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Swedish Radiation Safety Authority

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Technical Note

2016:16

Possible influence from stray currents from high voltage DC power transmission on copper canisters

Main Review Phase

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SSM:s perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Det övergripande syftet med denna rapport är att ta fram synpunkter på SKB:s säkerhetsredovisning SR-Site eller dess underlagsrapporter. Specifikt för denna rapport är syftet att granska SKB:s redovisning av eventuell påverkan på slutförvaret av läckströmmar från högspänningskablar.

Författarnas sammanfattning

Denna rapport granskar SKB rapport TR-14-15 med avseende på följande områden:

1. Om rapporterat spänningsfall över kapseln är korrekt.
2. Om den presenterade analysen beskriver nuvarande och framtida analyser i tillräcklig omfattning.
3. Effekterna av jordströmmar på spänningsfallet över kapseln.

Den granskade rapporten innehåller en analys av påverkan av HVDC (högspänningslikström) med monopolärt överföringssystem på korrosion av kopparkapslarna i det planerade slutförvaret för använt kärnbränsle. Granskningen berör de områden som nämns ovan.

Generellt sett har rapporten en välstrukturerad analys med vissa områden för förbättringar.

Spänningsfallet över kapslarna beräknas med FEM-metoden med stor- och småskaliga beräkningar vilket är ett acceptabelt sätt att förenkla beräkningarna. Det finns dock vissa förenklingar och antaganden som inte är motiverade i detalj.

Antaganden om framtida scenarier gällande utveckling av nuvarande teknik bedöms av författarna som korrekta och rimliga. Det finns dock ingen bedömning av teknik som ännu inte är utvecklade.

Rapporten behandlar endast HVDC monopolära ledningar som en källa till jordströmmar. Initialt hänvisar rapporten till en annan rapport som analyserar källor till jordströmmar och drar slutsatsen att den huvudsakliga källan till jordströmmar är HVDC-överföringssystem.

Den samlade bedömningen av rapporten är att slutsatserna är välgrundade och metodiken sund, men att antaganden och förenklingar skulle kunna beskrivas mer i detalj.

Projektinformation

Kontaktperson på SSM: Lena Sonnerfelt
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Aktivitetsnummer: 3030012-4119

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The general objective of the present project is to provide independent review comments for one area of SKB:s post closure safety analysis, SR-Site. With this in mind, the purpose of this report is to review SKB's presentation on possible influence from stray currents from high voltage DC power transmission on a repository for nuclear fuel.

Summary by the authors

This report reviews the SKB report TR-14-15 with regards to the following areas:

1. If the voltage drop across the canister that are reported are accurate
2. If the presented analysis adequately describes the current and future analysis cases
3. The impact of telluric current on the voltage drop over the canister

The reviewed report contains an analysis of the influence of HVDC monopolar transmission systems on the corrosion of the copper canisters in the planned spent fuel repository. The review touches the areas mentioned above.

Generally the reviewed report presents a well structured analysis with some areas for improvement.

The voltage drop over the canisters are calculated using FEM measurement using large and small scale calculations which is an acceptable way of simplifying calculations. There are however some simplifications and assumptions that are not motivated in detail.

Assumptions regarding the future scenarios with respect to development of current technologies are assessed by the Authors as correct and reasonable. There are however no assessment of technologies which are not yet developed.

The report only deals with HVDC monopolar transmission lines as a source of telluric currents. Initially the report refers to another report that analyses the sources of the telluric currents and concludes that the main source of telluric current are HVDC transmission systems.

The overall assessment of the report is that the conclusions are well founded and the methodology is sound, but that the assumptions and simplifications could be described in more detail.

Project information

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This report was commissioned by the Swedish Radiation Safety Authority (SSM). The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of SSM.

Contents

1. Introduction

As part of the Swedish Radiation Safety Authority's (SSM) review of the Swedish Nuclear Fuel and Waste management company (SKB) license application for a final storage for spent nuclear fuel, SSM has asked for complementary information regarding the effect of stray currents from high voltage cables on copper corrosion (SSM 2012). SKB therefore has performed an extended study of the effects of high voltage DC power transmission as support for answering SSM. This study has been presented in the report SKB TR-14-15 [1].

