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An Eddy Current Testing Round Robin Program Using a Retired Steam Generator

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1. Introduction

The integrity of steam generator tubes is a critical element for securing the safe operation of Pressurized Water Reactors. Various types of stress corrosion cracking and wear have been found during operation of nuclear steam generators. Those flaws are detected by in-service inspection during outages. If those flaws are left to keep growing undetected by in-service inspection, then tube rupture or leakage accidents occurs. The series of tube rupture incidences reported so far indicates that the structural and leakage integrity of steam generator tubes are critical elements for safe operation of PWRs [1~3].

Integrity assessment of steam generator tube is the core element of the steam generator management program, details of which are described elsewhere [4]. The soundness of the steam generator against potential flaws are assessed, and the optimum in-service inspection program is established each outage. The integrity assessment depends on in-service inspection using eddy current testing.

The performance of ECT inspection is defined by detection capability and sizing capability of flaws. The performance of ECT depends on many factors including type and size of flaws, inspection techniques, quality of inspection signals, performances of analysts. So that probability and statistics are essential to define the performance of ECT. The detection capability can be defined as the probability of detection, a function depending on the size of flaws. The sizing capability can be defined as a set of statistical parameters defining the correlation between the real size and ECT-measured size.

An ECT round robin program was performed in order to define the performance of ECT inspection using flaws in a retired steam generator. The target of the long-term round robin program is to enhance the safety of PWRs by improving the key technology.

2. Methods and Results

2.1 A Retried Steam Generator

The two steam generators of Kori Unit One were replaced in 1998 after twenty years of service. There had been extensive cracking degradation.

The SG-A was chosen arbitrarily for the round robin. The inspection and repair records of the steam generator were reviewed to make a single database. 347 tubes are as plugged and 488 tubes are as repaired by sleeve among the total of 3,388 tubes.

2.2 ECT Round Robin using a RSG

Motorized Rotating Pancake Coil probe inspection, which is the standard ECT technology for detecting cracks in the plants, was performed for 796 tubes, +/- 5 inches of top of tube sheet, and 542 tubes, +/- 2inches of the first tube support plate.

The field inspection signals were analyzed to build the inspection signal database for the round robin analysis, which covers signals from 410 tube sections at TTS and 102 tube sections at TSP. The cracks are classified into four groups, as ID axial, ID circumferential, OD axial, and OD circumferential cracks. There were extensive OD axial cracks near TSP, and other cracks are mostly populated near TTS zone.

27 analysts were grouped into 9 separate analysis teams for the POD round robin.

The total of 91 tube sections were pulled out, and then analyzed by destructive examination in the hot laboratory to define the shape and size of each crack. The real shape and size of cracks are compiled into a single database file.

7~14 typical tube sections were chosen for the sizing round robin for each group of cracks. Some tubes had multiple cracks. The sizes of each crack were analyzed by 10 separate analysis teams, applying 6~14 different combinations of analysis parameters. Both the maximum depth and the length were analyzed. The ECT analyzed sizes were compared with the real size measured by destructive examination, as linear regressions with slopes and intercepts. Statistical parameters defining the significance of the regression, the coefficient of determination and the root mean square error, are defined. The best analysis techniques are suggested for each group of cracks based on the quality of regressions.

2.3 POD performance

The database of the POD round robin was reviewed in order to build POD templates for each group of cracks. The POD templates were analyzed to define POD using the Logistic function, details of which are found elsewhere [5,6].

Figure 1 shows an example of POD curves. The POD curves of OD axial cracks depending on the maximum depth of the cracks are shown for each separate round robin analysis team.

The technique POD is defined as the one analyzed by the perfect analyzer. If a crack is detected by any team among the nine teams, then it is assumed that the crack is detected by the perfect analyzer.

The composite POD is the one defined by summing all the separate teams' POD into a single curve. It is believed that the composite POD represents the average performance of all analyzers involved.

The POD functions are defined based on maximum depth, length, percent degraded area for circumferential cracks, and effective depth and length. The effective depth and length are defined by structural calculation of the resistance of tubes against tube rupture.

2.4 Sizing performance

Figure 2 represents an example of sizing performance. The real maximum depths of OD axial cracks as measured by destructive examination are regressed with the ECT measured maximum depth. The data represents the best regression chosen among the six different combinations of the analysis parameters.

Both the length and depth sizing are defined for each group of cracks. Percent degraded area is another sizing parameter of importance for circumferential cracks. The effective depth and length are also sizing parameters of significance.

2.5 Discussion

A value of the RSG ECT round robin is using real cracks rather than artificial flaws. The limitations of artificial flaws are obvious. The cracks are clean and wide open while the cracks are very tight and covered by thick deposit in the plants. The tubes pulled out from operating steam generators may provide real crack data. The critical limitation of pulled tube database, however, is that most cracks are detected ones by in-service inspection. It is very unlikely to pull out a tube where flaws are not detected by in-service inspection. It should be noted that the undetected cracks cause problems, while detected ones are repaired.

Another big advantage of the round robin program using a retired steam generator is that combination of many technologies and many analysts can be applied under consistent control procedure in a single program.

The ECT round robin program provided with the ideal opportunity for defining the performance of ECT depending on types of cracks, analyzers, and analysis procedures. It should be noted that the in-service inspection by ECT is the crucial step to secure the integrity of nuclear steam generators.

The details of the results of ECT round robins will be published elsewhere.

3. Conclusions

An ECT round robin program was performed in order to define the performance of ECT, both detection and sizing of cracks, using a retired steam generator. The round robin program provided with an extensive database defining detection and sizing capabilities of ECT inspection, which is a crucial element to enhance the integrity of nuclear steam generators.

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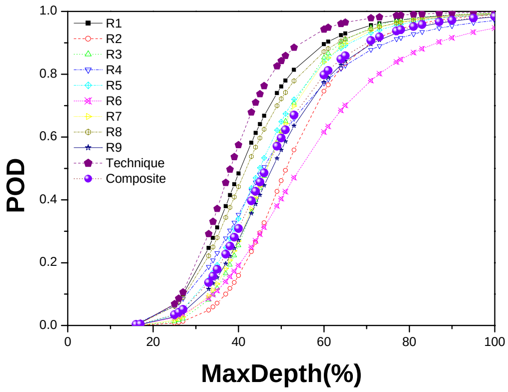

Figure 1 POD curves depending on the maximum depth of the cracks, OD axial cracks

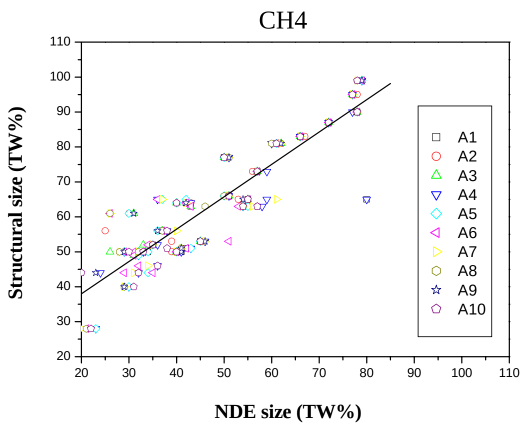

Figure 2 Real size vs. ECT size, maximum depth of OD axial cracks