety in the canister lid bolting amounts to [redacted] at maximum bolt preload under maximum temperature (see Table 3.6-12). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.9-23). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.6-12 ACS - Canister lid bolt assessment - End drop - Minimum factors of safety [-]

	Factor of Safety [-]			
	Min. Temp.		Max. Temp.	
ACS End Drop	Min. Preload	Max. Preload	Min. Preload	Max. Preload
Tension	[redacted]	[redacted]	[redacted]	[redacted]
Shear	[redacted]	[redacted]	[redacted]	[redacted]
Tension plus Shear	[redacted]	[redacted]	[redacted]	[redacted]
Maximum Stress S	[redacted]	[redacted]	[redacted]	[redacted]

3.6.4 Verification - Basket

The stress assessment is based on the calculated stress values from SAR (transport), while the admissible stresses are calculated based on the temperatures from storage conditions. The stress criteria for the basket under ACS are fulfilled as the evaluation in Table 3.6-13 shows. The minimum factor of safety amounts to [redacted] in the round segments. A covering acceleration of [redacted] is considered in the assessments of the basket parts, while the acceleration for ACS in storage condition amounts to 35 g. The detailed stress calculation is documented in the SAR (transport).

Table 3.6-13: Basket; Evaluated factors of safety under HAC acc. to SAR (transport)

	Membrane stress HAC [MPa] *acc. to SAR transport*	**Allow. membrane stress HAC [MPa]** [Table 3.9-26]	**Factor of safety [-]** $S = \frac{allowable\ stress}{stress\ acc.\ to\ SAR}$
Structure Sheet	[redacted]	[redacted]	[redacted]
Outer Sheets	[redacted]	[redacted]	[redacted]
Shielding elements	[redacted]	[redacted]	[redacted]
Round segments	[redacted]	[redacted]	[redacted]

3.6.5 Verification - Fire accident

The fire accident of the DSS is demonstrated by the assessment performed for the fire in transport configuration documented in the SAR (transport). The comparison of the temperatures in Table 3.6-14 shows, [redacted] as documented in SAR (transport). Due to the resulting higher thermal stresses and the lower admissible stresses, the conducted assessment in the SAR (transport) bounds the fire accident in storage configuration. [redacted] The details of the temperature evaluation are documented in chapter 4.

Table 3.6-14 Comparison of temperatures in load case fire accident between transport and storage configuration [°C]

Component name	Max. Design Temperatures Storage config. [°C]	Max. Design Temperatures SAR Transport config. [°C]	ΔT [°C]
Fuel rods	[redacted]		
Storage cask surface	[redacted]		
Cavity surface	[redacted]		
Canister	[redacted]		
Canister lid gaskets	[redacted]		
Storage cask lid gaskets	[redacted]		

The assessed minimum factors of safety acc. to the SAR (transport) are presented in Table 3.6-15.

Table 3.6-15 Summary of the minimum factors of safety in fire accident acc. to SAR (transport)]

Part	Min. Factor of safety [-]
Storage cask body	[redacted]
Canister Lid	
Storage cask lid bolts	
Canister lid bolts	

3.7 Test Loads

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

The Test loads for the storage cask are bounded by the results of the test load case in the SAR (transport), since the applied test pressure values in SAR (transport) are higher as shown in Table 3.7-1. Therefore, the minimum factors of safety acc. to the SAR (transport) are presented in Table 3.7-2.

Table 3.7-1 Comparison of Pressure values for test load SAR (transport) and storage conditions

Part	SAR (transport) Pressure [MPa]	SAR (storage) Pressure [MPa]
Storage cask	[redacted]	[redacted]

Table 3.7-2 Summary of the minimum factors of safety during test loads acc. to the SAR (transport)

Part	Min. Factor of safety [-]
Storage cask Lid	[redacted]
Storage cask lid bolts	[redacted]

The test pressure for the canister amounts to p = [redacted] acc. to Division 3, WC-6221 and Appendix 3-1 (Table 3.9-1).

The test loads are simulated under room temperature, no thermal expansion is considered. Stresses in the assessed components are obtained by a combination of individual loads as described in Appendix 3-1. Max. lid bolt preload effects (acc. to Appendix 3-1, Table 3.9-2) and internal test pressure (acc. to Appendix 3-1, Table 3.9-1) are combined to give the maximum stress intensity in each component for this load combination. A summary is presented in Appendix 3-1.

The stress results indicate that the canister structure can withstand the applied loadings used in the analysis. The assessment criteria are satisfied.

The stress criteria for the canister parts are fulfilled, as the following evaluation shows. Table 3.7-3 presents the assessed minimum factors of safety of the critical components of the canister parts. The minimum factor of safety amounts to [redacted] for the P_m criterion and occurs at Pos. 4 in a pocket of the canister lid. The assessment at this location is performed with the local stress intensity value. A summary is presented in Appendix 3-2 (Table 3.7-3, Figure 3.9-23).

Table 3.7-3 Summary of stress assessment of canister components under Test loads; Minimum Factors of Safety [-]

Position No.	Location	Material	Stress category	Factor of Safety [-]
1	Headring (Hole) Item 2-5	[redacted]	τ	[redacted]
2	Headring (Section) Item 2-5		P_m	
			$P_m + P_b$	
3	Canister Body (Bottom) Item 2-3		P_m	
			$P_m + P_b$	
4	Lid Item 3		$S_{Intensity}$	
5	[redacted] Item 4		τ	

The assessment criteria of the canister lid bolting under test loads are fulfilled. The minimum factor of safety in the canister lid bolting amounts to [redacted] at maximum bolt preload (see Appendix 3-2 Table 3.7-4). The evaluated bolt stresses are summarized in Appendix 3-2 (Table 3.7-4). The sufficient gasket compression is demonstrated, since the bolt assessment criteria are observed.

Table 3.7-4 Test Loads - Canister lid bolt assessment - Minimum factors of safety [-]

	Factor of Safety [-]
	RT
Test Loads	Max. Preload
Tension	[redacted]
Shear	
Tension plus Shear	
Maximum Stress S	

3.8 Fuel Rods

	Name, Function	Date	Signature
Prepared	[redacted]		
Reviewed			

Cladding is not considered to provide containment of radioactive material under NCT or HAC as described in chapter 7.

3.9 Appendix

	Name, Function	Date	Signature	
Prepared	[redacted]			
Reviewed				

Appendix 3-1 Description of the structural analysis for the storage cask, canister and transfer cask

Appendix 3-2 Results of the structural analysis of storage cask, canister and transfer cask parts

Appendix 3-3 GNS Proprietary Report GNB B 086/2012 EN, Rev. 3
Verification of the ANSYS® FE Program for Mechanical Calculations on Heterogeneous Hardware and Operating Systems

Appendix 3-1 Description of the structural analysis for the storage cask, canister and transfer cask

The basic FE-Models that are used in the analyses are identical to the models described and documented in the SAR (transport). Boundary conditions that deviate are described in the following.

The pressures depicted in Table 3.9-1 are applied. Internal overpressure acts in hot temperature conditions, while external overpressure is considered in cold temperature conditions as stated in NRC Regulatory Guide 7.8. The depicted pressure values are overpressures considering the difference between the states of maximum internal and minimum external, as well as minimum internal and maximum external values, whereas the canister is located inside the storage cask cavity. The covering values are evaluated separately for storage cask and canister.

Table 3.9-1 Applied pressure values [MPa]

Containment	Load Cases	Internal Overpressure [MPa]	External Overpressure [MPa]
Storage cask	Applied max. pressure covering all conditions	[redacted]	[redacted]
Canister	Applied max. pressure under NCS (covering for off normal conditions)	[redacted]	[redacted]
	Applied max. pressure covering under ACS	[redacted]	[redacted]
	Test Load	[redacted]	[redacted]
Transfer cask (Inner and outer water enclosure)	Pressure due to water expansion	[redacted]	[redacted]

The applied design temperature dependant bolt preloads for the storage cask and canister lids are depicted in the SAR (transport), a brief summary is presented in Table 3.9-2.

Table 3.9-2 Applied bolt preloads acc. to SAR (transport) [kN]

Bolting	Min. Design Temperature		Room Temperature		Max. Design Temperature	
	Min. preload	Max. preload	Min. preload	Max. preload	Min. preload	Max. preload
Storage cask Lid Bolting	[redacted]					
Closure Plate	[redacted]					
Impact Limiter Lid Side	[redacted]					
Impact Limiter Bottom Side	[redacted]					
Canister Thread Bolts	[redacted]					

1 Determination of decelerations for tip-over analyses

For a freestanding CASTOR® geo69 DSS, positioned in an upright position, onto a reinforced concrete pad in an ISFSI it is shown that the DSS remains kinematically stable. Nevertheless, a hypothetical tip-over event is postulated, as stated in NUREG-2215. The structural integrity of a loaded storage cask after a tip-over, onto a reinforced concrete pad/subsoil (target), is demonstrated by analysis. To demonstrate the integrity of the storage cask the rigid body deceleration obtained from this scenario is used in this analysis to proof the integrity of the DSS (storage cask and canister). The storage cask tip-over is defined as a non-mechanistic event as described in NUREG-2215.

The storage cask in the ISFSI is classified as ITS (important to safety) however the reinforced concrete pad on which the storage cask is positioned is a non-ITS structure. In a storage facility with freestanding storage casks, the non-mechanistic tip-over requirement is limited by the stiffness of the pad.

The CASTOR® geo69 DSS in an ISFSI is considered for the tip-over event as a rigid body and the geometry of the DSS is a homogenous cylinder with enveloped dimensions and equivalent mass. The geometric parameters of the DSS are the outer diameter ([redacted]), the storage cask height/length ([redacted]) including the protection plate in the ISFSI. The center of gravity (CoG) in storage cask axis is located approximately at half of the storage cask height ([redacted]) for a full loaded storage cask. The radial location of the CoG is located on the rotational axis. The design of the CASTOR® geo69 DSS has nearby an axial symmetric shape.

The impact analysis is based on the methodology descripted in the report EPRI NP-4830. The mass and geometry of the storage cask are considered and it is assumed that the stiffness of the storage cask is rigid compared with the concrete pad with subsoil. Properties of the storage pad with subsoil and a simplified storage cask geometry are used to determine the hardness parameter of the pad in a wide range of parameters. All design variables are combined in a single non-dimensional variable called hardness number (S). The results in EPRI NP-4830 are parametric analyses with design charts and formulas for the evaluation of the concrete pad and graphs are used to determine the deceleration of the storage cask as a function the storage pad hardness parameter. The report in combination with EPRI TR-108760 is used for the end drop and side drop to bound the non-mechanistic tip-over event according to NUREG-2215 (4.5.3.3.1). The validation of the methodology in EPRI NP-4830 for analysis of spent fuel storage cask drop and tip-over events is conducted in the report EPRI TR-108760 and is based on experimental data from full-scale drop tests and a large number of detailed nonlinear finite element dynamic analysis. Parameters as pad thickness, concrete compressive strength, cracking and crushing of concrete, yielding steel reinforcement, compaction of underlying sub-base soil and variations for drop orientation and drop height were investigated.

The model agrees well with the experimental data and EPRI consider the model to be adequately verified and suited for such applications.

During the impact of the storage cask with the pad, the stiffness of the ISFSI concrete pad and the impacted surface are relevant to determine the rigid body deceleration of the storage cask. The rigid body deceleration is primarily depending from the stiffness of the concrete pad while the subsoil beneath the concrete pad has only a secondary effect on the peak deceleration. The concrete pad has a thickness of [redacted] and consists of a concrete with a compressive strength of $f_c' =$ [redacted] The elastic modulus of concrete is determined from $E_c =$ [redacted] to $E_c =$ [redacted] with a poisson ratio of $\nu_c =$ [redacted]. The reinforcing bar cross section area is [redacted] per strip length and a rebar yield strength of $f_s' =$ [redacted] is considered. The effective concrete cover of the reinforcing bars is [redacted]

The subsoil is characterized by the plate bearing subgrade stiffness k = [redacted] a soil elastic modulus of $E_s =$ [redacted] and a poisson ratio of $\nu_s =$ [redacted] The shape of the pad bearing area is considered in a conservative way for the end drop as a square with a factor $\alpha = 1.08$ and for the side drop as a rectangle with a factor $\alpha = 1.41$. A detailed description of all formulas with various parameters and recommended ranges of applications are specified in EPRI NP-4830 and EPRI TR-108760.

The formula for the calculation of the target hardness parameter S is given by

$$S_{end\ drop} = \frac{2 \cdot r \cdot A \cdot k \cdot M_u \cdot f_c'}{G^3 \cdot (1 - e^{-\beta \cdot r} \cdot \cos(\beta \cdot r))} = 41800$$

$$S_{side\ drop} = \frac{2 \cdot b \cdot L \cdot E_s \cdot M_u \cdot f_c'}{G^3 \cdot \beta} = 6310$$

With:

r: Radius of storage cask

A: Footprint of storage cask

k: Plate bearing subgrade stiffness ([redacted])

Mu: Ultimate moment of capacity of slap ([redacted])

f'_c: Compressive strength of concrete ([redacted])

G: Mass of the storage cask

β: Load parameter ([redacted])

L: Length of storage cask

b: Width of storage cask-slab contact area [redacted])

E_s: Elastic modulus of soil ([redacted])

The fundamental assumption of the target hardness model is that under low velocity impact the damaging force of the pad is conservatively estimated from the equivalent steady deceleration of the storage cask during the pre-rebound impact. The formulas and diagrams are used to express the steady deceleration of the storage cask as a function of the target hardness number, which represent the resistance of the target. The analysis in EPRI NP-4830 shows that the storage cask steady deceleration increase with the drop height but in decreasing rate and reach a limiting value due to energy dissipation mechanism in the concrete. The calculated g-factors G(S), using the formulas given in EPRI TR-108760 as a function of the target hardness represent the limiting equivalent static deceleration of the storage cask due to the ultimate load capacity of the storage pad. The calculated impact deceleration G is specified as a multiple of the free fall acceleration, i.e. g-force. A storage cask drop analysis with the longitudinal axis horizontal (side drop) together with a storage cask drop analysis with the longitudinal axis vertical (end drop) are used for the non-mechanistic tip-over analysis.

The calculated steady state deceleration for the storage cask CASTOR® geo69 are $a_{end\ drop}$ =[redacted] and $a_{side\ drop}$ = [redacted]. Taken into account only the fins length in axial direction ([redacted]) the deceleration decrease slightly for the side drop to [redacted]. The DSS deceleration is defined as [redacted]

2 Structural analysis model of storage cask for normal conditions of storage

The structural analysis model of the storage cask is supported at the trunnions in the area of the storage cask head (see Figure 3.9-1). This means, that the storage cask is situated in a handling condition. Gravity times the hoist factor of 1.15 acc. to CMAA specification #70 for slow crane operations acts on the weight of the storage cask. Inside the storage cask bottom, the weight of the canister is considered as distributed mass on the inside bottom faces. At the same time, the temperature is applied. Since thermal expansion is activated, thermal stresses are included. Internal, resp. external overpressure is applied acc. to Table 3.9-1.

[redacted]

Figure 3.9-1 Structural analysis model of storage cask - Boundary conditions for NCS

3 Structural analysis model of the canister for normal conditions of storage

The structural analysis model of the canister is placed inside a part of the transfer cask (see Figure 3.9-1). This means, that the storage cask is situated in a handling condition while being loaded inside of the transfer cask. This is done, because of the higher temperature conditions inside of the transfer cask compared to the storage cask. The fraction of the transfer cask parts (liner, bottom ring and bottom lid) is supported vertically at the section across the liner. Gravity times the hoist factor of 1.15 acc. to acc. to CMAA specification #70 for slow crane operations acts on the weight of the canister. Inside the caniste[redacted] At the same time, the temperature is applied. Since thermal expansion is activated, thermal stresses are included. Internal, resp. external overpressure is applied acc. to Table 3.9-1.

[redacted]

Figure 3.9-2 Structural analysis model of canister - Boundary conditions for NCS

4 Structural analysis model of the transfer cask for normal conditions of storage

[redacted] Dimensions of the transfer cask are taken from parts list [5] and the drawings therein cited. The parts are meshed with hexahedron and tetrahedron solid elements (SOLID185, SOLID187). Thin sheets are meshed with solid shell elements (SOLSH190). [redacted] Filled welds are not considered, since they are not part of the structural integrity of the transfer cask. The mesh is presented in Figure 3.9-3 to Figure 3.9-5. [redacted]

[redacted]

Figure 3.9-3 Structural analysis model of transfer cask - Mesh total view

[redacted]

Figure 3.9-4 Structural analysis model of transfer cask - Mesh detail view top

[redacted]

Figure 3.9-5 Structural analysis model of transfer cask - Mesh detail view bottom

The structural analysis model of the transfer cask is supported at the trunnions in the area of the head ring intersection faces to the trunnions (see Figure 3.9-6). This means, that the transfer cask is situated in a handling condition. Gravity times the hoist factor of 1.15 acc. to CMAA specification #70 for slow crane operations acts on the weight of the transfer cask. [redacted]

At the same time, the temperature is applied. Since thermal expansion is activated, thermal stresses are included.

