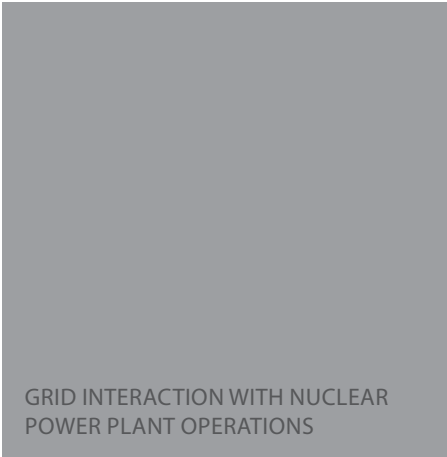


EARTHING GRID STATUS

REPORT 2024:1047



Earthing grid status

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Foreword

The Energiforsk Grid Interaction with Nuclear power plant Operations (GINO) Program aims to increase the knowledge of aspects of the interactions between the external grid and the Nordic nuclear power plants. Part of this is to investigate technical issues.

Every nuclear power plant has an underground earthing grid as part of the plant electrical safety system. It is difficult to monitor the ageing of this grid – but likewise very important. This study was initiated to investigate methods for measuring the ageing process in an earthing grid. As a step two, ageing measurements were made in a specific ageing grid.

The study found that none of the methods for no-dig measurements that had been evaluated were applicable in this specific case, and the measurements were therefore performed on dug-up samples. The measurements showed no significant signs of advanced ageing.

The study was carried out by Ingrid Stenholm, Sweco Sverige AB. The study was performed within the Energiforsk GINO Program, which is financed by Vattenfall, Uniper, Fortum, TVO, Skellefteå Kraft, Karlstads Energi, SSM and SvK.

These are the results and conclusions of a project, which is part of a research Program run by Energiforsk. The author/authors are responsible for the content.

Summary

Part one: Sweco Sverige AB was assigned to perform a feasibility study of measurements of the degradation of the earthing grid after more than 40 years in service.

The assigned site was at Ringhals HV-switchgear area, next to the nuclear plant. The existing 400 kV-switchgear was taken out of operation and removed. The earthing grid was also removed. Thereafter new HV-switchgear was installed at the same site, using a new earthing grid. The project "MYS" at Ringhals was in charge of removal and installation of the HV-switchgear at site. An opportunity was identified to make measurements of the earthing grid, in the time gap when the existing switchgear was out of operation and before the earthing grid was removed.

The contractor was part of the project "MYS" at Ringhals. According to the contractor the best available dates for performing the measurements at site was 30 of May to 1st of June, 2022. During these dates the assigned switchgear was planned to be out of operation, before being removed. It was important not to delay or cause additional costs affecting the project "MYS".

Peter Ulriksen and Torleif Dahlin at LU were contacted regarding measurement methods, measurement equipment and available personnel for measurements. Due to the short time span, methods where no development is needed would be the most promising. The suggested way to perform the measurements was using equipment and personnel from LU. They were used to the equipment and have experience of measurements. Matteo Rossi from LU was available for performing measurements.

Suggested method due to short preparation time:

Ground Penetrating Radar (GPR) – They have most experience of this method.

During the discussions a suggestion was made to compare the measurements with the actual earthing grid when it had been taken out of the ground. In case of unexpected degradation, some parts might be sent for detailed analysis. We were discussing with the contractor the possibilities to collect specified parts of the earthing grid when it was being removed by them. This required a tight dialogue with the contractor and presence at site to collect and mark the desired pieces.

It was finally decided, in dialogue with Energiforsk GINO, not make any of the suggested measurements with GPR. The reasons were that the time schedule for the renewal of the switchgear was too tight and the impact on surrounding switchgears and their safe operation could not be assessed in short time (i.e. switchgears still in operation but interconnected with the ground grid of the switchgear subject to renewal).

A dialogue with RISE in Kista was initiated regarding detailed analysis of corrosion of specific parts of the grid as well as analysis of the soil.

