



## **MKG input to SSM review of SKB LOT results autumn 2020**

**Meeting with SSM and Galson Sciences, Sept 30 2020**

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# Main points

- Why the interest from MKG and its member organisations for the copper corrosion results from the LOT A3 and S2 packages?
- Input from the FEBEX experiment
- Input from the reporting of the LOT A2 Package
- What do we know about oxygen consumption?
- What do we know about the LOT S2 and A3 packages?
- What do we know about Taxén/Kimab and Clay Technology?
- What do we know about SKB:s contracts with consultants?
- What do we need to see from the reporting of LOT S2 and A3?
- MKG plans to follow up the meeting with a document with appendixes

## Why the interest from MKG and its member organisations for the copper corrosion results from the LOT A3 and S2 packages? (1)

- The interest is not based on a belief that the results of a 20-year experiment can be extrapolated into the long term.
- The important question that can hopefully be answered is if the unexpectedly high corrosion with pitting that may be taking place in hard rock laboratory experiments with clay and copper is a sign that the theoretical understanding of copper's behaviour in an anoxic repository environment is flawed.
- To be able to answer this there has to be a correct description of the corrosion that has taken place in the 20-year LOT A3 and S2 packages.
- There also has to be made a qualified judgement after what time the packages became anoxic, how much corrosion could have taken place before that and how much has to be attributed to corrosion under anoxic conditions.
- MKG understands that the LOT experiment, despite the fault of not measuring the oxygen in the system, is likely the best available experiment – and possibly the only one done by SKB – that can answer the important question with some confidence.
- MKG acknowledges that if the question of when the LOT packages became anoxic remains a controversy after the reporting of the LOT A3 and S2 results, there will only be the need of simple and relatively short-term additional experiments to resolve the issue.

## Why the interest from MKG and its member organisations for the copper corrosion results from the LOT A3 and S2 packages? (2)

- In 2008 and 2009 MKG closely studied the reporting of the LOT A2 experiment regarding copper corrosion – and has understood how very inadequate it was when it was clear how much corrosion had taken place after 5-6 years on the central copper tube.
- MKG has closely followed the development of knowledge of how fast repository systems become anoxic, and understands that even large experiments normally become anoxic after only a matter of months after sealing.
- MKG has noted that SKB has not wanted to retrieve the LOT A3 and S2 packages (that are actually intended as a 10-year and a 5-year package), and that a reason for this could have been the risk of the copper corrosion results being negative for the theoretical framework that underlies the KBS method, i.e. that copper is basically immune to corrosion after the repository conditions become anoxic. [Yes, it is understood that sulphides may cause a little corrosion].
- MKG wants it noted that the organisation with good cause is sceptical to SKB:s scientific integrity on copper corrosion issues, as well as the scientific integrity and independence of the contractors the company is using for the analysis of the LOT results. This means that the SSM review of the work is extremely important.

## Input from the FEBEX experiment

- There is quite intensive corrosion ( $\approx 100 \mu\text{m}$  and pitting) on copper coupons after 18 years in the FEBEX experiment (Nagra NAB 16-16).
- There is less corrosion after 5 years and no clear pitting (ENRESA Technical Publication 08/2004).
- In Nagra NAB 16-16 it is claimed that all the corrosion in FEBEX is oxidic. But it appears the author has not understood that there is normally anoxic steel corrosion from water and claims that the steel in the experiment must have corroded with an external oxygen source.
- There is a discussion in the FEBEX reporting that there may have been a two-year period where oxygen has leaked into FEBEX. There are two reports of relevance for understanding this possibility (Nagra NAB 14-55 and NAB 16-13). Although there has been some sampling of oxygen at times after closure the general conclusion is that the experiment has likely been anoxic from very early on.
- It is difficult to understand how oxygen could be in the environment of the metal coupons for any length of time. As there is normally anoxic groundwater in an experiment after only a few months (see separate slide) it is unclear how any oxygen that leaks in from a distance many meters away could reach the metal coupons as oxygen would be consumed by bacteria on the way in.

## Input from the reporting of the LOT A2 Package (1)

- There is no reporting of the unexpectedly large copper corrosion from the central tube in SKB TR-09-29. The copper coupons at 70° C are reported as damaged and there are no pictures or analysis of them in the report.
- There are only general photographs and microscopic pictures of surfaces copper coupons at 30° C in the reporting in Appendix 3. No microscopic cross sections are shown and there is just a statement that there is no obvious sign of pitting corrosion. The general and microscopic pictures do show quite large corrosion and a micro hardness indentation mark of unknown depth had disappeared.
- In 2008 MKG was sent a draft of the LOT A2 report (1). The final report differs from the draft report in that there is an attempt to explain the corrosion in the package by oxygen trapped in the system.
- There is also a separate report (TR-13-17) written by the same consultant that authored the FEBEX corrosion report that tries to estimate the corrosion on the central tube by using measurements of copper in the clay. He comes up with a case where the corrosion can almost be explained if all possible oxygen inside the package causes copper corrosion.

