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Investigation of Increased Hydriding of Guide Tubes in Ringhals 2 During Cycle Start-up

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There are two main sources for hydrogen uptake into Zr alloy components. Beside the uptake of hydrogen from the corrosion reaction, direct uptake of hydrogen from the PWR primary water is the second source and can occur under certain conditions.

In Ringhals 2 two guide tubes broke during insertion of control rods in the pool during the outage in 1990 resulting from high hydrogen contents which were found in the Zry-4 guide tubes. The hydrogen content showed large variations between different guide tubes from the same assembly at the same axial elevation. In extreme cases rims of massive hydrides were seen at the inner surface. In the most affected guide tubes, the oxide thickness at the ID was about 20 µm whereas normal oxide was only about 5 µm. Hot cell examination revealed that the hydrogen content was up to 3000 ppm (average in wall thickness) which means that the hydrogen pickup fraction was well above 100 %. This was a clear indication that a significant amount of hydrogen was stemming from a different source than corrosion.

The inner surfaces of these particular guide tubes were sand blasted with a stainless steel lance. The root-cause analysis revealed by SEM and GDOS that the sandblasting with such a lance resulted in embedding small stainless steel particles at the guide tube inner surface which in-pile acted as "hydrogen windows". When Ni deposited on the surface during the start-up procedure, hydrogen was picked up catalytically after it was added to the coolant at about 150°C.

Autoclave tests simulating the start up of a PWR were used to demonstrate the increased hydrogen pickup. The tests showed that this type of accelerated hydriding can be reproduced in the laboratory with guide tube samples sandblasted on the inside. A necessary condition was that Ni in the coolant was high during the start-up phase and hydrogen was added to the water before the formation of a protective oxide layer can prevent the hydrogen uptake. The tests revealed a significant effect on hydriding by the peak Ni concentration during start-up, the applied hydrogen overpressure, the point of time when hydrogen was added, and the pH of the primary coolant. A "late hydrogen addition" reduced the enhanced hydriding significantly. After modification of the surface treatment process, the increased hydrogen uptake was resolved.

As an intermediate countermeasure, hydrogen addition during start-up was performed in Ringhals 2 at a late point of time during start-up, after reaching operation temperature. This late hydrogen addition strategy is now applied in all Ringhals PWRs.