The best way to access the site for preparations and measurements was by using a “cicerone”, since the process with independent access at Ringhals at SvK-sites was time consuming. In that case Sweco could probably provide a cicerone and two guests from LU could enter.

An estimation of the activities, times and cost are described in Table 1 Activities, time schedule and cost in the last chapter 7 Conclusion.

Part two: As a result of the feasibility study, measurements of corrosion and soil content of iron were performed. Parts of the earthing grid were collected and sent for corrosion analysis and samples of soil were taken at the same places and sent for analysis. The results were included in the last chapters.

The samples of the earthing grid were not particularly affected by corrosion. The copper content in the samples of soil did not contradict low level of corrosion.

The conclusion is that the samples would have lasted another 40-year-period (or more) in the ground during similar conditions without being severely corroded.

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Bilagor:

1. PM Markprovtagning vid ställverk Ringhals inkl.bilagor
2. RISE KIMAB O100439-A62 Bedömning av status på jordningslinor vid ställverk

1 INTRODUCTION

Part one: Sweco Sverige AB was assigned to perform a feasibility study of measuring the degradation of the earthing grid at a 400kV-switchgear site at Ringhals, that was to be taken out of operation after more than 40 years in service. A possibility to make real measurement of a used earthing grid and comparing the results to the earthgrid when it had been removed from ground was identified.

According to the following steps:

1. Study of documentation, drawings and reports.
2. Interviews with SvK, OKG and Ringhals.
3. Co-planning with Ringhals and the contractor of the future 400kV-switchgear at site.
4. Report

Part two: As a result of the feasibility study Energiforsk decided to collect samples of the earthing grid and soil samples at the site and send for analysis regarding corrosion and copper content in the soil. Sweco Sweden AB was assigned to manage the second part.

According to the following steps:

1. Collect parts of the earthing grid and soil at the site at Ringhals.
2. Send samples of earthing grids to RISE for corrosion analysis.
3. Send samples of soil to a laboratory for analysis. (Eurofins Sweden AB)
4. Update report with new results.

2 PART ONE: DOCUMENTATION AND SOURCES

This report was mainly based on documentation and discussions/correspondence according to below:

2.1 DOCUMENTATION

Drawing of the earthing grid at site, Ringhals (1-636732)

Corrosion In Earthing Networks In Nuclear Power Plants, Report 2017:397
Energiforsk

Grounding Grid Integrity, Report 2017:405 Energiforsk

Strategisk underhållsplan för jordlinenät (2155862)

R1-R4 Bedömning av påverkan på jordlinenätet (2417700)

R3 stationsjordning (51300625228)

2.2 DISCUSSION/CORRESPONDANCE

Monica Adsten, Mattias Wondolek and Urban Andersson at Energiforsk.

Sofia Johansson, Klas Sjöberg and Magnus Knutsson at Ringhals.

Erik Thunberg at SvK.

Jonas Jonsson at OKG.

Peter Ulriksen and Thorleif Dahlin at Lund University (LU).

Contractor and part of the MYS-project in charge of removing and installing HV-switchgear at the site at Ringhals.

Greger Eliasson – Ringhals installation manager of the MYS-project at the site at Ringhals.

3 PART ONE: INTERVIEW / DISCUSSION

3.1 RINGHALS

The aim of Ringhals was to better understand how the earthing grid ages especially regarding planned operation of 60-80 years and the complexity of replacing an earthing grid with equipment installed. An aim was to understand how the process of degradation works, even though Ringhals expect the earthing grid to be in a satisfactory condition.

Special considerations: The site assigned for the measurements of the degradation of the earthing grid was covered by asphalt. In other places gravel is more common. There was a special process of cleaning the isolators of the site by using large amount of water. Hence the site was not just subject to the amount of rainwater, but also the water used in the cleaning process, which should be taken into consideration, when evaluating the measurements.

The representatives of Ringhals did not wish this project to delay the MYS-project (removing/installing HV-switchgear at site). They wished to study the test-plan regarding this. Coordination between the testing personnel and the contractor at site in order to minimize the interference was very important.

