Kronan cannon (Sweden)

Description: The Kronan cannon study is an archaeological analogue that investigated the effects of corrosion on the copper barrel of a 17th Century bronze canon (Figure 1).

Figure 1 Examination of the Kronan cannon soon after it was recovered from the Kronan shipwreck. Photograph courtesy of the Kalmar County Museum/The Kronan Project.

The Kronan was a Swedish warship built in 1668 which exploded and sank in June 1676 during the Battle of Öland. At the time, she was the most powerful warship in the Swedish navy and was armed with 126 bronze cannon. In the period from 1680 to 1686, around 60 cannon are known to have been salvaged from the wreck. In recent times, between 1980 and 1987, a further 32 cannon were salvaged from the marine sediments.

The analogue study focussed on a particular bronze cannon which had remained partly buried in a vertical position, muzzle down in clay sediments since the ship sank (Neretnieks, 1986; Hallberg et al., 1987). The cannon studied has a very high copper content (96.3 wt%) and is analogous to the copper outer shells of the canisters planned to be used for spent fuel in the Swedish and Finnish repository designs.

Analysis of the cannon surface showed that corrosion had progressed at a mean rate of 0.15 µm/y since the Kronan sank and that this process was constant over the whole cannon surface, except where some copper oxide (CuO) inclusions had corroded more quickly. Identified corrosion products include Cu_2O and Fe_3O_4 which confirm a generally oxidising environment. No change in oxidation product with change in redox potential due to limited seawater penetration at depth was observed. Hallberg et al. (1987) concluded that oxygen may not be the principal oxidising agent because the corrosion products were the same all over the cannon surface.

At the corrosion rate of 0.15 µm/y, it would take some 70,000 years to corrode away 1 cm thickness of copper. This provides strong supporting evidence for the predicted long life of the copper shells of the canisters. That the cannon had suffered only minor corrosion after 300 years of burial increases confidence in the suitability of copper as a canister material.

The marine clay is also an approximate analogue to the bentonite buffer which will surround a canister. The water-saturated marine clay was partly composed of montmorillonite and was tightly packed around the cannon muzzle. Chemical analysis of the clay from around the cannon showed that Cu had been leached from the cannon metal and had diffused 4 cm into the clay, causing a reduction in the Cu content at the surface of the cannon from 96.3 to 95.2 wt%. The sediment pore waters around the cannon had neutral pH with variable Eh; pore waters nearest the top of the sediments were more strongly oxidising due to ingress of seawater. The change in redox potential with depth was evident from a change in sediment colour from brown in the top several centimetres to grey at depth.

Relevance: The Kronan bronze cannon studied had a high copper content (96.3 wt%) and is regarded as an analogue for the copper shells of the canisters planned to be used in the Swedish and Finnish repository designs for spent fuel.

The marine clay tightly packed around the cannon is partly composed of montmorillonite and is water-saturated. It is considered to be analogous to the bentonite buffer that would be placed around a copper canister.

The Kronan cannon study helps to answer the question: How long would a copper canister last?

Position(s) in the matrix tables: The Kronan cannon study illustrates the Copper/Corrosion box and the Physical Integrity/Clay Buffer box in the near-field matrix table.

Limitations: The copper purity in the cannon is not as high as that of the proposed copper canister shells. Therefore the estimated mean corrosion rate of 0.15 µm/y for the cannon may only be a limiting value for a canister. In reality, the corrosion rate of a copper canister should be slower due to (a) the use of higher purity copper metal, with no oxide inclusions, and (b) the development of a reducing rather than an oxidising environment in a deep repository.

The mineral and pore water compositions of the marine clay and the degree of its compaction would be different to the composition and compaction of bentonite buffer in a deep repository. Also, the temperature regime of a buffer would be much higher than the marine clay, which weakens the analogy significantly.

Quantitative information: The precise age of the cannon's burial make this a valuable analogue investigation for evaluating a mean copper corrosion rate (0.15 µm/y) for use in a PA model.

Uncertainties: On a scale of low-medium-high, the uncertainties in both the qualitative and quantitative information from the study are assessed as being low.

Time-scale: The time-scale of the analogue is historical, involving just over 300 years of burial and corrosion of the cannon.

PA/safety case applications: This analogue study has been used and cited in a number of PA exercises including: SKB's SR-97; Finland's TVO-92; and Canada's 1994 AECL EIS.

Communication applications: The Kronan cannon study featured in the natural analogue video prepared jointly by SKB, Nagra and others.

References:

Hallberg RO, Östlund P and Wadsten T (1987) A 17th century cannon as analogue for radioactive waste disposal. In: B Côme and NA Chapman (eds) Natural analogues in radioactive waste disposal. CEC Radioactive Waste Management Series, EUR 11037, 135-139, CEC, Luxembourg.

Neretnieks I (1986) Investigations of old bronze cannons. In: B Côme and NA Chapman (eds) Natural analogue working group, second meeting, Interlaken, June 1986. CEC Nuclear Science and Technology Report, EUR 10671, 191-197, CEC, Luxembourg.

Added value comments: No comments to add.

Potential follow-up work: No comments to add.

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