Steam Generator Primary Side Fouling Determination Using the Oxiprobe Inspection Technique

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ABSTRACT

Build up of deposits on the primary side of CANDU steam generator tubes can lead to a loss of heat transfer between primary and secondary circuits. This fouling contains radionuclides that cause high radiation fields around the steam generators. It is important to determine the amount and nature of the deposits including radionuclides and their distribution in the tubes to assess the need for cleaning, selection of cleaning technologies, disposal of cleaning residues and other related maintenance issues. The Oxiprobe is an inspection technique developed by Ontario Hydro Technologies that measures the extent of primary side fouling at various positions along the length of a steam generator tube. Deposits are chemically removed from selected locations by means of tooling inserted from the primary head. Deposit loadings in each location can be quantitatively calculated and their elemental composition, which includes the determination of alpha, beta and gamma emitting radionuclides, can be determined.

1.0 INTRODUCTION

The primary side piping in CANDU reactors is made of carbon steel. Upon exposure to the primary coolant conditions the material rapidly forms a protective magnetite passive layer. Release rates of this oxide are very low and in the order of 1 mg Fe/dm^2.day(mdd) in flowing coolant at 250 °C, pH 10 with LiOH and saturated in dissolved iron/1/. The stable iron oxide species under CANDU normal operating conditions is magnetite and, in the presence of other transition metals such as cobalt and nickel, their thermodynamically stable species are mixed oxides. The solubility of magnetite and the mixed oxides varies with the redox potential of the primary coolant and it increases when this parameter becomes reducing. Under oxidizing conditions the most stable oxide is hematite which is significantly less soluble than magnetite. It is therefore difficult to model the particulate and corrosion product transport and deposition since the redox potential in the primary coolant changes especially if there is boiling in the core.

It has been postulated that steam generator fouling may be responsible for the observed increases in reactor inlet header temperature at some CANDU plants. In fact, at some plants the deposit buildup has been sufficiently high to impede access by inspection tooling.

Not only is it important to determine the total amount of deposits on the tube but also their distribution along the tube which allows us to assess their impact on the heat transfer coefficient.

The Oxiprobe technique was developed to determine the accumulation of deposits on the inside wall of the steam generator tubes, in terms of the deposit elemental composition, the deposit loading distribution along the tube length, and the total tube deposit loadings. An additional objective was to determine the identity and loadings of alpha, beta and gamma emitting radionuclides and their distribution along the tube length.

2.0 EXPERIMENTAL

The Oxiprobe hardware consists of an end effector or probe, shown in Figure 1, which is positioned at predetermined locations inside the steam generator tube. Solvent is delivered to the probe to dissolve the deposits within the probe cavity.

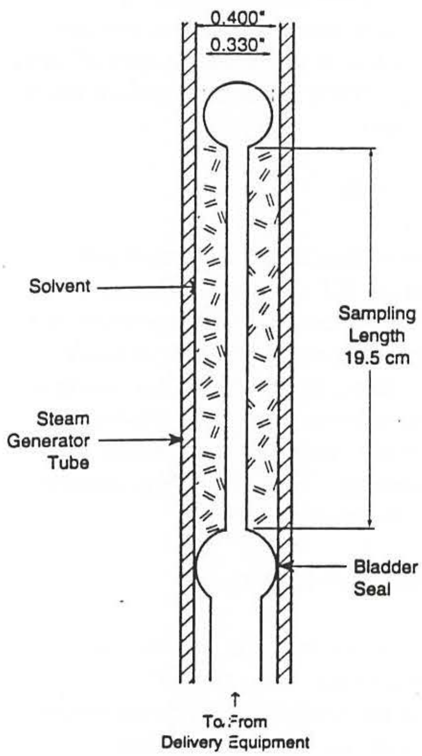

Figure 1: Schematic of Oxiprobe end effector inside a steam generator tube.

Feed and return polymeric tubing connect the end effector to a solvent /water delivery system which includes flow metering equipment, solvent and water rinsing tanks, and pumping capabilities. Figure 2 reveals the schematics of the flow delivery system.

The present setup allows two tube determinations to be carried out simultaneously. This capability saves significant time during field sampling and results in reduced personnel dose and a shorter plan window requirement in the station plan.

