

Assessment of Corrosion Lifetime of a Copper Disposal Canister Based on the Finnish Posiva Methodology

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In this paper, an approach developed by the Finnish nuclear waste management organization, Posiva, for the construction license of a geological repository was reviewed. Furthermore, a computer program based on the approach was developed. By using the computer program, the lifetime of a copper disposal canister, which was a key engineered barrier of the geological repository, was predicted under the KAERI Underground Research Tunnel (KURT) geologic conditions. The computer program was developed considering the mass transport of corroding agents, such as oxygen and sulfide, through the buffer and backfill. Shortly after the closure of the repository, the corrosion depths of a copper canister due to oxygen in the pores of the buffer and backfill were calculated. Additionally, the long-term corrosion of a copper canister due to sulfide was analyzed in two cases: intact buffer and eroded buffer. Under various conditions of the engineered barrier, the corrosion lifetimes of the copper canister due to sulfide significantly exceeded one million years. Finally, this study shows that it is necessary to carefully characterize the transmissivity of rock and sulfide concentration during site characterization to accurately predict the canister lifetime.

Keywords: Spent nuclear fuel, Disposal, Copper canister, Corrosion, Buffer

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1. Introduction

Spent nuclear fuel (SNF) is inevitably generated through the usage of nuclear power, and countries that depend on nuclear energy are developing policies and technologies for the final management of SNF. Sweden and Finland, who first proposed the KBS-3 type geological disposal concept, are developing the method of excavating a disposal tunnel and deposition holes in a granitic rock formation 500 meters below the ground and directly disposing SNF using a copper-cast iron double structure disposal canister [1, 2]. France and Japan, who are reprocessing SNF, are developing a geological repository to dispose of vitrified waste using a carbon steel disposal canister [3, 4]. Korea Atomic Energy Research Institute (KAERI) has developed and proposed geological disposal systems for high-level waste, including SNF using a copper-cast iron disposal canister under KAERI Underground Research Tunnel (KURT) geological conditions [5, 6].

The safety of a geological disposal system for high-level radioactive waste relies mainly on multiple barriers consisting of a disposal canister, buffer, backfill, host rock, and biosphere. The disposal canister is the most important of the multiple barriers. According to Nuclear Safety and Security Commission Notice 2017-74, the lifetime of a disposal canister should be greater than several thousand years. The authors have already modified a disposal canister to improve the efficiency of the disposal system for SNF. Two kinds of disposal canisters, R-SF canister and S-SF canister, were designed, with the copper-cast iron double-layered structure taking into account the lengths of SNF generated in Korea [7]. This double-layered disposal canister is considered not only in Korea, but also in Sweden, Finland and Canada. The Finnish Posiva was the first organization to obtain the construction permit using the copper-cast iron disposal canisters [2]. The major role of a copper layer is to resist corrosion under deep geological environments and to protect SNF. Thus, the lifetime of a disposal canister strongly depends on the corrosion rate of

the copper layer.

The mechanisms by which a disposal canister corrodes under deep geological environments are strongly dependent on the materials of the canister, groundwater composition, and properties of buffer material. The corroding agents that can corrode a copper canister under the deep geological environments considered in this paper are dissolved oxygen and sulphide [8-10]. Soon after the closure of a repository, the oxygen introduced during the operational period will be consumed by various kinds of oxidation reactions. In the long run, sulphide is the only corroding agent for copper canisters. It is impractical to observe in real time whether a copper canister lifetime will be longer than one hundred thousand years. Therefore, disposal canister lifetimes are predicted through numerical modelling by countries planning to construct a geological repository [11, 12].

In this paper, the authors developed a computer program using Microsoft Excel to predict the lifetime of a copper canister based on the approach used by Posiva to apply for a construction license. Using the developed computer program, the lifetime of a R-SF canister was predicted together with the design specifications of buffer and backfill. The corrosion depth by oxygen during the operation of the repository was calculated, and the lifetime of the canister due to long-term corrosion by sulphide after the repository closure was predicted. Two cases, intact buffer and eroded buffer, were considered for the corrosion by sulphide. The results of corrosion lifetime of the R-SF canister were compared with those of Posiva's disposal system.

2. Engineered barriers for KRS⁺ repository

KAERI developed a geological repository called KRS for the direct disposal of pressurized water reactor (PWR) SNF [5, 6]. With a view to improving the efficiency of the KRS repository, a newer geological repository called KRS⁺ was recently proposed by the authors [7]. The largest difference between KRS and KRS⁺ lies in the disposal

Table 1. Dimensions of R-SF disposal canister

Item	Dimension
Copper shell	
- Length (cm)	478.0
- Diameter (cm)	103.0
- Bottom plate thickness (cm)	5.0
- Lid thickness (cm)	5.0
- Volume (cm ³)	803,753
- Weight (kg)	7,153
- Surface area (m ²)	17.13
- Lid cross-section area (m ²)	0.83

canisters. The KRS⁺ repository is designed with two different sized canisters, reflecting the sizes of domestic PWR SNF based on the analysis of past and future PWR SNF.