An suggestion was to cut off "C-clamps" and connections points and other parts of unsuspected degradation and send for analysis and detailed studies.

3.2 SVK

SvK was the owner of the site where the testing of the earthing grids could take place. Being the owner they allowed Energiforsk to use the site of the existing 400 kV-switchgear connected to Ringhals 3 for the tests.

SvK has been a part of GINO-collaboration for some time. A couple of years ago the owners of the nuclear plants started to discuss the status of the earthing grids, especially considering a long time had passed since the construction and some reconstructions had taken place in some places. SvK was interested in the result of the measurements in order to find methods to further evaluate the degradation process regarding other earthing grids in other places i.e around Forsmark, where the HVDC-station of Fenno-Skan 2 with cables to Finland was situated. It had been in monopolar-operation for 20 years and they had learned the electron-currents created increase the corrosion of the earthing grid.

SvK did not expect any large problems with earthing grids at the SvK-stations, except Forsmark/Fenno-Skan 2 and the stations along the west coast ie Ringhals, Barsebäck due to salty rain and winds.

If reconstruction will take place some time in the future in Forsmark, Energiforsk would be welcome to use the corresponding site of Forsmark to do more testing and measuring.

3.3 OKG

OKG has been a part of this GINO-collaboration all the way and was interested in the results. Unfortunately, there had not identified any possibilities to do measurements at OKG. Later on (other project) OKG looks forward to measurements done at Forsmark.

In the future, it would be ideal to develop at least two methods to measure the earthing grids in a satisfactory way without digging at the sites.

An evaluation of the measurement methods chosen and a motivation why they were chosen.

OKG expected the earthing grid to be in good condition and an even degradation was expected all over the area. If a specific part of the earthing grid turned out to be in worse conditions than other parts, it would be good to discuss why.

4 PART ONE: THE SITE, RINGHALS 400kV REACTOR 3

The switchgear belonging to the outgoing 400 kV-line from Ringhals reactor 3, was to be taken out of operation by the end of May, 2022. Before the equipment and the earthing grid was removed by the project “MYS” and the contractor, there was a possibility to measure the earthing grid.

The site available for measurements was part of larger site so even though the equipment of the test-site was not energized, there was other equipment around the site that was energized and in operation.

The site was covered by asphalt.

The following images show the ground of the site and foundations of switchgears, see Figure 1 and Figure 2 They were cut to avoid showing sensitive information.



Figure 1 Ground at site with asphalt and foundations



Figure 2 Ground at site with asphalt and foundations

4.1 DESCRIPTION OF THE EARTHING GRID AT SITE

The drawing (1-636732) describing the on-site earthing grid was from 1979. The scanned version was hard to read, but the paper version was a bit better. At the site of the switchgear there was a grid of copper 120 mm² in the ground with a square distance of about 5x5 m to 10x15m depending on the location. Within these squares there were smaller squares of copper 35 mm². 120 mm² copper earth lines from the on-site grid were connected the earth grid of the Ringhals Power Plant and further on into the water.

The part that could be tested was approximately 50 x 50m and it was out of operation. However, it was part of a larger grid, that was still in operation. See Figure 3.

