THE MAINTENANCE STRATEGY AND LIFE EXTENSION OF THE ANGRA 1 STEAM GENERATORS

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ABSTRACT

The premature degradation of steam generator (SG) tubes is one of the greatest problems in the nuclear industry. Data from several plants in the world indicate that the degradation is due to stress corrosion cracking (SCC), a mechanism responsible for the initiation and propagation of the cracks, which has potential to cause the material failure. The international experience shows a growing number of tubes removed from service by damage caused by SCC. Because this impacts the plant performance, an option adopted by several utilities is to replace the equipment. As in Angra 1 Nuclear Power Plant a similar tendency has been verified, the decision to replace the component over the next several years was set. Meanwhile, it is necessary to develop an action plan to manage the life of the steam generator up to the moment of its replacement.

The purpose of the work presented in this paper is to describe the main mechanisms that affect the Angra 1 steam generator tubes and the plans to define the best maintenance program up to its retirement. Based on the degradation projection, determined using a simple statistical analysis, it will be also described the methodology adopted to estimate the residual life of the equipment.

Keywords: Angra, steam generator, degradation.

I. INTRODUCTION

Angra 1 is a 625 MWe Westinghouse two-loop plant with a model D3 steam generator (SG). Each SG has 4674 tubes made of alloy 600 MA hardrolled at the tube sheet. Each tube has an outside diameter of 19.05 mm (0.75 inches) and a tube wall thickness of 1.09 mm (0.043 inches). In order to restrict tube movement due to flow induced vibration, several support plates and anti-vibration bars made of carbon steel are installed. At the beginning of the 10th operational cycle (May 2001), the effective full power days (EFPD) was 2370.

Since the 1990 inspection, tube degradation has been detected in different regions of the equipment. This damage is caused by stress corrosion cracking (SCC), a corrosion mode caused by a combination among the aggressive environment, tensile stresses, and susceptible materials. The most unfavorable the combination the worst will be the consequences on the material. The damage mechanism is denominated PWSCC (Primary Water Stress Corrosion Cracking) when it initiates cracks on the internal side of the SG tube. If the damage starts from the external side of the tube it is named ODSCC (Outside Diameter Stress Corrosion Cracking).

The main concern related to the SG degradation is that the tube bundle is part of the pressure barrier of the pressurized water reactors and isolate fission products from the primary to the secondary side. The barrier is jeopardized when, under certain conditions, a crack penetrates the tube wall, causing undesirable leaks, which request plant shutdown. To avoid unplanned outages, the tubes are preventively removed from service (plugged) whenever the cracks sizes measured during the periodic inspections reach the allowable limits.

The Eddy Current Test (ECT) is the nondestructive method adopted in Angra 1 to inspect the tubes. Because plugging reduces the heat transfer area from primary to secondary systems, the SG performance is impacted. To overcome this problem the sleeving repair method has been adopted. The sleeving allows tubes to stay in operation, which, in turn, increases the residual life of the equipment.

The goal of this work is to present the strategy adopted by Eletronuclear to minimize SG degradation and, as a consequence, to extend its lifetime. The analysis takes into account the results from ECT and is based on the identification of each damage mechanism and the affected tube location. The paper describes the actual situation of the Angra 1 steam generators in terms of the damage distribution, shows the solutions implemented to control the forms of corrosion, and presents the inspection program philosophy and the projection of the tube degradation.
II. MODES OF DEGRADATION

After the 2001 inspection, there were 649 tubes plugged in SG 1 and 364 in SG 2. The total number of plugged tubes was 1013, being the average between the two steam generators equal to 10.8%. At that time, the main degradation mechanisms were the axial cracks due to PWSCC at top of tube sheet, circumferential cracks due to ODSCC at top of tube sheet and at the tube support plate, axial cracks due to ODSCC at tube support plates and freespan, pitting, and wastage at anti-vibration bars. All these areas are identified in Fig. 1.

In order to avoid an excessive number of plugged tubes, 79 sleeves (33 sleeves at SG 1 and 46 at SG 2) were installed at the top of the tube sheet region during the 2001 inspection. Despite this solution being very expensive and time consuming, the option allows tubes to stay in operation, and, as a consequence, the life of the SG is increased.

Figure 2 shows the repaired tubes for the most important degradation mechanisms detected in Angra 1. It can be noted that the ODSCC at tube support plate (TSP) is the predominant cause of tube repair. However, since the 1997 inspection an increase in ODSCC circumferential cracks at the top of the tube sheet (TS) has been observed.

Therefore, one can conclude that this degradation will control the SG lifetime.

The ODSCC degradation at the two locations are due to residual stress induced by the rolling process (hardrolled) adjacent to the top of tube sheet and by denting phenomena at tube support plate. Circumferential cracks at top of tube sheet is also accelerated by the sludge pile and by a caustic in the crevices at this zone. This type of degradation is the most active form of degradation found in these steam generators.

In order to minimize the degradation several actions have been implemented in Angra 1. For example, in the early stage of the plant operation, tubes were shot-peened at the top of tube sheet (expansion transition zone) and thermally treated at U-region, both solutions adopted to alleviate PWSCC. On the other hand, starting in the middle of 90’s, ODSCC was inhibited by improving the quality of the secondary water chemistry, with boric addition, and with the application of high pressure sludge lancing process to remove the sludge at top of tube sheet. Finally, to remove cooper from the secondary system, all admiralty and aluminum brass tubes from heaters and condenser were replaced by others with better corrosion strength.
III. INSPECTION PROGRAM

The inspection program that has been adopted in Angra 1 is oriented by the Eddy Current Test at each refueling outage. In order to minimize the leakage possibility an extensive non-destructive examination is performed. The ECT uses bobbin coil and pancake coil to detect several forms of degradation, including PWSCC, ODSCC, pitting, and wastage. The scope of the inspection includes 100% full-length bobbin coil of all tubes in each steam generator and 100% pancake coil at hot leg top of tube sheet. The pancake coil is also used at the two first rows of the U-bends region and at some tubes/tube support plates intersections.