This report is a review of SKB report TR-14-15 and is the authors' assessment in response to the following three questions raised by SSM together with relevant support analysis and technical material:

1. If the voltage drop across the canister that are reported are accurate
2. If the presented analysis adequately describes the current and future analysis cases
3. The impact of telluric current on the voltage drop over the canister

The assessments made in this report are mainly based on the authors' respective experience from previous work within electrical analysis, nuclear and HVDC. The authors' combined university studies have also been used in parts of the review, mostly within the theoretical parts of the report.

2. General assessment

The report [1] is well structured and it is easy to follow the analysis done. The method and simulations are described clearly and in detail. The language that is used is well adapted to the recipient of the document. Derivations and approximations are however not presented in detail.

The report is structured according to general international guidelines of a technical report. The general assessment is therefore that the report covers the scope of the investigated topics in a clear and concise way.

3. Assessment of calculated voltage drop over canister

3.1. Methodology and simplifications

3.1.1. SKB's presentation

SKB has calculated the voltage drops over the canisters using FEM analysis modelling in large scale to determine the potential fields in the vicinity of the repository. With known large scale potential fields a smaller scale model has been developed with the repository modelled according to different variables.

The analysis has been performed recalculating the low seabed slope at the site to an equivalent resistivity, different bedrock resistivities and alternating positions of the electrode and repository with regards to the global electrical field.

FEM analysis has been used to calculate the voltage drop over the canister with dry and wet bentonite surrounding the canisters and with different bentonite resistivities.

3.1.2. WSP's assessment

Using FEM calculation is an established method of numerical calculation when analytical solutions do not exist. However boundary conditions must be clearly stated and sound for the calculations to yield accurate results. In the reviewed report TR-14-15 [1] boundary conditions are clearly stated and the assumptions are in this regard both presented and reasonable.

The report also calculates the resistivity of the bedrock and water mix to take into consideration the angle of the seabed that in the presented model is valid only for higher angles than the one in Forsmark. This calculation is not proved within the report.

The proof for this equation is shown below. Using equation (1) for the resistance along the length in a non-uniform object and (2) as the cross-section area of the slice of sea and bedrock respectively. Using here the assumption that $\sin\varphi = \sin\varphi_{sea} + \sin\varphi_{bedrock}$, which is true for small φ [2].

$$R = \int \frac{\rho \cdot dl}{A} \tag{1}$$

$$A = d \cdot l \cdot \sin\varphi \tag{2}$$

Calculating the integral according to previous yields the equation (3)

$$
\begin{aligned}
R &= \int \frac{\rho \cdot dl}{A} \\
&= \int \frac{\rho \cdot dl}{d \cdot l \cdot \sin\varphi} \\
&= \frac{\rho}{d \cdot \sin\varphi} \int \frac{1}{l} \cdot dl \\
&= \frac{\rho \cdot \ln l}{d \cdot \sin\varphi}
\end{aligned}
\tag{3}
$$

Since the sea and bedrock can be assumed to form a parallel circuit – this assumption is stated in the report and the authors agree with it – the equivalent resistance can be calculated as equation (4)

$$
\frac{1}{R_{eq}} = \frac{1}{R_{sea}} + \frac{1}{R_{bedrock}} = \frac{R_{sea} + R_{bedrock}}{R_{sea} \cdot R_{bedrock}} \xrightarrow{yields} R_{eq} = \frac{R_{sea} \cdot R_{bedrock}}{R_{sea} + R_{bedrock}} \tag{4}
$$

The resistance as a function of the distance l (3) is then inserted into the equation for the parallel connection of two resistors (4) and results in equation (5).

$$
\begin{aligned}
&\frac{\left(\frac{\rho_{sea} \cdot \ln l}{d \cdot \sin\varphi_{sea}}\right) \cdot \left(\frac{\rho_{bedrock} \cdot \ln l}{d \cdot \sin\varphi_{bedrock}}\right)}{\left(\frac{\rho_{sea} \cdot \ln l}{d \cdot \sin\varphi_{sea}}\right) + \left(\frac{\rho_{bedrock} \cdot \ln l}{d \cdot \sin\varphi_{bedrock}}\right)} \\
&= \frac{\ln l}{d} \cdot \frac{\frac{\rho_{sea}}{\sin\varphi_{sea}} \cdot \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}{\frac{\rho_{sea}}{\sin\varphi_{sea}} + \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}
\end{aligned}
\tag{5}
$$

