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Project NORDZINK – A Zinc Injection Demonstration Campaign in the Barsebäck-2 NPP

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ABSTRACT

Barsebäck Unit 2, an ABB built BWR with external re-circulation loops, has recently implemented zinc injection to the primary system. During almost one year depleted zinc oxide has been injected in order to mitigate an increasing trend in shutdown radiation levels. The project, called NORDZINK, will be finally evaluated in the beginning of year 2001.

On-line monitoring of the activity build-up in a pipe connected to the primary circuit has contributed to useful information about the mechanisms and effects of zinc injection to a low crud plant like Barsebäck 2. The effects of zinc injection in Barsebäck 2 differ from the effects observed in high crud plants. Cobalt activity concentration in reactor water increases, but the deposition rate of activity on system surfaces decreases. The net effect seems to result in a long-term reduction of radiation levels in the Barsebäck 2 plant. No negative effect on fuel behaviour as a result of zinc injection has so far been observed. The different measuring campaigns being performed in the NORDZINK project have significantly improved the understanding of the mechanisms controlling the activity build-up in BWRs.

INTRODUCTION

The Barsebäck NPP consists of two units, each 1800 MW_{th} ABB Atom built BWRs. Barsebäck Unit 1 (B1) started operation in 1975, and Barsebäck Unit 2(B2) started operation in 1977. B1 is since 1999 permanently closed as a result of political decisions.

B2 is a BWR with 4 main circulation loops (PLR). Pipes and components in the PLR, the residual heat removal (RHR) and reactor water clean-up system (RWCU) have gradually shown an increasing trend in shutdown radiation levels. The main reasons for the increase are believed to be:

1. the introduction of hydrogen water chemistry (HWC) in 1992,
2. the gradually reduced zinc content in the reactor water after brass condenser tube removal in 1981,
3. the power up-rate to 106% in 1986, combined with higher fuel burn-up, and
4. a significant contribution of Co from Stellite in valves in the re-circulation circuit.

The Swedish Nuclear Power Inspectorate introduced in 1994 new, stricter regulations concerning the inspections of welds in components and pipes. As a consequence, the number of inspections in high radiation areas increased. A number of cases of environmental assisted cracks in austenitic steels were also located during the following years. The overall effect of higher radiation levels and increased amount of inspection and repair work was higher occupational exposure. Co60 and Co58 are the main contributors to the shutdown radiation fields.

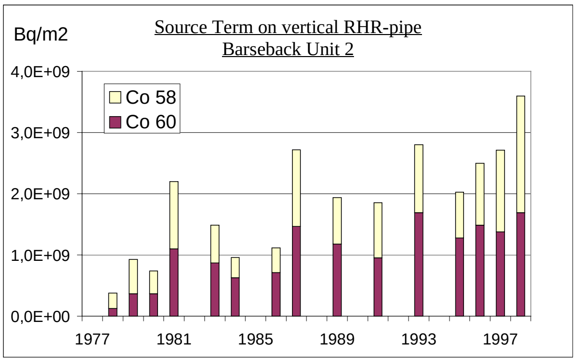

Figure 1: RHR Source Term in B2

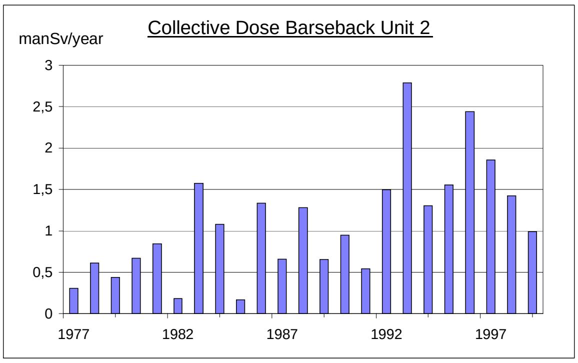

Figure 2 Annual occupational exposure in B2

The plant management decided in 1997 that specific actions must be taken to reduce the negative occupational exposure trend. The Swedish Radiation Protection Institute had issued a five year average dose limit of 2,0 manSv/GW_{el} for Swedish LWRs, which corresponds to an average annual dose limit of 1.2 manSv in the case of B2. Based on the favourable experiences of zinc injection reported from GE-built BWRs [1], it was decided to try this concept at Barsebäck 2 during a campaign from March 1999 to August 2000. The project is called NORDZINK, referring to the fact that B2 is the first of eleven Nordic BWRs to implement zinc injection.

Project NORDZINK

The effect of zinc on occupational radiation levels will be studied within the NORDZINK project by measurements during outages. Water chemistry analyses and on-line-monitoring of activity build-up in pipes (OLA) make it possible to further improve the understanding of the mechanisms controlling the activity build-up. B2 differs from many US BWRs by having very low levels of iron in the feedwater (≤0.1 ppb). One important aspect of the NORDZINK project is to evaluate how zinc injection works during such circumstances. The eventual impact of zinc on fuel cladding material will also be studied by oxide thickness measurements and analyses of fuel crud composition.