Bolt preloading is not considered, since no leak tightness requirement exists.

[redacted] In an additional load step, internal overpressure is considered inside of the enclosures of the inner and outer water chambers (see Figure 3.9-6). For the transfer cask linear - elastic material behaviour is defined.

[redacted]

Figure 3.9-6 Structural analysis model of transfer cask - Boundary conditions for NCS

5 Structural analysis model of the storage cask for accident conditions of storage for side and end drop

For this load case, the loads and general boundary conditions according to the introduction of this Appendix 3-1 are applied. For the storage cask and simplified canister linear - elastic material behaviour is defined.

[redacted] At the same time, the temperature is applied. Temperature dependent stiffness of the parts is considered. Internal overpressure is applied acc. to Table 3.9-1, bolt preloads are applied according to Table 3.9-2. The impact load of 35 g is applied in vertical (Y) direction. The decelerations are calculated acc. to section 1.

[redacted]

Figure 3.9-7 Structural analysis model of Storage cask - Boundary conditions for ACS - Content and protective cover - mass definitions

Resulting from the applied acceleration, a surface pressure is acting onto the outer surfaces of the impact area between the concrete and the storage cask, to achieve a state of equilibrium. The length of the impact area is considered from the top ring to the end of the bottom ring with a width of 127 mm (5 In) acc. to EPRI NP-4830. [redacted]

[redacted]

Figure 3.9-8 Structural analysis model of the Storage cask - Boundary conditions for ACS - Area of applied surface pressure resulting from acceleration

For the end drop load case, the loads and general boundary conditions according to the introduction of this Appendix 3-1 are applied. For the storage cask, linear - elastic material behaviour is defined.

[redacted]

[redacted] The temperature dependent stiffness of the parts is considered. Internal overpressure is applied acc. to Table 3.9-1, bolt preloads are applied according to Table 3.9-2. The impact load of 35 g is applied in longitudinal direction. The impact decelerations are determined in section 1. [redacted]

[redacted]

Figure 3.9-9 Structural analysis model of Storage cask - Boundary conditions for ACS - End drop; Content and protective cover - mass definitions; Application area of force

6 Structural analysis model of the canister for accident conditions of storage for side and end drop

For this load case the loads and general boundary conditions according to the introduction of this Appendix 3-1 are applied. For the storage cask and canister linear - elastic material behaviour is defined.

[redacted] At the same time, the temperature is applied. Temperature dependent stiffness of the parts is considered. Internal overpressure is applied acc. to Table 3.9-1, bolt preloads are applied according to Table 3.9-2. The impact load of 35 g is applied in vertical (X) direction. The decelerations are calculated acc. to section 1.

[redacted]

Figure 3.9-10 Structural analysis model of Canister - Boundary conditions for ACS - Side Drop; Content and protective cover - mass definitions

[redacted] The impact area is considered from the top ring to the end of the bottom ring with a width of 127 mm (5 In) acc. to EPRI NP-4830. The area is presented in Figure 3.9-11.

[redacted]

Figure 3.9-11 Structural analysis model of Canister - Boundary conditions for ACS - Area of vertical displacement boundary condition

For the end drop load case, the loads and general boundary conditions according to the introduction of this Appendix 3-1 are applied. For the storage cask and canister linear - elastic material behaviour is defined.

[redacted] At the same time, the temperature is applied. Thermal expansion is not activated, thermal stresses are therefore not included, but the temperature dependent stiffness of the parts is considered. Internal overpressure is applied acc. to Table 3.9-1, bolt preloads are applied according to Table 3.9-2. The impact load of 35 g is applied in longitudinal (Y) direction. The decelerations are calculated acc. to section 1. Resulting from the applied acceleration, [redacted] in order to achieve a state of equilibrium with the impact acceleration load resulting from the 35 g. [redacted]

[redacted]

Figure 3.9-12 Structural analysis model of Canister - Boundary conditions for ACS - End drop; Content and protective cover - mass definitions; Application area of force

7 Structural analysis model of canister for test load

[redacted] The displacement boundary conditions are presented in Figure 3.9-13. Internal over-pressure is applied acc. to Table 3.9-1. No dead load or thermal load is considered. For all parts linear - elastic material behaviour is defined.

[redacted]

Figure 3.9-13 Structural analysis model of canister - Boundary conditions for test load

Appendix 3-2 Results of the structural analysis of storage cask, canister and transfer cask parts

1 Normal and off normal conditions of storage - Hot environment

Table 3.9-3 presents the evaluated stress intensities and factors of safety under NCS - Hot environment at the storage cask. Figure 3.9-14 presents the evaluated locations at the storage cask.

Table 3.9-3 Stress assessment of Storage cask Components in NCS - Hot environment; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of safety [-]
1	Cask Head Fillet	[redacted]	P_m	[redacted]	72.70	[redacted]
			$P_m + P_b$	[redacted]	109.05	[redacted]
2	Cask Lid	[redacted]	$S_{Intensity}$	[redacted]	138.00	[redacted]

[redacted]

Figure 3.9-14 Structural analysis model of Storage cask - Results for NCS - Hot Environment; Assessed positions acc. to Table 3.9-3

The evaluation of the acting forces on the clamping elements and the head ring in the handling condition Canister on Canister lid is presented in Table 3.9-4.

Table 3.9-4 Acting forces in handling conditions canister on Canister Lid

Canister Body weight	[kg]	[redacted]
Fuel bakset	[kg]	
Shielding elements	[kg]	
Inventory	[kg]	
Total	**[kg]**	

Acceleration	[m/s²]	9.81
Hoist factor	[-]	1.15
Deal Load	**[N]**	[redacted]

Number of Clamping elements	[-]	[redacted]
Force at 1 Cl. Element	[N]	
Bolt preload (max.)	[N]	
Total force at 1 Cl. Element	**[N]**	

With the cross section from the SAR (section 3.1.2.11), the following stresses in Table 3.9-5 result.

Table 3.9-5 Stress assessment of canister components in NCS - Handling condition canister on canister lid; Details [MPa]

Position No.	Location	Material	Stress category	Nominal Stress [MPa]	Criterion [MPa]	Factor of Safety [-]
1	Headring (Shear) Item 2-5	[redacted]	τ	[redacted]	126.60	[redacted]
2	[redacted] Item 4		τ	[redacted]	133.20	

Table 3.9-6 presents the evaluated stress intensities and factors of safety under NCS - Hot environment at the canister. Figure 3.9-15 presents the evaluated locations at the canister.

Table 3.9-6 Stress assessment of Canister Components in NCS - Hot environment; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of Safety [-]
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]	211.00	[redacted]
			$P_m + P_b$	[redacted]	316.00	[redacted]
2	Headring (Shear) Item 2-5		τ	[redacted]	126.60	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4		P_m	[redacted]	110.00	[redacted]
			$P_m + P_b$	[redacted]	165.00	[redacted]
4	Lid [redacted] Item 3		P_m	[redacted]	219.00	[redacted]
			$P_m + P_b$	[redacted]	328.00	[redacted]
5	[redacted] Item 4		τ	[redacted]	133.20	[redacted]

[redacted]

Figure 3.9-15 Structural analysis model of Canister - Results for NCS - Hot Environment; Assessed positions acc. to Table 3.9-6

Table 3.9-7 presents the evaluated stress intensities and factors of safety under NCS - Hot environment at the transfer cask. Figure 3.9-16 presents the evaluated locations.

Table 3.9-7 Stress assessment of Transfer cask Components in NCS - Hot environment; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of Safety [-]
1	Head ring Item 2-2	[redacted]	S_{int}	[redacted]	224.00	[redacted]
2	Liner Item 2-3	[redacted]	P_m	[redacted]	115.00	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	172.00	[redacted]
3	Bottom Ring Item 2-4	[redacted]	P_m	[redacted]	115.00	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	169.00	[redacted]
4	Bottom Lid Item 7	[redacted]	S_{int}	[redacted]	214.00	[redacted]
5	Enclosure inner water chamber Item 2-8	[redacted]	P_m	[redacted]	115.00	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	172.00	[redacted]
		[redacted]	τ	[redacted]	69.00	[redacted]
6	Enclosure outer water chamber Item 2-9	[redacted]	P_m	[redacted]	115.00	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	172.00	[redacted]
		[redacted]	τ	[redacted]	69.00	[redacted]
7	Enclosure lead shield Item 2-6	[redacted]	P_m	[redacted]	115.00	[redacted]
		[redacted]	$P_m + P_b$	[redacted]	172.00	[redacted]
		[redacted]	τ	[redacted]	69.00	[redacted]

[redacted]

Figure 3.9-16 Structural analysis model of Transfer cask - Results for NCS - Assessed positions acc. to Table 3.9-7

Table 3.9-8 to Table 3.9-9 depict the evaluated bolt stress intensities for the storage cask and canister.

Table 3.9-8 Bolt stress assessment of Storage cask lid bolts in NCS - Hot environment [MPa]

	Max. Stress [MPa]	
	Max. Temp.	
NCS Hot Environment	Min. Preload	Max. Preload
Tension	[redacted]	
Shear	[redacted]	
Tension plus Shear	[redacted]	
Maximum Stress S		

Table 3.9-9 Bolt stress assessment of Canister lid bolts in NCS - Hot environment [MPa]

	Max. Stress [MPa]	
	Max. Temp.	
NCS Hot Conditions	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

2 Normal and off normal conditions of storage - Cold conditions

Table 3.9-10 presents the evaluated stress intensities and factors of safety under NCS - Cold conditions at the storage cask. Figure 3.9-17 presents the evaluated locations.

Table 3.9-10 Stress assessment of Storage cask Components in NCS - Cold conditions; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of safety [-]
1	Cask Head Fillet	[redacted]	$S_{Intensity}$	49.43	[redacted]	[redacted]
2	Cask Bottom		P_m	4.85	[redacted]	
			$P_m + P_b$	13.59	[redacted]	
3	Cask Lid		$S_{Intensity}$	63.64	[redacted]	

[redacted]

Figure 3.9-17 Structural analysis model of Storage cask - Results for NCS - Cold conditions; Assessed positions acc. to Table 3.9-10

Table 3.9-11 presents the evaluated stress intensities and factors of safety under NCS - Cold conditions at the canister. Figure 3.9-18 presents the evaluated locations at the canister.

Table 3.9-11 Stress assessment of Canister Components in NCS - Cold conditions; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of Safety [-]
1	Headring (Section) Item 2-5	SA-182M Grade FXM-19	P_m	[redacted]	230.00	[redacted]
			$P_m + P_b$	[redacted]	345.00	[redacted]
2	Headring (Shear) Item 2-5	SA-182M Grade FXM-19	τ	[redacted]	138.00	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4	SA-240M Grade 316L	$S_{Intensity}$	[redacted]	115.00	[redacted]
4	Lid [redacted] Item 3	SA-965M Grade FXM-19	P_m	[redacted]	230.00	[redacted]
			$P_m + P_b$	[redacted]	345.00	[redacted]
5	[redacted] Item 4	SA-479M Grade XM-19	τ	[redacted]	138.00	[redacted]

[redacted]

Figure 3.9-18 Structural analysis model of Canister - Results for NCS - Cold conditions; Assessed positions acc. to Table 3.9-11

Table 3.9-12 to Table 3.9-13 depict the evaluated bolt stress intensities for the storage cask and canister.

Table 3.9-12 Bolt stress assessment of Storage cask lid bolts in NCS - Cold conditions [MPa]

	Max. Stress [MPa]	
	T= -29°C	
NCS Cold Conditions	Min. Preload	Max. Preload
Tension	[redacted]	[redacted]
Shear	[redacted]	[redacted]
Tension plus Shear	[redacted]	[redacted]
Maximum Stress S	[redacted]	[redacted]

Table 3.9-13 Bolt stress assessment of Canister lid bolts in NCS - Cold conditions [MPa]

	Max. Stress [MPa]	
	T= -29°C	
NCS Cold Conditions	Min. Preload	Max. Preload
Tension	[redacted]	[redacted]
Shear	[redacted]	[redacted]
Tension plus Shear	[redacted]	[redacted]
Maximum Stress S	[redacted]	[redacted]

3 Accident conditions of storage - Side and End drop

Table 3.9-14 presents the evaluated stress intensities and factors of safety under side drop. Figure 3.9-19 presents the evaluated locations at the storage cask.

Table 3.9-14 Stress assessment of Storage cask Components in ACS - Side drop; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of safety [-]
				Max. design temperature	Max. design temperature	Max. design temperature
1	Cask body - center inside	[redacted]	P_m	[redacted]	203	[redacted]
			$P_m + P_b$		291	
2	Cask body - Ring		P_m		203	
			$P_m + P_b$		291	
3	Cask body - center outside		P_m		203	
			$P_m + P_b$		291	
4	Cask Lid		$S_{Intensity}$		331	

[redacted]

Figure 3.9-19 Structural analysis model of Storage cask - Results for ACS - Side drop; Assessed positions acc. to Table 3.9-14

Table 3.9-15 presents the evaluated stress intensities and factors of safety for the canister under side drop. Figure 3.9-20 presents the evaluated locations at the canister.

Table 3.9-15 Stress assessment of Canister Components in ACS - Side drop; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]		Criterion [MPa]		Factor of Safety [-]	
				Min. design temperature	Max. design temperature	Min. design temperature	Max. design temperature	Min. design temperature	Max. design temperature
1	Headring (Section) Item 2-5	SA-182M Grade FXM-19	P_m	[redacted]	[redacted]	482.00	468.00	[redacted]	[redacted]
			$P_m + P_b$	[redacted]	[redacted]	689.00	669.00	[redacted]	[redacted]
2	Headring (Shear) Item 2-5	SA-182M Grade FXM-19	τ	[redacted]	[redacted]	289.38	280.98	[redacted]	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4	SA-240M Grade 316L	P_m	[redacted]	[redacted]	276.00	276.00	[redacted]	[redacted]
			$P_m + P_b$	[redacted]	[redacted]	414.00	414.00	[redacted]	[redacted]
4	Lid (Pocket) Item 3	SA-965M Grade FXM-19	$S_{Intensity}$	[redacted]	[redacted]	482.00	468.00	[redacted]	[redacted]
5	Clamping Element Item 4	SA-479M Grade XM-19	τ	[redacted]	[redacted]	283.92	283.92	[redacted]	[redacted]

[redacted]

Figure 3.9-20 Structural analysis model of Canister - Results for ACS - Side drop; Assessed positions acc. to Table 3.9-15

Table 3.9-16 and Table 3.9-17 depict the evaluated bolt stress intensities under side drop for the storage cask and canister.

Table 3.9-16 Bolt stress assessment of Storage cask lid bolts in ACS - Side drop [MPa]

	Max. Stress [MPa]	
	Max. Temp.	
ACS Side Drop	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

Table 3.9-17 Bolt stress assessment of Canister lid bolts in ACS - Side drop [MPa]

	Max. Stress [MPa]			
	Min. Temp.		Max. Temp.	
ACS Side Drop	Min. Preload	Max. Preload	Min. Preload	Max. Preload
Tension	[redacted]			
Shear				
Tension plus Shear				
Maximum Stress S				

Table 3.9-18 summarizes the evaluated stress intensities and factors of safety for the storage cask under end drop. Figure 3.9-21 presents the evaluated locations at the storage cask.

Table 3.9-18 Stress assessment of Storage cask Components in ACS - End drop; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of safety [-]
				Max. design temperature	Max. design temperature	Max. design temperature
1	Cask Bottom (Section)	[redacted]	P_m	[redacted]	[redacted]	
			$P_m + P_b$			
2	Cask Lid		$S_{Intensity}$			

[redacted]

Figure 3.9-21 Structural analysis model of Storage cask - Results for ACS - End drop; Assessed positions acc. to Table 3.9-18

Table 3.9-19 Stress assessment of blind flange and protection cap in ACS - End drop; Details [MPa]

Lid	Blind Flange Item 89	Protection Cap Item 113
Material	[redacted]	[redacted]
Diameter [mm]	[redacted]	[redacted]
Force from internal Pressure [MPa]	[redacted]	[redacted]
Dead Load [N]	[redacted]	[redacted]
Resulting Line Pressure [N/mm]	[redacted]	[redacted]
Resulting Bending moment in center [N/mm]	[redacted]	[redacted]
Moment of resistance [mm³]	[redacted]	[redacted]
Bending stress in Lid center [MPa]	[redacted]	[redacted]
Adm. P_m+P_b criterion [MPa]	[redacted]	[redacted]
Factor of safety [-]	[redacted]	[redacted]

Table 3.9-20 presents the evaluated stress intensities and factors of safety for the canister under end drop. Figure 3.9-22 presents the evaluated locations at the canister.

