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Canister Insert Steel Lid – Investigation into the need for damage tolerance analyses

Sammanfattning

I detta dokument utreds om skadetålighetsanalyser bör genomföras för kapselns stållock. Arbetet föranleds av en fråga från Strålsäkerhetsmyndigheten (SSM2011-2426-193). Utredningen baseras på lastfallen *isostatiskt tryck* och *skjuvning på grund av jordbävning*.

Vid dessa laster är stållockets enda funktionskrav att bidra till kapselns integritet, i den meningen att locket lokalt stöder kapselns gjutjärnsinsats och kopparhölje.

Kopparhöljet och gjutjärnsinsatsen är komponenter och material för vilka det finns begränsat erfarenhetsunderlag från jämförbara applikationer.

Stållocket tillhör en annan kategori, eftersom det är en konventionell, vanlig komponent, gjord av ett konventionellt material med användning av traditionella tillverkningsprocesser. Sådana komponenter har länge levererats från många leverantörer, med intyg där överensstämmelse med standardiserade kvalitetskrav dokumenteras.

I detta dokument beaktas inte kapselns exceptionellt långa funktionstid, med därav följande risk för långsamma processer som krypning, korrosion och materialförsprödning orsakad av bestrålning.

Med denna avgränsning kan konstruktionsregler i ASME WC och ASME NB appliceras på stållocket. I detta dokument anvisas hur alla relevanta krav avseende material, konstruktion, tillverkning, kontroll och provning kan uppfyllas.

När dessa krav är uppfyllda kan krav på maximalt acceptabla defektstorlekar enligt ASME Section XI appliceras på det färdiga locket i en *preservice* provning. Acceptabel defektstorlek beror på defektens *aspect ratio* (längd/bredd) och, för defekter under komponentens yta, på avståndet till ytan. Enligt ASME Section XI, A-1100, krävs analys av defekter (skadetålighetsanalys) endast om dessa gränsvärden överskrids.

För M30 skruv accepteras utan skadetålighetsanalys maximalt 25 mm långa axiella ytdefekter; konservativt bör inga icke-axiella ytdefekter accepteras.

<u>Slutsats:</u> Om alla relevanta krav enligt ASME WC och ASME NB uppfylls, bland annat beträffande materialval, beräknas största acceptabla defektstorlekar enligt ASME Section XI, IWB-3500. Skadetålighetsanalys krävs endast om dessa gränsvärden överskrids.

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Summary

The purpose of this document is to examine whether the steel lid of the canister insert should be subjected to damage tolerance analyses. The work is prompted by a request by the Swedish Radiation Safety Authority (SSM2011-2426-193). In this document the assessment is based on the load cases *isostatic pressure* and *earthquake induced rock shear*.

At these loads, the only functional requirement for the steel lid is to contribute to the structural integrity of the canister, in that it locally supports the insert and the copper shell.

The copper shell and the nodular cast iron insert are components and materials for which there is limited prior experience from use in comparable applications.

The steel lid is in a different category, since it is an ordinary, unexceptional component, made of a common steel plate material using traditional fabrication methods. Such components have for a long time been routinely delivered from many suppliers, accompanied by certificates documenting compliance with standardized acceptance criteria.

This document does not discuss potential degradation processes that could occur due to the extraordinarily long required functional life, such as repository-temperature creep phenomena, possible effects of irradiation, or potential long term corrosion processes.

Within this limitation the rules of ASME WC and ASME NB are applicable for the lid. In this document it is shown how all applicable requirements of these rules regarding material, design, fabrication, examination and testing can be satisfied.

Given compliance with these rules, the flaw size acceptance standards of ASME Section XI can be applied in a preservice inspection of the finished lid. Maximum allowable flaw size depends on the flaw's aspect ratio, and, for subsurface flaws, on the proximity to the surface of the lid. According to ASME Section XI, A-1100, analyses of flaws (i.e. damage tolerance analyses) are required only if these limits are exceeded.

For the M30 screw, a 25 mm length limit on axial surface flaws is specified, while as a conservative precaution, no nonaxial surface flaws should be accepted.

<u>In conclusion:</u> Given compliance with all applicable requirements of ASME WC and ASME NB, e.g. regarding choice of materials, maximum allowable flaw sizes in the finished lid are computed in accordance with ASME Section XI, IWB-3500. Damage tolerance analyses are required only if these limits are exceeded.

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1 Introduction

The purpose of this document is to examine whether damage tolerance analyses are required for the steel lid inside the canister. The work is prompted by a request by the Swedish Radiation Safety Authority (SSM2011-2426-193). In this document the assessment is based on the load cases *isostatic pressure* and *earthquake induced rock shear*.

The following includes a general discussion on the subject of damage tolerance analyses, as well as how such analyses are generally utilized for nuclear components.

General background information on the steel lid is also presented, as well as a discussion on the applicability of established design codes such as ASME and Eurocode.

This document does not discuss potential degradation processes that could occur due to the extraordinarily long required functional life, such as repository-temperature creep phenomena, possible effects of irradiation, or potential long term corrosion processes.

1.1 Damage tolerance analyses – General

In a damage tolerance analysis a number of actual or postulated defects in the component are studied, and a maximum allowable size of each type of defect is determined, that will ensure that the component fulfils the functional requirements.

The results from a damage tolerance analysis are of practical use if the postulated defects can be reliably detected and measured in each fabricated component using non-destructive testing methods. Any defects, and consequently the component, can then be categorized as acceptable or not acceptable.

Such analyses have been performed for the copper shell and for the nodular cast iron insert. These are materials and components for which there is limited prior experience from use in comparable applications.

The steel lid is in a different category, since it is an ordinary, unexceptional component, made of a common steel plate material using traditional fabrication methods. Such components have for a long time been routinely delivered from many suppliers, accompanied by certificates documenting compliance with standardized acceptance criteria.

1.2 Typical damage tolerance analyses for nuclear components

For nuclear components damage tolerance analyses are typically performed if inspections have revealed fatigue cracks, corrosion damage, or other degradation that might compromise structural integrity. Components or parts of components that are potentially susceptible to excessive in-service degradation must be accessible for inspection, and must be inspected at predetermined intervals.

Inspection intervals should be based on damage tolerance analyses or experience, so that no unacceptable degradation can develop between inspections. If potentially unacceptable degradation is discovered, a damage tolerance analysis (e.g. a probabilistic fracture mechanics analysis) is performed to determine if a repair must be performed immediately or if it is safe to schedule the repair at a later date. If it is determined that the degradation or flaw (e.g. surface crack, pitting, porosity, inclusion, cavity) will not worsen in service, no action is needed apart from continued routine monitoring.