In this paper, of the two disposal canisters, the lifetime of the R-SF canister, which would be used for around 77% of SNF, was analyzed. As shown in Fig. 1, the R-SF canister was designed to contain four PWR SNF assemblies. The outer layer of the canister was made of copper so as to resist corrosion under the disposal environment, and the inner layer was made of cast iron. The outer diameter of the canister was 1,030 mm, and the length was 4,780 mm. The thickness of the copper layer was 50 mm [7]. The mass of the copper layer is important for the calculation of corrosion lifetime of a canister. Some important dimensions of the R-SF canister, including the weight, are summarized in Table 1.

Another engineered barrier that greatly influences the lifetime of a copper canister is a buffer. The material of the buffer was domestic Ca-bentonite with a dry density of 1.6 g·cm⁻³. According to the current design shown in Fig. 2, the thickness of the buffer around the canister cylinder was 360 mm. Also, the thicknesses of the bottom and upper part were 360 mm and 2,500 mm, respectively. The particle density of the domestic Ca-bentonite was 2.632 g·cm⁻³, and the porosity of the bentonite block was calculated to be 39.23% [13]. According to the thermal analysis on the

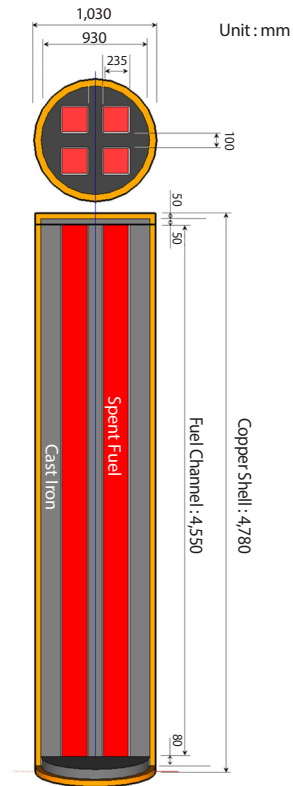


Fig. 1. Schematic of the R-SF disposal canister [7].

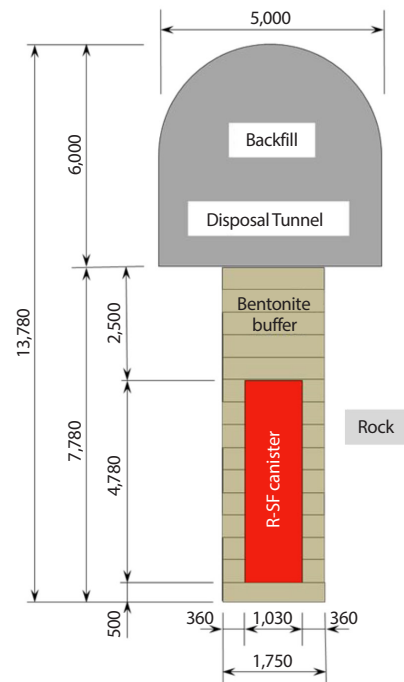


Fig. 2. Conceptual schematic of a disposal unit [7].

Table 2. Comparison of buffer properties used for the calculation of corrosion depth

	KAERI [7]	Posiva [2]
Dry density of rings ($\text{g}\cdot\text{cm}^{-3}$)	1.6	1.752
Dry density of disk blocks ($\text{g}\cdot\text{cm}^{-3}$)	1.6	1.701
Outer diameter (mm)	1,750	1,650
Height of buffer (mm)	7,780	8,244
Radial thickness of ring blocks around canister (mm)	360	290
Grain density ($\text{g}\cdot\text{cm}^{-3}$)	2.632	2.750
Total porosity of rings [-]	0.392	0.363
Total porosity of disk blocks [-]	0.392	0.381
Total area of canister outside surface (m^2)	17.13	17.63
Water content (%)	10.96	17
Oxygen in buffer (moles)	24.74	20.10
Equivalent copper moles	98.95	80.4
Corrosion depth due to the oxygen in buffer (mm)	0.0412	0.0326

KRS⁺ repository [7], the disposal tunnel spacing and deposition hole spacing were determined to be 40 m and 7.5 m, respectively. The cross-sectional area of a disposal tunnel was 28.69 m² [14].

