Errata 2011-12

SKB TR-10-14

Design, production and initial state of the canister

In the earlier distributed report, there are errors that have now been corrected. The corrected pages 29, 50, 55, 102, 108, 110 are enclosed. The changed text is marked with a vertical line in the page margin. An updated pdf version of the report, dated 2011-12, can be found at www.skb.se/publications.

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3.1.1 Material composition

To avoid gamma irradiation induced hardening and embrittlement in the cast iron the:

- copper content in nodular cast iron shall be < 0.05% (see Table 2-1).

To ensure that that criticality will not occur:

- iron content in nodular cast iron shall be > 90%,
- carbon content in nodular cast iron shall be < 6%,
- silicon content in nodular cast iron shall be < 4%.

3.1.2 Material properties

The governing material properties for the strength of the insert are the mechanical properties of the nodular cast iron and the steel lid. The material properties of the cast iron are mainly defined by a stress-strain curve. The properties of the nodular cast iron of importance for the insert are the compression yield strength and fracture toughness (K_{Ic}) at isostatic loads and tensile yield strength and fracture toughness (J_{2mm}) at shear loads. Fracture toughness is a property that describes the ability of a material containing a crack to resist fracturing.

At this stage of the production, the nodular cast iron in the insert and the structural steel in the lid shall meet the minimum specifications for strength and ductility stipulated in Table 3-2. The given data is based on material testing of manufactured BWR inserts. The same data is used for analyses of PWR inserts as representative data from PWR inserts remain to be determined.

3.1.3 Dimensions

The dimensions of the cast iron insert with the steel lid are given in the figures and tables below. All dimensions are specified at room temperature, 20°C.

The given dimensions for the insert are used either as input to verifying analyses of the canister strength or analysis of prevention of criticality. A critical dimension for the strength of the reference canister is the edge distance. The distance between the channel tubes is important for criticality.

To facilitate replacement of the atmosphere in the insert the steel lid has a valve and there are milled notches in the insert top, a notch is shown in Figure 5-4. In addition, the steel lid has a gasket to ensure a gas tight seal.

Table 3-2. Minimum strength and ductility for nodular cast iron and structural steel for steel lid.

Design parameter	Cast nodular iron	Structural steel in steel lid
Yield strength (MPa)	> 267 (in tension, true stress) > 270 (in compression, true stress)	> 335 (tension, engineering stress)
Ultimate strength (MPa)	> 480 (in tension)	> 470
Fracture toughness in 0°C	J_{2mm} > 88 kN/m (lower 90% confidence) J_{1c} > 33 kN/m (lower 90% confidence) K_{Ic} > 78 MPa $(m)^{1/2}$ (lower 90% confidence)	–
Elongation[1] (%)	> 12.6 (lower 90% confidence)	–

[1] mainly used as quality check.

4.6 Corrosion load

One of the barrier functions of the canister is to provide a corrosion barrier. The design premise in Table 2-1 specified that the required nominal thickness of the copper shell is 5 cm. This is derived from Section 2.4 in **Design premises long term safety**.

The nominal copper shell thicknesses with acceptable tolerances for the reference canister are:

- copper tube: 49 ± 0.3 mm,
- welds: 48.5 ± 0.7 mm,
- lid: 50 ± 0.6 mm,
- base: 50 ± 1.0 mm.

4.7 Prevention of criticality

The spent fuel properties and geometrical arrangement in the canister should be such that criticality is avoided even if water should enter a canister.

In the analysis of the propensity for criticality of fuel assemblies placed in the canister, the sensitivity of the canister material composition and dimensions are investigated, see Section 4.4.1 in **Spent fuel report.** The analyses are based on an insert made of nodular cast iron with an iron content of at least 90%. To prevent criticality elements that absorb neutrons are favourable. Of the elements occurring in nodular cast iron silicon (Si) and carbon (C) are less favourable from this point of view than iron (Fe). The content of these elements shall therefore be kept below 6% (C) and 4% (Si). The important dimension of the canister insert is the distance between the channel tubes, which shall conform to the reference design.