Differentiate to get the average and multiply by $\frac{l \cdot \sin\varphi_{eq}}{\sin\varphi_{eq}}$ to get the resistance over the distance and substitute equation (5) from above. This results in the equation (6)

$$
\begin{aligned}
&\frac{\frac{\rho_{sea}}{\sin\varphi_{sea}} \cdot \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}{\frac{\rho_{sea}}{\sin\varphi_{sea}} + \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}} \cdot \frac{l \cdot \sin\varphi_{eq}}{d \cdot l \cdot \sin\varphi_{eq}} \\
&= \frac{\frac{\rho_{sea}}{\sin\varphi_{sea}} \cdot \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}{\frac{\rho_{sea}}{\sin\varphi_{sea}} + \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}} \cdot \frac{l \cdot \sin\varphi_{eq}}{A}
\end{aligned}
\tag{6}
$$

From this equation identify the corresponding part of ρ to calculate the resistivity, which yields (7).

$$
\begin{aligned}
\rho &= \sin\varphi_{eq} \cdot \frac{\frac{\rho_{sea}}{\sin\varphi_{sea}} \cdot \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}{\frac{\rho_{sea}}{\sin\varphi_{sea}} + \frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}} \\
&= \frac{\sin\varphi}{\frac{1}{\frac{\rho_{sea}}{\sin\varphi_{sea}}} + \frac{1}{\frac{\rho_{bedrock}}{\sin\varphi_{bedrock}}}} \\
&= \frac{\sin\varphi_{eq}}{\frac{\sin\varphi_{sea}}{\rho_{sea}} + \frac{\sin\varphi_{bedrock}}{\rho_{bedrock}}}
\end{aligned}
\tag{7}
$$

Calculate the conductance κ according to (8).

$$\frac{1}{\rho} = \kappa = \frac{\frac{\sin\varphi_{sea}}{\rho_{sea}} + \frac{\sin\varphi_{bedrock}}{\rho_{bedrock}}}{\sin\varphi_{eq}} \tag{8}$$

Which in combination with the assumptions according to [2], see eq (9) results in the used equation in the report.

$$\begin{aligned} \sin\varphi_{sea} &\approx \varphi_{sea} \\ \sin\varphi_{eq} - \sin\varphi_{sea} &\approx \sin\varphi_{bedrock} \\ &\approx \varphi_{bedrock} \end{aligned} \tag{9}$$

The authors consider that, while the proof is long and not in line with the report per se, it would have been useful to include the proof, or at least some verification of correctness. The corrosion current is dependent on the internal resistance, which is highly dependent on the correct resistivity being used.

It is then stated that the given depth of water at the site is small compared to the depth of the repository, however the authors' assessment is that more than 10 % might not be small and that this assumption should have been discussed more in detail. It would predominately have an effect in the case with horizontal voltage gradient, and this case has lower voltages than the case with vertical voltage gradient. When the voltage gradient is vertical the decreased seabed level will decrease the internal resistance of the circuit model and therefore also decrease the corrosion current.

3.2. Comparison with measured values

3.2.1. SKB's presentation

Comparisons with measurements are also performed showing that there is a good correlation between calculation and measurements for some resistivity functions for large distances from the electrode, but shows much higher values for distances closer to the electrode. The maximum potential is 500 V 5 km from the electrode with resistivity function f6, compared to the measured potential of 200 V.

> *Compared to the measured values, resistivity functions f2, f3 and f6 show good agreement at distances around 15 km from the electrode. At distances lower than about 6 km all resistivity functions give potentials much higher than the measured. The differences between calculated and measured potentials show that the electrical field close to the Fenno-Skan electrode cannot be described using any of the resistivity functions in combination with the used sea water resistivity and constant slope angle.*
>
> [1, p. 30]

The explanation for these differences may be:

- *The coast at the location of the electrode is more open than assumed in the model. Figure 4-1 shows that there is open sea not only east-northeast but also due north and to some extent north-northwest.*
- *The coast is not a straight line. The distance of 2.3 km between the electrode and the shoreline is the shortest distance. For the comparison with model results it would be more relevant to consider the shortest distance to an 'average shoreline'. No 'average shoreline' is estimated here but it is evident that the distance between the electrode and an imagined 'average shoreline' is longer than 2.3 km and if a longer distance was introduced in the model, the resulting voltages would be lower and in better agreement with observations.*
- *The sea water may be deeper at the site of the electrode than average for that distance from the shoreline.*

[1, p. 30]

These differences may stem out of the fact that the site was not chosen randomly, but chosen to minimize the transmission losses. The differences are however not accounted for during calculations as the model is designed to work at any randomly selected site.