3. Calculation of corrosion lifetime of a disposal canister

Copper corrosion is strongly influenced by the groundwater chemistry. The groundwater taken from the KURT borehole was used as reference groundwater conditions under which the major corroding agents are oxygen and sulphide. The roles of the corroding agents in the repository change depending on the surrounding environment with time. In general, the geological repository will be closed after around one hundred years of operation. During both the operational period and soon after the closure of the repository, the oxygen present in the repository will be exhausted by oxidation reaction. After that point, sulphide will be the major corroding agent for a very long time. The corrosion of a copper canister by oxygen and sulphide was calculated separately.

3.1 Corrosion by oxygen

The corrosion of a copper canister by oxygen was evaluated at two stages, that is, during the periods before and after the closure of a repository. When a disposal canister is exposed to air during the operation period, the assessment of the corrosion depth by oxygen is carried out by evaluating the corrosion rate of copper in the atmospheric conditions rather than by quantitative analysis. In the Posiva Safety Case assessment [2], the corrosion depth due to oxygen was estimated to be less than 1 μm even when the copper canister was exposed to the atmosphere for up to two years. In this paper, the same corrosion rate was used considering that the R-SF canister would not be exposed to the atmosphere for more than two years in the KRS⁺ repository.

After closure of a repository located 500 meters below ground, the continuous supply of oxygen to the repository is hampered. The oxygen present around a disposal canister is soon exhausted by the oxidation reaction with copper. In the Posiva Safety Case, it was conservatively assumed that all the oxygen around a disposal canister was used just for the corrosion of copper. The following oxidation reaction with copper was considered:

Table 3. Data for the backfilled tunnel

	KAERI [7]	Posiva [2]
Cross-section area of a disposal tunnel (m ²)	28.69	16.46
Distance between deposition holes (m)	7.5	9.0
Total porosity	0.348	0.382
Total oxygen in a backfilled tunnel (moles)	416.9	340.5
Equivalent copper moles	1667.7	1362.0
Corrosion depth due to the oxygen in buffer (mm)	14.29	11.23

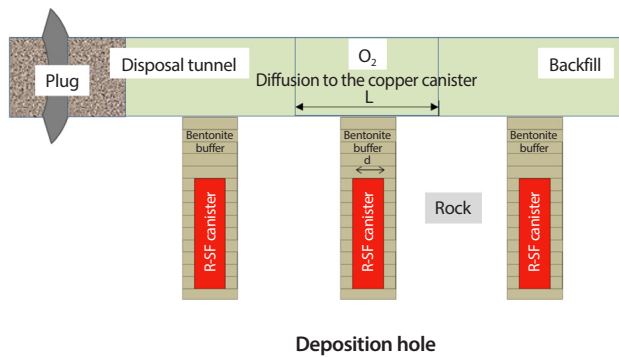


Fig. 3. Conceptual drawing of a disposal tunnel and deposition holes.



As given in equation (1), it was calculated that four moles of copper atoms were consumed per one mole of oxygen molecules (32 g). The corrosion depth of a copper canister was calculated for two cases based on this equation.

The first case concerns the corrosion of copper by oxygen in the buffer pores that surround a disposal canister. The total porosity of the buffer is the most important item for calculating the amount of oxygen that can corrode a copper canister. The total porosity was determined using the values given in Table 2. It was assumed that all oxygen in the buffer pores, except for the groundwater portion filling the pores, reacted with copper corrosion. The calculation results in Table 2 show that the corrosion depth for the KAERI R-SF canister was 0.0412 mm (41.2 μm), and the corrosion depth for the Posiva canister was 0.0326 mm (32.6 μm). The reason why the KAERI R-SF canister showed a deeper corrosion depth was that it had a larger

surface area and the amount of oxygen in the thicker buffer was more than in the Posiva case.

The second case concerns the corrosion depth caused by oxygen present in the pores of the backfill that filled the disposal tunnel (conceptual diagram, Fig. 3). It was conservatively assumed that all oxygen was consumed by the reaction with a copper lid of a disposal canister. The following equation was used to calculate the corrosion depth (C_d) of a copper lid:

$$C_d = 4 \times \frac{4mM}{\pi d^2 \rho_c} \quad (2)$$

where m is the number of oxygen molecules in backfill pores (moles),

M is the atomic weight of copper (63.546),

d is the diameter of a copper canister lid (cm),

and ρ_c is the density of copper (8.9 g·cm⁻³).