1. <http://www.mkg.se/mkg-lagger-ut-rapporter-fran-forsoken-i-skbs-berglaboratorium-i-aspo>

## Input from the reporting of the LOT A2 Package (2)

- The explanation of copper corrosion by trapped oxygen in TR-13-17 misses that 1) there is an extensive crust of corroded copper still in the central tube that involves much more corrosion and that can therefore not be explained by trapped oxygen and 2) that it is impossible that all the oxygen from remote parts of the package reaches the hottest part of the heater. In fact most of the trapped oxygen in the package is likely consumed by bacteria and chemical processes and never takes part in any copper corrosion.
- In addition, the LOT packages are filled with groundwater from the bedrock that is likely anoxic as it enters the package. This water has filled the space between the clay and the bedrock and the space between the clay and the copper tube. This groundwater will remain anoxic and any oxygen that reaches the water will be consumed immediately and never reach the copper tube.
- So with high likelihood most, if not all, the corrosion of the central metal tube has been due to anoxic corrosion.
- There was also correspondence between Stephan Kaufhold (BGR) and Peter Szakálos (KTH) doing similar calculations of corrosion using clay measurements as done in SKB TR-13-17.

## What do we know about oxygen consumption?

- The REX experiment. Results presented in SKB TR-01-05 show anoxic conditions in groundwater in bedrock in a matter of days with a substantial contribution by bacterial activity.
- The MiniCan experiment: Electrochemical potential measurements in SKB TR-09-20 show anoxic conditions in compacted bentonite in 2-3 months.
- Measurements during the emplacement of the FE experiment at the Swiss Mont Terri hard rock laboratory shows that an over 20 m long tunnel section filled with clay became anoxic after a few months (Müller et al., Swiss J Geosci (2017) 110:287–306) (Diomidis & King, pp 371-389 in Nuclear Corrosion Research, Progress and Challenges European Federation of Corrosion (EFC) Series 2020).
- It is thus very likely that all the copper corrosion in the FEBEX and LOT experiments have been under anoxic conditions already from the start.
- Even if the SKB claim that the copper corrosion in the LOT A2 package is only due to all the trapped oxygen is accepted, there is no more oxygen available for any further corrosion in the A3 and S2 packages. Any further corrosion compared to the A2 package can not be explained as oxic.



## What do we know about the LOT S2 and A3 packages?

- Information on approximate temperatures in different parts of the packages can be found in SKB TR 20-11.
- The copper in all LOT copper tubes is DHP copper (SS 5015-04), i.e., deoxidised 99,9% copper with 0,04% phosphorus. This copper is quite comparable to the OFP copper with 50 ppm phosphorus to be used in the copper canisters in the KBS method.
- At the time of emplacement anoxic ground water from a specific tube drilled into the bedrock was used to fill the spaces in the packages and the air was let out. So anoxic groundwater was in the gap between the copper and the clay from the start.
- All eight copper coupons from the S2 and A3 packages were retrieved (SKB TR 20-11). In SKB TR-09-29 appendix 3 the author (Rosborg) mentions that he saved a reference coupon for later to allow a comparison during cleaning procedures.

## What do we know about Taxén/Kimab and Clay Technology?

- Claes Taxén at Swerea/Kimab has a long history of working for SKB on projects. Two projects showing problematic results for SKB have not been published by SKB.
  - A 2009 Swerea/Kimab report on exposure of copper in Aspö groundwaters (discovered by SSM in 2014 – Dnr SSM2011-2306)
  - A 2007 report on corrosion from earth currents in Forsmark (information was sent by MKG to SSM on 25<sup>th</sup> October 2012, unclear under what Dnr it was registered)
- A recent example of work done by Claes Taxén for SKB providing support for the company is in SKB TR-17-16.
- Clay Technology Sweden AB (started by L. Börgesson, co-owned by H. Hökmark and O. Karnland) with its daughter company Clay Technology Lund AB has since the companies were started in the mid-1990s only worked for SKB and much of the work has been with the experiments at the Äspö hard rock laboratory. Scientifically the company can not be separated from SKB.

## What do we know about SKB:s contracts with consultants?

- MKG has through a freedom of information request to Uppsala University obtained a research contract between SKB and researchers at a university department. (1)
- The contract includes a part with general conditions for an SKB research contract.
- One clause regarding “Ownership” states that “Alla resultat som framkommer i samband med Uppdraget, inklusive datorprogram med tillhörande källkod och dokumentation, ska utgöra SKB:s egendom. Resultatet av Uppdraget får fritt disponeras, ändras och bearbetas av SKB”.
- Freely translated this means that “All results that transpire from the Assignment, including computer programmes with associated source code and documentation, are to be owned by SKB. The results from the Assignment may freely be used by, changed by and processed by SKB”.

1. <http://www.mkg.se/skbs-forskningsavtal-ger-aganderatt-till-resultat>

## What do we need to see from the reporting of LOT S2 and A3

- Overall corrosion pictures of all the copper coupons and the central copper tubes, especially of the heated bottom parts.
- Clearly traceable pictures, microscopic pictures and microscopic cross sections of the most corroded parts.
- Comparable measurements of copper in clay to compare to the measurements from LOT A2. Also an estimate of copper in corrosion products left on the surface of the copper tube when clay is removed.
- Corrosion rate results from the copper coupons and the central copper tubes (best estimate)
- Has there been more corrosion in LOT A3 than in LOT A2? What is the difference in corrosion with LOT S2 at repository temperature?

## **MKG plans to follow up the meeting with a document with appendixes**

- MKG will follow up this meeting with a written document to SSM where the points made may be elaborated on.
- MGG will as appendixes provide the documents mentioned in this presentation as well as other documents that may be relevant for SSM's work.



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