Table 3.9-20 Stress assessment of Canister Components in ACS - End drop; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]		Criterion [MPa]		Factor of Safety [-]	
				Min. design temperature	Max. design temperature	Min. design temperature	Max. design temperature	Min. design temperature	Max. design temperature
1	Headring (Section) Item 2-5	[redacted]	P_m	[redacted]	[redacted]	482.00	468.00	[redacted]	[redacted]
		[redacted]	P_m+P_b	[redacted]	[redacted]	689.00	669.00	[redacted]	[redacted]
2	Headring (Shear) Item 2-5	[redacted]	τ	[redacted]	[redacted]	289.38	280.98	[redacted]	[redacted]
3	Canister Body (Bottom) Item 2-2, 2-3, 2-4	[redacted]	P_m	[redacted]	[redacted]	276.00	276.00	[redacted]	[redacted]
		[redacted]	P_m+P_b	[redacted]	[redacted]	414.00	414.00	[redacted]	[redacted]
4	Lid [redacted] Item 3	[redacted]	$S_{Intensity}$	[redacted]	[redacted]	482.00	468.00	[redacted]	[redacted]
5	[redacted] Item 4	[redacted]	τ	[redacted]	[redacted]	289.38	283.92	[redacted]	[redacted]

[redacted]

Figure 3.9-22 Structural analysis model of Canister - Results for ACS - End drop; Assessed positions acc. to Table 3.9-20

Table 3.9-21 to Table 3.9-23 depict the evaluated bolt stress intensities for the storage cask and canister under end drop.

Table 3.9-21 Bolt stress assessment of Storage cask lid bolts in ACS - End drop [MPa]

	Max. Stress [MPa]	
	Max. Temp.	
ACS End Drop	Min. Preload	Max. Preload
Tension	[redacted]	
Shear		
Tension plus Shear		
Maximum Stress S		

Table 3.9-22 Bolt stress assessment of blind flange and protective cap bolts in ACS - End drop [MPa]

	Assessment of Blind Flange Bolting	Assessment of Protection Cap Bolting
Item	Item 37 to Blind Flange Item 89	Item 37 to Protection Cap Item 113
Material	[redacted]	[redacted]
Mass m [kg]	[redacted]	[redacted]
Inertia Load a [g]	35	35
Number of Bolts n [-]	[redacted]	[redacted]
Resulting total dead load F [N]	[redacted]	[redacted]
Resulting dead load F per Bolt [N]	[redacted]	[redacted]
Gasket pressure [N/mm]	[redacted]	[redacted]
Gasket diameter [mm]	[redacted]	[redacted]
Resulting Gasket Force per Bolt [N]	[redacted]	[redacted]
Internal Pressure [MPa]	[redacted]	[redacted]
Resulting Force from pressure per Bolt [N]	[redacted]	[redacted]
Total acting force F on Bolt [N]	[redacted]	[redacted]
Bolt nominal stress diameter [mm]	[redacted]	[redacted]
Bolt cross section [mm²]	[redacted]	[redacted]
Max. Bolt preload Fv [N]	[redacted]	[redacted]
Tensilse stress resulting from preload [MPa]	[redacted]	[redacted]
Tensile stress resulting from operating load [MPa]	[redacted]	[redacted]
Tensile stress resulting from preload plus operating load [MPa]	[redacted]	[redacted]
Adm. Stress "Tension" [MPa]	[redacted]	[redacted]
Factor of Safety [-]	[redacted]	[redacted]
Residual torsional stress [MPa]	[redacted]	[redacted]
Maximum Stress Intensity S	[redacted]	[redacted]
Adm. Max. Stress Intesity [MPa] (under T_{max}=100°C)	[redacted]	[redacted]
Factor of Safety [-]	[redacted]	[redacted]

Table 3.9-23 Bolt stress assessment of Canister lid bolts in ACS - End drop [MPa]

	Max. Stress [MPa]			
	Min. Temp.		Max. Temp.	
ACS End Drop	Min. Preload	Max. Preload	Min. Preload	Max. Preload
Tension	[redacted]			
Shear				
Tension plus Shear				
Maximum Stress S				

4 Test Loads

Table 3.9-24 presents the evaluated stress intensities and factors of safety for the canister under test loads. Figure 3.9-23 presents the evaluated locations at the canister.

Table 3.9-24 Stress assessment of Canister Components under Test Loads; Details [MPa]

Position No.	Location	Material	Stress category	Stress from linearization [MPa]	Criterion [MPa]	Factor of Safety [-]
				Room temperature	Room temperature	
1	Headring (Hole) Item 2-5	[redacted]	τ	[redacted]	138.0	[redacted]
2	Headring (Section) Item 2-5		P_m		341.0	
			$P_m + P_b$		511.0	
3	Canister Body (Bottom) Item 2-3		P_m		154	
			$P_m + P_b$		232	
4	Lid Item 3		$S_{Intensity}$		341	
5	[redacted] Item 4		τ		138.0	

[redacted]

Figure 3.9-23 Structural analysis model of Canister - Results for Test Loads; Assessed positions acc. to Table 3.9-24

Table 3.9-25 depicts the evaluated bolt stress intensities under test loads for the canister.

Table 3.9-25 Bolt stress assessment of Canister lid bolts under Test Loads [MPa]

	Max. Stress [MPa]
	RT
Test Loads	Max. Preload
Tension	[redacted]
Shear	[redacted]
Tension plus Shear	[redacted]
Maximum Stress S	[redacted]

Table 3.9-26 Admissible stress criteria under NCS and ACS

	Item No.	T	S_m	S_u	E-Modulus	Therm. Expansion	Poisson´s Ration	Admissible stress [MPa]					
								Level A (NCS)			Level D (ACS)		
		[°C]	[MPa]	[MPa]	[MPa]	[1x10$^{(-6)}$1/K]	[-]	P_m	P_l	P_m+P_b	P_m	P_l	P_m+P_b
Cask Design Part List 1014-DPL-30934 [1]													
Storage cask [redacted]	2	-29	75.0	300.0	165320	10.3	0.29	75.0	112.5	112.5	210.0	300.0	300.0
		125	72.7	291.0	153000	11.1		72.7	109.1	109.1	203.7	291.0	291.0
Storage cask lid [redacted]	55	-29	138.0	517.0	198240	15.3	0.31	138.0	207.0	207.0	331.2	496.8	496.8
		100	138.0	516.0	18900	16.2		138.0	207.0	207.0	331.2	497.0	497.0
Trunnion [redacted]	12	100	264.0	793.0	194100	11.2	0.31	164.0	246.0	246.0	-	-	-
Trunnion Bolts [redacted]	13	100	185.0	758.0	194100	11.2	0.31	185.0	277.0	277.0	-	-	-
Canister Design Part List 1014-DPL-36855 [2]													
Canister Headring [redacted]	2-5	-29	230.0	689.0	198240	14.7	0.31	230.0	345.0	345.0	482.0	689.0	689.0
		190	211.0	633.0	183600	16.0		211.0	316.0	316.0	443.0	633.0	633.0
Canister Body [redacted]	2-2 2-3 2-4	-29	115.0	483.0	198240	15.3	0.31	115.0	172.0	172.0	276.0	414.0	414.0
		190	110.0	431.0	183600	16.9		110.0	165.0	165.0	264.0	396.0	396.0
Canister Lid [redacted]	3	-29	230.0	689.0	198240	14.7	0.31	230.0	345.0	345.0	482.0	689.0	689.0
		135	219.0	659.0	186900	15.6		219.0	328.0	328.0	461.0	659.0	659.0
Clamping element [redacted]	4	-29	230.0	689.0	198240	14.7	0.31	230.0	345.0	345.0	482.0	689.0	689.0
		120	222.0	669.0	187800	15.6		222.0	333.0	333.0	468.0	669.0	669.0
Form piece [redacted]	5	-29	115.0	483.0	198240	15.3	0.31	115.0	172.0	172.0	276.0	414.0	414.0
		120	115.0	456.0	187800	16.4		115.0	172.0	172.0	276.0	414.0	414.0
Thread Bolt [redacted]	6	-29	-	-	207240	11.5	0.30	-	-	-	-	-	-
		120	-	-	198800	12.3		-	-	-	-	-	-

	Item No.	T [°C]	S_m [MPa]	S_u [MPa]	E-Modulus [MPa]	Therm. Expansion [$1x10^{(-6)}$1/K]	Poisson´s Ration [-]	Admissible stress [MPa] Level A (NCS) P_m	P_l	P_m+P_b	Level D (ACS) P_m	P_l	P_m+P_b
Transfer Cask Design Part List 1015-DPL-37509 [5]													
Head Ring [redacted]	2-2	115	224.0	672.0	188100	15.5	0.31	224.0	336.0	336.0	-	-	-
Liner, Bottom Ring, Enclosure Lead Shield, Enclosure inner water chamber, Enclosure outer water chamber, Sheets, Supporting Sheets, Lid [redacted]	2-3, 2-4, 2-6, 2-8, 2-9, 2-10, 2-11, 2-12, 2-13, 2-17, 2-18, 10	100	115.0	467	189000	16.2	0.31	115.0	172.5	172.5	-	-	-
		115	115.0	459.0	188100	16.3		115.0	172.5	172.5	-	-	-
		165	113.0	437.0	185100	16.7		113.0	169.0	169.0	-	-	-
Bottom Lid [redacted]	7	165	214.0	643.0	185100	15.8	0.31	214.0	321.0	321.0	-	-	-
Lid Bolts, Trunnion Bolts [redacted]	10, 13	115	183.0	756.0	194100	11.2	0.31	183.0	-	-	-	-	-
Trunnion [redacted]	12	115	264.0	793.0	194100	11.2	0.31	264.0	-	-	-	-	-

	Item No.	T [°C]	S_m* [MPa]	S_u [MPa]	E-Modulus [MPa]	Therm. Expansion [$1x10^{(-6)}$1/K]	Poisson´s Ration [-]	Admissible stress [MPa] Level A (NCS) Max.	-	-	Level D (ACS) Max.	-	-
Basket and shielding elements Design Part List 1014-DPL-30984 [3] and 1014-DPL-33604 [4]													
Structure Sheet AL-B4C-MMC	10-27	[redacted]											
Outer Sheet [redacted]	30, 31	[redacted]											
Shielding Elements Round segments [redacted]	1	[redacted]											

* = *S_m values determined acc. to SAR (transport)*

Table 3.9-27 Admissible yield strength [MPa] of the bolts for the storage and transfer cask lid and the canister thread bolts

T [°C]	Yield strength S_y [MPa]	Stress criterion avg. Tension [MPa]	Stress criterion avg. Shear [MPa]	Stress criterion Max. Stress [MPa]
[redacted]				
T_{min} = -29°C	586	390	234	527
RT = 20°C	586	390	234	527
T_{max} = 110°C	530	353	212	477
[redacted]				
T_{min} = -29°C	894	596	357	804
RT = 20°C	894	596	357	804
T = 110°C	848	565	339	763
T_{max} = 120°C	843	562	337	758

Table 3.9-28 Admissible stress criteria under testing limits

	T [°C]	S_y [MPa]	Admissible stress [MPa] Testing Limits P_m	For $P_m \leq (0.67S_y)$ P_m+P_b	For $(0.67S_y) < P_m \leq (0.9S_y)$ P_m+P_b
Cask [redacted]	RT	200	180	270	214
Cask lid [redacted]	RT	207	186	279	221
Canister Headring [redacted]	RT	379	341	511	405
Canister Body [redacted]	RT	172	154	232	185
Canister Lid [redacted]	RT	379	341	511	405
Clamping element [redacted]	RT	315	283	425	337
Form piece [redacted]	RT	172	154	232	185

Appendix 3-3 GNS Proprietary Report GNB B 086/2012 EN, Rev. 3
Verification of the ANSYS® FE Program for Mechanical Calculations on Heterogeneous Hardware and Operating Systems

Non-Proprietary Version
Proprietary Information withheld per 10CFR 2.390

GNS

Verification of the ANSYS® FE Program for Mechanical Calculations on Heterogeneous Hardware and Operating Systems

Report No.:	GNB B 086/2012 EN	Rev. 3
Date:	03.09.2019	
No. of pages:	39	

	Name	Signature	Date
Author	[redacted]		
Approval by specialist department			
Release			
Translation approved			

4 Thermal Evaluation

4.0 Overview

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed	[redacted]	22.03.2021	

In this chapter, it is shown that the CASTOR® geo69 storage cask fulfils all requirements for storage with regard to thermal aspects. The thermal design for storage complies with the performance requirements of 10 CFR part 72 for normal conditions of storage (NCS), off-normal conditions and accident conditions of storage (ACS). During storage, the cask stands in vertical position in the storage hall of a storage facility.

Furthermore, short-term operations inside the reactor facility are investigated. This comprise the fuel loading of the canister inside the transfer cask under water, the dewatering, vacuum drying and helium backfilling of the canister interior as well as the transport of the transfer cask inside the reactor building.

In the storage configuration, the cask itself and the content are identical to the transport configuration. For that reason, in the following sections the Safety Analysis Report of the CASTOR® geo69 (SAR transport) for the package approval application is cited correspondingly wherever appropriate.

The temperature distribution within the cask and the maximum temperatures of the components are calculated by numerical methods applying the finite element method (FEM).

The proofs show that all calculated temperatures are below the corresponding admissible values with large safety margins and a save heat removal during storage is ensured.

The following verification objectives are considered for the thermal design under NCS and off-normal conditions:

1. The safe enclosure of the content has to be ensured. For this purpose, the temperatures of the design-relevant lid gaskets shall not exceed the admissible limit value of [redacted] to chapter 8 for continuous operation. Furthermore, the temperatures of the lid gaskets and the mean temperature of the canister filling gas are used for the verification of the containment in chapter 7.

2. The integrity of the fuel rod cladding has to be ensured. For this purpose, it is shown that the maximum cladding temperature does not exceed the admissible limit value of 400 °C according to [1].

3. The effectiveness of the shielding has to be ensured. For this purpose, the maximum temperatures for the moderator components shall stay permanently below the maximum admissible temperature of [redacted] according to chapter 8. Furthermore, the

mean temperatures of the moderator components are taken into account for the shielding analyses in chapter 5.

The admissible component temperatures of the cask are not exceeded under NCS and meet sufficiently large safety margins.

The following verification objectives are taken into account for the thermal design under ACS:

4. The safe enclosure of the content has to be ensured even for ACS. Therefore, the maximum temporary temperatures of the cask and canister lid gaskets are limited to [redacted] and for the pressure switch gasket, the protection cap gasket and the tightening plug gasket to [redacted]. These are the maximum temporary temperatures for which failure of the metal gaskets can be excluded according to chapter 8.

5. The cladding temperatures are shown to remain below the admissible value of 570 °C for ACS according to [1].

6. The thermal degradation of the moderators shielding effectiveness under ACS is taken into account in the shielding analyses in chapter 5, therefore the assessment of the moderator component temperatures is omitted.

The admissible component temperatures of the cask are not exceeded under ACS and meet sufficiently large safety margins.

List of References

[1] Cladding Considerations for the Transportation and Storage of Spent Fuel
Interim Staff Guidance – 11, Rev. 3
Spent Fuel Project Office
U.S. Nuclear Regulatory Commission (2003)

4.1 Discussion

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed	[redacted]	22.03.2021	

4.1.1 Design Features

A detailed description of the CASTOR® geo69 storage cask can be found in section 1.2. The cask consists of a thick-walled cask body made of ductile cask iron (DCI) and an inner canister made of stainless steel. The canister accommodates up to 69 spent fuel assemblies (FA) from boiling water reactors (BWR). Their maximum decay heat amounts to 18.5 kW, while different homogeneous and heterogeneous loading patterns are possible. A description of the different loading patterns can be found in section 4.1.2.

During storage, the cask stands in vertical position in the storage hall of a storage facility. It is assumed that the cask is fixed with a storage frame to the base plate of the storage hall. This conservatively leads to slightly higher temperatures compared to the case without storage frame. In storage configuration, a protection cover is mounted at the top of the cask.

The safe enclosure of the content is ensured by two independent barriers, the canister with reopenable lid and the cask with bolted lid. Both are sealed by metal gaskets. The temperature of the gaskets is examined in the thermal evaluation for NCS and ACS to ensure the long-term tightening function.

The FA are kept in position by the basket sheets and the outer sheets which ensure besides criticality safety a sufficient heat removal from the FA. The basket sheets are made of boronized aluminium, the outer sheets are made of stainless steel. Additional components inside the canister are the round segments and the shielding elements which are both made of aluminium.

The heat removal within the cask is achieved by conduction, convection and radiation. Conduction takes place mainly inside the walls of the cask and the canister and within the basket sheets. Radiation takes place between all surfaces which border on gas atmosphere. Heat removal from the cask surface to the environment takes place by convection and radiation to the ambience without using active cooling mechanisms or additional coolants. In order to improve the heat dissipation on the outer surface, the cask lateral surface is equipped with cooling fins. Due to the high thermal resistance of the gaps in the lid system, the majority of the thermal energy is dissipated by the fin zone.

To enhance heat removal from the FA, the space between cask and canister and the interior of the canister are backfilled with helium, which has a comparably high thermal conductivity. Additionally, the temperature gradients that occur radially cause a convective flow, which further enhances the heat removal.