The calculation results showed that there was much more oxygen in the backfill pores than in the buffer pores. This large amount of oxygen consumed by the copper lid of a R-SF canister resulted in deeper a corrosion depth (14.29 mm) compared with the previous case. This corrosion depth was also deeper than that of the Posiva case (11.23 mm). This was because the cross-sectional area (28.69 m²) of the KRS⁺ disposal system was larger than that of the Posiva tunnel (16.46 m²) as shown in Table 3.

3.2 Corrosion by Sulphide

Provided that the oxygen in the buffer and backfill

pores disappears due to the oxidation reaction with copper after the closure of a repository, the environment around a disposal canister becomes anoxic. Under the anoxic condition, sulphide can corrode a copper canister. In most underground environments sulfur ions exist as sulphate, but they are converted to sulphide by the reaction with microbes, and so on. The sulphide reacts with copper through the following reaction [15, 16]:



As shown in equation (3), one mole of sulfur atom reacts with two moles of copper atom. It was considered that this reaction continued over more than hundreds of thousands years. In the Posiva Safety Case, two cases depending on the buffer conditions (intact buffer and eroded buffer) were assessed separately. It was judged that the copper canister failed if the following condition was satisfied:

$$\int_{t=0}^{t=t_{fail}} j \cdot dt = d \quad (4)$$

where j is the corrosion rate [$\text{m}\cdot\text{y}^{-1}$], and d is the initial thickness of the copper canister [m].

The corrosion rate (j) in equation (4) was calculated with the following equation:

$$j = 2 \frac{N_c}{N_s} \frac{F}{\rho_c A} \quad (5)$$

where N_c is the atomic weight of copper (63.546),

N_s is the molecular weight of sulphide (33),

F is the rate of transport of sulphide to a canister surface [$\text{kg}\cdot\text{y}^{-1}$],

A is the area of a canister surface over which corrosion occurs [m^2].

3.2.1 Sulphide from groundwater through intact buffer

The Posiva Safety Case [2] analyzed two cases for the intact buffer scenario. The first case involved the corrosion

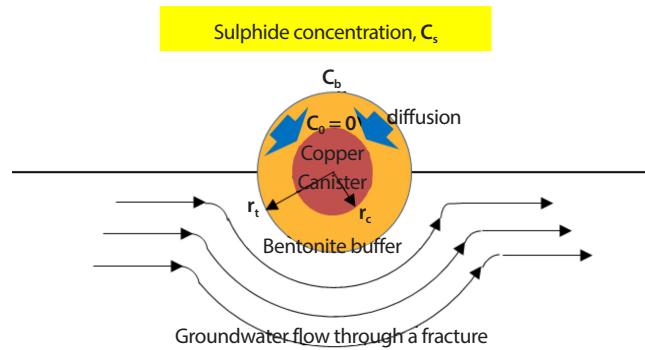


Fig. 4. Schematic of groundwater flow around a deposition hole.

caused by sulphide that diffused through the buffer to the copper canister surface from groundwater flowing in a horizontal fracture that intersected the deposition hole filled with intact buffer. The second case related to the corrosion caused by sulphide that diffused vertically to the canister surface through the backfill and buffer from a deposition tunnel.

In the case where groundwater flows in a fracture with an aperture of $2b$, sulphide in flowing groundwater diffuses through a buffer to a canister surface due to the concentration difference and reacts with copper (conceptual diagram, Fig. 4). The rate of transport of sulphide to the canister surface is denoted by F_{ib} , and A_{ib} denotes an effective area of the canister surface over which corrosion occurs. Smith et al. [17] derived F_{ib}/A_{ib} in equation (5), as follows:

$$\frac{F_{ib}}{A_{ib}} = \frac{\pi D_e C_b}{2(r_t - r_c) \ln[2(r_t - r_c)/b]} \quad (6)$$

where D_e is the effective diffusion coefficient of sulphide in buffer [$\text{m}^2\cdot\text{y}^{-1}$],

C_b is the sulphide concentration at the buffer/rock interface [$\text{kg}\cdot\text{m}^{-3}$],

r_t is the deposition hole radius [m],

r_c is the canister radius [m],

$2b$ is the fracture aperture [m].