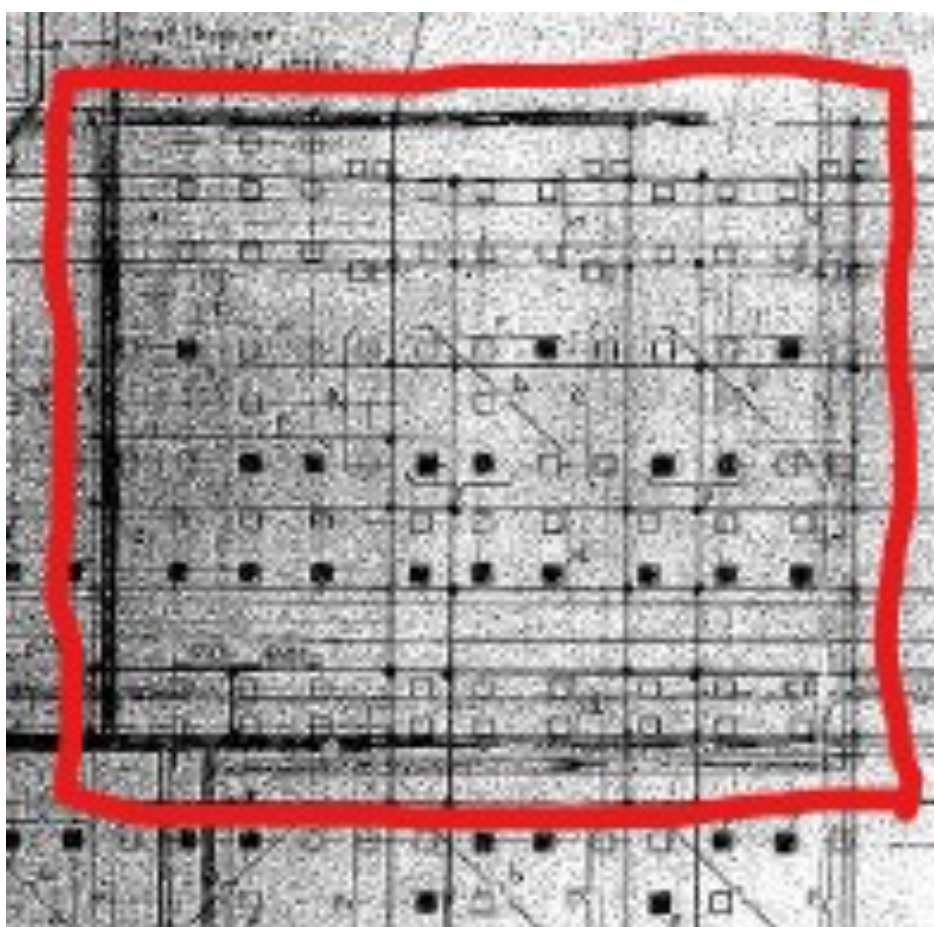


Figure 3 Affected part of drawing of the on-site earthing grid ~50x50m

There were numerous foundations at site and all of them were connected to the earthing grid. Possible connection-points to the earthing grid are shown in Figure 4 and Figure 5:



Figure 4 Connections to earthing grid



Figure 5 Connection to the earthing grid

5 PART ONE: DIFFERENT METHODS FOR TESTING THE EARTHING GRID AT SITE – LUND UNIVERSITY (LU) – PETER ULRIKSEN AND THORLEIF DAHLIN

Peter Ulriksen and Thorleif Dahlin at LU have written the report “Grounding Grid Integrity” Report 2017:405 in collaboration with Energiforsk, where different methods for measuring the earthing grid were discussed. They were contacted regarding choice of measuring methods, measuring equipment and personell for performing the measurements at the suggested site.

The methods of testing were based on the rapport “Grounding Grid Integrity” Report 2017:405 and are the following:

Connecting strong current ie 300 A (Inkoppling av starkström typ 300A)

Very Low Frequency VLF

Total magnetic field

Electric field

Electric surface potential

Geonics EM-61

Mine detector

Leica cable finder

Ground Penetrating Radar GPR

Additionally, LU suggested and offered a measurement of the step-voltages on the ground at the switchgear site, since the primary function of a earthing grid is to minimize step-voltages. This measurement should be done with the corresponding switchgear energized and in operation.

5.1 CONNECTING STRONG CURRENT (INKOPPLING AV STARKSTRÖM)

Access: LU had two three-phasefas-using amplifiers (Crown) with the capacity of injecting 180A each.

Other equipment needed (not LU): Amperemeters, cables etc.

Execution: Should be done by someone with experience of this kind of measurements.

Resultat: Approximate location of interruptions may be possible to find. The location would probably not be very precise since the current would spread in all

parts of the earthing grid between the connection points.
Further development: Might be needed.