3.2.2. WSP's assessment

The authors agree with the assumption that the difference between calculated and measured values may be the result of the presented differences between model and physical location. It would however be of interest to also calculate the voltage potential for a case with a coastline that resembles the coastline at Fenno-Scan to determine if these assumptions are valid.

Since the voltages are highest in the case with the electrode close to the repository using the presented resistivity functions yields values that are likely much higher than the actual values. The calculations are done for any random location with the worst combination of coastline, seabed slope, etc which leads to a large safety margin. The authors' assessment is that the used resistivity functions are realistic in the general case, but conservative in the proposed repository location. The measured potential of 200 V can be compared to the calculated potential of up to 500 V. Since the calculations show that the voltage is below minimum corrosion voltage this only adds to the safety margin.

3.3. Modelling of voltage drop

3.3.1. SKB's presentation

The voltage drop over the canister is modelled using an equivalent circuit of the bentonite cladding on the top and bottom of the deposition hole in series with the parallel circuit that comprises the canister and the bentonite cladding:

It is found that the voltage that develops along the height of a canister is determined by three parameters, mainly. These are, the electromotive force, E, the internal resistance, R i and the resistance in the bentonite parallel to the canister, R b2 . Equal attention is therefore given to the estimation of values for these three parameters.

[1, p. 30]

The driving potential for the current is the calculated applied external electrical field from the tunnel floor down to the bottom of the deposition hole. The resistance of the bentonite cladding is analysed for different levels of saturation.

Only the voltage along the height of the canister is assessed, since the voltage across the diameter of the canister is much lower than across the height. The reason for this is that the height of the canister is much larger than the diameter and the voltage across the canister is proportional to the resistance of the surrounding material. The surrounding material's resistance in turn is proportional to the length of the current path through it:

The transition from the FEM-model to the equivalent circuit requires some assumptions. Only the current in the direction along the height of the canister is considered relevant. There is also a component of the current in each of the two directions perpendicular to the axis of symmetry of the canister and the deposition hole. The possible effects of these current components are not studied here. The reasons are that the diameter of the hole and of the canister is much smaller than the corresponding height and that the sequence of the resitivities for current passing perpendicular to the axis of symmetry would be determined by rock-deposition hole-rock whereas the sequence of the resitivities for current passing along the axis of symmetry would be determined by tunnel-deposition hole-rock. Both these factors contribute to make the voltages that arise, across a canister, perpendicular to the axis of symmetry much smaller than the voltages that arise along the axis of symmetry.

[1, p. 36]

3.3.2. WSP's assessment

The report [1] calculates the voltage along the longest axis of the canister, but in the case with uniform electrical field it can be assumed that the highest voltage gradient is perpendicular to the height of the canister, and that the voltage gradient is highest along the diameter of the canister. This higher voltage gradient is however offset by the shorter distance which leads to less resistance and total voltage. The authors concur with the assumption that the highest voltage drop will be along the height of the canister but feel that a discussion regarding this influence is missing from the report.

In case 3 with the electrode on top of the repository the voltage will be highest along the length of the canisters, and in this case the voltage drop model is accurate. Since this case also represents the highest voltages of all cases the lack of discussion mentioned in the previous paragraph does not pose any problem for the general conclusion of the report.

In the other cases similar issues can be raised, for instance, the case with varying position it should be taken into account the longest length of the canister, which is the diagonal from the top of the canister to the bottom of the canister along the diameter of it. This only contributes about 2 % to the length of the canisters and may be neglected.

The report [1] also details how the voltage across the canister is changing dependent on the electrical field angle aligned to the tunnels. The presented calculations are however done only for a few angles and there is no assessment if the maximum is a local or global maximum. The report is assuming that it is a global maximum without any further analysis or discussion. It is a possibility that there are other maximum with less favourable result. The authors' assessment is that this does not affect the results adversely, but it is not possible to accurately evaluate this within the scope of this assignment. The reason behind this assessment is that the case with varying distance between electrode and repository does not have voltages higher than case 3 with the electrode on top of the repository.

As a side note to this review it would have been interesting to see the analysis performed for the alternate deposition proposal with horizontal deposition holes. The authors assume that the voltage along the canisters in this case will be higher than 0.5 V and resulting in higher corrosion speeds.