In equation (6), the concentration of sulphide at the boundary between the rock and the buffer (C_b) has not yet been determined. This value is given as follows:

Table 4. Parameter values for calculating corrosion depth due to sulphide in groundwater flowing in a fracture around the deposition hole

Parameters	KAERI	Posiva
Sulphide concentration in groundwater away from the interface, C_s ($\text{kg}\cdot\text{m}^{-3}$)	0.003	0.003
Radius of a deposition hole, r_i (m)	0.875	0.875
Radius of a disposal canister, r_c (m)	0.515	0.525
Thickness of a copper layer, d (cm)	5.0	4.9
Diffusion coefficient of anions in groundwater, D_w ($\text{m}^2\cdot\text{s}^{-1}$)	1.0×10^{-9}	1.0×10^{-9}
Effective diffusion coefficient of sulphide in buffer, D_c ($\text{m}^2\cdot\text{s}^{-1}$)	7.8×10^{-12}	7.88×10^{-12}
Fracture aperture, $2b$ (mm)	1.58×10^{-2}	1.58×10^{-2}

$$C_b = C_s \frac{Q_f}{Q_f + Q_b} \quad (7)$$

where C_s is the sulphide concentration in groundwater away from the interface [$\text{kg}\cdot\text{m}^{-3}$],

Q_f is the flow rate through a layer of water within the fracture [$\text{m}^3\cdot\text{y}^{-1}$],

Q_b is the effective flow rate describing the steady-state rate of mass transfer across the buffer by diffusion driven by a unit concentration difference [$\text{m}^3\cdot\text{y}^{-1}$].

Q_b and Q_f are given as follows:

$$Q_b = \frac{2\pi^2 D_e r_t}{\ln\left[2\left(\frac{r_i - r_c}{b}\right)\right]} \quad (8)$$

$$Q_f = \frac{A_{\text{frac}}}{\pi} \sqrt{\frac{2D_w T i_0}{r_t b}} \quad (9)$$

where D_w is the diffusion coefficient of anions in water [$\text{m}^2\cdot\text{y}^{-1}$],

T is the transmissivity [$\text{m}^2\cdot\text{s}^{-1}$],

i_0 is the hydraulic gradient [0.01].

An illustrative calculation was performed using the values cited from the Posiva Safety Case. The input data for the calculation of corrosion lifetime of a copper canister with equations (6) to (9) are summarized in Table 4, in which the sulphide concentration of 3 ppm was used as the most conservative value in Finnish case. In Table 4, most of the data show similar values for both KAERI and Posiva. Transmissivity was the one of most important

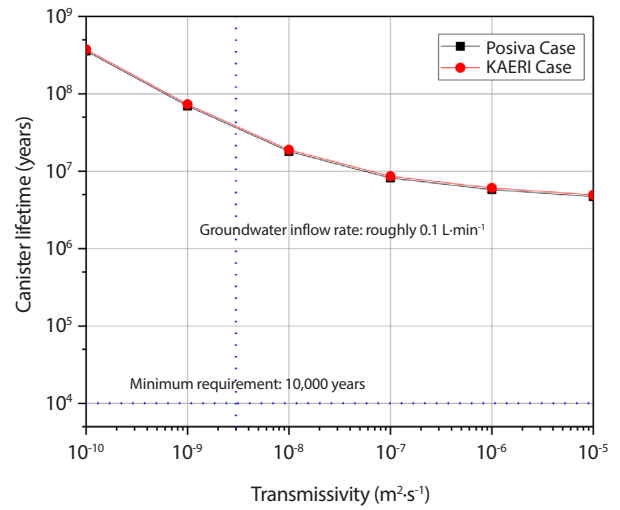


Fig. 5. Canister lifetime due to sulphide from groundwater.

characteristics of rock where the deposition hole was located, and thus by changing this value, the corrosion lifetime of a copper canister was obtained. Smith et al. [17] considered a value of 50 as the uneven corrosion of copper factor when calculating corrosion lifetime, and we used the same value.

The calculated corrosion lifetime of a copper canister by sulphide in groundwater is shown in Fig. 5 for the case of the intact buffer. The lifetimes of the disposal canisters for both the KAERI and Posiva designs were compared by changing the transmissivity values. There were differences only in the specifications of the compacted buffers and disposal canisters. Since the concentration of sulphide in groundwater and the diffusion coefficient of sulphide in the buffer were the same, both cases showed almost

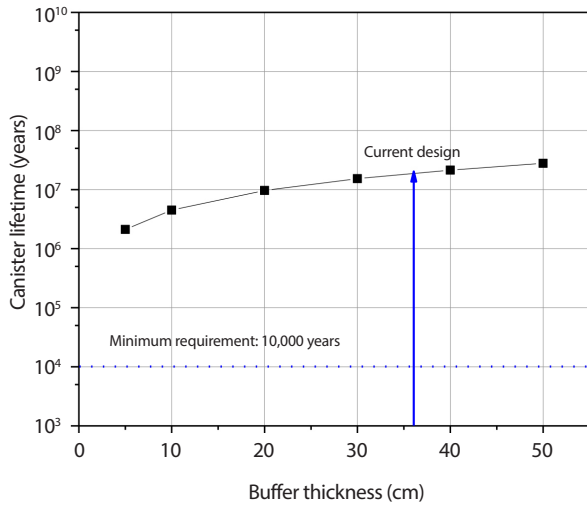


Fig. 6. Effect of buffer thickness on canister lifetime with the transmissivity ($10^{-8} \text{ m}^2 \text{ s}^{-1}$).