Inside the cask wall, [redacted] moderator rods are placed for radial neutron shielding. Furthermore, moderator plates are placed in the cask bottom and in the lid area for axial neutron shielding. All moderator components are made of [redacted].

The containment relevant components of the storage cask are designed in accordance with the 2017 edition of the ASME Boiler and Pressure Vessel Code (BPVC), Section III, Division 3 [1].

4.1.2 Description of the Content

The cask can be loaded with 69 FA of six different types from BWR according to section 1.2.3. The types of FA considered here are listed in Table 4.1-1. The active length of the FA and the axial heat power distribution depend on the type of the FA, the burn-up profile additionally depends on the irradiation time and the decay time. For the modelling of the FA, the most unfavourable characteristics are considered, see section 4.4.1.4 for details.

The maximum summarized decay heat of the FA is limited to 18.5 kW. Three bounding loading patterns are defined, all fitting into a certain scheme of six position groups of FA in the fuel basket. These loading patterns are identified by their decay heat per FA and are called thermal requirements. The three thermal requirements considered here are shown in Figure 4.1-1. [redacted] For the thermal evaluation of NCS, all thermal requirements are examined. The most unfavorable thermal requirement is investigated for the evaluation of ACS.

Table 4.1-1 Considered types of FA

[redacted]

[redacted]

Figure 4.1-1 Thermal Requirements 1–3 with maximum decay heat per FA position in W

4.1.3 Summary Tables of Temperatures

The component temperatures of the storage cask are summarized in Table 4.4-2 for NCS with a conservatively high ambient temperature (hot case) and discussed in section 4.4.2. For NCS with a conservatively low ambient temperature (cold case), the component temperatures are assumed to be uniformly at -40 °C as discussed in section 4.4.3. The maximum temperatures for ACS together with the time of occurrence are given in Table 4.6-1 and discussed in section 4.6.2. The applicable temperature limits of the materials and components are given in Table 4.3-1.

4.1.4 Summary Tables of Maximum Pressures

The calculation of the maximum pressures for NCS, off-normal conditions and ACS and a discussion on flammable gases can be found in the containment evaluation in chapter 7.

List of References

[1] 2017 ASME Boiler and Pressure Vessel Code, An International Code
Section III Rules for Construction of Nuclear Facility Components
Division 3 Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material

4.2 Summary of Thermal Properties of Materials

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed	[redacted]	22.03.2021	

The relevant material data of the components of the cask used in the thermal calculations are

- the thermal conductivity k, W/(m·K),
- the density ρ, kg/m³,
- the specific heat capacity c, J/(kg·K) and
- the emissivity ε.

In the following tables, only the material data of components of the cask in storage configuration is listed which are additional to the transport configuration. This comprises the material data for the protection cover, the storage frame and the concrete base plate of the storage hall. The values are in accordance with the ASME Boiler and Pressure Vessel Code, Part II Section D (Metric) and are listed in Table 4.2-1 and Table 4.2-2. The enhancement of the thermal conductivity due to the reinforcement of the concrete base plate is neglected conservatively. The remaining material data of the cask is documented in the SAR (transport).

Table 4.2-1 Material data of cask and canister components

Component (Material)	Reference	Temperature, °C	Heat conductivity, W/(m·K)	Density, kg/m³	Specific heat capacity, J/(kg·K)
Protection cover, storage frame[1] (SA-738M Gr. C)	Chapter 8	20 50 100 150 200 250 300 350 400	60.4 59.8 58.0 55.9 53.6 51.4 49.2 47.0 44.9	7750	431 453 480 500 516 534 553 575 600
Base plate of the storage hall (concrete)	[1], [2]	–	2.1	2000	920

[1] Material assumed for storage frame.

Table 4.2-2 Emission coefficients

Surface	Reference	Emissivity
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
Emissivity of the fire	10 CFR 71 (§ 71.73(c)(4))	0.9
Sooted cask surface (during fire and cooling phase)	10 CFR 71 (§ 71.73(c)(4))	0.8

List of References

[1] [redacted]

[2] [redacted]

4.3 Specifications for Components

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

The temperatures of the following components of the cask and content are limited to certain maximum admissible values under NCS and off-normal conditions (see section 4.0):

- the lid gaskets,
- the fuel rod cladding and
- the moderator material.

The applicable temperature limits of the components and materials are listed in Table 4.3-1.

The integrity of the fuel rod cladding has to be ensured. For this purpose, the maximum cladding temperature shall not exceed the admissible limit of 400 °C for NCS and off-normal conditions according to [1].

The safe enclosure of the content has to be ensured. For this purpose, the temperatures of the design-relevant lid gaskets have to stay below the admissible limit value of [redacted] according to chapter 8 for continuous operation. Furthermore, the temperatures of the lid gaskets and the mean temperature of the filling gas in the cask cavity are used for the verification of the containment in chapter 7.

The effectiveness of the shielding is ensured when the maximum temperatures of the moderator components are below the maximum admissible application temperatures of [redacted] according to chapter 8. Furthermore, the mean temperatures of the moderator components are used for the shielding analyses in chapter 5.

The shielding elements and the round segments in the fuel basket are made of aluminium (SB-209 Alloy 5454). For these components it is shown that the calculated temperatures are far below the melting temperature of 603 °C.

Under ACS, the safe enclosure of the content has to be ensured. Therefore, the maximum temperatures of the cask and canister lid gaskets are limited to [redacted]. The maximum temperatures of the gaskets of the protection cap, the pressure switch and the tightening plug are limited to [redacted]. These are the maximum temporary temperatures for which failure of the metal gaskets can be excluded according to chapter 8.

The cladding temperatures are shown to remain below the admissible value of 570 °C for ACS according to [1].

As the thermal degradation of the moderators shielding effectiveness under ACS is taken into account in the shielding analyses in chapter 5, assessment of the moderator component temperatures is omitted.

Table 4.3-1 Temperature limits of components

Component (Material)	Literature	Maximum admissible temperature NCS, °C	Maximum admissible temperature ACS, °C
Cladding	[1]	400	570
Gaskets	Chapter 8	[redacted]	[redacted]
Moderator material [redacted]	Chapter 8	[redacted]	–
Cask body (Ductile cast iron SA-874M)	Chapter 8	343	–
Canister body (SA-240M 316L)	Chapter 8	427	–
Head ring (SA-182M FXM-19)	Chapter 8	427	–
Canister lid (SA-965M FXM-19)	Chapter 8	427	–
Cask lid, retention ring (SA-182M Gr F316)	Chapter 8	427	–
Closure plate (SA-240M 22Cr-5Ni-3Mo-N)	Chapter 8	316	–
Basket sheets (Al-B4C-MMC)	Chapter 8	[redacted]	–
Outer sheets (SA-240M 316)	Chapter 8	427	–

List of Reference

[1] Cladding Considerations for the Transportation and Storage of Spent Fuel
Interim Staff Guidance – 11, Rev. 3
Spent Fuel Project Office
U.S. Nuclear Regulatory Commission (2003)

4.4 Thermal Evaluation for Normal Conditions of Storage

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

In this section, the thermal performance of the cask during storage under NCS is evaluated. The cask stands in vertical position in the storage hall of a storage facility.

4.4.1 Thermal Model

The calculation methods based on a numerical model following the finite element method (FEM), including the geometrical model, the boundary conditions and further assumptions under NCS are described in the following sections. For the evaluation under NCS, steady-state calculations are carried out for the cask standing in an array of equal casks in a storage hall.

4.4.1.1 Calculation Methods

The calculation methods for the thermal analyses are validated for the thermal design of transport and storage casks for steady-state and transient investigations. This includes especially the comparison of calculation results with experimental test results.

For the numerical calculations, the FEM software ANSYS® Mechanical [1] is used. ANSYS®, Inc. extensively verifies and validates the ANSYS® program as part of a quality assurance process. Additionally, each used program version is verified and validated especially for the application to the thermal design of transport and storage casks by GNS.

4.4.1.2 Geometric Modelling

For the numerical calculations, a three-dimensional finite element (3D FE) model is used, representing in circumferential direction one half of the cask and content taking into account its symmetry. The FE model is shown in Figure 4.4-1 to Figure 4.4-3. The FE model consists of approximately [redacted]. The FE model contains all thermally relevant components of the design parts lists. Section 1.2.1 contains the design parts lists and the corresponding design drawings with the component dimensions. The material properties as described in section 4.2 are used.

In the storage configuration, the cask itself and the content are identical to the transport configuration. In contrast to the transport configuration, impact limiters are not mounted. In storage configuration, a protection cover is mounted at the top of the cask (see Figure 4.4-1). The cask is fixed with a storage frame to the base plate of the storage hall. Additionally, the FE model contains a section of the base plate [redacted]

The FA are not resolved in detail but are modelled as homogenized zones with effective material properties. The calculation of these effective material properties is described in section 4.4.1.4. The cooling fins on the cask cylindrical surface are not modelled explicitly, too. Instead, the improved convective heat transfer is taken into account by an effective surface enlargement factor, which is explained in section 4.4.1.3.

[redacted]

The free space within the canister and the space between canister and cask are backfilled with the filling gas helium. The gap around the bottom moderator plate is filled with dry air.

As heat transfer mechanisms thermal conduction in the solids and the gas atmospheres as well as heat radiation between all free surfaces are considered. Heat transfer by radiation is modelled explicitly using the radiation matrix method in ANSYS® [1]. All gases inside the cask are assumed as stagnant. The positive effects on heat transfer by convective flows are neglected.

Conservatively, the FA are centrically arranged in the basket positions, as well as the basket in the canister and the canister in the cask. The individual basket sheets have no contact among each other. Gaps are modelled conservatively between the individual basket sheets in radial and axial direction. This applies also to the connection to the round segments and the shielding elements.

For all component dimensions, nominal values from the design drawings are used. The manufacturing tolerances of the components are tight, so that their impact on the temperature distribution is neglected.

Exceptions are the radial gaps between cask and canister and between canister and basket because they significantly influence the heat removal which mainly takes place in radial direction. The SAR (transport) contains a discussion about the gap widths for nominal dimensions and under consideration of the most unfavourable manufacturing tolerances. Comparative calculations show that even for this worst case the gap widths can be extended up to two times until the maximum admissible temperatures are reached. This shows that sufficiently large safety margins exist.

[redacted]

Figure 4.4-1 3D FE model of the storage cask – overall view

[redacted]

Figure 4.4-2 3D FE model of the storage cask – detailed view

[redacted]

Figure 4.4-3 3D FE model of the storage cask – cross section

4.4.1.3 Modelling of the Fins

The cask cylindrical surface is equipped with radial fins in order to improve the convective heat removal. The cooling fins are not modelled explicitly in the FE model. Instead, the improved convective heat transfer is taken into account by an effective surface enlargement factor. At the smooth cylindrical cask surface in the FE model, where the fins are located, the convective heat transfer coefficient (see section 4.4.1.7) is multiplied by this surface enlargement factor accordingly.

The improvement of the convective heat removal is not identical to the factor of the geometrical enlargement of the surface. This is because a temperature gradient occurs inside the fins due to the finite heat conductivity of the fins which reduces the effectiveness of the fins.

The effective surface enlargement factor is calculated with an analytical approach according to [2]. The analytical approach and the input data are described in detail in the SAR (transport). A conservatively low effective surface enlargement factor of [redacted] results.

4.4.1.4 Modelling of the Fuel Assemblies

The FA are not modelled in detail in the 3D FE model. Instead a simplified geometry is used as shown in Figure 4.4-1 to Figure 4.4-3. [redacted]

The SAR (transport) contains a detailed description of the applied approaches for the modelling of the FA and the resulting effective material data. In the following sections, these approaches are summarized.

4.4.1.4.1 Axial Thermal Conductivity, Density and Heat Capacity

[redacted]

[redacted]

[redacted]

4.4.1.4.2 Radial Thermal Conductivity

[redacted]

[redacted]

[redacted]

Figure 4.4-4 Comparison of the simplified and the detailed FA model

[redacted]

Figure 4.4-5 Comparison of the temperature distribution in the detailed and the simplified FA model

[redacted]

[redacted]

4.4.1.4.3 Axial heat power distribution

The decay heat power is distributed heterogeneously along the active length of the FA with a peaking approximately at half height. The detailed axial heat power distributions are calculated for all intended types of FA and for various decay times. The calculations are based on the burn-up calculations presented in section 1.2.3. The resulting peaking factors are summarized in Table 4.1-1 in section 4.1.2.

[redacted]. The detailed profiles [redacted]re shown in Figure 4.4-6.

[redacted]

4.4.1.4.4 Summary

[redacted]

[redacted]

Figure 4.4-6 Detailed and simplified axial heat power profiles

4.4.1.5 Heat Removal Mechanisms

The heat removal from the storage cask to the ambience is purely passive. An active heat removal system is not necessary.

The decay heat generated in the pellets is transferred by thermal conduction and radiation to the cladding tubes. From there, it is transferred via thermal radiation, convection and conduction to the fuel channels, the fuel basket and the canister body and lid. Between the canister and the cask bodies and lids, the heat transfer also occurs by conduction, convection and radiation. Within the canister and cask bodies and lids, the heat is transferred by conduction only. Most of the heat is transferred radially to the cask surface.

Conservatively, the calculation does not take into account the convective heat transfer inside the canister and the cask. Therefore, in all gaps filled with helium or air, only conduction and radiation is considered.

From the outer surface of the cask, the heat is mainly removed by convection to the ambient air inside the storage hall. To enhance convective heat transfer, the cylindrical surface of the cask is equipped with fins. Additionally, heat is transferred by thermal radiation to the colder structures of the storage hall. The heat removal by radiation is restricted by the neighbouring casks having the same surface temperature because they are assumed to be of the same type and have the same heat power. A minor part of the heat is removed by conduction through the base plate of the storage hall.

4.4.1.6 Modelling of the Neighbouring Casks and the Storage Hall

Under NCS, the storage cask stands in an array of equal casks inside a storage hall. The pitch of the array (distances between the cask axes) amounts to 3 m. Figure 4.4-7 (left) shows the cask standing in an array with other casks.

[redacted]

Figure 4.4-7 Cask in an array [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.4.1.7 Boundary Conditions

This section describes the boundary conditions applied under NCS. The storage cask stands in an array of equal casks inside a storage hall. The heat removal from the cask surface occurs by free convection to the surrounding air and radiative heat transfer to the colder structures of the storage hall. The heat removal by thermal radiation is reduced by neighbouring casks [redacted]

For the ambient temperature for convection $T_{A,conv}$, an air temperature of [redacted] is applied. This is the maximum air temperature between the casks [redacted]

[redacted]

On the cylindrical surface of the cask, a convective heat transfer coefficient h_{conv} is applied which is derived from the following Nusselt law according to [2] for turbulent heat transfer by free convection at a vertical cylinder:

[redacted]

with: [redacted]

The Nusselt number Nu is defined as:

$$Nu = h \cdot L / k$$

with:
- h – heat transfer coefficient, $W/(m^2 \cdot K)$
- L – characteristic length (cask height), m
- k – thermal conductivity, $W/(m \cdot K)$

The Grashof number Gr is defined as:

$$Gr = g \cdot \beta \cdot \Delta T \cdot L^3 / \nu^2$$

with:
- g – gravitational acceleration, $g = 9.81\ m/s^2$
- β – coefficient of thermal expansion, 1/K
- ΔT – difference between cask surface and ambient temperature $T_C - T_{A,conv}$, K
- L – characteristic length (cask height), m
- ν – Kinematic viscosity, m^2/s

The temperature dependency of the material properties of air is considered according to Table 4.4-1. According to [3], for all material data the mean value over the cask surface temperature and the bulk temperature is taken as reference temperature with the exception of the coefficient of thermal expansion, for which the bulk temperature is used.

For the convective heat transfer within the fin zone of the cask surface, an effective surface enlargement factor of [redacted] is applied which is explained in section 4.4.1.3. The convective heat transfer coefficient h_{conv} is multiplied by this factor.

Table 4.4-1 Material properties of dry air according to [2]

Temperature, °C	k, 10^{-3} W/(m·K)	β, 10^{-3} 1/K	ν, 10^{-7} m^2/s	Pr, –
20	25.69	3.421	153.5	0.7148
30	26.43	3.307	162.9	0.7134
40	27.16	3.200	172.7	0.7122
60	28.60	3.007	192.7	0.7100
80	30.01	2.836	213.5	0.7083
100	31.39	2.683	235.2	0.7070
120	32.75	2.546	257.5	0.7060
140	34.08	2.422	280.7	0.7054
160	35.39	2.310	304.6	0.7050
180	36.68	2.208	329.3	0.7049
200	37.95	2.115	354.7	0.7051
250	41.06	1.912	421.2	0.7063
300	44.09	1.745	491.8	0.7083
350	47.05	1.605	566.5	0.7109
400	49.96	1.486	645.1	0.7137
800	71.54	0.932	1402	0.7342

[redacted]

[redacted]

[redacted]

[redacted] is modelled using the radiation matrix method in ANSYS® [1].