The zinc injection equipment was installed during the outage in 1998. The principle is based on passive dissolution of zinc oxide pellets into the feedwater. A flow rate of the order of 2-3 kg/s at 155°C dissolves sufficiently amount of zinc to keep the reactor water concentration of zinc at 3-4 ppb. The equipment was initially loaded with 10 kg of zinc oxide, and reloaded with 5 kg of zinc oxide during the following outage. The amount of zinc dissolved depends on temperature, flow-rate and amount of zinc oxide loaded. The zinc oxide used is ^{64}Zn depleted oxide (DZO), less than 1% ^{64}Zn, in order to reduce the formation of Zn65.

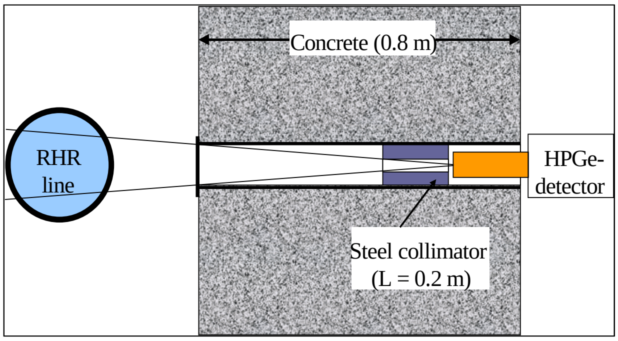

Figure 3 The OLA measuring system at B2.

Six months before zinc injection was started a collimated HPGE-detector was installed at a pipe in the RHR bypass line close to the re-entry into the containment [2]. The selected location means a decay time of about 60 s. from the PLR loop, and therefore a reasonably low background level from short-lived N16. The system enables on-line monitoring (OLA) of activity build-up during operation.

RESULTS

Zinc injection started in the middle of cycle, at 3rd March 1999. During the first period daily samples of feed water and reactor water were analysed.

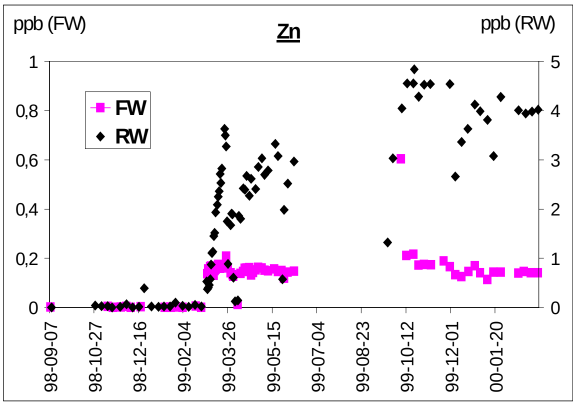

Figure 4: B2 - Zinc in feedwater and reactor water.

A zinc concentration of about 0.15 ppb was immediately established in the feedwater. The feedwater system showed no signs of zinc accumulating in the pre-heaters. The zinc concentration in reactor water increased quite rapidly during the following weeks, levelling off at about 3 ppb. A short stop in hydrogen injection made the zinc concentration decrease. After outage the reactor water zinc concentration is kept at about 4 ppb.

It is known that the effect of zinc depends on how much iron is available to react and form $ZnFe_2O_4$. Calculations based on the feed water metal input, pre-existing hematite on fuel crud, and additional iron from other systems as a consequence of hydrogen water chemistry have shown that during the period of zinc injection the molar ratio of Fe/(Zn and Ni) has been higher than 2.

The Zirconium fuel cladding showed no sign of enhanced oxide formation at the 1999 inspection. This inspection was, however, made only after 3 months of zinc injection. After the ongoing cycle more extensive inspections and measurements will be made.

Dose rate measurements during the 1999 outage showed about the same levels as the previous outage. On-line activity measurements are more interesting to study. The following figures present Co58, Co60, Zn65 and Zn69m on pipe surface (OLA measurements) compared with the concentrations of soluble activity in the reactor water.

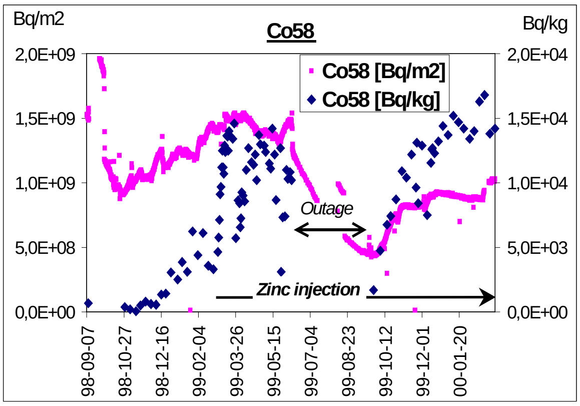

Figure 5 Co58 in B2. OLA and reactor water.

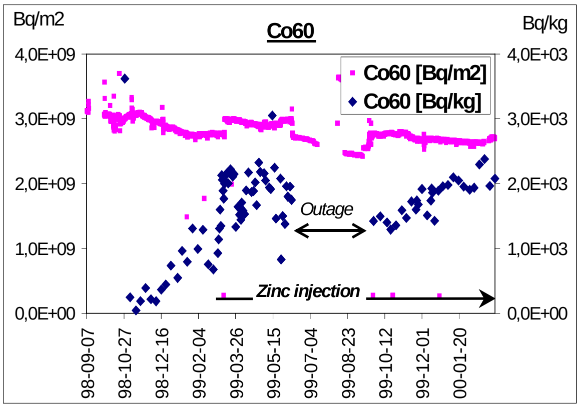

Figure 6 Co60 in B2. OLA and reactor water.