similar results. All the cases for KAERI and Posiva showed that the lifetimes of the copper canisters were much longer than 10^6 years in cases where the buffer maintains its initial capacity. It was thought that the reason why the KAERI canister had a slightly longer lifetime was that the compact buffer was slightly thicker than the Posiva buffer. For more accurate analysis on corrosion lifetime, transmissivity of rock should be characterized during site characterization in the future.

The transmissivity of rock was set as $10^{-8} \text{ m}^2 \text{ s}^{-1}$, and the corrosion lifetime of a canister was compared by changing the thickness of a compacted buffer. As shown in Fig. 6, even though the buffer thickness became sufficiently thin, the corrosion lifetime was sufficiently longer than 10^6 years. This result meant that there was no possibility that the copper canister could be penetrated within 1 million years due to corrosion by sulphide in groundwater flowing in a fracture if the compacted buffer maintained its capacity as designed. It was recommended that the minimum buffer thickness of 200 mm was sufficient from the viewpoint of copper canister corrosion.

In addition, for a more conservative analysis, the lifetime of a canister was calculated even when equation (7) became $C_b = C_s$, which does not take into account the

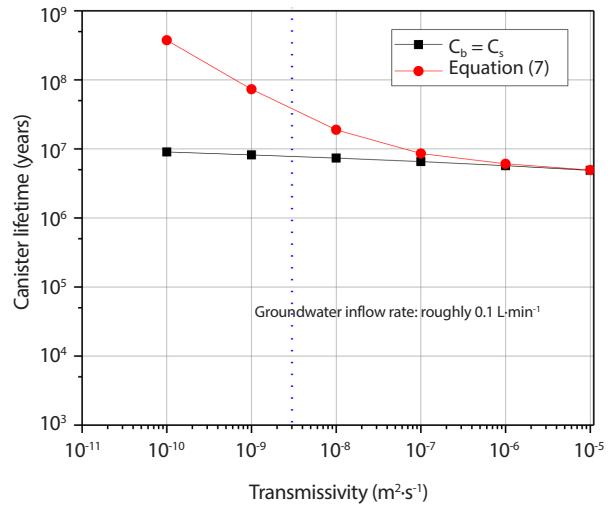


Fig. 7. Effect of sulphide concentration on canister lifetime.

effect of diffusion in the boundary layer around the deposition hole. This was the case in which the concentration of sulphide in groundwater maintained the highest value (C_s) on the outer surface of the buffer. The calculation results for this case are shown in Fig. 7. In the results, when the groundwater velocity was very slow (low transmissivity case), the differences in the lifetime were more than ten times. When the groundwater velocity was very high, the effect of diffusion in the boundary layer decreased, and the lifetimes of the two cases converged.

3.2.2 Sulphide from backfill through intact buffer

The corrosion lifetime of a disposal canister was calculated when sulphide was present in the backfill of a disposal tunnel. According to the Posiva model shown in Fig. 8, the concentration of sulphide in the backfill far away from the deposition hole had a constant value (C_s), and advection occurred along the disposal tunnel. The amount of sulphide, M [kg], transferred from the disposal tunnel to the interface between the disposal tunnel and the deposition hole was calculated by the following equation [2]:

$$M = 2\pi r_t^2 (C_s - C_t) \sqrt{\frac{\epsilon D_{et} t_{adv}}{\pi}} \quad (10)$$

Table 5. Parameters for sulphide in backfill

Parameters	KAERI	Posiva
Effective diffusion coefficient of sulphide in backfill ($\text{m}^2\cdot\text{s}^{-1}$)	7.8×10^{-11}	7.8×10^{-11}
Effective diffusion coefficient of sulphide in buffer ($\text{m}^2\cdot\text{s}^{-1}$)	7.8×10^{-12}	7.8×10^{-12}
Sulphide concentration in groundwater away from the interface, C_s ($\text{kg}\cdot\text{m}^{-3}$)	0.003	0.003
Vertical distance from the top of the canister to the top of the deposition hole (m)	2.5	2.5
Thickness of the canister lid (mm)	50	50