The ASME code for inservice inspection; Section XI (ASME 2010g) describes inservice inspection methods and corresponding flaw indication acceptance standards, as well as analyses procedures (damage tolerance analyses) for flaws that exceed the acceptance standards.

2 Description of the steel lid

2.1 Design and construction

The lid is a flat circular disc of nominal diameter 910 mm and thickness 50 mm. The edge is bevelled, and includes a groove for a gasket that ensures a gas tight seal against the cast iron insert. A central bolt hole is provided for a M30 screw that secures the lid to the insert. The lid has an opening for a valve to facilitate replacement of the atmosphere in the insert; see ”Ritningsförteckning för kapselkomponenter” (SKBdoc 1203875).

There is a 2 mm nominal gap between the steel lid and the inside of the canister’s copper lid, as listed in Table 3-6 in the canister production report (SKB 2010a, p 34).

2.2 Material

The lid is manufactured from hot rolled plate, structural carbon manganese steel S355J2 in accordance with Eurocode for general technical delivery conditions (SS-EN 10025-1:2004) and for technical delivery conditions for non-alloy steels (SS-EN 10025-2:2004). Minimum specified yield strength is 355 MPa (335 MPa for the thickness needed for the lid). ’J2’ refers to a Charpy V-notch longitudinal impact energy requirement of minimum 27J at -20°C.

The screw is manufactured from round bar, structural carbon manganese steel S355JR in accordance with Eurocode for general technical delivery conditions (SS-EN 10025-1:2004) and for technical delivery conditions for non-alloy steels (SS-EN 10025-2:2004). Minimum specified yield strength is 355 MPa (335 MPa for the thickness needed for the screw). ’JR’ refers to a Charpy V-notch impact energy requirement of minimum 27J at 20°C.

The materials are given in the drawings listed in ”Ritningsförteckning för kapselkomponenter” (SKBdoc 1203875).

2.3 Installation

In the encapsulation plant the nuclear fuel assemblies are placed in the cast iron insert inside the canister. The steel lid is then attached to the insert using a M30 screw through the hole in the centre of the lid.

Using the valve in the lid the atmosphere inside the insert is replaced by >90% argon, to minimize the potential formation of corrosive nitric acid. This minimizes the risk of corrosion on the steel lid.

The copper lid is then installed by welding, to seal the canister.

The installation procedure is described in the spent fuel report (SKB 2010c, pp 35–36).

3 Design requirements

3.1 Functional requirements

After the canister has been sealed, the steel lid shall contribute to the integrity of the canister in the load cases *isostatic pressure* and *earthquake induced rock shear*.

This requirement is derived from the description of the lid in Raiko et al. (2010, p 7) as a "load bearing steel lid". Also, support from the lid is credited in the verification reports for the insert and the copper shell for earthquake induced rock shearing (SKBdoc 1415152) and for isostatic pressure (SKBdoc 1177857).

3.2 Detailed requirements

In this document the assessment is based on the load cases *isostatic pressure* and *earthquake induced rock shear*. The detailed requirements discussed below focus on those loads.

3.2.1 Isostatic pressure load

During the postulated glacial period the canister is subjected to a maximum external pressure of 45 MPa (SKB 2009). Structural analyses (SKBdoc 1177857) of this load case show that deflections in the copper lid will cause it to make contact with the steel lid. Resulting forces on the steel lid will lead to deflections in the cast iron insert. The net effect on the steel lid is out-of-plane bending deflections. Local deflection maxima occur at the locations of the insert channel tubes, where the steel lid is not supported by the insert. No significant in-plane radial forces on the lid are generated for this load case.

3.2.2 Earthquake induced rock shear

The corrosion barrier of the canister should remain intact after a 5 cm shear movement at 1 m/s for all locations and angles of the shearing fracture in the deposition hole (SKB 2009). Structural analyses in Detailed models for PWR- and BWR-canisters for earthquake induced rock shearing (SKBdoc 1415152) of this load case show that the steel lid, due to its higher strength and stiffness relative to other canister components, has a considerable influence on local stresses and strains in the copper shell and the cast iron insert. Significant in-plane radial forces on the lid are generated when the rock shear is assumed to occur at the lid location.

4 Design codes

4.1 General

Being an ordinary, unexceptional component (see section 1.1), the steel lid is conceivably covered by established and widely recognized design codes.

The design codes considered here are Eurocodes for steel structures and pressure equipment, the ASME code for storage of spent nuclear fuel and high level radioactive material and waste, and the ASME code for Class 1 nuclear facility components.

4.2 Eurocodes and PED

Eurocode for steel structures (SS-EN 1993-1-1:2005) applies to the design of buildings and civil engineering works in steel, and is not intended for nuclear applications; see section 1.1.1(1) of the code.

The PED, Pressure Equipment Directive of the European Parliament (97/23/EC), excludes "items specifically designed for nuclear use, failure of which may cause an emission of radioactivity"; see Article 1, section 3.8 of the PED.

The use of Eurocode or PED is therefore not studied here.

4.3 ASME codes

The ASME code for transportation and storage containments (ASME 2010a), subsection WC, is judged to be the most relevant of available design codes. The ASME code for Class 1 components, subsection NB (ASME 2010b) is also relevant.

The various ASME codes use the terms *flaws*, *imperfections* and *defects* when discussing irregularities at or below the surface of components (cracks, pitting, porosity, inclusions, cavities, etc.). These terms are taken to be synonymous and interchangeable.

Regarding non-destructive testing methods and maximum acceptable flaw sizes, the ASME code for Class 1 nuclear facility components, subsection NB (ASME 2010b) references the ASME code for inservice inspection; Section XI (ASME 2010g).

For the finished steel lid, the requirements for *preservice inspection* are appropriate. *Inservice inspection* during or after the studied load cases *isostatic pressure* and *earthquake induced rock shear* is not possible. NCA-3252(c) (ASME 2010c) stipulates that *the owner* shall specify the category and method of preservice inspection/examination to be performed in accordance with Section XI (ASME 2010g).

Acceptance standards (maximum allowable flaw sizes) are given in IWB-3500 (ASME 2010g). According to A-1100 (ASME 2010g), analyses of flaws (i.e. damage tolerance analyses) are required only if the limits of IWB-3500 are exceeded. Detailed discussions are included in section 4.3.4 below.

