An Experience on RCS CRUD Sampling in European PWR Plants

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1. Abstract

In most PWRs the normal method of corrosion product sampling is to collect a "grab" sample from either the RCS hot or cold leg. This method is not ideal and the results are often dominated by soluble and particulate transients that can bias them high by factors of between ten and one hundred times. Nevertheless "grab" samples can still give relatively satisfactory results from which qualitative trends of total soluble plus particulate corrosion product concentrations can be determined and, although "grab" sampling may not be ideal, it is useful in detecting and following abnormal particulate releases from the core. It is possible to eliminate the worst of the transient effects by collecting a sample from continuously flowing RCS sample line, but the changes necessary to operate in this way are major, will be costly and may not be practicable for many existing plants. The evaluation of changes in corrosion product concentrations, particularly when the changes increase the particulate concentrations, can indicate that there is a risk that an Axial Offset Anomaly (AOA) may develop, or a risk of increased corrosion product releases when the plant shuts down for refueling.

Recently, Diablo Canyon and Callaway in United States America, Ringhals in Sweden, Sizewell B in Great Britain, Vandellòs in Spain and Doel in Belgium, these PWR plants have applied capillary sampling method to CRUD Analysis in parallel with grab sampling method under the recommendation of EPRI.

In this thesis, it will show the practice based on actually tested method in European PWR plants.

2. Introduction

PWR sampling systems are not normally designed to obtain representative samples of trace corrosion products species. Instead the main design criterion is to deliver a representative liquid sample for soluble boron and soluble fission product analysis without exposing the operator to excessive radiation dose. The installed sample lines are long, small-bore tubing and have an uneven temperature gradient over their length. When used to measure corrosion products, particulate interactions occur with the sample line walls and crud traps and there are changes in corrosion product solubility. The latter are the result of the change in acidity of the primary coolant as the sample cools, both of which increase corrosion product solubility. Unless care is taken, these changes prevent the collection of samples that are sufficiently expectative of the actual coolant state to enable quantitative interpretation of change in particulate and soluble chemistry and transport from the core/plant surfaces to be made.

At Ringhals plant in Sweden, it replaced Inconel 600 SG with Inconel 690 SG and introduced the capillary sampling system in order to verify movement of corrosion product before and after the SG replacement for the first time in 1989. It also validated movement of CRUD at the rate of sampling flow rate.

At Vandellòs PWR in Spain, it tentatively applied capillary sampling method and installed capillary sampler in CVCS letdown line instead of RCS continuous intake method which is relatively higher cost.

This has the potential disadvantage that the lower temperature and flow rate in the letdown line might modify the distribution between RCS soluble, colloidal and particulate species and that it might reduce the total particulate burden. However, it has the important advantages that interactions that occur between soluble species and the oxides present in the high temperature parts of the sample line are absent. At Vandellòs plant, it has been shown that using a CVCS sample line gives very reliable corrosion product measurements that are similar to those obtained using the best RCS sampling methods.

3. Experimental

The RCS capillary sampling lines, three per station, are fitted at Ringhals 2, 3 and 4 and Sizewell B. At each station AEA Technology (formerly the Atomic Energy Authority) designed capillary heads are installed near the outlets of the normal RCS hot leg sample lines in the auxiliary building sample room. The capillary lines flow continuously at 30 to 40 ml min^{-1} and there is a continuous hot leg sample bypass line running at approximately 200 kg h^{-1} to the volume control tank, which satisfies the requirement for a continuous high sample line flow to the capillary sample heads. The lines are used for particle size measurements and to collect RCS coolant samples in a filter stack over a 3-4 day period, equivalent to an integrated volume of 200 to 300 liters, depending on other operational demands that can affect the flow rate. During this period, valve movements in the hot leg sample line are not permitted, nor are flow rate changes, so that transients are minimized. Samples are collected using a 47 mm pressure-rated Millipore holder, containing an upper 0.45 μm Millipore filter on top and two Gelman cation