3.4. Effect of electrode placement

3.4.1. SKB's presentation

Four different scenarios have been studied which corresponds to three different electrical fields. The cases are:

- *A close to horizontal gradient field if the electrode is several km from the repository (case 1).*
- *A close to vertical gradient field if a foreign grounding system is located directly on top of the repository and interacts with the HVDC system, resulting in a local secondary gradient field (case 2).*
- *A close to vertical gradient field if the HVDC system is located directly on top of the repository (case 3).*
- *A gradient field with an angle if the electrode is closer than a few km (case 4).*

[1, p. 19]

For each of these cases the resultant electrical field have been calculated, taking the physical aspects of the site, e.g. deposition tunnels, halls and refilling properties, into consideration.

A repository depth of 500 m is used for calculations, and for one case the depth is also set at 700 m yielding a 20 % drop in voltage.

3.4.2. Assessment of electrode placement

The different cases present different electrode placements with regards to the repository. These cases represent the different voltage gradients that can be present within the repository. The previous section discusses the result of these cases.

It is not reasonable to assume that any other placements will yield a different electrical field. The only field that is not calculated within the report is a highly divergent field corresponding to a deep electrode, but this case is implausible due to the high difference in resistivity between water and bedrock. The authors' assessment is therefore that the presented cases represent all applicable voltage fields that may occur.

With varying depth of the repository the field will change, but only in the cases with vertical voltage gradients. These cases are case 2 to 4, and between these three the 3rd case is the worst in this regard. Placement of the repository any higher than 500 m below ground will result in voltages higher than 0.5 V, but the conservative assumptions that are made in the report guarantee that this level will not see voltages higher than 0.5 V. Placement 700 m below ground is also assessed and this results in an expected lowering of the voltage, in this case by roughly 20 %.

4. Assessment of future scenarios

4.1. SKB's presentation

The current technologies are by SKB assumed to be able to reach 1500 MW at 600 kV in the future. This corresponds to a current of 2500 A.

> *For a sea cable connection it is the HVDC cable, which limits the capacity of the transmission. The first HVDC subsea cable was delivered to the transmission system supplying Gotland with electricity in 1954 having the capacity of 20 MW at 100 kV. In 1994 The Baltic Cable was installed designed for 600 MW/ 450 kV. Today it is possible to produce cables with a capacity of 1,000 MW at 550 kV corresponding to a current of 1,820 A. It is foreseen that in the future cables can be produced capable of transmission of 1,500 MW at 600 kV, which would mean a current of 2,500 A.*
>
> [1, p. 12]

The periods of time that the current can be directed through the electrode is concluded not to be the normal, but a possible mode of operation during longer time periods and thereby included in the investigation.

> *Due to high risk for interference with the infrastructure, monopolar systems are, in principle not installed any more. Bipolar systems with the possibility to operate as monopolar are however common. Periods of maintenance/repair can be as long as one year why we have to consider the possibility of monopolar operation even in the future, at least for limited periods.*
>
> [1, p. 12]

The report [1] discusses the possibility that a land based electrode will be used in the future:

> *A monopolar HVDC system in the surroundings of Forsmark or any other part of northern Uppland will most probably never use a land-based electrode. The bedrock has a very high resistivity and the soil layer is thin which would result in unacceptable power losses in combination with massive interference and hazards to human lives. Any system installed in this area in the future will most likely be used for transmission of energy across the Baltic Sea using a sea-based electrode.*
>
> [1, p. 20]

The report also discuss the power loss of the electrode and the calculated power loss gives an indication that this loss may be of interest to reduce with newer technologies.

4.2. WSP's assessment

The possibility to increase the capacity and thus the telluric currents are limited by the technology of the monopolar HVDC system. As long as the monopolar and bipolar HVDC systems, as defined today, is the used technology it is reasonable to assume that the telluric currents are within the delimitations made in the report. In the foreseeable future the HVDC will be dominated by monopolar and bipolar technology equal to what is used today.

It is also reasonable to expect that future development will aim for lower losses hence less voltage drop and less telluric currents. However research and development within the field of high voltage transmission is obviously very hard to predict. This implies there might be possible technologies, not developed today, where telluric currents at times can be higher than the assumed worst case scenario in the report.

Since there is a limitation in magnitude of electric field strength that a human being and animal can cope with before getting physically affected, the authors' assessment is that telluric currents originating from HVDC transmission systems most probably will be kept within the values in the report.