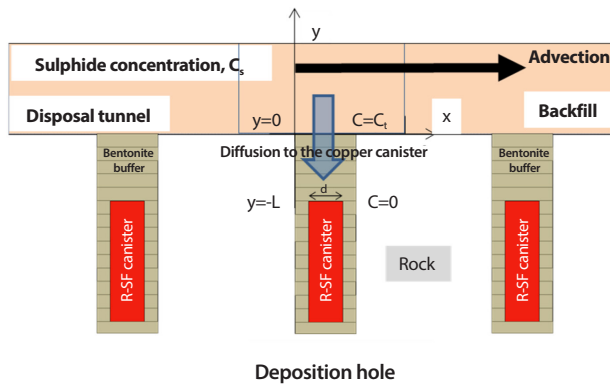


Fig. 8. Schematic of sulphide in a backfilled tunnel.

where ε is the porosity of the backfill [-], and

D_{et} is the vertical effective diffusion coefficient of anions (sulphide) in the backfill [$\text{m}^2\cdot\text{y}^{-1}$].

The mean travel time (t_{adv}) in equation (10), which is the time a particle takes to move through a disposal tunnel together with groundwater passing a deposition hole, was calculated with the following equation:

$$t_{adv} = \frac{\pi}{2} \frac{r_t \varepsilon}{q} \quad (11)$$

where q is the Darcy velocity in the backfill [$\text{m}\cdot\text{y}^{-1}$].

From equation (10) and (11) the following equation was obtained:

$$\frac{M}{t_{adv}} = 2r_t^2(C_s - C_i) \sqrt{\frac{2D_{et}q}{r_t}} = F_{vD} \quad (12)$$

Also, the steady-state vertical diffusive flux through the buffer from the mouth of a deposition hole to the surface of a canister lid is given by:

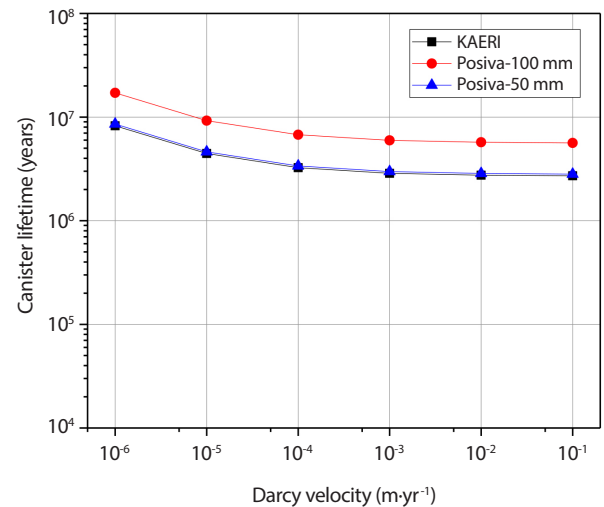


Fig. 9. Calculation of canister lifetime with sulphide from backfill.

$$F_{vb} = \frac{\pi r_t^2}{L} C_i D_e = F_{vD} \quad (13)$$

where L is the vertical distance from the top of a canister to the top of a deposition hole [m].

Considering the mass balance, equation (12) should be the same as equation (13). If we eliminate C_i from both equations, the following equation could be obtained:

$$\frac{F_{vD}}{A_{vD}} = \frac{2C_s r_t^2 D_e}{L r_c^2} \sqrt{\frac{2D_{et}q}{r_t}} \left/ \left(2 \sqrt{\frac{2D_{et}q}{r_t}} + \frac{\pi}{L} D_e \right) \right. \quad (14)$$

The corrosion lifetime of a copper canister lid by sulphide in the backfill of a disposal tunnel was calculated using equations (14) and (5). The effective diffusion coefficients in the backfill and buffer were given in Table 5, and the diameters of deposition hole and disposal canister given in Table 4 were used in the calculation. Since the

Darcy velocity in the backfill was not available, the corrosion lifetimes were obtained by changing this value. The calculation results are shown in Fig. 9. The results show that the lifetime of the KAERI canister lid was almost similar to that of the Posiva canister lid. A comparative calculation was also performed for the case where the lid thickness was 10 mm. The lifetime of a canister lid was more than one million years regardless of the Darcy velocity in the disposal tunnel.