ASME is an integrated set of codes. The limits on acceptable flaw sizes are thus valid only if all other relevant ASME requirements (for material, design, fabrication and installation, examination and testing) are satisfied. This is stated in the *Introduction* section in the *Preface to Section XI* (ASME 2010g):

> … Application of this Section of the Code begins when the requirements of the Construction Code have been satisfied.

In this document the *Construction Code* is assumed to be ASME WC (ASME 2010a) and ASME NB (ASME 2010b).

The scope and applicable requirements of the codes are discussed in section 4.3.1 below. How compliance with the requirements is ensured for the steel lid is discussed in section 4.3.2 and 4.3.3. Flaw detection requirements and maximum allowable flaw sizes are given in section 4.3.4.

4.3.1 ASME III Division 3 subsection WC and Division 1 subsection NB

Scope of ASME III Division 3

The scope of the rules is detailed in Subsection WA-1110:

WA-1100 SCOPE

WA-1110 NATURE OF THESE RULES AND CONTAINMENTS TO WHICH THEY ARE APPLICABLE

The rules of this Division constitute requirements for the construction of:

(a) Containments used for the transportation and storage, including disposal[1] of spent nuclear fuel and high level radioactive material and waste, and

(b) Structures internal to the containment[2] necessary to support and maintain geometric configuration of the spent nuclear fuels and high level radioactive materials and waste.

The referenced footnotes are:

[1] Rules for Disposal Containments are not yet developed.

[2] Rules for internal support structures are under development.

Further limits of the rules are stated in subsection WA-1130:

WA-1130 LIMITS OF THESE RULES

(a) The rules of this Division provide requirements for new construction including consideration of mechanical and thermal stresses due to cyclic operation. They do not cover deterioration which may occur in service as a result of radiation effects, corrosion, erosion, or instability of the material. These effects shall be addressed in the Design Specification by requiring appropriate measures to be included in the design.

(b) The rules are intended to be applicable to any item that serves a containment or internal support[2] function.

(Footnote 2 is shown above)

The rules address two containment categories:

- Subsection WB – Class TC Transportation Containments
- Subsection WC – Class SC Storage Containments

Subsection WC rules are the most relevant for the steel lid.

Scope of Subsection WC – Class SC Storage Containments

The scope of subsection WC is detailed in subsection WC-1100:

WC-1100 SCOPE

(a) Subsection WC contains rules for the material, design, fabrication, examination, testing, marking, stamping, and preparation of reports by the Certificate Holder for Class SC storage containments for spent nuclear fuel and high level radioactive waste and materials.

(b) The rules of Subsection WC cover the strength and containment integrity of items the failure of which would violate the containment boundary. The rules cover load stresses but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of containment materials. WA-1130 further limits the rules of this Subsection.

WC-1120 RULES FOR CLASS SC CONTAINMENTS

(a) Class SC storage containments shall be in accordance with the rules of this Subsection.

(b) Valves, classified as part of the containment by the Design Specification, shall be classified as Class 1 or Class 2 and shall meet the requirements of Division 1 in lieu of all other requirements of this Division.

(c) Subsection WC does not contain rules to cover all details of construction of Class SC containments. Where complete details are not provided in this Subsection, it is intended that the N3 Certificate Holder, subject to review by the Inspector, shall provide the details of construction which will be consistent with those provided by the rules of this Subsection.

Scope of ASME III Division 1 subsection NB – Class 1 Components

The scope of the rules is detailed in Subsection NB-1110 of the code:

NB-1100 SCOPE

NB-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NB contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of items which are intended to conform to the requirements for Class 1 construction.

(b) The rules of Subsection NB cover the requirements for strength and pressure integrity of items, the failure of which would violate the pressure-retaining boundary. The rules cover initial construction requirements, but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of material. NCA-1130 gives further limitations to the rules of this Subsection.

The limitations of NCA-1130 (ASME 2010c) do not apply here.

Subsection WC – Requirements for plate material

Requirements for materials that are permitted for use in conjunction with the rules are given in subsection WC-2121 (partial copy):

WC-2120 CONTAINMENT MATERIAL

WC-2121 Permitted Material Specifications

(a) Containment material shall conform to the requirements of one of the specifications for materials given in Tables 2A, 2B, and 4, Section II, Part D, Subpart 1 including all applicable footnotes in the table, and to all of the requirements of this Article which apply to the product form in which the material is used. Only materials listed in Tables 2A and 2B for which P-numbers are listed in Table WC-4622.1-1 may be used. Attachments that perform a containment function shall be containment material.

Subsection WC – Requirements for bolting material

Requirements for permitted bolting materials are given in subsection WC-2128:

WC-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Table 4, Section II, Part D, Subpart 1. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Table 4, Section II, Part D, Subpart 1.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

Subsection NB – Requirements for plate material

Requirements for materials that are permitted for use in conjunction with the rules are given in subsection NB-2121 (partial copy):

NB-2120 PRESSURE-RETAINING MATERIAL

NB-2121 Permitted Material Specifications

(a) Pressure-retaining material shall conform to the requirements of one of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable footnotes in the table, and to all of the requirements of this Article which apply to the product form in which the material is used.

Subsection NB – Requirements for bolting material

Requirements for permitted bolting materials are given in subsection NB-2128:

NB-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

Subsection WC and NB – Further requirements for materials

Further requirements for materials are summarized in Table 4-1.

Table 4-1. Summary of additional relevant requirements for materials

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB
Certification of material	WC-2130	NB-2130
Welding material	WC-2140	NB-2140
Material identification	WC-2150	NB-2150
Deterioration of material in service	WC-2160	NB-2160
Heat treatment to enhance material properties	WC-2170	NB-2170
Procedures for heat treatment of materials	WC-2180	NB-2180
Attachment material/Nonpressure-retaining material	WC-2190	NB-2190
Procedure for obtaining test coupons from plates	WC-2222	NB-2222
Procedure for obtaining test coupons from bolting material	WC-2224.3	NB-2224(b)
Material to be impact tested	WC-2310	NB-2310
Impact test procedures	WC-2320	NB-2320
Test requirements and acceptance standards for plates	WC-2331 and WC-2332.1	NB-23311 and NB-2321.2
Test requirements and acceptance standards for bolting material	WC-2332.3	NB-2333
Number of impact tests required – Plates	WC-2341	NB-2341
Number of impact tests required – Bolting material	WC-2345	NB-2345
Retests	WC-2351	NB-2350
Calibration of instruments and equipment	WC-2360	NB-2360
Welding material	WC-2400	NB-2400
Examination and repair of plate	WC-2532.1	NB-2532.1
Time of examination	WC-2537(a)	NB-2537(a)
Elimination of surface defects	WC-2538	NB-2538
Repair by welding	WC-2539	NB-2539
Examination of bolts	WC-2580	NB-2580
Material organizations' quality system programs	WC-2600	NB-2600

Subsection WC and NB – Requirements for design

Requirements for design are given in article WC-3000 and NB-3000. The detailed requirements are summarized in Table 4-2.