[redacted]

The lateral surfaces of the storage hall base plate are set adiabatic for symmetry reasons. The lower surface of the base plate is conservatively set adiabatic, too, so that the heat flux into the ground beneath is neglected completely. [redacted]

4.4.2 Maximum Temperatures

The resulting maximum temperatures for various components of the storage cask and the content are summarized in Table 4.4-2. The three thermal requirements, as defined in section 4.1.2, only have a minor impact on the temperatures. For thermal requirement 3, the highest temperatures result. The temperature differences compared to thermal requirement 2 are below the rounding tolerance of 1 K. The temperatures of thermal requirement 1 are up to 3 K lower compared to thermal requirement 1.

Figure 4.4-8 to Figure 4.4-10 show the temperature distribution in the cask for all three thermal requirements. Figure 4.4-11 shows the temperature distribution in the lids of the cask and the canister for thermal requirement 3.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The maximum temperature of the fuel rods amounts to 216 °C and is therefore significantly lower than the maximum admissible temperature of 400 °C.
- The maximum temperature for the inner moderator rods is 106 °C, for the bottom moderator plate 118 °C and 94 °C for the lid moderator plate. Therefore, the maximum temperatures of all moderator material are far below the maximum admissible temperature of [redacted].
- The highest gasket temperature of 99 °C occurs in the tightening plug gasket. The maximum admissible temperature for continuous operation of the gaskets is [redacted]. Therefore, all gasket temperatures are far below the temperature limit.
- Furthermore, temperature limits for structural components (e.g. fuel basket sheets) listed in Table 4.3-1, which are relevant for the mechanical integrity, are met.

The evaluation of the results show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins. Large additional safety margins exist because of the conservative approaches for the thermal modelling. The main conservatisms are listed below:

- All components are centrically arranged in their respective mounting positions without contact. This applies especially to the FA, which are centrically arranged in the basket positions, as well as the basket, which is centrically arranged in the canister, and the canister, which is centrically arranged in the cask. In reality, local contacts between the components exist which enhance the heat removal.
- The individual basket sheets have no contact among each other. Instead, gaps are modelled between the individual basket sheets in radial and axial direction. This applies also to the connection to the round segments and the shielding elements.
- The enhanced heat transport by convection in the gas atmospheres inside cask and canister cavities is neglected completely.
- Conservative boundary conditions and material properties are applied.

[redacted]

Table 4.4-2 Component temperatures for NCS for thermal requirements 1–3

Component – type of temperature	Temperature, °C Thermal requirement		
	1	2	3
Fuel rods – maximum	214	216	215
Cask surface – maximum, hottest plane	90	90	91
Cask surface – circumferential average, hottest plane	89	90	90
Cask surface – longitudinal average	88	89	89
Cavity surface – maximum, hottest plane	100	101	101
Cavity surface – circumferential average, hottest plane	99	100	100
Cavity bottom – maximum	120	121	121
Cavity bottom – area average	113	114	115
Closure plate, underside – maximum	102	102	102
Closure plate, underside – area average	99	100	100
Moderator rods, inner row (MR-i) – maximum	105	106	106
MR-i – area average, hottest plane, hottest rod	102	103	103
MR-i – volume average, hottest rod	96	96	96
Moderator rods, outer row (MR-o) – maximum	101	102	102
MR-o – area average, hottest plane, hottest rod	98	99	99
MR-o – volume average, hottest rod	92	93	93
Inner canister surface – maximum	121	122	122
Inner canister surface – circumfer. average, hottest plane	119	120	121
Outer canister surface – maximum	120	121	121
Outer canister surface – circumfer. average, hottest plane	118	120	120
Canister bottom – maximum	136	137	137
Moderator plate, bottom – maximum	117	118	118
Moderator plate, bottom – volume average	108	109	109
Moderator plate, lid – maximum	93	94	94
Moderator plate, lid – volume average	85	86	86
Retention ring – maximum	84	85	85
Closure plate – maximum	102	103	103
Closure plate – volume average	100	100	101

Table 4.4-2 Component temperatures for NCS for thermal requirements 1–3 (continued)

Component – type of temperature	Temperature, °C Thermal requirement 1	2	3
Trunnion – maximum	96	97	97
Trunnion screws[1] – maximum	105		
Fuel channels – maximum	205	203	204
Basket sheets – maximum	202	201	202
Round segment – maximum	160	162	162
Outer sheets – maximum	166	168	169
Shielding element – maximum	165	168	167
Canister filling gas – volume average	166	168	169
Cask filling gas – volume average	99	99	100
Canister lid – maximum	107	108	108
Canister lid – volume average	100	101	101
Canister lid gasket – maximum	96	97	97
Canister lid screws[1] – maximum	105		
Cask lid – maximum	82	82	82
Cask lid – volume average	80	81	81
Cask lid gasket – maximum	82	82	82
Cask lid screws[1] – maximum	90		
Protection cap gasket – maximum	81	81	81
Pressure switch gasket – maximum	81	81	81
Tightening plug gasket – maximum	98	99	99

[1] for the screw temperatures, the surface temperature of the corresponding component plus a safety margin is used

[redacted]

Figure 4.4-8 Temperature distribution in the cask for NCS for thermal requirement 1

[redacted]

Figure 4.4-9 Temperature distribution in the cask for NCS for thermal requirement 2

[redacted]

Figure 4.4-10 Temperature distribution in the cask for NCS for thermal requirement 3

[redacted]

Figure 4.4-11 Temperature distribution in the lids for NCS for thermal requirement 3

4.4.3 Minimum Temperatures

In this section, the temperatures of the storage cask are examined for a conservatively low ambient temperature of −40 °C and the minimum admissible content heat power which is assumed to be zero. Therefore, all components of the cask are assumed to be at ambient temperature of −40 °C.

4.4.4 Maximum Internal Pressures

The calculation of the MNOP and a discussion on the generation of flammable gases is documented in the containment evaluation in chapter 7.

4.4.5 Maximum Thermal Stresses

The occurrence of thermal stresses is minimized by sufficiently large gaps in axial and radial direction, which allows for free thermal expansion of the different components without contact and restraint. The discussion of thermal stresses due to temperature gradients within the components can be found in the structural evaluation in chapter 3.

In the SAR (transport) radial and axial gap widths between cask and canister and between canister and basket are investigated under consideration of thermal expansion. The results in the SAR (transport) show that these gaps are sufficiently large to prevent contact and restraint forces. This applies also to NCS because compared to the SAR (transport) the temperatures of the outer components like the cask body are slightly higher whereas the temperatures of the inner components like the basket are approximately the same. For that reason, the outer components expand more for NCS resulting in larger gaps compared to the SAR (transport).

4.4.6 Evaluation of Cask Performance for Normal Conditions of Storage

It is demonstrated that the CASTOR® geo69 storage cask fulfils all requirements for NCS with regard to thermal aspects. The following items summarize the results of the thermal design:

- The evaluation of the results in section 4.4.2 show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.
- It is demonstrated in section 4.4.2 that additional safety margins exist because of the conservative approaches for the thermal modelling.
- It is proved that the calculated maximum temperatures of the gaskets do not lead to a degradation of the tightening function which is requirement for ensuring the safe enclosure of the content.
- It is shown that the calculated maximum temperatures of the fuel rods do not lead to a degradation of the cladding material which is requirement for ensuring the integrity of the fuel rod cladding. The effects of potential fuel rod failure are discussed in section 4.8.
- It is demonstrated that the calculated maximum temperatures of the moderator components do not lead to a thermal degradation of the moderator material which is requirement for ensuring the effectiveness of the shielding.

- The calculated maximum temperatures of all relevant structural components (e.g. fuel basket sheets) are far below the maximum admissible values guaranteeing the mechanical integrity which is requirement for ensuring heat removal performance and criticality safety.

- It is shown in section 4.4.5 that the main gaps in axial and radial direction are sufficiently large to allow for free thermal expansion of the different components without contact and restraint.

- It is discussed in section 4.4.1.2 that the heat removal capability is still ensured even under consideration of the most unfavourable manufacturing tolerances for the radial gaps between cask and canister and between canister and basket and an additional extension of these gap widths by a factor of two.

- The evaluation of the maximum pressure and a discussion on the generation of gases is documented in the containment evaluation in chapter 7.

- The influence of the calculated temperatures on the mechanical material properties and thermal stresses is evaluated in the structural evaluation in chapter 3.

List of References

[1] ANSYS®
Release 17.2 UP20160718, © 2016 SAS IP Inc.

[2] [redacted]

[3] [redacted]

4.5 Thermal Evaluation for Off-Normal Conditions

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

In the following sections the influence of off-normal conditions on the thermal design is discussed.

4.5.1 Loss of Power and Instrumentation Failures

The CASTOR® geo69 is a completely passive storage system. In particular, no active cooling system is required for heat removal. For that reason, loss of power and instrumentation failures are not relevant as off-normal conditions.

4.5.2 Blockage of Ventilation Openings

The cask is standing inside a storage hall on the base plate. The cask itself has no ventilation openings but is cooled passively at the outer surface. The prevention of the blockage of ventilation inlets and outlets of the storage hall has to be ensured by adequate constructive measures.

4.5.3 Temperatures beyond Normal

The cask is standing inside a storage hall without direct influence by the environmental temperature at the storage facility site and by insolation. For the calculations under NCS, sufficiently high values are chosen in 4.4.1.7 as maximum ambient temperatures inside the storage hall. These ambient temperatures already consider seasonal variations so that for off-normal conditions no additional calculations are required concerning this matter.

[redacted]

The minimum air temperature inside the storage hall of -40 °C according to section 4.4.3 is sufficiently low to consider off-normal seasonal variations.

4.5.4 Temperatures and Pressures considering Fuel Rod Failure

The CASTOR® geo69 is designed to withstand loads due to off-normal pressure what is shown in the structural evaluation in chapter 3. The temperatures under off-normal conditions including a failure of 10 % of the fuel rods are calculated in section 4.8. The internal pressure under off-normal conditions including a failure of 10 % of the fuel rods is calculated in the verification of the containment in chapter 7.

List of References

4.6 Thermal Evaluation for Accident Conditions

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

Under ACS, a fire accident during storage is considered. The evaluation under ACS comprises an initial steady state, a transient fire phase, when the cask is exposed to a fully-engulfing pool fire with an average flame temperature of 800 °C, and the subsequent transient cooling phase.

4.6.1 Thermal Model

The thermal analyses for ACS are based on the same calculation methods as for NCS. The differing boundary conditions and assumptions under ACS are described in the following sections.

4.6.1.1 Geometric Modelling

For ACS, the same numerical model is used as for NCS with the only exception that [redacted] is not used (see section 4.4.1 and Figure 4.4-1 to Figure 4.4-3).

For the transient calculation under ACS, the heat storage capacity of the fins, which are not modelled in the FE model explicitly, is taken into account. [redacted]

4.6.1.2 Initial State before the fire accident

The initial conditions before the fire accident correspond to the steady state for NCS described in section 4.4. The cask dissipates heat by natural convection and thermal radiation according to the boundary conditions described in section 4.4.1.7.

For ACS, only thermal requirement 3 is considered, as it leads to slightly higher temperatures than the thermal requirements 1 and 2. Therefore, the initial temperature field of the cask is identical to the one shown in Figure 4.4-10 for thermal requirement 3 under NCS.

4.6.1.3 Boundary Conditions during the Fire Phase

As fire accident for storage, the spillage and ignition of 200 l liquid fuel of a transporter vehicle is considered. The following fire conditions are applied according to 10 CFR 71 (§ 71.73(c)(4)):

- The cask is exposed to a fully-engulfing pool fire
- with a constant flame temperature of 800 °C,
- an emissivity of the fire of 0.9 and
- an emissivity of the sooted cask surface of 0.8.
- The fuel source extends horizontally at least 1 m but not more than 3 m beyond the external surface of the cask.

The heat impact by the fire takes place at the external surface of the cask and the upper side of the storage hall base plate by natural convection and thermal radiation. The cask is assumed to still standing in a vertical position so that there is no direct impact of the fire at the bottom-side front face.

An effective heat transfer coefficient h_{eff} is defined on the surfaces exposed to the fire which consists of a convective portion h_{conv} and a radiative portion h_{rad}:

$$h_{eff} = h_{conv} + h_{rad}$$

For the ambient temperature for convection $T_{A,conv}$ and for radiation $T_{A,rad}$, the flame temperature of 800 °C is applied.

For the fire phase, a conservatively high heat transfer coefficient for forced convection h_{conv} of 15 W/(m^2·K) is used which is calculated in the SAR (transport). Within the fin zone of the cask surface, an effective surface enlargement factor of [redacted] is applied which is explained in section 4.4.1.3. The convective heat transfer coefficient h_{conv} is multiplied by this factor.

The radiative portion h_{rad} of the effective heat transfer coefficient is calculated using the Stefan Boltzmann law according to [1]:

[redacted]

with: [redacted]

For the calculation of the effective emission coefficient, the fire is treated as a cylinder surrounding the cask at a distance of 3 m from the external surface of the cask. According to [1], the effective emissivity between two concentric cylinders is given by:

$$\varepsilon_{eff} = [1/\varepsilon_1 + d_1/d_2 \cdot (1/\varepsilon_2 - 1)]^{-1} = 0.779$$

with:
- d_1 – diameter of the cask, $d_1 = 2.54$ m
- ε_1 – emission coefficient of sooted cask surface, $\varepsilon_1 = 0.8$
- d_2 – diameter of the engulfing fire, $d_2 = 2.54\text{ m} + 2 \cdot 3\text{ m} = 8.54$ m
- ε_2 – emission coefficient of fire, $\varepsilon_2 = 0.9$

For the fire accident, the spillage and ignition of 200 l of transporter fuel is assumed conservatively. The fire duration is determined from the fuel volume of 200 l, which is assumed to be spread around the cask in an annular spillage. It is assumed that the liquid fuel has the minimum horizontal extension of 1 m beyond the external surface of the cask. Using the minimum ring width yields a deeper pool for a fixed quantity of liquid fuel and thereby a conservatively long fire duration. This leads to an outer diameter of the fuel ring of 2.54 m + 2 · 1 m = 4.54 m and to a maximum fuel depth of 18 mm. The fuel consumption rate is assumed to be 0.15 in/min (corresponding to 3.8 mm/min), which is the minimum fuel consumption rate given in the Sandia report [2] on large pool fire testing. This leads to a fire duration of 4.7 min. Conservatively, a fire duration of 5 min is assumed for the calculations.

4.6.1.4 Boundary Conditions during the Cooling Phase

Due to the thermal inertia of the cask, the maximum temperatures inside the cask are reached several hours after the end of the fire phase. In the calculations, the cooling phase comprises a sufficiently long time period of 36 hours so that all temperatures of the components of cask and content reach their peak values and decrease again afterwards.

Basically, the boundary conditions during the cooling phase are similar to those for NCS (see section 4.4.1.7). Differing boundary conditions are described below.

At the external surface of the cask and the upper side of the base plate, an effective heat transfer coefficient is applied, which consists of a convective portion h_{conv} and a radiative portion h_{rad}:

$$h_{eff} = h_{conv} + h_{rad}$$

The convective portion h_{conv} is calculated using the following Nusselt law according to [3] for turbulent heat transfer by free convection at vertical planes and cylinders:

[redacted]

The Nusselt number Nu, the Grashof number Gr and the Prandtl number Pr are defined in section 4.4.1.7.

For the first 24 h of the cooling phase, heat removal by thermal radiation is neglected completely to take into account conservatively that the neighbouring casks and structures of the storage hall are heated up to same temperature level as the cask itself:

$$h_{rad} = 0$$

Afterwards, the radiative portion h_{rad} is calculated using the Stefan Boltzmann law according to [2]:

[redacted]

4.6.2 Maximum Temperatures

The basic calculations are carried out with the protection cover mounted at the top of the cask. Within comparative calculations the case without protection cover is considered. Table 4.6-1 lists the maximum temperatures and their time of appearance (t = 0: beginning of fire) for various components of cask and content for the case with mounted protection cover.

Figure 4.6-1 shows the temperature distribution in the cask at the end of the fire phase 5 min after the beginning of the fire when the maximum cask surface temperature is reached. Figure 4.6-2 shows the temperature distribution in the cask 23 h after the beginning of the fire when the hottest fuel rod reaches its maximum temperature. Figure 4.6-3 shows the temperature distribution of the lid system for the times when maximum tempe[redacted] of the cask and the canister lid gaskets are reached. Figure 4.6-4 to Figure 4.6-6 show the temperature courses over time for various components of cask and content.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The hottest fuel rod reaches after 23 h its maximum temperature of 221 °C, which is significantly lower than the maximum admissible fuel rod temperature for ACS of 570 °C.
- The temperatures of the gaskets are between 98 °C and 109 °C, which is considerably lower than the maximum admissible temperatures of [redacted] for the cask lid gasket and canister lid gasket and [redacted] for the pressure switch gasket, the protection cap gasket and the tightening plug gasket.