4.8 Additional design premises derived from the safety assessment

In addition to the design premises related to required barrier functions and loads in the repository, there are several additional design premises on the canister that have been derived from the safety assessment. These are given as specifications or similar in Section 3.1.5 of **Design Premises long term safety** and are listed in Section 2.3.1 of this report.

- The copper content in cast iron shall be < 0.05% to avoid that gamma radiation induce hardness and embrittlement in cast iron.
- The copper material is a highly pure copper to avoid corrosion at grain boundaries. Oxygen contents of up to some tens of ppm can, be accepted. However the material used in trial production has had the specification O < 5 ppm. The creep ductility of the copper material is upheld if; phosphorus 30–100 ppm, sulphur < 12 ppm, average grain size < 800 µm , and embrittlement is avoided if the hydrogen content is < 0.6 ppm. These figures assume that the content of other elements are also limited.

These design premises are all considered in the specification of the reference canister, see Chapter 3, and will not be further discussed here. The measures taken in the production to verify that the produced canisters conform to these specifications are described in Chapter 5.

Further, it is stated that corrosion due to formation of nitric acid can be neglected if the radiation dose rate is less than 1 Gray/h. The radiation dose rate at the canister surface will depend both on the radiation shielding provided by the canister and the radioactivity of the encapsulated spent nuclear fuel. The design premise is verified for the reference design of the canister and the fuel assemblies selected for encapsulation, see the **Spent fuel report,** Sections 4.4.1 and 4.7.2.

4.11.4 Corrosion load

One of the barrier functions of the canister is to provide a corrosion barrier. The copper in the canister is of high purity (> 99.99% Cu) and an oxygen content of up to some tens of ppm is accepted. The related canister properties and design parameters determined in the design (see Sections 3.1 and 3.2) are:

- copper shell dimension – thickness including defects,
- copper shell material composition – oxygen content.

The nominal copper shell thicknesses with acceptable tolerance for the reference canister are:

- copper tube: 49 ± 0.3 mm,
- welds: 48.5 ± 0.7 mm,
- lid: 50 ± 0.6 mm,
- base: 50 ± 1.0 mm.

The reference canister conforms to the specified oxygen content in the copper shell. The conformity of the copper shell thickness in the reference canister to the design premises is further discussed in Sections 7.1.1 and 7.1.5.

4.11.5 Prevention of criticality

The canister shall prevent criticality and in the analysis of the propensity for criticality of the encapsulated spent fuel assemblies, it was shown that from a reactivity standpoint the worst case is when the assemblies are located close together towards the centre of the canister. With respect to this, it must not be possible to place the fuel assemblies closer to each other than the minimum distance between the channel tubes specified for the reference design. To prevent criticality elements that absorb neutrons are favourable. Of the elements occurring in nodular cast iron silicon (Si) and carbon (C) are less favourable from this point of view than iron (Fe). The content of these elements shall therefore be kept below 6% (C) and 4% (Si).

4.11.6 Additional design premises derived from the safety assessment

In addition to the design premises related to the required barrier functions discussed in previous sections there are several additional design premises derived from the safety assessment. The reference canister conforms to the following specifications:

- composition in insert: copper content in cast iron < 0.05%,
- composition in copper shell:, phosphorus 30–100 ppm, sulphur < 12 ppm, hydrogen content < 0.6 ppm, oxygen up to some tens of ppm and average grain size < 800 μm.

Table 7-1. Material composition at the initial state.