References to subsection NCA are to provisions in the ASME code with general requirements (ASME 2010c).

Table 4-2. Summary of relevant requirements for design

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB
Loading conditions	WC-3111	NB-3111
Design pressure	WC-3112.1 and WA-2123.1(a)	NB-3112.1 and NCA-2142.1(a)
Design temperature	WC-3112.2 and WA-2123.1(b)	NB-3112.2 and NCA-2142.1(b)
Design mechanical loads	WC-3112.3 and WA-2123.1(c)	NB-3112.3 and NCA-2142.1(c)
Design stress intensity values	WC-3112.4	NB-3112.4
Operating and test conditions	WC-3113	NB-3113
Configuration	-	NB-3125
Requirements for acceptability	WC-3211.2	NB-3211
Stress analysis	-	NB-3214
Pressure and temperature relationships	WC-3215.1	-
Stress tables	WC-3216.1	-
Coefficient of thermal expansion and modulus of elasticity	WC-3216.2	-
Stress limits for bearing loads	WC-3216.3(a)	NB-3227.1
Design criteria	WC-3217	-
Fatigue evaluation	WC-3219	NB-3222.4
Stress limits	-	NB-3220
Limit analysis	-	NB-3228.1

Subsection WC and NB – Requirements for fabrication

Requirements for fabrication are given in article WC-4000 and NB-4000. The applicable detailed requirements are summarized in Table 4-3.

Table 4-3. Summary of relevant requirements for fabrication

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB
Certification of materials and fabrication	WC-4120	NB-4120
Repair of material	WC-4130	NB-4130
Cutting, forming and bending	WC-4210	NB-4210
Forming tolerances	WC-4220	NB-4220
Bolting and threading	WC-4710	NB-4710

Subsection WC and NB – Requirements for examination

Requirements for examination are given in article WC-5000 and NB-5000. These requirements apply for welded components, but applicable parts are conservatively applied for the steel lid, even though no welding is performed. The applicable detailed requirements are summarized in Table 4-4.

Table 4-4. Summary of relevant requirements for examination

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB
Examination of adjacent base material	WC-5140	NB-5140

Subsection WC and NB – Requirements for testing

Requirements for testing are given in article WC-6000 and NB-6000. These requirements are not applicable for the steel lid, since no pressure testing is specified for the canister.

4.3.2 ASME III Division 3 subsection WC and Division 1 subsection NB as applied to the canister and steel lid

The scope and the applicable requirements of ASME III Division 3 subsection WC and Division 1 subsection NB are summarized in section 4.3.1. How fulfilment of the applicable requirements is ensured for the steel lid is discussed below.

Scope of ASME III Division 3 subsection WC

The canister is a disposal containment, and is thus according to WA-1110 not covered by the rules. Subsection WC-1100 further limits the scope of the rules.

Potential degradation processes that could occur due to the extraordinarily long required functional life, such as repository-temperature creep phenomena, possible effects of irradiation, or potential long term corrosion processes, are however outside the scope of this investigation (see section 1).

For the purpose of this document, ASME III Division 3 subsection WC is therefore judged to apply.

Scope of ASME III Division 1 subsection NB

For the canister, the pressure load is the isostatic external pressure. The pressure-retaining boundary of the canister is the copper shell. The copper shell can however not support the pressure load alone, but relies on support from the cast iron insert. The local strength and stiffness of the insert is significantly influenced by the presence of the steel lid. The insert, and by extension the steel lid, is therefore a structural attachment performing a pressure-retaining function; a pressure boundary stiffener, in accordance with NB-1132.1(b)(1) and NB-1132.1(c)(1)(a).

In conclusion: The lid contributes to the local strength and stiffness of the insert, and is thus part of a structural attachment performing a pressure-retaining function. According to NB-1132.2(b) the lid shall therefore be considered part of the component (i.e. the part of the pressure-retaining boundary) which is covered by the rules of the code.

Subsection WC and NB – Requirements for plate material

The lid is manufactured from hot rolled plate, structural carbon manganese steel S355J2 in accordance with Eurocode general technical delivery conditions (SS-EN 10025-1:2004) and technical delivery conditions for non-alloy steels (SS-EN 10025-2:2004). See drawing listed in ”Ritningsförteckning för kapselkomponenter” (SKBdoc 1203875). Minimum specified yield strength is 355 MPa (335 MPa for the thickness needed for the lid). ’J2’ refers to a Charpy V-notch longitudinal impact energy requirement of minimum 27J at -20°C.

If structural verification of the lid in accordance with the ASME design code (ASME 2010a) or (ASME 2010b) is desired, the requirements of subsection WC-2121 or NB-2121 must be satisfied, using one of two possible routes:

- A request must be submitted to the ASME Boiler and Pressure Vessel Committee to adopt for inclusion in Section II the S355J2 material; see Mandatory Appendix 5 of the ASME code for materials (ASME 2010d), or
- The lid material must be changed to a material that conforms to the requirements of one of the specifications for material given in ASME code for materials (ASME 2010d, Subpart 1, Tables 2A and 2B, including all applicable footnotes in the tables). All other relevant requirements of subsection WC-2121 and NB-2121 also apply. No welding is involved in the fabrication of the lids, so the requirement that P-numbers must be listed in Table WC-4622.1 is not relevant.

For the purpose of this investigation it is assumed that the material is changed to a close ASME equivalent, in accordance with the second bullet point above.

In Table 4-5 the mechanical properties of the S355J2 material is compared with two possible ASME code (ASME 2010d) materials.

Table 4-5. Comparison of mechanical properties for plate materials

	Min. yield strength [MPa]	Tensile strength [MPa]	Min. elongation [%]
S355J2	335	470-630	22[1]
SA-537, Class 1 (normalized)	345	485-620	22[2]
SA-516, grade 70 (normalized)	260	485-620	21[2]

[1] Proportional length test piece
[2] 50 mm length test piece

Chemical composition is compared in Table 4-6.