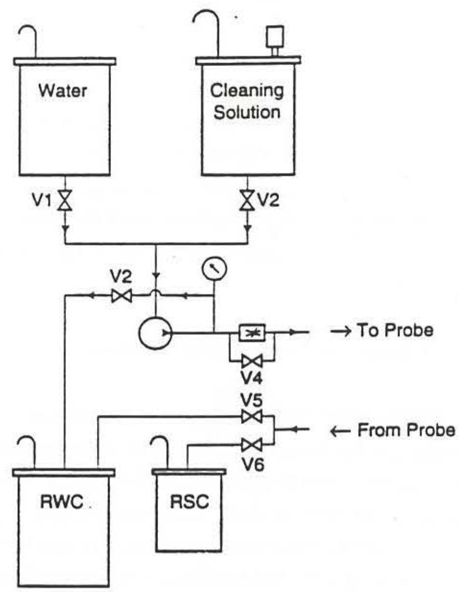

Figure 2: Oxiprobe delivery system.
RWC - Return Water Container
RSC - Return Solution Container

The Oxiprobe used in all the deposit measurements discussed here had a sampling length of 19 cm. For each position this distance represents the length of steam generator tubing inside the Oxiprobe cavity in which the oxide is dissolved by the solvent. The probe length determines the resolution of the measurement with respect to the steam generator tube length. The probe consisted of a central element with a round head to minimally disturb the tube deposits during insertion and a bottom fitting that had a bladder seal and connections to the delivery tubing. The top seal was achieved by pressurizing the opposite end of the tube with air.

3.0 SOLVENT QUALIFICATION

3.1 Materials Compatibility

Oxiprobe measurements have been carried out at Pickering A, Bruce A and Bruce B. Application of the technology to these stations necessitated full qualification testing of the solvent compatibility with alloy 400 and 600, respectively, in advance of the fieldwork. The testing involved a complete corrosion assessment with the same solvents and materials and under extreme simulated field conditions. Testing results showed no significant corrosion of either alloy 400 or alloy 600 during the sampling time required in the procedure.

3.2 Deposit Dissolution Rates

Dissolution rates were evaluated in laboratory tests using solid magnetite samples. Additional confirmatory testing was also performed with tubes previously pulled from operating units. A factor of five times the laboratory time required for complete sample dissolution was used in the field implementation. The error resulting from the incomplete dissolution of the tube deposits was therefore negligible although no visual tube verification was performed in the fieldwork.

4.0 FIELD PROCEDURE

The field implementation of Oxiprobe measurements requires access to containment and the primary head of the steam generator. Setup of the delivery equipment should be carried out near the steam generator primary head access manhole. The end effector is inserted into the steam generator tube into a predetermined location.

Spill barriers are placed around the delivery systems and in the steam generator primary head. The probe is connected to the delivery systems via the polymer tubing. After the seals have been activated, water is first circulated to verify the leak tightness of the whole assembly. The solvent is then pumped into the probe cavity and it rapidly dissolves the deposits inside the tube. When the dissolution time has elapsed a thorough rinse of the probe cavity with water eliminates any solvent trace from the tube surfaces that have been exposed to the solution. The rinse effectiveness is verified using simple pH measurements on the effluent water. The probe is then moved to a different tube location and the operation is repeated. A total of one litre of solution is collected per sampling point.

The average time required per sample location is approximately one hour but several tubes can be simultaneously sampled. Setup time, excluding interruptions unrelated to the process, is three hours and the same length of time is required to remove the equipment from containment.

5.0 ANALYTIC

The solvent solutions collected are analyzed by ICP (Inductive Coupled Plasma Spectroscopy) to determine metal ion concentrations. Gamma activity measurements were performed using a Canberra gamma analyzer. Alpha and beta activity was also determined for some samples. The analytic precision was approximately 10%.

6.0 WASTE DISPOSAL

One litre of solvent and four litres of rinsing water per tube position were produced as waste. The rinsing water had undetectable gamma emitter contamination but it was slightly contaminated with tritium. After analysis, the radioactive solutions were concentrated by evaporation, solidified and then disposed.

7.0 FIELD APPLICATIONS OF OXIPROBE

7.1 Pickering NGS-A

7.1.1 Sampling Locations

The first trial with Oxiprobe was implemented at Pickering A/2/. Two tubes were preselected that were judged to be representative of the majority of the tubes in the bundle. The tubes were situated in the centre of the bundle near the divider plate. The tubes had never been inspected by eddy current or decontaminated using CANDECON.

Four locations were sampled in each tube. Two were in the hot leg, one near the tubesheet and the second at approximately mid distance in the tube hot leg straight length. However, one of the tubes was significantly dented at the first support intersection and the probe could only reach a position immediately below the dented region. The other two locations were in the cold leg. The lowest corresponded to the middle point in the pre-heater. The second cold leg location was at the same distance from the tubesheet as the hot leg second location. The sampling locations can also be referred to the distance along the tube from the primary face of the hot leg.

7.1.2 Deposit Composition

Iron, nickel, copper and zinc are identified as the main contributors to the deposit composition. Cobalt and chromium are present in trace amounts.

7.1.3 Deposit Loadings

If it is assumed that all metals are present as mixed oxides of the magnetite type (ferrites), total deposit loadings can be calculated.