The evaluation of the results show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.

Table 4.6-2 shows the results for the case without mounted protection cover. Compared to the results for the case with protection cover in Table 4.6-1, the maximum temperatures of the gaskets in the cask lid are by 44–58 K higher because of the direct impact of the fire whereas the maximum temperatures of the gaskets in the canister lid remain approximately the same ($\Delta T \leq 2$ K).

The temperatures for the post-fire steady-state conditions are similar to the temperatures for the results of the initial state. Exemplarily, the post-fire steady-state temperature for the cask surface amounts to approximately 95 °C, which is 4 K above the temperature of the results for the initial state (see Figure 4.6-6). This is mainly due to the fact that the emissivity after the fire of the sooted cask surface ([redacted]) is lower than for the initial state ([redacted]). All other component temperatures shift accordingly.

Table 4.6-1 Maximum component temperatures for ACS with protection cover and time of appearance after beginning of the fire

Component – type of temperature	Maximum temperature, °C	Time of appearance, h
Fuel rods – maximum	221	23.0
Cask surface – maximum, half height	212	0.1
Cavity surface – maximum, half height	118	2.8
Moderator rods, inner row (MR-i) – maximum	119	1.0
MR-i – area average, hottest plane, hottest rod	117	2.2
MR-i – volume average, hottest rod	114	2.8
Moderator rods, outer row (MR-o) – maximum	145	0.2
MR-o – area average, hottest plane, hottest rod	119	1.2
MR-o – volume average, hottest rod	113	1.7
Moderator plate (bottom) – maximum	126	16.0
Moderator plate (bottom) – volume average	116	14.0
Moderator plate (lid) – maximum	105	35.0
Moderator plate (lid) – volume average	99	14.0
Canister wall – maximum	134	3.5
Basket sheets – maximum	208	24.0
Shielding elements – maximum	174	17.0
Canister filling gas – volume average	175	21.0
Cask filling gas – volume average	111	5.0
Canister lid gasket – maximum	107	20.0
Cask lid gasket – maximum	100	3.0
Protection cap gasket – maximum	98	6.5
Pressure switch gasket – maximum	99	5.5
Tightening plug gasket – maximum	109	32.0

[redacted]

Figure 4.6-1 Temperature distribution at the time of the end of the fire (ACS)

[redacted]

Figure 4.6-2 Temperature distribution in the cask at the time of maximum fuel rod temperature (ACS)

[redacted]

Figure 4.6-3 Temperature distribution in the lid system at the time of maximum gasket temperatures (ACS)

[redacted]

Figure 4.6-4 Temperatures of the hottest fuel rod and the filling gases over time (ACS)

[redacted]

Figure 4.6-5 Temperatures of the lid gaskets over time (ACS)

[redacted]

Figure 4.6-6 Temperatures on the surfaces of cask, cavity and canister on half height over time (ACS)

Table 4.6-2 Maximum component temperatures for ACS without protection cover and time of appearance after beginning of the fire

Component – type of temperature	Maximum temperature, °C	Time of appearance, h
Fuel rods – maximum	222	23.0
Cask surface – maximum, half height	212	0.1
Cavity surface – maximum, half height	118	2.8
Moderator rods, inner row (MR-i) – maximum	119	1.0
MR-i – area average, hottest plane, hottest rod	117	2.2
MR-i – volume average, hottest rod	114	2.8
Moderator rods, outer row (MR-o) – maximum	145	0.2
MR-o – area average, hottest plane, hottest rod	119	1.2
MR-o – volume average, hottest rod	113	1.7
Moderator plate (bottom) – maximum	126	16.0
Moderator plate (bottom) – volume average	116	14.0
Moderator plate (lid) – maximum	123	0.7
Moderator plate (lid) – volume average	111	2.2
Canister wall – maximum	134	3.5
Basket sheets – maximum	208	24.0
Shielding elements – maximum	174	17.0
Canister filling gas – volume average	175	20.0
Cask filling gas – volume average	115	3.0
Canister lid gasket – maximum	109	8.5
Cask lid gasket – maximum	145	0.2
Protection cap gasket – maximum	142	0.2
Pressure switch gasket – maximum	157	0.1
Tightening plug gasket – maximum	110	14.0

4.6.3 Maximum Internal Pressures

The calculation of the maximum internal pressures under ACS and a discussion on the generation of flammable gases is documented in the containment evaluation in chapter 7.

4.6.4 Maximum Thermal Stresses

The occurrence of thermal stresses is minimized by sufficiently large gaps in axial and radial direction, which allows for free thermal expansion of the different components without contact and restraint. The discussion of thermal stresses due to temperature gradients within the components can be found in the structural evaluation in chapter 3.

The radial and axial gap widths between cask and canister and between canister and basket are sufficiently large for the following reasons. The temperatures in initial state before the fire are the same as for NCS. For that reason the argumentation of section 4.4.5 applies also for the initial state. In the SAR (transport), the temporal courses of the gap widths during a fire and cooling phase are calculated. The results show that with increasing time the gap widths grow to peak values and decrease again afterwards. That is because the outer components like the cask body heat up and expand earlier and stronger than the inner components like the basket. The temperatures in the final steady state are identical to the initial state so that the same gap widths appear.

4.6.5 Evaluation of Cask Performance for Accident Conditions of Storage

It is demonstrated that the CASTOR® geo69 storage cask fulfils all requirements for the fire accident under ACS with regard to thermal aspects. The following items summarize the results of the thermal investigation:

- The evaluation of the results in section 4.6.2 show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.
- It is proved that the calculated maximum temperatures of the gaskets do not lead to a degradation of the tightening function which is requirement for ensuring the safe enclosure of the content.
- It is shown that the calculated maximum temperatures of the fuel rods do not lead to a degradation of the cladding material which is requirement for ensuring the integrity of the fuel rod cladding. The effects of potential fuel rod failure are discussed in section 4.8.
- It is shown in section 4.6.4 that the main gaps in axial and radial direction are sufficiently large to allow for free thermal expansion of the different components without contact and restraint.
- The evaluation of the maximum pressure and a discussion on the generation of gases is documented in the containment evaluation in chapter 7.
- The influence of the calculated temperatures on the mechanical material properties and thermal stresses is evaluated in the structural evaluation in chapter 3.

List of References

[1] [redacted]

[2] [redacted]

[3] [redacted]

4.7 Thermal Evaluation for Short-Term Operations

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

In this section, short-term operations inside the reactor facility are investigated. The different operation phases comprise the fuel loading of the canister inside the transfer cask under water, the dewatering, vacuum drying and helium backfilling of the canister interior as well as the transport of the transfer cask inside the reactor building.

4.7.1 Thermal Properties of Materials

The relevant material data of the components of the cask used in the thermal calculations are

- the thermal conductivity k, W/(m·K),
- the density ρ, kg/m^3,
- the specific heat capacity c, J/(kg·K) and
- the emissivity ε.

The following tables contain the material data of components of the transfer cask. The values are in accordance with the ASME Boiler and Pressure Vessel Code, Part II Section D (Metric) and are listed in Table 4.7-1 and Table 4.7-2. The material data of the canister, the fuel basket and the content are the same as described in the SAR (transport). Table 4.7-3 contains the thermal properties of helium, air and water vapour which are considered in the calculations as gas atmospheres in the interior of the transfer cask.

Table 4.7-3 also contains the thermal properties of liquid water filled in in the inner and outer water chamber in the cask wall. To take into account the enhanced heat transfer by free convection, an effective heat conductivity k_{eff} is defined for the water in the chambers:

[redacted]

Liquid water has a high heat transfer coefficient for free convection o[redacted]

Table 4.7-1 Material data of the transfer cask

Component (Material)	Reference	Temperature, °C	Heat conductivity, W/(m·K)	Density, kg/m³	Specific heat capacity, J/(kg·K)
Liner, bottom ring, enclosure lead shield, enclosure inner/outer water chamber, lid (SA-240M 316L)	Chapter 8	20 100 150 200 250 300 350 400	14.1 15.4 16.1 16.8 17.6 18.3 19.0 19.7	8030	492 511 519 526 533 540 546 553
Head ring, bottom lid (SA-182M FXM-19)	Chapter 8	See SA-240M 316L			
Lead shield (DIN EN 12659 PB940R)	Chapter 8	0 25 127 150 200 227 250 300 326	35.5 – – 33.0 – – 31.8 – 31.0	11340	– 129 132 – – 137 – – 142

Table 4.7-2 Emission coefficients

Surface	Reference	Emissivity
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 4.7-3 Material data of fluids

Fluid	Reference	Temperature, °C	Heat conductivity, W/(m·K)	Density, kg/m³	Specific heat capacity, J/(kg·K)
Helium	[2]	25 100 200 300 400	0.1536 0.1793 0.2116 0.2420 0.2708	0.166	3115 (ρ = const.)
Air	[2]	20 100 200 300 400	0.0257 0.0314 0.0380 0.0441 0.0500	1.188	720 (ρ = const.)
Water vapour	[2]	25 100 200 300 400	0.0186 0.0251 0.0332 0.0433 0.0555	0.0046 (0.01 bar)	1870 (ρ = const.)
Liquid water (in inner/outer water chamber)	[2]	20 30 40 50 60 70 80 90 100	[redacted] (inner/outer, including free convection)	998 996 992 988 983 978 972 965 959	4185 4180 4179 4180 4183 4188 4196 4205 4216

4.7.2 Fuel Loading under Water

In the operation phase considered here, the transfer cask is loaded with fuel in the pool under water. The interior of the transfer cask is filled with water and the lid of the canister is not yet mounted. This allows for a free interchange of water by convection between the interior of the canister and the pool. For the pool water a conservatively high temperature of 50 °C is assumed.

The temperature of the water in the interior of the transfer cask has almost the pool water temperature of 50 °C because of the free interchange by convection with the pool water. The temperatures of the transfer cask components also have almost the pool water temperature of 50 °C because of the good heat transfer conditions at the surfaces bordering on water. Liquid water has a high heat transfer coefficient for free convection o[redacted] according to [1].

Consecutively, the cladding temperatures of the FA are estimated. The surface of the fuel rods of a single FA of type GE8x8-1 in the area of the active zone amounts to $63 \cdot 3.708\ m \cdot \pi \cdot 12.52\ mm = 9.2\ m^2$ (see Table 4.1-1 and SAR (transport)). With a maximum heat power of 450 W per FA, the heat power density amounts to 49 W/m^2. With a conservatively low heat transfer coefficient for free convective in water of [redacted], the temperature difference between the fuel rod surface and the pool water is ΔT = [redacted].

Conservatively, a constant temperature of 50 °C is chosen for the components of the water-filled transfer cask and the content for the time under water until the canister lid is mounted.

As long as the water-filled transfer cask is under water and the canister lid is not yet mounted, no temporal restrictions are required for this operation phase.

4.7.3 Water-Filled Cask

In the operation phase considered here, the interior of the transfer cask is filled with water and the lid of the canister is mounted. This operation phase starts with mounting the canister lid under water and ends with the beginning of the dewatering. As estimated in the previous section 4.7.2, the components of the transfer cask and the content have a constant temperature of 50 °C at the beginning of the operation phase when the canister lid is mounted.

After mounting the canister lid, the components of the transfer cask and the content continuously heat up because the interchange of water by convection between the interior of the canister and the pool is interrupted. Furthermore, the heat removal at the outer surface of the transfer cask degrades after partly lifting out of the pool water because the heat is now partly transferred to air with a significantly lower convective heat transfer coefficient than water.

During heating, the heat power of the FA is stored partly in the transfer cask. Furthermore, a portion of the heat power is dissipated over the transfer cask surface which conservatively is neglected completely.

With the following analytical calculation the duration within the transfer cask heats up from 50 °C to 100 °C, which is the boiling temperature at a pressure of 1 bar, is estimated. It is assumed that all components of the transfer cask and the content heat up uniformly because of the good heat transfer conditions inside the water-filled transfer cask. For the heat power the maximum value of 18.5 kW is considered.

The time period is calculated using the following equation for the internal energy according to [2]:

$$\Delta t = \sum(m_i \cdot c_{p,i}) \cdot (T_E - T_S) / \dot{Q}$$

with:
- m_i – mass of the component i (see Table 4.7-4), kg
- $c_{p,i}$ – specific heat capacity of the component i (see Table 4.7-4), J/(kg·K)
- T_S – start temperature of the transfer cask and content, T_S = 50 °C
- T_E – end temperature of the transfer cask and content, T_E = 100 °C
- $\dot{Q}$ – heat power of the content, $\dot{Q}$ = 18500 W

The time period until the boiling temperature of 100 °C at a pressure of 1 bar is reached inside the transfer cask amounts to Δt = [redacted] In reality, it will take longer because the portion of the heat power dissipated over the transfer cask surface is neglected completely, although most of the transfer cask surface is still under water.

For the operation phase with the water-filled transfer cask, the time period after mounting of the canister lid until the beginning of the dewatering has to be restricted to [redacted]

Table 4.7-4 Heat capacity of the components of transfer cask and content

Component	Mass, kg	Specific heat capacity, J/(kg·K)	Heat capacity, J/K
Cask body	15999	492	7871508
Cask lid	764	492	375888
Bottom lid	4488	492	2208096
Water in inner water chamber	1403	4185	5871555
Water in outer water chamber	1834	4185	7675290
Lead shield	17073	130	2219490
Content (69 BWR-FA)	22011	303	6669333
Basket, aluminium parts	7080	898	6357840
Basket, shielding elements	1980	898	1778040
Outer sheets	1720	492	846240
Canister, empty with canister lid	10910	482	5258620
Water in canister	5700	4185	23854500
Sum	90962		**70986400**

4.7.4 Vacuum Drying

The vacuum drying follows the dewatering of the canister. During the vacuum drying, the interior of the canister is filled with pure water vapour. Because of the low thermal conductivity of water vapour in comparison to liquid water or helium, the most unfavourable conditions for heat removal of all operation phases exist during vacuum drying. Conservatively, it is assumed that the space between canister and transfer cask is dewatered at the same time and is afterwards also filled with water vapour.

The following investigations comprise an initial steady state and a subsequent transient heating phase. Aim is to determine the maximum admissible time period until the first limit temperature in the transfer cask is reached.

4.7.4.1 Thermal Model

The calculation methods for short-term operation in principle correspond to the approach for NCS described in section 4.4.1. In the following sections mainly the differences in the thermal modelling are described.

4.7.4.2 Geometric Modelling

For the numerical calculations, a 3D FE model is used, representing in circumferential direction one half of the transfer cask and content taking into account its symmetry. The FE model is shown in Figure 4.7-1 to Figure 4.7-3. The FE model consists of approximately [redacted] elements. The FE model contains all thermally relevant components of the design parts lists. Section 1.2.1 contains the design parts lists and the corresponding design drawings with the component dimensions. The material properties as described in section 4.7.1 are used.

The geometrical model corresponds to the FE model described in section 4.4.1 for NCS with the only exception that the canister during operation is loaded in the transfer cask instead of the storage cask. The modelling of the canister, the fuel basket and the FA is exactly the same and is described in section 4.4.1 in detail. The transfer cask is not equipped with cooling fins. The interior of the canister and the space between canister and transfer cask are filled with pure water vapour.

[redacted]

Figure 4.7-1 3D FE model of the transfer cask – overall view

[redacted]

Figure 4.7-2 3D FE model of the transfer cask – detailed view

[redacted]

Figure 4.7-3 3D FE model of the transfer cask – cross section

4.7.4.3 Initial Steady State

Respecting the temperature limit derived in section 4.7.2 for the transfer cask filled with liquid water, the FA have a temperature of not more than 100 °C. For the initial steady state, conservatively a fixed temperature of 110 °C is impressed as boundary condition to the FA.

At the external surface of the transfer cask, a fixed temperature of 83 °C is impressed as boundary condition for the initial steady state conservatively. This is the maximum cask surface temperature according to Table 4.7-6 after completely heating up to steady state.

4.7.4.4 Boundary Conditions

This section describes the boundary conditions applied to the transfer cask during vacuum drying. The transfer cask stands inside the reactor facility. The heat removal from the cask surface occurs by free convection to the surrounding air and radiative heat transfer to the colder structures of the reactor facility.

For the ambient temperature for convection $T_{A,conv}$, a conservatively high air temperature of 35 °C is applied. The ambient temperature for radiation $T_{A,rad}$ represents the temperature of the inner structures of the reactor facility and is set also to 35 °C.

At the external surface of the cask, an effective heat transfer coefficient is applied, which consists of a convective portion h_{conv} and a radiative portion h_{rad}:

$$h_{eff} = h_{conv} + h_{rad}$$

On the cylindrical surface of the cask, a convective heat transfer coefficient h_{conv} is applied which is derived from the following Nusselt law according to [2] for turbulent heat transfer by free convection at a vertical cylinder:

[redacted]

with: [redacted]

The Nusselt number Nu, the Grashof number Gr and the Prandtl number Pr are defined in section 4.4.1.7.