Table 4-6. Comparison of chemical composition for plate materials – % max. or % range (product analysis)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
S355J2	0.24	0.60	1.7	0.035	0.035	0.60	-[1]	-[1]	-[1]
SA-537, Class 1	0.24	0.13-0.55	0.92-1.72[2]	0.035	0.035	0.38	0.28[2]	0.29	0.09
SA-516, grade 70	0.30	0.13-0.45	0.79-1.30	0.035	0.035	-[1]	-[1]	-[1]	-[1]

[1] Not specified. Shall be mentioned in inspection document if added.
[2] Value may be exceeded in accordance with ASME 2010e, SA-537/SA-537M, Table 1, note (2).

An additional limit on the Cu content should be considered, to minimize the potential for embrittlement due to neutron and gamma radiation from the fuel. Calculations have shown that the copper content will have to be lower than 0.05% to avoid precipitation embrittlement (Brisonneau et al. 2004, cited in SKB 2010b, p 93).

Subsection WC and NB – Requirements for bolting material

The M30 screw is manufactured from round bar, structural carbon manganese steel S355JR in accordance with Eurocode general technical delivery conditions (SS-EN 10025-1:2004) and technical delivery conditions for non-alloy steels (SS-EN 10025-2:2004). See drawing listed in ”Ritningsförteckning för kapselkomponenter” (SKBdoc 1203875). Minimum specified yield strength is 355 MPa (335 MPa for the thickness needed for the screw). ’JR’ refers to a Charpy V-notch longitudinal impact energy requirement of minimum 27J at 20°C.

If structural verification of the screw in accordance with the ASME code for transportation and storage containments (ASME 2010a) or the ASME code for Class 1 components, subsection NB (ASME 2010b) is desired, the requirements of subsection WC-2128 or NB-2128 must be satisfied, using one of two possible routes:

- a request must be submitted to the ASME Boiler and Pressure Vessel Committee to adopt for inclusion in Section II the S355JR material; see Mandatory Appendix 5 of the ASME code for materials (ASME 2010d), or
- the material must be changed to a material that conforms to the requirements of one of the specifications for bolting material given in ASME code for materials (ASME 2010d, Subpart 1, Table 4).

For the purpose of this investigation it is assumed that the material is changed to an ASME code bolting material, in accordance with the second bullet point above.

In Table 4-7 the mechanical properties of the S355JR material is compared with two possible ASME code (ASME 2010d) materials. Chemical composition is compared in Table 4-8. No ASME code bolting materials are close equivalents to S355JR. The two proposed alternatives are widely used for bolting.

Table 4-7. Comparison of mechanical properties for bolting materials

	Min. yield strength [MPa]	Tensile strength [MPa]	Min. elongation [%]
S355JR	335	470-630	22[1]
SA-193, Grade B7	720	860 min.	16[2]
SA-540, Grade B21 Class 5	689	793 min.	15[3]

[1] Proportional length test piece
[2] 4 x diameter length test piece
[3] 50 mm length test piece

Table 4-8. Comparison of chemical composition for bolting materials – % max. or % range (product analysis)

	C	Si	Mn	P	S	Cu	N	Ni	Cr	Mo	V
S355JR	0.27	0.60	1.7	0.045	0.045	0.60	0.014[1]	-[2]	-[2]	-[2]	-[2]
SA-193, Grade B7	0.35-0.51	0.13-0.37	0.61-1.14	0.040	0.045	-[2]	-[2]	-[2]	0.70-1.25	0.13-0.27	-[2]
SA-540, Grade B21 Class 5	0.34-0.46	0.13-0.37	0.41-0.73	0.025[3]	0.025[3]	-[2]	-[2]	-[2]	0.75-1.20	0.47-0.68	0.22-0.38

[1] The max. value does not apply if sufficient N binding elements are present, as specified in note f in Table 4 of SS-EN 10025-2:2004.
[2] Not specified. Shall be mentioned in inspection document if added.
[3] 0.04% max. when open-hearth steel is specified.

Table 4-9 below describes how further requirements for materials (Table 4-1) will be fulfilled by requirements imposed by SKB on suppliers.

Table 4-9. Fulfilment of additional relevant requirements for materials

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB	Validation
Certification of material	WC-2130	NB-2130	A Certified Material Test Report (CMTR) will be delivered with the material, containing actual results of all required chemical analyses, tests and examinations. If heat treatment at specific times and temperatures are required by the material specification, actual times and temperatures will be reported.
Welding materials	WC-2140	NB-2140	Not applicable, since no welding is involved in the fabrication of the lids.
Material identification	WC-2150	NB-2150	Controls will be established to assure that only correct and accepted material is used. Identification will be maintained on the material, on a document traceable to the material, or in a manner that ensures that the identification is established and maintained. Traceability to CMTRs will be maintained.
Deterioration of material in service	WC-2160	NB-2160	*(Outside the scope of this document, since potential degradation processes that could occur due to the extraordinarily long required functional life, such as repository-temperature creep phenomena, possible effects of irradiation, or potential long term corrosion processes are not discussed here. See section 1.)*
Heat treatment to enhance material properties	WC-2170	NB-2170	The material will be heat treated if necessary, to satisfy impact property requirements.
Procedures for heat treatment of materials	WC-2180	NB-2180	Any heat treatment will be performed under the strict controls required by these rules. Times and metal temperatures will be recorded, to document compliance with the material specification.
Attachment material/Nonpressure-retaining material	WC-2190	NB-2190	Not applicable, since the lid is outside the scope of the subsection.
Procedure for obtaining test coupons from plates	WC-2222	NB-2222	Test coupons will be taken from the plate or from separate pieces as stipulated in WC-2222.1 or WC-2222.2.
Procedure for obtaining test coupons from bolting material	WC-2224.3	NB-2224(b)	Test coupons will be obtained as specified.