Component	Design parameter	Reference design	Initial state value	Comment and reference to relevant sections
Insert	Copper content (%)	<0.05	<0.05	Embrittlement Sections 5.2.10 and 7.2.6
	Iron content (%)	>90	>90	Prevent criticality
	Carbon content (%)	<6	<6	Sections 5.2.10 and 7.1.6 and 7.2.5
	Silicon content (%)	<4	<4	
Copper shell	Phosphorus (ppm)	30–100	30–100	Creep ductility Sections 5.3.9, 5.4.9, 5.5.7 and 7.2.6
	Sulphur (ppm)	<12	<12	Creep ductility Sections 5.3.9, 5.4.9, 5.5.7 and 7.2.6
	Hydrogen (ppm)	<0.6	<0.6	Brittleness during manufacturing Sections 5.3.9, 5.4.9, 5.5.7 and 7.2.6
	Oxygen (ppm)			Corrosion
	– Tube	up to some tens	<5	Sections 5.3.9 and 7.1.5
	– Lid and base	up to some tens	<5	Sections 5.4.9, and 7.1.5
	– Weld	up to some tens	up to some tens	Sections 5.5.7 and 7.1.5

Table 7-2. The material properties at the initial state.

Component	Design parameter	Reference design	Initial state value	Comment and reference to relevant sections
Insert	Compression yield strength (MPa)	>270	>270	Isostatic loads See Sections 5.2.10 and 7.1.2
	Fracture toughness K_{Ic} (MPa(m)^{½})	>78	>78	
	Tensile yield strength (MPa)	>267	>267	Resistance to shear loads See Sections 5.2.10 and 7.1.3
	Fracture toughness, J_{2mm} (kN/m)	>88	>88	
Copper shell	Elongation (%)	>40	>40	Isostatic and shear loads Sections 5.3.9, 5.4.9, 5.5.7, 7.1.2 and 7.1.3
	Creep ductility (%)	>15	>30	Isostatic and shear loads Sections 5.3.9, 5.4.9, 5.5.7, 7.1.2 and 7.1.3

7.1.2 Isostatic load in the repository

The dimensions, occurrence of defects and the material properties in the insert and in the copper shell affect the resistance to isostatic loads.

Material properties in the insert and the copper shell

The results from inspections of manufactured canister components (see Chapter 5) show that the material properties conform to the specified values and the variations both within and between components are small. This shows that the manufacturing processes are reliable and deliver canisters that conform to the material properties specified for the reference design. The specified values for the important design parameters; fracture toughness (K_{Ic}) and yield compression strength ($Rp_{0.2}$) in the manufactured series of inserts and elongation and creep ductility in the copper shell conform to the reference design, see Table 7-4.

In addition to the above mentioned design parameters, the yield tensile strength of the steel lid is described in the verifying analysis. The lids are manufactured from steel plates and delivered with certificates that verify they conform to the specified yield strength. This parameter has not been further tested and inspected in the test production.

The following hot-forming, i.e. extrusion and forging, are deemed not to have any major impact on the material composition since the material composition analyses performed on 10 forged lids where the highest measured oxygen content was 2.6 ppm and the mean value was 2.2 with a standard deviation of 0.3. There were no deviations compared to the concentrations in the ingots.

The material composition in the welds has been examined in six samples taken from three welds from the welding demonstration series and in three samples from one weld produced in argon gas. Analyses of the welds produced in air showed a mean oxygen content (with standard deviation) of 11.1 ± 12.2 ppm. The high standard deviation can be explained by the highest measured oxygen content that varies from 9 ppm in the steady-state sequence to 44 ppm in the overlap sequence. In the weld produced in argon gas the highest measured oxygen content was 2 ppm and the mean oxygen content (with standard deviation) was 1.8 ± 0.4 ppm.

To summarise, the values from the weld produced in argon gas is well below some tens of ppm stated in the design premises in Table 2-1, while the welds produced in air have an increased oxygen content in the overlap sequence.

It should be noted that the welding procedure is currently being developed to minimise oxygen content. In addition, the influence of oxides formed at the inner lid/tube interface (at the root of the weld zone) on weld integrity is under investigation.

In addition to oxygen, the welds also include traces of tool material. A clear reduction of this contaminant has been seen by introduction of a tool with PVD coating of chromenitride (CrN). The levels of Ni, Co and Cr are all less than 1 ppm to be compared to the mean levels (with standard deviation) when using non coated tools (18 samples from 3 welds) of Ni, Co and Cr that were 6.0 ± 6.8 ppm, 1.8 ± 2.8 ppm and 1.6 ± 1.8 ppm respectively /SKBdoc 1175162/.