The ECT measurement parameter is degradation specific and is expressed in function of the several structural parameters such as throughwall percentage flaw depth (%TW), crack length (mm), angle (degree), and voltage (V). In order to decide if one particular tube should be repaired, the ECT data shall be less than the allowable limits, determined for each degradation and the location where it is detected.

According to the NEI 97-06 Nuclear Energy Institute’s Steam Generator Program Guidelines (1), it is necessary to check, after each inspection, the ability of the SG to perform required safety functions in terms of structural stability and leakage. The guidelines of NEI 97-06, that has been adopted by the american utilities since 1998, define the industry program for the management of degradation of SG. This document requires that a performance criteria has to be demonstrated at the end of an operational period and if it will be maintained throughout the next planned cycle. These processes are called condition monitoring and operational assessment, respectively, and the industry standard for performing this evaluation is introduced in (2).

The compliance with the performance criteria ensure that structural integrity is maintained over the range of normal and accident operating conditions. The essential elements of the criteria is to perform the condition monitoring and operational assessment, and to determine their respective limits. Failure to meet these limits during an inspection leads to actions such as perform a causal analysis and take the necessary corrections, additional tests, adjust the tube repair criteria or even to reduce the length of the next operating cycle.

The structural limit (SL) is calculated from experimental or analytical correlation between the burst pressure (e.g. 3.0 times the differential pressure between primary and secondary side at normal operating), ECT measurement parameter, tube material and crack geometry. Burst is the gross structural failure of the tube wall. When the SL is adjusted to take into account the uncertainties from the correlation, material properties, and data from the inspection, the condition monitoring limit (CM) is determined. The operational assessment limit (OA) is calculated when the estimated crack growth rate for a period of time between inspections is subtracted from the CM limit. To verify if the performance criteria is met, these values are converted to the measurement parameter and compared with the ECT results for each degraded tube.

Figure 3, which is adapted from (2), represents the calculation procedure for SL, CM, and OA for each form of degradation that can occur within the steam generator. The SL, CM, and OA limits are calculated according to EPRI Management Flaw Handbook, (3).

As an example of tube degradation evaluations, the results for SL, CM, and OA for some of the most actives mechanisms are present in Table 1. The calculation is performed using a simple bounding approach, where the uncertainties and crack growth are simply added to determine the limits. The results are typical because these quantities do not represent Angra 1 actual values. To demonstrate structural integrity of SG tubes all indications detected during an inspection campaign have to meet these limits.

IV. REPAIR PROJECTION

The residual life of Angra 1 steam generators (SG) can be estimated from the ECT results obtained during each inspection. The number of tubes with degradation confirmed (which do not meet the repair criteria) after the end of each operating cycle is used as input for a calculation based on the Weibull distribution, which is capable of predicting the amount of repaired tubes (plugged or sleeved) at the subsequent inspections. The life estimation is based on the projection of the plugged tubes taking into account all degradation mechanisms. This average value has to be compared with the allowable 20% of tubes removed.
time when the replacement of the Angra 1 SG has to take place.

The degradation projection to the next outages is obtained through a technique described in (4), (5) and (6). The actual Angra 1 inspection data are used to determine a two-parameter Weibull distribution that provides the tubes expected to be repaired in each inspection.

The technique summarized above, used by several plants in operation, (4), is adequate for projections at small intervals of time (365 to 750 Effective Full Power Days, EFPD). However, in the lack of another methodology for immediate application, the Weibull distribution is adopted, observing that the projections are consistent only when the operational profiles between inspections (represented by EFPD) and the operation conditions are similar to those of the previous cycles. Besides, the projection models are dependent on the repair criteria adopted in each inspection. Therefore when they are altered, there are changes in the estimates obtained here.

The projection of the damaged tubes for each mode of degradation is obtained using information such as defect location, EFPD and the repaired tubes per SG. Based on the projections, the circumferential crack at the top of the tube sheet is the most significant failure mechanism.

The result of the analyses for the most important modes of corrosion observed in Angra 1 is depicted in Fig. 4. The figure shows the projection of the tubes plugged as a function of EFPD at each inspection up to the outage which precedes that foreseen for SG replacement. This is an upper bound solution to the statistical sum that accounts for the fact that a tube can only fail once. It is observed that if the predictions are confirmed, the limit of 20% for tubes plugged will be exceeded before 2003 inspection (extrapolation of the continuous line). To keep the Plant operating without power reduction it is necessary to repair the largest possible number of tubes with circumferential indication at the top of the tube sheet and at the first support plate elevation. If this strategy is adopted the average percentage of plugged tubes at the replacement will be approximately 16%.

V. CONCLUSION

From the ECT inspection results in Angra 1, the circumferential crack at the top of the tube sheet due to ODSCC is the degradation mode that limits the life of the steam generators. The actual trend indicates that more than 20% of the tubes will be plugged before 2003 inspection. In order to keep on generating the rated output of the Plant up to 2006, the foreseen date for the SG replacement, a repair strategy is necessary. It is important to mentioned that the projection method presented here, based on Weibull distribution, is a good tool for planning and has to be reevaluated after each inspection outage.

The repair method selected to be applied in Angra 1 is to sleeve at each outage the largest possible number of tubes with circumferential indication at the top of the tube sheet and at the first support plate elevation. If this strategy is adopted the average percentage of plugged tubes at the replacement will be approximately 16%.

REFERENCES