5.2 VERY LOW FREQUENCY VLF

Access: LU had a VLF-instrument of type ABEM WADI.

Execution: It was not certain if the resolution was enough to localize small interruptions, depending on if suitable VLF-senders were switched on. It might be an advantage if the switchgear was not energized. It was necessary that the measurement are made in small squares. Should be able to automate using a ground drone.

Resultat: Using low frequencies might make the precision when deciding the locations of faults.

Further development: None

5.3 TOTAL MAGNETIC FIELD

Access: Equipment (held by hand) for measuring a dynamic magnetic field was available at LU.

Execution: They had no experience of this kind of measurements. The earthing grid does not create a magnetic field. The magnetic field has to be created by applying an oscillating voltage. This method was very similar to Leicas equipment for localizing cables.

Resultat: The localization of the earthing grid could probably be decided, but an interruption in the grid might probably not be localized.

Further development: Was needed.

5.4 ELECTRIC FIELD

Access: This method used a high voltage source that could be continuous or pulsed. LU has a continuous source of 6kV. It was not certain that it would work in this kind of experiments.

Execution: No experience of this method. The method was based on voltage differences being created across local interruptions. LU had no suitable equipment developed except for simple dipole-antennas.

Resultat: An interruption in the earthing grid should be detectable.

Further development: Needed.

5.5 ELECTRIC SURFACE POTENTIAL - MISE-À-LA-MASSÉ (MALM)

Access: This was a galvanic version of the method above by measuring the electric field.

Execution: LU had instruments for this kind of measurements but it required access to the earth line (bus) around the grid to inject a current between the grid and a distant electrode. Measurements would be done using an electrode that would be moved around the surface within the sites that measure the voltage to a fixed potential reference-electrode. By measuring current pulses with alternating polarity, irrelevant potentials would be filtered.

Resultat: The localization of the earthing grid could probably be found, but it was uncertain if an interruption in the grid could be localized.

Further development: Might be needed.

5.6 GEONICS EM-61

Access: LU did not have this equipment, but it could be rented from i.e. Georeva or Geomatrix Earth Science Ltd.

Execution: LU had personnel used to this equipment.

Resultat: Uncertain.

Further development: None.

5.7 MINE-DETECTOR

Access: LU did not have this equipment, but it could probably be rented from the military/army.

Execution: LU had personnel used to this equipment.

Resultat: The localization of the earthing grid could probably be found, but it was uncertain if an interruption in the grid could be localized.

Further development: Some, but not much.

5.8 LEICA CABLE FINDER

Access: LU had this equipment, both a stationary sender (Digitex) and a portable receiver (Digicat).

Execution: LU had personnel used to this equipment.

Resultat: The localization of the earthing grid could probably be found, but it was uncertain if an interruption in the grid could be localized.

Further development: None.

5.9 GROUND PENETRATING RADAR

Access: LU had many different radar systems and antennas, as well as experience of this kind of measurements.

Execution: An antenna on wheels would be pulled around on the ground which would register an anomaly when passing an earthing line. It might be an advantage to cover the ground by something smooth when the antenna is pulled around.

Resultat: The localization of the earthing grid could probably be found, but a singular interruption would probably not be found.

Further development: None.

5.10 STEP-VOLTAGE TEST WITH SWITCHGEAR IN OPERATION

Access: LU could probably perform this measurement and had the available equipment.

Execution: The voltage in one step would be measured in order to verify if the earthing grid still fulfills the principal task, to allow personnel to walk on the ground safe and undisturbed.

Result: Weakness in the grounding grid integrity does not always cause a high step voltage, and a high step voltage could be caused by other reasons than the weakness of grounding grid capacity.

Further development: None.

6 PART ONE: CO-PLANNING WITH PROJECT “MYS” AT RINGHALS AND THE CONTRACTOR

The Project “MYS” at Ringhals was in charge of the change of HV-switchgear at the

suggested site, i.e removal of existing switchgear and earthing grid, designing, installing and testing the new switchgear. A contractor was hired by Project “MYS” to

remove and instal the equipment.