A corrosion study /Gubner and Andersson 2007/ on the weld zones from welds made in air and with non coated tools was performed and concluded that the FSW tool is cathodic compared to the copper – small particles in the weld are cathodic protected by surrounding copper, resulting in a very small cathode compared to large copper anode. The good corrosion resistance of the FSW tool material will even further reduce the risk of corrosion of the surrounding weld material. Therefore, small metallic particles from FSW tool do not pose a risk for accelerated corrosion of the welds. The study also concluded that a negative effect of copper oxides close to the surface could not be detected.

7.1.6 Prevention of criticality

The canister production related design parameters used to verify that criticality is prevented are the carbon and silicon content in the nodular cast iron and the distance between fuel channels in the insert.

C-C distance between compartments

So far, no verification of the C-C distance between compartments by physical measurement has been done on manufactured inserts.

Material composition

The analyses of the material compositions of the nodular cast iron used for the five serial-manufactured BWR inserts and three PWR inserts are shown Table 5-1. The carbon content is below 6% and the silicon content is below 4% in all manufactured inserts.

7.2 Conformity to design premises long-term safety at the initial state

This section summarise the conformity to the design premises stated in **Design premises long-term safety** at the initial state.

For the BWR inserts the following uncertainties apply to the shear load case:

- Sensitivity analysis for the material and defect parameters has not been performed in the damages tolerance analysis. Furthermore, the damages tolerance analysis needs to be further developed to give more precise input to the requirements for the NDT.
- The statistical ground for determining material properties and occurrence of defects is limited.
- NDT methods that fully meet the acceptance criteria from the damage tolerance analysis for the shear load case have not yet been developed. Hence, the detection limit for defects has not been determined.

7.2.3 Uneven pressure from bentonite buffer

The canister properties and design parameters that are important for loads from the case of uneven pressure from bentonite buffer on the canister are in principle the same as for the isostatic load case. This justifies the conclusions in Section 7.2.1, that the probability that the canister will not withstand the loads is negligible.

7.2.4 Corrosion load

The design premise for the corrosion barrier is given as a nominal thickness of 5 cm. The minimum copper thicknesses at the initial state given in Table 7-3 are the manufactured and inspected thicknesses of the corrosion barrier after the final machining of the canister components. The initial state copper thickness may locally be reduced due to the occurrence of internal defects in the copper shell and surface damages occurring during handling, transportation and deposition. The size of acceptable surface defects has at this stage not been quantified.

The oxygen content in the major part of the copper shell is well below some tens of ppm, the exception is the welds produced in air where higher values have been measured in the overlap sequence. Based on this further investigations are needed to determine if the welding process will be performed in air or in argon gas.

7.2.5 Prevention of criticality

The reference design of the insert prevents criticality.

The iron (> 90%), silicon (< 4%) and carbon (< 6%) content in the insert is verified by conventional material analyses during production. The verification parameter to prevent criticality has not yet been determined and has to be further investigated.

7.2.6 Additional design premises

This section summarised the initial state of the additional design premises.

Copper content in cast iron insert

The maximum copper content of < 0.05% in the insert is verified by conventional material analysis during production. This will guarantee that this design premises will be fulfilled.

Composition and grain size in copper shell

The material composition in the copper shell regarding content of oxygen, sulphur, phosphorus and hydrogen is verified by conventional material analysis during production. The destructive inspections during manufacturing and the following ultrasonic inspection verify that the average grain size in the copper shell will be below 360 μm. This will guarantee the conformity to these design premises.

Temperature on the surface of the copper shell

The temperature on the surface of the copper shell must not be above 100°C, this has to be considered in the instructions for handling the canister in the facilities and during transportation as well as in the detailed design of the canister transport cask (KTB). Based on current knowledge, this design premise can be met as the temperature is a parameter that is relatively trivial to measure.