Material to be impact tested	WC-2310	NB-2310	The two proposed materials SA-537, Class 1 and SA-516, Grade 70 (Table 4-5) may be exempt from impact testing according to WC-2311(a)(7) and ASME appendices (ASME 2010f), Appendix R, since the lowest service temperature in the final repository (exact value to be determined) exceeds the -19°C exemption criterion by a comfortable margin. Impact testing (supplementary requirement S5, Charpy V-notch impact test in the material specifications) will nevertheless be specified, due to possible lower temperatures during transportation and handling.
Impact test procedures	WC-2320	NB-2320	Charpy V-notch impact tests will be performed in accordance with WC-2321.2 and NB-2321.2, using the specified three full-size 10 mm X 10 mm specimens. The location and orientation of the specimens will be as detailed in WC-2322.1(a), WC-2322.2(a) and NB-2322.2(a)(3) & (4).
Test requirements and acceptance standards for plates	WC-2331 and WC-2332.1	-	Charpy V-notch impact tests will be performed at or below the lowest service metal temperature. As stipulated in Table WC-2332.1-2 the average energy value for the three specimens shall be ≥ 54 J, and the lowest value among the three shall be ≥ 47 J.
Test requirements and acceptance standards for plates	-	NB-2331 and NB-2321.2	Charpy V-notch impact tests will be performed as stipulated in NB-2331(a) & (b).
Test requirements and acceptance standards for bolting material	WC-2332.3	NB-2333	Charpy V-notch impact tests will be performed at or below the lowest service metal temperature. As stipulated in Table WC-2332.3-1 and Table NB-2333-1 the lateral expansion for all three specimens shall be ≥ 0,64 mm.
Number of impact tests required – Plates	WC-2341	NB-2341	One test (comprising three specimens) will be made from each plate as heat treated.
Number of impact tests required – Bolting material	WC-2345	NB-2345	One test will be made from each lot (≤1350 kg) of material.
Retests	WC-2351	NB-2350	A Charpy V-notch retest may be performed if necessary, provided the provisions of WC-2351 and NB-2350 are satisfied.
Calibration of instruments and equipment	WC-2360	NB-2360	Temperature instruments and Charpy V-notch test machines will be calibrated and the calibration results will be recorded as required by WC-2360. Maximum calibration interval for temperature instruments is three months. Maximum calibration interval for Charpy V-notch test machines is one year.
Welding material	WC-2400	NB-2400	Not applicable, since no welding is involved in the fabrication of the lids.

Examination and repair of plate	WC-2532.1	NB-2532.1	Straight beam ultrasonic examination shall be performed, and acceptance criteria applied, as specified.
Time of examination	WC-2537(a)	NB-2537(a)	The straight beam ultrasonic examination shall be performed after rolling to size and after heat treatment, as stipulated.
Elimination of surface defects	WC-2538	NB-2538	Surface defects shall be removed, provided the specified requirements are met.
Repair by welding	WC-2539	NB-2539	Material from which defects have been removed may be repaired, provided the specified requirements are met and the stipulated repair procedures are used.
Examination of bolts	WC-2580	NB-2580	The retaining bolt shall be visually examined in accordance with WC-2582 and NB-2582.
Material organizations' quality system programs	WC-2600	NB-2600	The supplier of material will have a quality system program as stipulated in WC-2600 and NB-2600.

Subsection WC and NB – Requirements for design

Table 4-10 below describes how requirements for design (Table 4-2) will be fulfilled.

In subsection WC the design rules of WC-3200 details stress limits based on elastic stress analyses. The rules however also references ASME appendices (ASME 2010f), Appendix XIII, where alternative strength criteria based on plastic analyses are specified, and these are used in the structural verification of the steel lid. Similar alternative criteria are also specified in the ASME code for Class 1 components, subsection NB (ASME 2010b), indicating that the resulting level of safety is satisfactory for the steel lid as well.

Table 4-10. Fulfilment of relevant requirements for design

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB	Validation
Loading conditions	WC-3111	NB-3111	The design premises (SKB 2009) specifies the loads that are within the scope of this report: Isostatic external pressure load and earthquake induced rock shearing, with corresponding metal temperatures.
Design pressure	WC-3112.1 and WA-2123.1(a)	NB-3112.1 and NCA-2142.1(a)	The specified external design pressure of 45 MPa, see design premises (SKB 2009, p 15), is the maximum difference in pressure between the outside and the inside of the canister. The steel lid is located inside the canister and is therefore not directly exposed to the external pressure, but is affected by the load since the copper shell deforms and contacts the steel lid. This pressure is applied in the structural verification analyses of the canister for earthquake induced rock shearing (SKBdoc 1415152) and for isostatic pressure (SKBdoc 1177857). No internal pressure is specified.
Design temperature	WC-3112.2 and WA-2123.1(b)	NB-3112.2 and NCA-2142.1(b)	The highest and lowest metal temperature that will occur in the lid are taken into consideration in the structural verification analyses of the canister.
Design mechanical loads	WC-3112.3 and WA-2123.1(c)	NB-3112.3 and NCA-2142.1(c)	Earthquake induced rock shearing is the only mechanical load within the scope of this investigation that influences the steel lid. The load is detailed in the design premises (SKB 2009), p 15).
Design stress intensity values	WC-3112.4	NB-3112.4	Since no welding is involved in the fabrication of the lids, the provisions of WC-3112.4(a) do not apply. Since plastic stress analyses are used in the verification, design stress intensity values are not used in the evaluation of calculated stresses.

Operating and test conditions	WC-3113	NB-3113	Level A service limits will be specified for the 45 MPa external pressure combined with the minimum design temperature, since the canister and the lid will be subjected to this load in the performance of its specified service function. See the ASME code with general requirements (ASME 2010c), NCA-2142.4(b)(1). In accordance with Raiko et al. (2010, p 21) are Level C or D service limits specified for the earthquake induced rock shearing load, combined with specified concurrent pressure and temperature, since no active function of the canister is required after the event (there are no active components in the canister), only the passive barrier function to prevent release of radioactivity. Removal from service for inspection and repairs is not possible, and is not required.
Configuration	-	NB-3125	Not applicable for most of the required functional life, since inspection is neither specified nor possible after the repository is sealed.
Requirements for acceptability	WC-3211.2	NB-3211	Structural verification and WC-3217 are discussed below. The provisions of WC-3211.2(c) do not apply for a flat disc such as the steel lid.
Stress analysis	-	NB-3214	Structural verification reports will show that applicable requirements are satisfied.
Pressure and temperature relationships	WC-3215.1	-	Conservative combinations of external pressure, metal temperature and rock shearing loads will be applied in the structural verification analyses of the canister. Within the scope of this investigation no corrosion of the steel lid is anticipated.
Stress tables	WC-3216.1	-	Since plastic stress analyses are used in the verification, design stress intensity values are not used in the evaluation of calculated stresses.
Coefficient of thermal expansion and modulus of elasticity	WC-3216.2	-	The referenced modulus of elasticity will be used in the elastic portion of the material's stress-strain curve. Thermal stresses are insignificant, due to the limited temperature range, so coefficients of thermal expansion are not important.
Stress limits for bearing loads	WC-3216.3(a)	NB-3227.1	Not applicable, since plastic stress analyses are used in the verification. The limited local yielding is discussed in the structural verification reports, and is shown to be acceptable.
Design criteria	WC-3217	-	Not applicable, since plastic stress analyses are used in the verification.
Fatigue evaluation	WC-3219	NB-3222.4	Not applicable, since cyclic loads are not specified.
Stress limits	-	NB-3220	Structural verification reports will show that applicable requirements are satisfied.
Limit analysis	-	NB-3228.1	Structural verification reports will show compliance with the provisions of this subsection.