6.1 SCHEDULE FOR MEASUREMENTS

According to the schedule of the contractor, the switchgear would be taken out of operation at the end of May 2022, hence there was a time gap before they start to remove the switchgear. This gap could be used for the measurements of the earthing grid. The dates according to the schedule were initially 30-31 of May and 1st of June, a three day period.

6.2 EXCAVATION OF THE EARTHING GRID

Regarding the suggestion to compare the measurements to specific parts of the earthing

grid, when it had been removed from the ground required a close collaboration with

the contractor during the digging and removal of the earthing grid. The installation manager of the Project “MYS” from Ringhals was contacted and he estimated the cost of one excavator and operator to 2000 kr/h. Approximately one day of careful digging at site would be needed.

6.3 ACCESS

Getting independent access to SvK and Ringhals sites required control of registers and it would be a time consuming process. Hence, we recommend using a “ciceron” who could bring two other persons. Sweco could provide a “ciceron”. Even so, the access process required planning:

1. The entrance service at Ringhals (Tillträdes service) must be contacted in advance with names of ciceron and guests at Access.ringhals@vattenfall.com.
2. Ringhals operational department had a coordinator for the activities at site. He must be contacted in advance and a co-planning
3. meeting must be attended by the ciceron, two weeks prior to testing.

4. Since it is necessary to pass an area of the contractor, to reach the site, the BAS-U of the contractor must be informed.

7 PART ONE: CONCLUSION

It was a unique opportunity to learn more about the degradation of the earthing grid and possible methods for measuring methods, that should not be missed, However since the date offered to make the measurements is 30-31 of May and 1 st of June 2022, there was little time for preparation. For that reason, a test method that required little or no further development was necessary. Personnel from Lund University (LU) with previous experience of the test methods were the most realistic option.

The methods that were under consideration:

Ground Penetrating Radar – They had most experience of this method.

An estimation of the activities considered to continue the work and perform the measurements are shown in Table 1.

The activity of provoking an interruption in the earthing line would better be done at a later occasion, after evaluating if the measurements show enough details. However, if the measurements would have shown such accuracy and a time gap would have been found that suited LU, ciceron, excavator and operator as well as the Switchgear project at site, the provoking of an interruption could have been performed. Deciding a date for this activity was unfortunately not yet possible regarding the Switchgear-project at site.

It was finally decided, in dialogue with Energiforsk GINO, not make any of the suggested measurements. The reasons were that the time schedule for the renewal of the switchgear was too tight and the impact on surrounding switchgears and their safe operation could not be assessed in short time (i.e. switchgears still in operation but interconnected with the ground grid of the switchgear subject to renewal).

Table 1 Activities and time schedule

1.	Activity	When	Performed by	Hours
2.	Working permits at Ringhals and access for LU-personnel	April-May before measurements take place	Project manager	90 h
3.	2 days Measurement	30-31th of May	1 LU	16 h
			1 Ciceron	16 h
4.	Digging and collecting special parts of the Earthing Grid	Beginning of June	1 Excavator & operator	8 h
			1 Ciceron	8 h
5.	Analysis of data and report	June?	LU	32 h
6.	Renting equipment (measuring)		LU	
7.	Sending specific parts of the earthing grid for analysis		RISE Infrastructure and Energy	

8 PART TWO: CHOSEN ANALYSIS-CORROSION AND SOIL

After a discussion Energiforsk decided to collect some parts of the earthing grid at the site and send for corrosion analysis. Sweco Sweden AB was assigned to manage the collection of samples and analysis. Samples of soil were collected at the same locations and sent for analysis regarding content of copper.

Most samples were single parts of the earthing grid. Sample 2 consisted of two parts of the earthing grid, connected to each other. Sample 11 and 12 were connections of a part of the earthing grid to a part of foundation earthing. The foundation earthing had a larger diameter. Sample 3 and 9 were soil-samples only.