In order to take into account partial disturbance of the convective heat transfer by a scaffold or potential additional shielding mounted to the transfer cask, the convective heat transfer coefficient h_{conv} is reduced by a factor of [redacted].

At the lid-side front face of the cask, the convective portion h_{conv} is calculated using the following Nusselt law according to [2] for turbulent heat transfer by free convection at a horizontal plane in case of heat release at the upper side:

[redacted]

The radiative portion h_{rad} is calculated using the Stefan Boltzmann law according to [2]:

[redacted]

The bottom-side front face of the cask is set adiabatic conservatively.

4.7.4.5 Maximum Temperatures

After dewatering, the interior of the canister and the space between canister and transfer cask are filled with pure water vapour. Accordingly, the transfer cask and the content heat up during vacuum drying. The following results apply for the time period when the first limit temperature in the transfer cask is reached. This occurs at the end of a time period of [redacted] with pure water vapour atmosphere for the basket sheets which have a limit temperature of [redacted] according to Table 4.3-1. At the end of a time period of [redacted], the backfilling of the interior of the canister with helium has to start.

During dewatering, the water level declines continuously. Conservatively, the time period of dewatering is included completely in the time limit for vacuum drying of [redacted]

For the time limit of vacuum drying of [redacted] Table 4.7-5 summarizes the resulting maximum temperatures for various components of the transfer cask and the content. Figure 4.7-4 shows the temperature distribution in the transfer cask at the time limit of vacuum drying.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The maximum temperature of the fuel rods amounts to 281 °C and is therefore significantly lower than the maximum admissible temperature of 400 °C.
- The maximum temperature for the lead shield is 79 °C which is far below the melting temperature of 327 °C.
- The highest gasket temperature of 92 °C occurs in the tightening plug gasket. The maximum admissible temperature for continuous operation of the gaskets is [redacted]. Therefore, all gasket temperatures are far below the temperature limit.
- The maximum temperature inside the water chambers amounts to 77 °C which is below the boiling temperature of 100 °C at a pressure of 1 bar. In reality, a higher safety margin exits because the water chambers are designed for a gauge pressure of 3 bar in the structural evaluation in chapter 3. This corresponds to an absolute pressure of 4 bar leading to a boiling temperature of 143 °C.
- Furthermore, temperature limits for structural components listed in Table 4.3-1, which are relevant for the mechanical integrity, are met. For the fuel basket sheets, the limit value of [redacted] is reached. It has to be noted that this value is not a material limit of failure. According to fatigue strength analyses, a temperature of [redacted] is admissible for continuous operation. For that reason, a temperature of [redacted] is allowable for short-term operations.

The evaluation of the results show that all calculated maximum temperatures of the transfer cask components and the content are far below the maximum admissible values with large safety margins.

Table 4.7-5 Component temperatures for the transfer cask at the time limit of vacuum drying

Component – type of temperature	Temperature, °C
Fuel rods – maximum	281
Cask surface – maximum, hottest plane	72
Cask surface – circumferential average, hottest plane	72
Cask surface – longitudinal average	62
Water chamber, outer – maximum	74
Water chamber, inner – maximum	77
Lead shield – maximum	79
Cavity surface – maximum, hottest plane	88
Cavity surface – circumferential average, hottest plane	88
Bottom lid, upper side – maximum	130
Bottom lid, upper side – area average	112
Bottom lid, underside – maximum	128
Bottom lid, underside – area average	101
Inner canister surface – maximum	135
Inner canister surface – circumferential average, hottest plane	131
Outer canister surface – maximum	134
Outer canister surface – circumferential average, hottest plane	130
Canister bottom – maximum	166
Trunnion – maximum	56
Fuel channels – maximum	[redacted]
Basket sheets – maximum	[redacted]
Round segment – maximum	196
Outer sheets – maximum	207
Shielding element – maximum	210
Canister filling gas – volume average	216
Cask filling gas – volume average	85
Canister lid – maximum	101
Canister lid – volume average	93
Canister lid gasket – maximum	90
Tightening plug gasket – maximum	92
Cask lid – maximum	53
Cask lid – volume average	50

[redacted]

Figure 4.7-4 Temperature distribution in the transfer cask at the time limit of vacuum drying

4.7.5 Helium Backfilling

After dewatering and vacuum drying, the interior of the canister is backfilled with helium. The space between canister and transfer cask is filled with dry air. In this section, the maximum temperatures are calculated after heating up to steady state in thermal equilibrium.

4.7.5.1 Thermal Model

The calculation methods for short-term operation in principle correspond to the approach for NCS described in section 4.4.1. In the following sections mainly the differences in the thermal modelling are described.

4.7.5.2 Geometric Modelling

The same numerical model of the transfer cask is used as described in section 4.7.4.2 with the only exceptions that the interior of the canister is backfilled with helium and the space between canister and transfer cask is filled with dry air.

4.7.5.3 Boundary Conditions

The same boundary conditions are applied as described in section 4.7.4.4 with the only exception that the convective heat transfer coefficient h_{conv} is not reduced by a factor of [redacted] but applied to the full degree. That is because maximum temperatures occur after a long time when the transfer cask is completely heated up to steady state. At this time, a scaffold or potential additional shielding, which partially disturb the convective heat transfer, are no longer mounted to the transfer cask.

4.7.5.4 Maximum Temperatures

After dewatering and vacuum drying, the interior of the canister is backfilled with helium. For the steady state after heating up to thermal equilibrium, Table 4.7-6 summarizes the resulting maximum temperatures for various components of the transfer cask and the content. Figure 4.7-5 shows the temperature distribution in the transfer cask after helium backfilling.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The maximum temperature of the fuel rods amounts to 248 °C and is therefore significantly lower than the maximum admissible temperature of 400 °C.
- The maximum temperature for the lead shield is 96 °C which is far below the melting temperature of 327 °C.
- The highest gasket temperature of 116 °C occurs in the tightening plug gasket. The maximum admissible temperature for continuous operation of the gaskets is [redacted]. Therefore, all gasket temperatures are far below the temperature limit.
- The maximum temperature inside the water chambers amounts to 93 °C which is below the boiling temperature of 100 °C at a pressure of 1 bar. In reality, a higher safety margin exits because the water chambers are designed for a gauge pressure of 3 bar in the structural evaluation in chapter 3. This corresponds to an absolute pressure of 4 bar leading to a boiling temperature of 143 °C.
- Furthermore, temperature limits for structural components (e.g. fuel basket sheets) listed in Table 4.3-1, which are relevant for the mechanical integrity, are met.

The evaluation of the results show that all calculated maximum temperatures of the transfer cask components and the content are far below the maximum admissible values with large safety margins.

Table 4.7-6 Component temperatures for the transfer cask after helium backfilling

Component – type of temperature	Temperature, °C
Fuel rods – maximum	248
Cask surface – maximum, hottest plane	86
Cask surface – circumferential average, hottest plane	86
Cask surface – longitudinal average	77
Water chamber, outer – maximum	90
Water chamber, inner – maximum	93
Lead shield – maximum	96
Cavity surface – maximum, hottest plane	108
Cavity surface – circumferential average, hottest plane	107
Bottom lid, upper side – maximum	156
Bottom lid, upper side – area average	136
Bottom lid, underside – maximum	155
Bottom lid, underside – area average	123
Inner canister surface – maximum	162
Inner canister surface – circumferential average, hottest plane	161
Outer canister surface – maximum	162
Outer canister surface – circumferential average, hottest plane	160
Canister bottom – maximum	181
Trunnion – maximum	69
Fuel channels – maximum	238
Basket sheets – maximum	236
Round segment – maximum	199
Outer sheets – maximum	205
Shielding element – maximum	203
Canister filling gas – volume average	202
Cask filling gas – volume average	105
Canister lid – maximum	126
Canister lid – volume average	118
Canister lid gasket – maximum	115
Tightening plug gasket – maximum	116
Cask lid – maximum	65
Cask lid – volume average	59

[redacted]

Figure 4.7-5 Temperature distribution in the transfer cask after helium backfilling

4.7.6 Maximum Internal Pressures

The calculation of the maximum internal pressures and a discussion on the generation of flammable gases is documented in the containment evaluation in chapter 7.

4.7.7 Maximum Thermal Stresses

The discussion of thermal stresses due to temperature gradients within the components can be found in the structural evaluation in chapter 3.

4.7.8 Evaluation of Cask Performance for Short-term Operations

For the short-term operations of the transfer cask considered above, the following temporal restrictions apply:

- According to section 4.7.2, no temporal restrictions are required for the operation phase of the fuel loading in the pool as long as the water-filled transfer cask is still under water and the canister lid is not yet mounted.
- For the operation phase of the water-filled transfer cask with mounted lid, the time period after mounting of the canister lid until the beginning of the dewatering has to be restricted to [redacted] according to section 4.7.3.
- The time period for vacuum drying of the transfer cask interior is restricted to 49 h according to section 4.7.4.5. The time period for dewatering is included in this time limit of 49 h. At the end of the time period of [redacted], the backfilling of the interior of the canister with helium has to start at the latest.
- After the beginning of the backfilling with helium, the times for further operations and transport of the transfer cask inside the reactor building do not have to be restricted according to section 4.7.5.4.

If the above mentioned temporal restrictions are respected, it is demonstrated that the CASTOR® geo69 transfer cask fulfils all requirements for the short-term operations considered above with regard to thermal aspects. The following items summarize the results of the thermal investigations:

- The evaluation of the results in sections 4.7.2, 4.7.3, 4.7.4.5 and 4.7.5.4 show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.
- It is demonstrated in section 4.4.2 that additional safety margins exist because of the conservative approaches for the thermal modelling.
- It is proved that the calculated maximum temperatures of the gaskets do not lead to a degradation of the tightening function which is requirement for ensuring the safe enclosure of the content.
- It is shown that the calculated maximum temperatures of the fuel rods do not lead to a degradation of the cladding material which is requirement for ensuring the integrity of the fuel rod cladding. The effects of potential fuel rod failure are discussed in section 4.8.

- It is demonstrated that the calculated maximum temperature for the lead shield is below the melting temperature which is requirement for ensuring the effectiveness of the shielding.
- The calculated maximum temperatures of all relevant structural components (e.g. fuel basket sheets) are far below the maximum admissible values guaranteeing the mechanical integrity which is requirement for ensuring heat removal performance and criticality safety.
- The maximum temperatures inside the water chambers are far below the boiling temperature.
- The evaluation of the maximum pressure and a discussion on the generation of gases is documented in the containment evaluation in chapter 7.
- The influence of the calculated temperatures on the mechanical material properties and thermal stresses is evaluated in the structural evaluation in chapter 3.

List of References

[1] [redacted]

[2] [redacted]

4.8 Thermal Evaluation for Fuel Rod Failure

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[redacted]
Reviewed		22.03.2021	

In this section, the thermal evaluation in case of potential fuel rod failure is documented for the different storage conditions according to NUREG-2224 [1]

- NCS,
- off-normal conditions,
- ACS fire and
- ACS impact.

4.8.1 Description of the Content

Fuel rod failures can't be excluded for dry storage periods beyond 20 years in case of high burn-up fuel [1]. Analyses show that for a storage period beyond 20 years a uniform loading with FA of type ATRIUM-10A generates the most decay heat and is covering for all possible loadings. A depletion calculation yields a maximum heat power of ≤ 188 W per FA after 20 years of dry storage. For that reason, a homogenous loading with 69 FA with 188 W heat power each is employed in the following calculations. The total heat power of the cask loading amounts to 13 kW which is applied as a covering value. Most component temperatures will still be covered by the analyses without fuel rod failure and about 18.5 kW heat power, see sections 4.4, 4.5 and 4.6. In the following sections the main focus is on temperatures of the canister and components inside.

4.8.2 Thermal Properties of Gas Mixtures and FA in the Canister

In case of fuel rod failure, a release of filling gas (helium) and fission gases will lead to a pressure increase in the canister. The mechanical analyses in section 3 show that the canister remains leak tight for NCS, off-normal-conditions, ACS fire and ACS impact, so that the cask cavity is still filled with about [redacted] helium ([redacted]).

The main fission gases are xenon (86.5 %), krypton (7.4 %) and helium (4.0 %). The thermal conductivity of the fission gas mixture in the canister is much lower compared to helium because the thermal conductivity decreases with increasing molar mass. The maximum produced amount of fission gas is [redacted] (section 7), the averaged molar mass of the fission gas is [redacted]. In the thermal calculation, a mixture of 96 % xenon and 4 % helium with a slightly higher molar mass of [redacted] is assumed (see Table 4.8-1) leading to a slightly lower thermal conductivity.

The fractions of failed fuel rods and of the fission gas release for NCS, off-normal conditions, ACS fire and ACS impact in Table 4.8-1 are taken from [1]. The gas mixture in the canister includes the canister filling gas (helium), the fuel rod filling gas (helium) and the fission gases.

The thermal conductivity of mixtures of helium and xenon are calculated according to [2] in dependence on the individual volume fraction. Table 4.8-1 contains resulting thermal conductivities of the different fractions of xenon for NCS, off-normal conditions, ACS fire and ACS impact.

Table 4.8-1 Thermal conductivity of a mixture of helium and fission gases

[redacted]

The FA are modelled as homogenized zones with effective material values analogous to section 4.4.1.4. The effective radial thermal conductivity of the homogenized FA zones depends on thermal radiation and is reduced by the lower thermal conductivity of the gas mixture in case of fuel rod failure.

The influence of the gas mixture on effective axial thermal conductivity, on effective density and on the effective specific heat capacity is very low. The calculation of the effective material values is described in section 4.4.1.4.

The applied effective radial thermal conductivities of the homogenized FA zones are listed in Table 4.8-2 for the different storage conditions with fuel rod failure and the corresponding gas mixtures of Table 4.8-1.

Table 4.8-2 Effective thermal conductivity of the FA

[redacted]

4.8.3 Fuel Rod Failure for NCS

The temperatures for NCS are calculated for a canister gas atmosphere of 98 % helium and 2 % xenon according to Table 4.8-1.

4.8.3.1 Thermal Model

The same numerical model is used as described in section 4.4.1 for NCS. Exceptions are:

- Heat power = 13 kW after 20 a of dry storage according to section 4.8.1
- Thermal properties of the canister filling gas mixture and homogenized FA-zones are adapted according to section 4.8.2

4.8.3.2 Maximum Temperatures

The temperature field of the cask for NCS with fuel rod failure is shown in Figure 4.8-1, the resulting maximum temperatures of the storage cask are summarized in Table 4.8-3.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The maximum temperature of the fuel rods is 180 °C and is therefore significantly lower than the maximum admissible temperature of 400 °C.

- The maximum temperature for the inner moderator rods is 95 °C, for the bottom moderator plate 104 °C and 85 °C for the lid moderator plate. Therefore, the maximum temperatures of all moderator material are far below the maximum admissible temperature of [redacted].

- The highest gasket temperature of 89 °C occurs in the tightening plug gasket. The maximum admissible temperature for continuous operation of the gaskets is [redacted]. Therefore, all gasket temperatures are far below the temperature limit.

- Furthermore, temperature limits for structural components (e.g. fuel basket sheets) listed in Table 4.3-1, which are relevant for the mechanical integrity, are met.

The evaluation of the results show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.

[redacted]

Figure 4.8-1 Temperature field for NCS with fuel rod failure

Table 4.8-3 Component temperatures for NCS with fuel rod failure

Component – type of temperature	Maximum temperature, °C
Fuel rods – maximum	180
Cask surface – maximum	83
Cavity surface – maximum	90
Moderator rods, inner row (MR-i) – maximum	95
MR-i – area average, hottest plane, hottest rod	93
MR-i – volume average, hottest rod	87
Moderator rods, outer row (MR-o) – maximum	92
MR-o – area average, hottest plane, hottest rod	90
MR-o – volume average, hottest rod	85
Moderator plate (bottom) – maximum	104
Moderator plate (bottom) – volume averaged	97
Moderator plate (lid) – maximum	85
Moderator plate (lid) – volume averaged	79
Canister wall – maximum	107
Basket sheets – maximum	170
Shielding elements – maximum	138
Canister filling gas – volume average	143
Cask filling gas – volume average	89
Canister lid gasket – maximum	88
Cask lid gasket – maximum	77
Protection cap gasket – maximum	76
Pressure switch gasket – maximum	76
Tightening plug gasket – maximum	89

4.8.4 Fuel Rod Failure for Off-Normal Conditions

The temperatures for off-normal conditions are calculated for a canister gas atmosphere of 86 % helium and 14 % xenon according to Table 4.8-1.