Subsection WC and NB – Requirements for fabrication

Table 4-11 below describes how requirements for fabrication (Table 4-3) will be fulfilled. Subsections not listed in the table are not applicable, since the fabrication of the steel lid does not involve welding or brazing.

Table 4-11. Summary of relevant requirements for fabrication

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB	Validation
Certification of materials and fabrication	WC-4120	NB-4120	The required certification will be prepared.
Repair of material	WC-4130	NB-4130	Not applicable, since no welding is involved in the fabrication of the lids.
Cutting, forming and bending	WC-4210	NB-4210	Cutting will be performed in accordance with WC-4211 and NB-4211. Forming and bending will not be performed.
Forming tolerances	WC-4220	NB-4220	The listed tolerance are not applicable to the steel lid. Dimensional tolerances are specified on the drawings.
Bolting and threading	WC-4710	NB-4710	Adequate thread engagement and the suitability of any thread lubricant will be ensured.

Subsection WC and NB – Requirements for examination

Table 4-12 below describes how requirements for examination (Table 4-4) will be fulfilled. Subsections not listed in the table are not applicable, since there is no weld material on the lid.

Table 4-12. Summary of relevant requirements for examination

Requirement	ASME code (ASME 2010a) Subsection WC	ASME code (ASME 2010b) Subsection NB	Validation
Examination of adjacent base material	WC-5140	NB-5140	The entire lid will be examined using the radiographic and either the liquid penetrant or magnetic particle method. Acceptance standards in accordance with WC-5320(c) and NB-5320(b) apply (referenced in WC-2539.4 and NB-2539.4).

4.3.3 Ensuring compliance with ASME III Division 3 subsection WC and Division 1 subsection NB

Section 4.3.2 shows that the applicable requirements of the two sets of rules are almost identical.

As detailed in section 4.3.2, compliance with the rules can be ensured as follows:

1. Given the scope of this investigation, excluding potential degradation processes that could occur due to the extraordinarily long required functional life, the steel lid is judged to be within the scope of both sets of rules.
2. The requirements for materials will be satisfied when ASME approved materials, e.g. the last two materials listed in Table 4-5 and Table 4-7, is used in the lid and in the screw. The supplementary material related requirements must also be satisfied.
3. The requirements for design will be satisfied when loading conditions, analysis methods and acceptance criteria are as stipulated.
4. Specifically, with respect to the requirements for design: Regarding the verification report for isostatic pressure (SKBdoc 1177857) the analysis method and acceptance criterion is in compliance with the ASME code for Class 1 components, subsection NB (ASME 2010b), with reference to the criterion in NB-3228.3.
   To comply with ASME code for transportation and storage containments (ASME 2010a), the material model must be changed to bilinear elastic/ideally plastic (nonstrain-hardening) behaviour in accordance with WC-3211.1(b) which references the ASME appendices (ASME 2010f), Appendix XIII, in this case XIII-1152, with definitions of *limit analysis* and *lower bound collapse load* given in XIII-1123(aa) & (bb).
   An evaluation of the screw in accordance with the two sets of rules must be included in the report.
   The material models for lid and screw must be changed to reflect any change in material (see the discussion regarding materials).
5. Specifically, with respect to the requirements for design: Regarding the verification report for earthquake induced rock shearing (SKBdoc 1415152) an acceptance criterion in accordance with ASME NB is not referenced. A check must be included. The employed material model is compatible with the criterion given in NB-3228.3.
   To comply with ASME WC design rules the material model must be changed to bilinear elastic/ideally plastic (nonstrain-hardening) behaviour in accordance with WC-3211.1(b) which references XIII-1152, with definitions of *limit analysis* and *lower bound collapse load* given in XIII-1123(aa) & (bb).
   An evaluation of the screw in accordance with the two sets of rules must be included in the report.
   The material models for lid and screw must be changed to reflect any change in material (see the discussion regarding materials).
6. The requirements for fabrication will be satisfied when certifications, processes and procedures are as stipulated.
7. The requirements for examination will be satisfied when radiographic and either liquid penetrant or magnetic particle examinations are performed, and the results are within specified limits.

4.3.4 Maximum allowable flaw sizes

ASME XI Division 1

As discussed in section 4.3, the requirements for *preservice inspection* are appropriate for the steel lid. Corresponding acceptance standards are stipulated in IWB-3110 (ASME 2010g). The reference to IWB-3112(b) is conservatively ignored. The alternative reference to Table IWB-3410-1 is used, pointing to acceptance standards in various parts of IWB-3500. As also mentioned in section 4.3, *the owner* shall specify the category and method of examination to be performed. For the purpose of this investigation, examination category B-A or B-B is assumed for the lid.

Detected flaws are characterized using the rules in IWA-3300. For the assumed examination category B-A or B-B, Table IWB-3410-1 points to acceptance standards in IWB-3510. Maximum allowable flaw size depends on the flaw's aspect ratio, and, for subsurface flaws, on the proximity to the surface of the lid.

As an example, if a surface planar flaw is detected on the lid (thickness t = 50 mm) using a volumetric examination method (ultrasonic or radiographic), and the aspect ratio of the flaw is determined to be a/l = 0.3, the maximum allowable depth a of the flaw is 6.4% of the lid thickness, i.e. $a = 0.064 \cdot 50$ = 3.2 mm. See Table IWB-3520-1.

Using the same table, if a subsurface planar flaw of dimensions a = 2 mm and l = 20 mm (aspect ratio 2/20 = 0.10) is detected S = 10 mm below the surface of the lid, the corresponding flaw-to-surface proximity factor is $Y = S/a = 10/2 = 5$. The maximum allowable half-depth a of the flaw is then $4.3 \cdot Y^{0.72} = 4.3 \cdot 5^{0.72}$ = 13.7% of the lid thickness, i.e. $a = 0.137 \cdot 50$ = 6.9 mm. In this example the detected flaw is thus acceptable, since 2 mm < 6.9 mm.