membranes below, connected to the end of the capillary lines so that the sample is filtered without exposure to air. Anion membranes are not currently used, as they became highly active and were of poor quality, but could be re-introduced. After sampling, the holder is removed dried during storage for five to ten days to allow short-lived species to decay to improve detection limits. The holder is then opened and the Millipore filter and the two cation membranes measured separately by γ-spectroscopy to give the radionuclide concentrations. Finally, the filters and membranes are then dissolved in concentrated acids (1/3 HCl + 2/3 HNO_3) in a microwave oven and analyzed by ICPMS or ICPOES to give the elemental concentrations. This figure shows the RCS CRUD sampling flow diagram by using capillary sampler at Ringhals plants.

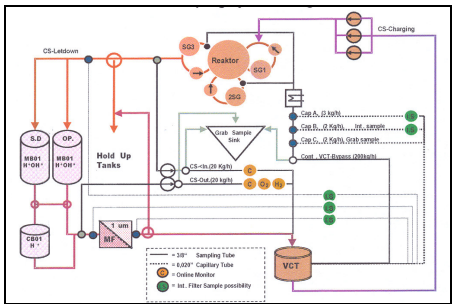

Fig. 1. Capillary system for RCS CRUD sampling

4. Results

A wide variety of analytical methods can be used to analyze elemental and activated corrosion products. For radionuclides, the main options are to count a liquid sample, or to count a Millipore or cation filter on to which the radionuclides are held or exchanged. There is now very considerable experience in European PWRs to show that using a filter-paper geometry gives very good results. When this is combined with integrated sampling and separation methods that are used before the sample is exposed to air, Fig.2 and 3 shows the homogeneous concentration and activity between soluble and particulate species in the coolant after using capillary sampler and also improved overall detection levels.

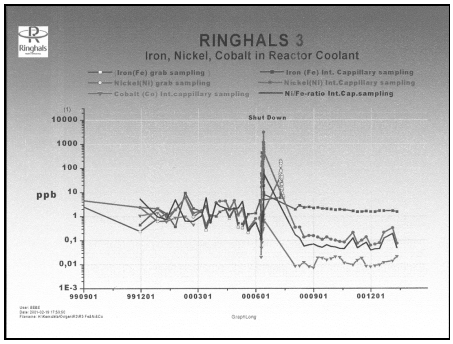

Fig. 2. Variation of metal ion (Fe,Ni,Co) before and after using capillary sampler in RCS (Sweden Ringhals unit3)

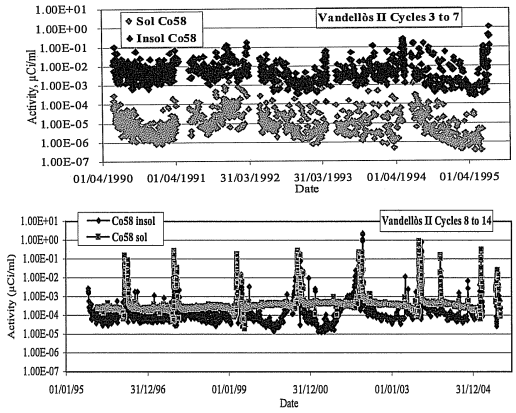

Fig.3. Comparative analysis results between grab sample(Cycle 3 to 7) and capillary sample(Cycle 8 to 14) in CVCS(Vandellòs II)

5. Conclusions

Measuring representative corrosion product concentrations in the RCS is a particularly difficult task, which is fraught with problems due to the way that the species interact with the oxides on the sample line walls and the way that pH and corrosion product solubility changes as the coolant flows along the sample line.

For RCS hot and cold leg samples;

- Corrosion product sampling is normally dominated by transient events that last hours or days and affect measured concentrations. Often the results can be biased high by up to one hundred times and will have a high scatter.
- A number of alternative methods of integrated sampling and analysis are possible and have been used in European stations. A similar integrated sampler has been developed in the U.S., although its original function was to collect RCS particulate before the distribution was modified as the sample stream cooled.
- Capillary RCS hot leg integrated samplers are used very successfully at Ringhals for routine corrosion product analysis.

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