4.8.4.1 Thermal Model

The same numerical model is used as described in section 4.4.1 for NCS. Exceptions are:

- Heat power = 13 kW after 20 a of dry storage according to section 4.8.1
- Thermal properties of the canister filling gas mixture and homogenized FA-zones are adapted according to section 4.8.2

4.8.4.2 Maximum Temperatures

The temperature field of the cask for off-normal conditions with fuel rod failure is shown in Figure 4.8-2, the resulting maximum temperatures of the storage cask are summarized in Table 4.8-4.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The maximum temperature of the fuel rods is 191 °C and is therefore significantly lower than the maximum admissible temperature of 400 °C.
- The maximum temperature for the inner moderator rods is 97 °C, for the bottom moderator plate 106 °C and 85 °C for the lid moderator plate. Therefore, the maximum temperatures of all moderator material are far below the maximum admissible temperature of [redacted].
- The highest gasket temperature of 90 °C occurs in the tightening plug gasket. The maximum admissible temperature for continuous operation of the gaskets is [redacted]. Therefore, all gasket temperatures are far below the temperature limit.
- Furthermore, temperature limits for structural components (e.g. fuel basket sheets) listed in Table 4.3-1, which are relevant for the mechanical integrity, are met.

The evaluation of the results show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.

[redacted]

Figure 4.8-2 Temperature field for off-normal conditions with fuel rod failure

Table 4.8-4 Component temperatures for off-normal conditions with fuel rod failure

Component – type of temperature	Maximum temperature, °C
Fuel rods – maximum	191
Cask surface – maximum	83
Cavity surface – maximum	89
Moderator rods, inner row (MR-i) – maximum	97
MR-i – area average, hottest plane, hottest rod	94
MR-i – volume average, hottest rod	87
Moderator rods, outer row (MR-o) – maximum	93
MR-o – area average, hottest plane, hottest rod	91
MR-o – volume average, hottest rod	85
Moderator plate (bottom) – maximum	106
Moderator plate (bottom) – volume averaged	99
Moderator plate (lid) – maximum	85
Moderator plate (lid) – volume averaged	80
Canister wall – maximum	106
Basket sheets – maximum	178
Shielding elements – maximum	144
Canister filling gas – volume average	150
Cask filling gas – volume average	90
Canister lid gasket – maximum	88
Cask lid gasket – maximum	77
Protection cap gasket – maximum	76
Pressure switch gasket – maximum	76
Tightening plug gasket – maximum	90

4.8.5 Fuel Rod Failure for ACS Fire

The temperatures for off-normal conditions are calculated for a canister gas atmosphere of 56.5 % helium and 43.5 % xenon according to Table 4.8-1.

4.8.5.1 Thermal Model

The same numerical model is used as described in section 4.6.1 for ACS. Exceptions are:

- Heat power = 13 kW after 20 a of dry storage according to section 4.8.1
- Thermal properties of the canister filling gas mixture and homogenized FA-zones are adapted according to section 4.8.2

4.8.5.2 Maximum Temperatures

Figure 4.8-3 shows the maximum fuel rod temperature and maximum average temperatures of the gases in cask and canister for ACS with fuel rod failure over time. Table 4.8-5 lists the maximum temperatures and their time of appearance (t = 0: beginning of fire) for various components of cask and content.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3:

- The hottest fuel rod reaches after 23 h its maximum temperature of 223 °C, which is significantly lower than the maximum admissible fuel rod temperature for ACS of 570 °C.
- The temperatures of the gaskets are between 93 °C and 101 °C, which is considerably lower than the maximum admissible temperatures of [redacted] for the cask lid gasket and canister lid gasket and [redacted] for the pressure switch gasket, the protection cap gasket and the tightening plug gasket.

The evaluation of the results show that all calculated maximum temperatures of cask components and content are far below the maximum admissible values with large safety margins.

[redacted]

Figure 4.8-3 Temperatures of the hottest fuel rod and the filling gases over time (ACS fire with fuel rod failure)

Table 4.8-5 Maximum component temperatures for ACS fire with fuel rod failure

Component – type of temperature	Maximum temperature, °C	Time of appearance, h
Fuel rods – maximum	223	23.0
Cask surface – maximum	205	0.1
Cavity surface – maximum	106	2.8
Moderator rods, inner row (MR-i) – maximum	112	1.0
MR-i – area average, hottest plane, hottest rod	110	2.2
MR-i – volume average, hottest rod	105	2.8
Moderator rods, outer row (MR-o) – maximum	139	0.2
MR-o – area average, hottest plane, hottest rod	113	1.2
MR-o – volume average, hottest rod	105	1.7
Moderator plate (bottom) – maximum	119	14.0
Moderator plate (bottom) – volume averaged	110	12.0
Moderator plate (lid) – maximum	98	17.0
Moderator plate (lid) – volume averaged	94	12.0
Canister wall – maximum	119	6.0
Basket sheets – maximum	207	21.0
Shielding elements – maximum	174	14.0
Canister filling gas – volume average	178	17.0
Cask filling gas – volume average	103	4.5
Canister lid gasket – maximum	100	12.0
Cask lid gasket – maximum	95	3.0
Protection cap gasket – maximum	93	6.0
Pressure switch gasket – maximum	94	5.5
Tightening plug gasket – maximum	101	15.0

4.8.6 Fuel Rod Failure for ACS Impact

The fuel rod failure for ACS impact considers a maximum amount of fission gas and will lead to maximum temperatures in the canister. The heating-up process needs a few days to get maximum steady-state cask temperatures due to the high thermal inertia. It is assumed, that the cask stands in vertical position after the ACS impact. For ACS impact, two scenarios – without and with release of fuel particles – are considered:

Scenario I: The temperatures for the ACS impact are calculated – analogous to NCS – for a canister gas atmosphere of 37 % helium and 63 % xenon according to Table 4.8-1.

Scenario II: This calculation is performed analogous to Scenario I, but in combination with a massive fuel particle release. It is hypothetically assumed that the gaps between the basket, FA and canister are filled with a fuel particle pouring. For the porosity of the fuel particle pouring within gaps, a typical value of ε = [redacted] is assumed. The total mass of fuel (≈ 14100 kg) in 69 FA in the bottom region corresponds to a height level of [redacted] (reduced active length) where the total heat power of 13 kW is dissipated in case of the hypothetical scenario II, see section 4.8.6.1. The heat power is strongly concentrated in the bottom part of the canister.

4.8.6.1 Thermal Model

For scenario I of ACS impact, the same numerical model is used as described in section 4.6.1 for ACS with the exception that the heat power amounts to 13 kW after 20 a of dry storage according to section 4.8.1 and the thermal properties of the filling gas are adapted according to section 4.8.2.

For scenario II the numerical model of Scenario I is used with the exception that heat power is concentrated in the bottom part of the canister. The gaps in the bottom basket zone and in the FA zones are filled with 58 % fuel particles and 42 % gas mixture (see canister model in Figure 4.8-4).

[redacted]

Figure 4.8-4 Fuel rod failure for ACS impact, scenario II – Thermal canister model with fuel particle release

The bottom part of the fuel rods is still filled with fuel without considering porosity. The volume of the fuel in 69 FA without porosity is about [redacted] leading to a heat power density of [redacted]. The heat power density in the fuel particle pouring is about [redacted].

The fractions of helium and fuel pellets in the homogenized active FA zones are 57 % and 31 %. The former helium fraction of 57 % is now filled with the fuel particle pouring. Table 4.8-6 shows the distribution of the heat power in all fuel filled zones. In the canister model (see Figure 4.8-4), the chosen height of [redacted] corresponds to a total fuel mass of about [redacted] (fuel pellets and gaps with pouring) leading to a covering total heat power of 13168 W instead of 13000 W (Table 4.8-6).

Table 4.8-6 Fuel rod failure for ACS impact, scenario II – Heat power zones in bottom part of the canister

[redacted]

The thermal conductivity in fuel and gap zones of the bottom part is increased because of 58 % of the gas mixture is replaced by the fuel pellet material. The effective thermal conductivity in the fuel filled gaps with a porosity of [redacted] is evaluated according to the model of [redacted] for packed beds. The following assumptions are made:

1. Temperature of fuel particle pouring: 100 °C, 200 °C and 300 °C
2. Diameters of fuel particles between [redacted] µm are considered
3. The gas atmosphere consists of 63 % Xe and 37 % He.

All input parameters and results for a temperature of 200 °C and a particle diameter of [redacted] are summarized in Table 4.8-7. The calculations show, that particle diameter in the range of [redacted] up to [redacted] has no effect. The effective thermal conductivity increases from [redacted]. For the calculations a constant thermal conductivity of [redacted] is chosen for gaps filled with fuel particles.

For the former active FA zone above [redacted], the thermal properties of the inactive FA zone without fuel are applied. For the reduced active zone of [redacted] with fuel pellets, fuel pouring and cladding, a constant thermal conductivity of [redacted] is conservatively chosen for the radial direction in active and inactive FA zones. This value is only slightly higher compared to the fuel filled gaps and conservative because of the much higher conductivity of cladding and fuel pellets.

Table 4.8-7 Fuel rod failure for ACS impact, scenario II – Calculation of effective thermal conductivity in fuel filled gaps

[redacted]

The axial thermal conductivity values in Table 4.8-2 for ACS impact are slightly increased by the higher thermal conductivity of fuel filled gap zones ([redacted]) compared to gas filled gaps (see Table 4.8-1). The former free gas volume in FA zones amounts to 57 %, which is now filled with the fuel particle pouring.

Axial thermal conductivity of active FA zone at 200 °C:

[redacted]

Axial thermal conductivity of inactive FA zone at 200 °C:

[redacted]

The heat conductivities in fuel filled gaps and FA zones are summarized in Table 4.8-8. The high power density of the bottom region of the canister leads to high temperatures in the bottom region and to lower temperatures in the upper zone without fuel. The heat resistance of fuel filled gaps is lower compared to the gas filled gaps above [redacted]. This effect leads to a temperature decrease, which may compensate the effect of the higher heat power density in the bottom region.

Table 4.8-8 Fuel rod failure for ACS impact, scenario II – Thermal conductivity in fuel filled gaps and FA zones

[redacted]

The free gas volume in the bottom region ≤ [redacted] is reduced by additional fuel and amounts to ≤ [redacted]). The free gas volume above (> [redacted]) without any fuel amounts to ≥ [redacted] ([redacted]). The additional gas volume of the empty part of the fuel rods (above [redacted]) is conservatively not taken into account to get a maximum average gas temperature and pressure in the canister in case of scenario II. Due to the cold large gas volume above the bottom region without any heat power the averaged gas temperature for scenario II will be much lower compared to scenario I.

4.8.6.2 Maximum Temperatures

The temperature field of the cask for scenario I and scenario II of ACS impact with fuel rod failure is shown in Figure 4.8-5 and Figure 4.8-6. Table 4.8-9 and Table 4.8-10 list the maximum temperatures for various components of cask and content.

Maximum temperatures of FA, basket and gaskets result for scenario I without any release of fuel. For scenario II, the increased thermal conductivity of the fuel filled gaps overcompensates the higher heat power density in the bottom region. Only the temperatures in the bottom region of cask and canister are 2 K to 25 K (bottom moderator plate) higher in case of scenario II compared to scenario I.

Below, the design-relevant temperatures are compared to their maximum admissible values according to section 4.3 (results of scenario II in brackets):

- The hottest fuel rod temperature is 238 °C for scenario I (222 °C for scenario II), which is far below the maximum admissible fuel rod temperature for ACS of 570 °C.
- The temperatures of the gaskets are between 76 °C (68 °C) and 95 °C (75 °C), which is considerably lower than the maximum admissible temperatures of [redacted] for the cask lid gasket and canister lid gasket and [redacted] for the pressure switch gasket, the protection cap gasket and the tightening plug gasket.

The evaluation of all results for ACS impact (scenario I and scenario II) show, that the calculated maximum temperatures of cask components and content are far below the maximum admissible values with large safety margins.

[redacted]

Figure 4.8-5 Fuel rod failure for ACS impact, scenario I – temperature field for ACS impact with fuel rod failure

Table 4.8-9 Fuel rod failure for ACS impact, scenario I – Maximum component temperatures for ACS impact with fuel rod failure

Component – type of temperature	Maximum temperature, °C
Fuel rods – maximum	238
Cask surface – maximum	82
Cavity surface – maximum	89
Moderator rods, inner row (MR-i) – maximum	101
MR-i – area average, hottest plane, hottest rod	98
MR-i – volume average, hottest rod	87
Moderator rods, outer row (MR-o) – maximum	97
MR-o – area average, hottest plane, hottest rod	95
MR-o – volume average, hottest rod	85
Moderator plate (bottom) – maximum	113
Moderator plate (bottom) – volume averaged	104
Moderator plate (lid) – maximum	91
Moderator plate (lid) – volume averaged	82
Canister wall – maximum	105
Basket sheets – maximum	220
Shielding elements – maximum	171
Canister filling gas – volume average	189
Cask filling gas – volume average	91
Canister lid gasket – maximum	91
Cask lid gasket – maximum	77
Protection cap gasket – maximum	76
Pressure switch gasket – maximum	77
Tightening plug gasket – maximum	95

[redacted]

Figure 4.8-6 Fuel rod failure for ACS impact, scenario II – temperature field for ACS impact with fuel rod failure and fuel particle release

Table 4.8-10 Fuel rod failure for ACS impact, scenario II – Maximum component temperatures for ACS impact with fuel rod failure and fuel particle release

Component – type of temperature	Maximum temperature, °C
Fuel rods – maximum	222
Cask surface – maximum	92
Cavity surface – maximum	103
Moderator rods, inner row (MR-i) – maximum	120
MR-i – area average, hottest plane, hottest rod	116
MR-i – volume average, hottest rod	88
Moderator rods, outer row (MR-o) – maximum	113
MR-o – area average, hottest plane, hottest rod	110
MR-o – volume average, hottest rod	86
Moderator plate (bottom) – maximum	138
Moderator plate (bottom) – volume averaged	124
Moderator plate (lid) – maximum	73
Moderator plate (lid) – volume averaged	70
Canister wall – maximum	128
Basket sheets – maximum	198
Shielding elements – maximum	155
Canister filling gas – volume averaged Gas in bottom region (14 %, 180 °C) + gas above bottom region (86 %, 125 °C) 1/[0.14/(180 °C + 273 K) + 0.86/(125 °C + 273 K)] = 405 K ≈ 132 °C	132
Cask filling gas – volume averaged	84
Canister lid gasket – maximum	74
Cask lid gasket – maximum	68
Protection cap gasket – maximum	68
Pressure switch gasket – maximum	68
Tightening plug gasket – maximum	75

4.8.7 Maximum Internal Pressures

The calculation of the MNOP and a discussion on the generation of flammable gases is documented in the containment evaluation in chapter 7.

4.8.8 Maximum Thermal Stresses

The discussion of thermal stresses due to temperature gradients within the components can be found in the structural evaluation in chapter 3.

4.8.9 Evaluation of Cask Performance for Fuel Rod Failure

For NCS and off-normal conditions in case of fuel rod failure, it is demonstrated that the CASTOR® geo69 storage cask fulfils all requirements with regard to thermal aspects. The following items summarize the results of the thermal investigations:

- The evaluation of the results in sections 4.8.3.2 and 4.8.4.2 show that all calculated maximum temperatures of the cask components and the content are far below the maximum admissible values with large safety margins.
- It is demonstrated in section 4.4.2 that additional safety margins exist because of the conservative approaches for the thermal modelling.
- It is proved that the calculated maximum temperatures of the gaskets do not lead to a degradation of the tightening function which is requirement for ensuring the safe enclosure of the content.
- It is shown that the calculated maximum temperatures of the fuel rods do not lead to a degradation of the cladding material which is requirement for ensuring the integrity of the fuel rod cladding. The effects of potential fuel rod failure are incorporated.
- It is demonstrated that the calculated maximum temperatures of the moderator components do not lead to a thermal degradation of the moderator material which is requirement for ensuring the effectiveness of the shielding.
- The calculated maximum temperatures of all relevant structural components (e.g. fuel basket sheets) are far below the maximum admissible values guaranteeing the mechanical integrity which is requirement for ensuring heat removal performance and criticality safety.
- The evaluation of the maximum pressure and a discussion on the generation of gases is documented in the containment evaluation in chapter 7.
- The influence of the calculated temperatures on the mechanical material properties and thermal stresses is evaluated in the structural evaluation in chapter 3.

For ACS fire and ACS impact in case of fuel rod failure, it is demonstrated that the storage cask fulfils all requirements with regard to thermal aspects. The following items summarize the results of the thermal investigations:

- The evaluation of the results in sections 4.8.5.2 and 4.8.6.2 show that all the calculated temperatures of cask components and the content are far below the maximum admissible values with large safety margins.
- It is proved that the calculated maximum temperatures of the gaskets do not lead to a degradation of the tightening function which is requirement for ensuring the safe enclosure of the content.
- The evaluation of the maximum pressure and a discussion on the generation of gases is documented in the containment evaluation in chapter 7.
- The influence of the calculated temperatures on the mechanical material properties and thermal stresses is evaluated in the structural evaluation in chapter 3.

List of References

[1] U.S.NRC NUREG-2224
Dry Storage and Transportation of High Burnup Spent Nuclear Fuel
Final Report

[2] [redacted]

[3] [redacted]

4.9 Appendix

	Name, Function	Date	Signature
Prepared	[redacted]	22.03.2021	[signature]
Reviewed		22.03.2021	[signature]

Appendix 4-1

With intent no items.