The authors have not been able to produce any other relevant scenarios than those presented in the report. Because of the limitation in the technology and the assumed worst placement of the electrode it is the authors' assessment that the impact of corrosion from the worst scenario cannot reasonably be any harsher.

5. Assessment of the impact of telluric currents on voltage drop over canister

5.1. SKB’s presentation

The report [1] presents in detail the calculated voltage drop over the canisters. Currents used in the calculations and measurements of the voltage drop are limited to stray currents from HVDC sources. Section 1 notes that the report only deals with stray currents from HVDC and that other sources has been discredited as a major source of corrosion [3], as seen below:

> *The presence of earth currents and their influence on copper corrosion in a repository for spent nuclear fuel was analyzed in the Process report for fuel and canister for the safety assessment SR-Site (SKB 2010b). Both natural and anthropogenic sources to earth currents were described, and the effects on corrosion discussed. Measured self-potentials and self-potential gradients at the Forsmark site were used to estimate possible potential gradients due to a High Voltage Direct Current (HVDC) installation over a canister in the planned repository. It was concluded that earth currents from natural sources were anticipated to be small, and that stray currents from an HVDC electrode station would not increase the extent of corrosion. The corrosion would still be limited by the availability of oxygen and sulfide.*
>
> *As part of the review of the SKB license application for a repository for spent nuclear fuel, SSM has asked for complementing information regarding the effect of stray currents from high voltage cables on copper corrosion (SSM 2012).*
>
> [1, p. 7]

Calculated ground potentials around an HVDC electrode is based on a current output in the electrode of 2500 A, which is considered to be the most pessimistic case:

> *Future subsea cables are anticipated to be capable of transmitting 1,500 MW at 600 kV, see Section 3.2. Two or more cables can, however, be installed in parallel. If two cables are installed it is most likely that they are operated as a bipolar system. With 3 cables there will be one bipolar and one monopolar system. In the most pessimistic case we would therefore have an electrode in the sea outside Forsmark transmitting 2,500 A in to the sea.*
>
> [1, p. 20]

5.2. WSP’s assessment

The authors’ assessment is that the assumption that telluric currents induced from the HVDC system is the major contributor to electrically induced corrosion is correct. Other sources of telluric currents may be neglected, since they are smaller in comparison.

The conclusion that earth currents from natural sources are small in comparison to the currents generated from an HVDC transmission can be found in a reference to the report [4]:

> *If removing the anthropogenic contribution to the earth currents, for example by closing the nuclear power plant and removing the HVDC transmission, the electromigratory flux would be negligible.*
>
> [4]

Looking in relative short time frame, using 2500A as electrode current is acceptable assuming the development of HVDC technology will not make any disruptive technology leaps. As discussed in section 3 it is difficult to predict the development and impact in a longer time frame.

6. WSP’s overall assessment

Based on the assessment in section 3 the authors’ overall assessment is that the calculated voltage drop over the canister is within reasonable tolerances. The aggregated conditions as well as the method and calculations give conservative but not unreasonable results.

The assessment is that presented analysis adequately describes current and future scenario based on today’s technology. Future technologies may have higher telluric currents than the assumed worst case scenario in the report. Such scenarios are however not possible to predict.

The assumption that the telluric currents are mainly induced by the HVDC system is correct and that all other sources of telluric currents can be neglected. The authors’ assessment is therefore that the calculated impact of telluric currents is correct within reasonable tolerances. This is based on the assessment made in section 5.

7. References

[1] Svensk Kärnbränslehantering AB, ”Possible influence from stray currents from high voltage DC power transmission on copper canisters,” Svensk Kärnbränslehantering AB, 2014.

[2] Wikipedia, ”Wikipedia,” 04 12 2015. [Online]. Available: https://en.wikipedia.org/wiki/Small-angle_approximation. [Använd 17 02 2016].

[3] Svensk Kärnbränslehantering AB, ”Fuel and canister process report for the safety assessment SR-site,” Svensk Kärnbränslehantering, Stockholm, 2010.

[4] Svensk Kärnbränslehantering AB, ”Geosphere process report for the safety assessment SR-PSU,” 2014.

Coverage of SKB reports

The authors' coverage of SKB report is presented in table 1 below.

Table 1: Report covered with in the authors' scope of work.

Reviewed report	Reviewed sections	Comments
TR-14-15	Complete report	

2016:16

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 300 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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