3.2.3 Sulphide transport through a partially eroded buffer with advection in fracture

A compacted buffer can be changed by the groundwater flow a long time after the closure of a repository. The Posiva Safety Case analyzed the case of a part of compacted buffer eroded by groundwater flowing in a fracture that horizontally intersected a deposition hole. The situation is illustrated in Fig. 10. The sulphide flux (F_{eb}) to the surface of a disposal canister was calculated using the following equivalent flow model derived by Neretnieks et al. [18] for a partially eroded buffer. That is, F_{eb} and A_{eb} in equation (5) for determining the corrosion rate were:

$$F_{eb} = Q_{eb} C_s \quad (15)$$

where Q_{eq} is the equivalent flow rate in the eroded buffer [$\text{m}^3 \cdot \text{y}^{-1}$], which is the smaller value in the following equation:

$$Q_{eb} = \left\{ \frac{Q_A}{\sqrt{Q_A Q_{lim}}} \right\} \quad (16)$$

In equation (16), Q_A is the flow rate through a fracture that had a width twice that of the deposition hole diameter. Q_{lim} was calculated by:

$$Q_{lim} = \frac{4}{\pi} \times \frac{VD_w}{(r_t - r_c)^2} \quad (17)$$

V in equation (17), denotes the volume [m^3] of eroded buffer and was calculated by:

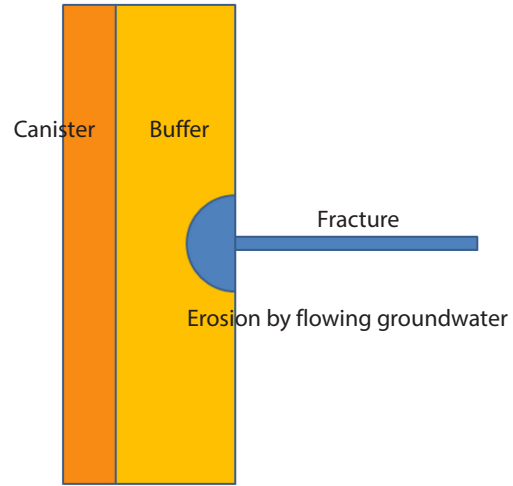


Fig. 10. Illustration of the geometry of buffer erosion (modified from SKB, 2010[18]).

$$V = \frac{\pi^2}{2} r_t (r_t - r_c)^2 - \frac{2\pi}{3} (r_t - r_c)^3 \quad (18)$$

In addition, A_{eb} is the effective area of the canister surface over which corrosion occurred and was obtained using the following equation:

$$A_{eb} = \pi r_c (r_t - r_c) \quad (19)$$

Using equations (5), (15) and (19), the corrosion depth of a copper canister was calculated for the case where the partial erosion of a compacted buffer occurred. When the transmissivity of a fracture intersecting a deposition hole was $3 \times 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$, the expected corrosion depth was 7.43 mm for the KAERI R-SF canister and 7.50 mm for the Posiva canister one million years after repository closure. It was estimated that the lifetimes of the KAERI R-SF canister and the Posiva canister for the partially eroded buffer were 6.73×10^6 years and 6.53×10^6 years, respectively.

4. Conclusion

The most important engineered barrier in a geological

Table 6. Comparison of canister corrosion lifetimes

Corroding agent	Case	KAERI	Posiva
Oxygen	Corrosion depth by oxygen during operation period	Less than 1 μm	Less than 1 μm
	Corrosion depth by oxygen in buffer	0.0412 mm	0.0326 mm
	Corrosion depth of a canister lid by oxygen in backfill	14.29 mm	11.23 mm
Sulphide	Canister lifetime by sulphide in groundwater flowing through a fracture [Transmissivity: $3 \times 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$]	3.63×10^7 years	3.46×10^7 years
	Canister lid lifetime by sulphide in backfill through intact buffer [Darcy velocity: $1 \times 10^{-3} \text{ m} \cdot \text{y}^{-1}$]	2.87×10^6 years	5.96×10^6 years
	Canister lifetime by sulphide in groundwater through partially eroded buffer [Transmissivity: $3 \times 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$]	6.73×10^6 years	6.53×10^6 years

repository is a disposal canister. The major role of a copper canister is to protect spent nuclear fuel and to withstand corrosion under deep geological environments for long periods. It was considered that oxygen and sulphide were the corroding agents that could corrode copper under given disposal conditions. We developed a computer program to predict the corrosion lifetime of a disposal canister.

The computer program was developed based on the numerical methodologies that were applied to the Safety Case prepared by Posiva, a Finnish nuclear waste management organization, in order to predict the lifetime of a copper disposal canister. Using our computer program, the corrosion lifetime of a R-SF canister that was used for the KRS⁺ geological repository developed for domestic pressurized water reactor spent nuclear fuel. The calculated corrosion lifetimes of the R-SR canister were compared with the lifetimes of the Posiva canister, and the results are summarized in Table 6. As shown in Table 6, the lifetimes of the R-SF canister were longer than the several thousand years required by Nuclear Safety and Security Commission Notice 2017-74. Also, this study shows that it is necessary to carefully characterize the transmissivity of rock and sulphide concentration during the site characterization in order to accurately predict the canister lifetime.

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