The locations where the samples were taken are described in Table 2. On the 21 of September 2022, the samples were dug up, cut and collected. They were put into plastic bags and on the 28 of September they were sent for analysis. Corrosion analysis was made by RISE and soil analysis was made by Eurofins Sweden AB.

All details of the soil- and corrosion analysis can be found in the reports "PM Markprovtagning vid ställverk Ringhals" and "RISE KIMAB O100439-A62 Bedömning av status på jordningslinor vid ställverk".

Table 2 Locations of samples

Sample	Kind of sample	Coordinates	Comments
1	Earthing and soil	N: 6350202,927 E: 326221,762	
2	Earthing and soil	N: 6350178,312 E: 326203,659	T-shaped part. Connecting two earth lines.
3	Soil	Coordinates missing	Might be close to a 130kV cable in the ground. The cable is out of operation nowadays.
4	Earthing and soil	N: 6350210,39 E: 326185,10	
5	Earthing and soil	N: 6350201,742 E: 326204,284	
6	Earthing and soil	N: 6350214,182 E: 326208,079	
7	Earthing and soil	N: 6350230,573 E: 326214,73	Close to surface
8	Earthing and soil	N: 6350192,178 E: 326234,681	Close to surface
9	Soil	N: 6350188,235 E: 326234,723	
10	Earthing and soil	N: 6350174,11 E: 326171,971	The other side of the "road". Earthing of a foundation that has a larger diameter the earthing grid.
11	Earthing and soil	N: 63501173, 722 E: 326170, 401	The other side of the "road". T-shaped sample where an earthing of a foundation (larger diameter) is connected to the earthing grid. From the same location as sample 10.
12	Earthing and soil	N: 6350189,845 E: 326158,945	The other side of the "road". T-shaped sample where an earthing of a foundation (larger diameter) is connected to the earthing grid.

9 PART TWO: CONCLUSION

9.1 SOIL ANALYSIS

Seven samples of soil show higher levels of copper than expected, all of them taken next to the earthing grid. The reference samples do not show elevated levels of copper. The elevated levels of copper in the soil next to the earthing might be a result of corrosion of the earthing grid.

9.2 CORROSION ANALYSIS

The long-term overall corrosion measured by weight loss was not possible to evaluate, since the original weight, at the time of installation of the grid, was not known. However, corrosion of copper in Swedish soil has been studied in other field studies for 7 years, where copper was very little affected by corrosion and the highest measured rate of corrosion (after 7 years) was 3,9 micrometer per year, which is so low that it will not affect the technical lifetime of the copper.

The most relevant evaluation in our case was the local corrosion by evaluating the deepest pits of the samples. The level of local corrosion of all analyzed samples was very low. It corresponded to the corrosion expected and in some cases it was even lower. The clamps of the T-shaped samples (2, 11,12) had a higher rate of local corrosion of up to 22,5 micrometers. The clamps were manufactured using other methods than the cables. The alloy used for the clamps may also be different. Mechanical damage during installation might have affected the clamps. The cables are less affected than the clamps. The outer parts were a bit more affected than the inner parts. The outer parts corresponded to a corrosion rate of up to 3,5 micrometer per year. The corrosion of the inner parts was negligible.

The corrosion rates measured corresponded well to what could be expected based on previous corrosion studies.

The conclusion was that the samples would have lasted another 40-year-period (or more) in the ground during similar conditions without being severely corroded.

EARTHING GRID STATUS

Every nuclear power plant has an underground earthing grid as part of the plant electrical safety system. It is difficult to monitor the ageing of this grid – but likewise very important. This study was initiated to investigate methods for measuring the ageing process in an earthing grid. As a step two, ageing measurements were made in a specific ageing grid.

The study found that none of the methods for no-dig measurements that had been evaluated were applicable in this specific case, and the measurements were therefore performed on dug-up samples. The measurements showed no significant signs of advanced ageing.

Corrosion analysis shows that the collected samples of earthing grid would have lasted another 40-year-period (or more) in the ground during similar conditions without being severely corroded.

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