Maximum allowable laminar (oriented within 10° of the lid's surface) flaw size is 3690 mm^2, according to Table IWB-3520-2, interpolated linearly to 50 mm thickness from the listed 65 mm.

Table IWB-3520-3 specifies the maximum allowable length of a surface linear flaw to be 17.4% of the lid thickness, i.e. $l = 0.174 \cdot 50$ = 8.7 mm. Maximum allowable length of a subsurface linear flaw is 28.6% of the lid thickness, i.e. $l = 0.286 \cdot 50$ = 14.3 mm.

For the M30 screw, examination category B-G-2 is assumed. Table IWB-3410-1 points to visual examination acceptance standards detailed in IWB-3517, where IWB-3517.1(a) in turn references IWB-3515.1. The limit on nonaxial surface flaws is there set to 6 mm length, with a 25 mm limit on axial surface flaws. Remaining parts of IWB-3517 also apply.

IWA-3200 specifies rules for rounding of observed flaw dimension values.

According to A-1100 (ASME 2010g), analyses of flaws (i.e. damage tolerance analyses) are required only if these limits, i.e. the limits of IWB-3500, are exceeded.

ASME III Division 3

The examination procedures described in subsection WC-2530 in the ASME code for transportation and storage containments (ASME 2010a) are performed at the time of manufacture of the lid (after rolling to size and after any heat treatment; WC-2537(a)), and are not relevant here. Flaws remaining in the finished lid will be detected in the preservice inspection according to ASME XI Division 1 (see above).

The examination procedures described in WC-5140 are conservatively taken to apply for the steel lid, although no welding is involved in its manufacture. Acceptance standards relating explicitly to weld penetration and fusion are however ignored. Applicable acceptance standards are listed in WC-5320(c) (referenced in WC-2539.4). Maximum acceptable length of an indication on the lid is $\frac{1}{3} \cdot t = \frac{1}{3} \cdot 50$ = 16.7 mm (see WC-5320(c)(2), and also WC-5330(a)(2) for ultrasonic examination). This limit is not directly comparable to all preservice inspection limits in ASME XI Division 1 (see above), but is conservatively larger than the example limits calculated there for surface planar flaws and for surface/subsurface linear flaws. Flaws remaining in the finished lid will be detected in the preservice inspection.

For the M30 screw, examination of the finished part is described in WC-2580. “Detrimental” discontinuities are not allowed, but quantified criteria are not given. No criteria are given in WC-5000.

ASME III Division 1 subsection NB

The examination procedures described in subsection NB-2530 in the ASME code for Class 1 components (ASME 2010b) are performed at the time of manufacture of the lid (after rolling to size and after any heat treatment; NB-2537(a)), and are not relevant here. Flaws remaining in the finished lid will be detected in the preservice inspection according to ASME XI Division 1 (see above).

The examination procedures described in NB-5140 are conservatively taken to apply for the steel lid, although no welding is involved in its manufacture. Acceptance standards relating explicitly to weld penetration and fusion are however ignored. Applicable acceptance standards are listed in NB-5320(b) (referenced in NB-2539.4). Maximum acceptable length of an indication on the lid is $\frac{1}{3} \cdot t = \frac{1}{3} \cdot 50 = 16.7$ mm (see NB-5320(b)(2), and also NB-5331(a)(2) for ultrasonic examination). This limit is not directly comparable to all preservice inspection limits in ASME XI Division 1 (see above), but is conservatively larger than the example limits calculated there for surface planar flaws and for surface/subsurface linear flaws. Flaws remaining in the finished lid will be detected in the preservice inspection.

For the M30 screw, examination of the finished part is described in NB-2583. Linear axial indications, from magnetic particle or liquid penetrant examination, greater than 25 mm in length are unacceptable. Linear nonaxial indications are unacceptable. As a conservative precaution the 6 mm length for nonaxial linear indication allowed by ASME XI Division 1 (see above) is ignored, and the requirement for no nonaxial linear indication is applied instead. No criteria are given in NB-5000.

5 Discussion and conclusion

The purpose of this document is to examine whether the steel lid of the canister insert should be subjected to damage tolerance analyses. The work is prompted by a request by the Swedish Radiation Safety Authority (SSM2011-2426-193). In this document the assessment is based on the load cases *isostatic pressure* and *earthquake induced rock shear*.

At these loads, the only functional requirement for the steel lid is to contribute to the structural integrity of the canister, in that it locally supports the insert and the copper shell.

The copper shell and the nodular cast iron insert are materials and components for which there is limited prior experience from use in comparable applications.

The steel lid is in a different category, since it is an ordinary, unexceptional component, made of a common steel plate material using traditional fabrication methods. Such components have for a long time been routinely delivered from many suppliers, accompanied by certificates documenting compliance with standardized acceptance criteria.

This document does not discuss potential degradation processes that could occur due to the extraordinarily long required functional life, such as repository-temperature creep phenomena, possible effects of irradiation, or potential long term corrosion processes.

Within this limitation the rules of ASME WC and ASME NB are applicable for the lid. In this document it is shown how all applicable requirements of these rules regarding material, design, fabrication, examination and testing can be satisfied.

Given compliance with these rules, the flaw size acceptance standards of ASME Section XI can be applied in a preservice inspection of the finished lid. Maximum allowable flaw size depends on the flaw's aspect ratio, and, for subsurface flaws, on the proximity to the surface of the lid. Section 4.3.4 above contains examples of calculated maximum allowable flaw sizes. According to ASME Section XI, A-1100, analyses of flaws (i.e. damage tolerance analyses) are required only if these limits are exceeded.

For the M30 screw, a 25 mm length limit on axial surface flaws is specified, while as a conservative precaution, no nonaxial surface flaws should be accepted.

<u>In conclusion:</u> Given compliance with all applicable requirements of ASME WC and ASME NB, e.g. regarding choice of materials, maximum allowable flaw sizes in the finished lid are computed in accordance with ASME Section XI, IWB-3500. Damage tolerance analyses are required only if these limits are exceeded.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.
References to SKB's unpublished documents are listed separately at the end of the reference list.
Unpublished documents will be submitted upon request to document@skb.se.

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Unpublished documents

SKBdoc id, version	Title	Issuer, Year
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1203875 ver 2.0	Ritningsförteckning för kapselkomponenter. (In Swedish.)	SKB, 2014
1415152 ver 2.0	Detailed models for PWR- and BWR-canisters for earthquake induced rock shearing	SKB, 2014