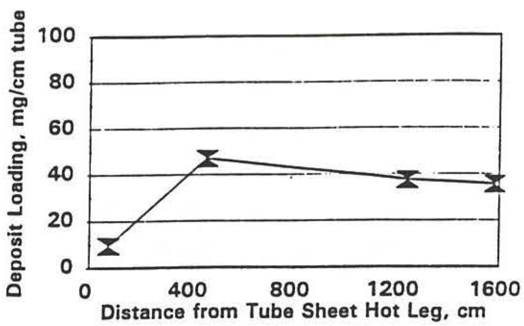

Figure 3: Variation of tube deposit loadings along tube length. PNGS-A, U-1, SG-8, tube R13C64.

Figure 3 shows the variation of tube deposit loadings expressed as milligrams of mixed oxide deposit per cm of tube versus the tube position measured from the primary face of the tubesheet hot leg.

The lowest deposit loading corresponds to the lowest position in the hot leg, i.e. the entry point of the primary coolant in the steam generator. There is an increase of the deposit loadings with increasing distance from the reference point in the hot leg; however, the reverse is true in the cold leg. The results that were obtained for the two tubes sampled compared well. The available data indicates that the deposit loadings go through a maximum at the top part of the bundle and slightly decrease in the bottom part of the cold leg where the pre-heater is situated.

The total amount of deposit in the tube can be calculated by integrating the values obtained at the specific locations over the complete length of the tube. The mass of deposit on each tube was comparable and for tube R13C64 was 67 grams.

Deposit thickness was calculated assuming an average deposit density is 5.2 g/cm^3. This value was measured by pycnometry from Bruce NGS-A U-bend deposits.

Tube Position, cm	Deposit Thickness, μm, 0% Porosity	Deposit Thickness, μm, 50% Porosity
74	6	12
457	29	58
1240	23	46
1580	22	44

Table1: Deposit thickness for extreme porosity values for tube R13C64 at different tube locations calculated from the deposit loadings and magnetite density.

Table 1 lists the calculated thickness for two different porosities, 0 and 50%, respectively. The latter is considered to be an extreme but realistic value based on

As in the BNGS-A measurements, the distribution pattern for the rest of the tubes is similar. The deposit loading/distance profile is similar to that of BNGS-A in that the highest loadings are near the U-bend. The corresponding deposit thickness calculated, 1 to 84μm, and the total amount of deposit per tube, 72 g, and its distribution among the hot and the cold legs and the U-bend is also similar to BNGS-A.

7.3.4 Radionuclide Distribution

The main radionuclide contributor to gamma activity is Co-60. Also important and contributing each to between 8 and 25% are Nb-95 and Zr-95.

Figure 8 shows the relative contributions of radionuclides to the total activity. The contributing radionuclides are the same as in BNGS-A but the total gamma activity levels are slightly higher in this measurement.

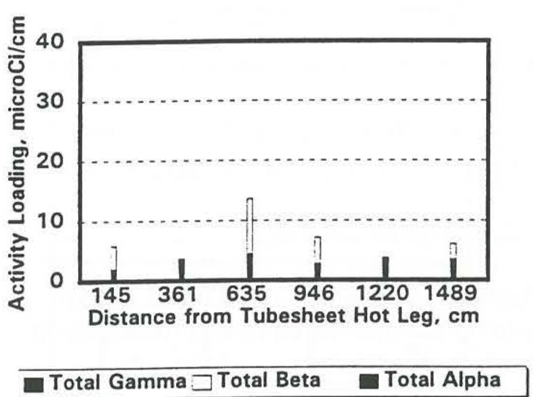

Figure 8: Radionuclide gamma, beta, and alpha activity loading variation along tube length. BNGS-B, U-5, SG-5, tube R42C42.

Data shows little contribution from fission products since there are very low levels of alpha emitting radionuclides.

8.0 CONCLUSIONS

Oxiprobe can perform successful sampling of primary side corrosion products in steam generator tubes.

Consistent data has been obtained at three CANDU stations. Deposit composition, loadings and distribution along the steam generator tubes are available from the measurements.

Alpha, beta and gamma radionuclide loadings and distribution along the tubes are now at hand for radiological requirements.

Minor process modifications and a redesign of the delivery system could reduce the time required for Oxiprobe implementation. This would enable the sampling of a larger number of tubes for a given time window which would improve the statistical confidence of the measurements.

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REFERENCES

1. K.A. Burrill, 1st Meeting of IAEA Coordinated Research Program on Modeling of Transport of Radioactive Substances in the Primary Circuit if Water-Cooled Reactor, Ontario Hydro Head Office, Toronto, 1997, May 5-9.

2. F. Gonzalez, A.M. Brennenstuhl, G. Palumbo, A. Robertson and J. Cocuzzi, Ontario Hydro Technologies Report No. A-NSG-95-162-P.

3. F. Gonzalez, A.M. Brennenstuhl, G. Palumbo, A. Robertson and J. Cocuzzi, Ontario Hydro Technologies Report No. A-NSG-95-163-P.

4. F. Gonzalez, A.M. Brennenstuhl, G. Palumbo, A. Robertson and J. Cocuzzi, Ontario Hydro Technologies Report No. A-NGS-95-164-P.