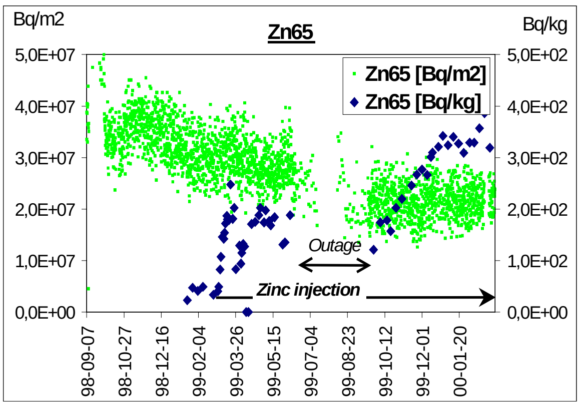

Figure 7 Zn65 in B2. OLA and reactor water.

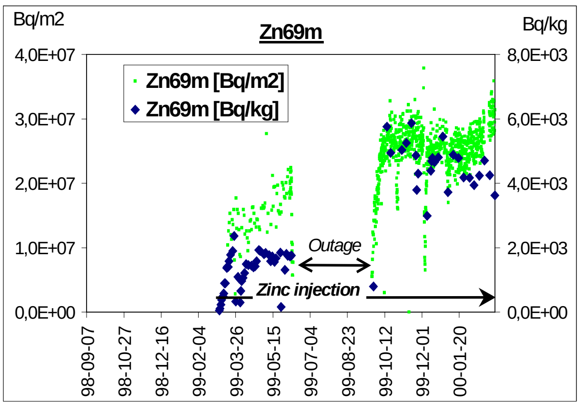

Figure 8 Zn69m in B2. OLA and reactor water.

Co58 is possible to use as an indicator to predict the long time behaviour of Co60. Equilibrium level of Co58 in the RHR pipe some months after the 1999 outage is only about 2/3 of the corresponding level before the Zn injection despite an increase of Co58 reactor water activity by a factor of 3. As Co60 in the water has increased by only a factor of 2, the future Co60 level in piping is expected to be reduced with up to 50%

Zn65 shows a similar behaviour, a 30% reduction of RHR pipe activity in parallel with an increase of reactor water concentration with almost a factor of 7.

The half-life of Zn69m is only 15 h. The measured RHR pipe activity of Zn69m is much higher than expected based on a previous calculation model for Zn65 assuming a rather long residence time for incorporated zinc. In fact, Zn69m compared with Zn65, as well as Mn56 compared to Mn54, indicates the presence of an outer surface layer with a high exchange rate with the reactor water. The observation is planned to be used to further improve a code for activity build-up modelling, the BwrCrud code [3].

DISCUSSION

Results from zinc injection at B2 differ in some aspects from observations made in US BWRs. The very rapid saturation of zinc on system surfaces, especially in the feedwater system, is probably explained by the fact that B2 is a low crud plant due to a very efficient condensate polishing plant.

The low crud content on fuel may be the main reason that B2 shows an increase of cobalt activity in reactor water after zinc injection, while many US plants show decreased activity concentrations. Zinc oxide being dissolved gives rise to increased pH. Increased pH lowers the solubility of most metals. Small amount of fuel crud means a low injection rate of zinc plus a low enrichment in the fuel crud, i.e. the pH effect is not so pronounced. On the other hand, the low amount of fuel crud means that the Fe/(Ni+Zn) ratio in oxides is more easily decreased which results in reduced deposition of Co isotopes both on fuel and on system surfaces and increased reactor water activity concentrations as a result of that.

The on-line monitoring of RHR activity build-up before and after introduction of DZO has made it possible to show that the incorporation of cobalt activity on system surfaces is significantly reduced. This effect seems to be very pronounced in a low-crud plant such as B2 due to the decreased Fe/(Ni+Zn) ratio in the oxide film on the surfaces.

The interpretation of the so far available Zn injection data from the B2 plant indicates an eventual long-term reduction of radiation field with up to 50%. The final evaluation of the NORDZINK project at the end of year 2000 will further address the effect of Zn injection on long-term occupational exposures in a low-crud plant as B2.

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2. L. Håkansson, K. Lundgren, T. Åberg, *"On-Line-Activity Measurement (OLA) on RHR-piping at Barsebäck"*, 1999 GE Chemistry & Material Workshop, Feb. 1999.
3. K. Lundgren, C. Bergström, K. Haraguchi, H. Nishimura, K. Kobayashi, K. Chikamoto, M. Nishi, G. Granath, *"BWR Crud – Development and Validation of a New Code for Improved Simulation of Activity Transport in BWR Primary Systems"*, 1998 JAIF Int. Conf. Water Chem. Nucl. Power Sys. , Oct. 1998.