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Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
Proposed Risk Informed Technical Specification Change Regarding Steam Generator Outer Diameter Intergranular Attack within the Upper Tubesheet

Gentlemen:

Attached for your review and approval are proposed Technical Specification (TS) changes revising the requirements associated with Arkansas Nuclear One - Unit 1 (ANO-1) provisions for steam generator tubing inspection and repair. The proposed changes affect ANO-1 TS Surveillance Requirements and applicable bases relevant to inservice inspection requirements for the portions of the once-through steam generator (OTSG) tubes regarding inspection and repairs of tubes having volumetric outer diameter intergranular attack (ODIGA) within the upper tubesheet.

The proposed alternate repair criteria (ARC) for ODIGA are desired to allow continued operation of ANO-1 beyond future OTSG inspection outages while preventing undue financial hardship, significantly increased radiological exposures, and unnecessary increases in outage duration due to repairs of ODIGA flawed tubes within the upper tubesheet. Current TSs, as revised by Amendment 202, allow ANO-1 to operate through its 16$^{th}$ core cycle with OTSG tube degradation due to ODIGA beyond the defined plugging limit. This current allowance is being proposed for permanent ANO-1 operation beyond the end of cycle 16. Cycle 17 operations will begin at the conclusion of the 1R16 refueling outage scheduled in the spring of 2001. These revised requirements affect the surveillance criteria for that portion of the OTSG tube regarded as a primary-to-secondary pressure boundary located within the upper tube sheet and impacted by ODIGA. Analysis of this tube region for this degradation mechanism has indicated a negligible failure potential under accident conditions.

During the NRC staff's review of the proposed change for Amendment 202 to the ANO-1 operating license dated October 4, 1999, the staff raised concerns regarding the approach and methodology as a permanent ODIGA repair criteria. The staff was primarily concerned with the ANO assessment of potential accident-induced leak rates not being performed in a conservative manner, assuming leakage occurs. The staff believed there was too much uncertainty associated with these estimates that had not been addressed. In addition, the staff

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concluded that the proposed criteria for ensuring that no growth is occurring were not sufficient. Therefore, the NRC was unable to approve this change on a permanent basis. The NRC requested that future submittals regarding proposed ODIGA repair criteria address this concern. Section 7.0 of the enclosed engineering report (ANO Engineering Report No. 00-R-1005-01) provides a description of the revised procedure for assessing the statistical significance of apparent changes in the IGA flaws. This new procedure provides greater sensitivity to detecting changes in the overall distribution of IGA flaws. More importantly, it requires that the largest growth values observed be consistent with previous historical extremes. The new information presented in this engineering report is from an evaluation of ANO-1 analyst-to-analyst variability for sizing these types of flaws. This NDE uncertainty information is required to separate analyst variability from the variability of the apparent growth rates that are obtained directly from the field measurements.

ANO will also be using a revised process for monitoring ODIGA growth. The new process is a multi-step method starting with simple statistical tests to detect changes in the apparent growth distributions. The existing 2-out-3t-tests are being replaced by a generalized test to detect changes in the mean and a new extreme value test that will identify changes in the "tail" of the distribution. If initial simple tests are unsuccessful, a second set of test alternatives would be applied which is less sensitive to assumptions on how the data is distributed. If the second set of alternatives is unsuccessful, a cycle-specific growth model would be applied. The leakage estimate and growth projection methodology is discussed in the enclosed engineering report.

Entergy has concluded that the OTSG tube degradation associated with ODIGA is of negligible risk and does not provide a concern to the public health and safety. The ODIGA degradation mechanism does not provide any potential for a tube to burst since the ODIGA flaws that would be left in service are restricted to the upper tubesheet. In addition, there is little potential for leakage of the tubes since testing and historical data does not indicate a significant weakening of the tube walls that would promote leakage. Calculations have been performed that assumes that even if all of the tubes containing ODIGA patches were to leak that the leakage is fully within the normal makeup capacity of one high pressure injection/makeup pump and this type of flaw is not significant from a risk perspective. Therefore, Entergy is proposing that the attached request to amend the operating license be reviewed under the guidelines of Regulatory Guide 1.174 as a risk informed amendment.

The proposed change has been evaluated in accordance with 10CFR50.91(a)(1) using the standards of 10CFR50.92(c) and it has been determined that this change involves no significant hazards considerations. The bases for these determinations are included in the attached submittal.

Entergy Operations requests that the effective date for this change be March 15, 2001 with an implementation period by the startup from the 16$^{th}$ refueling outage. Although this request is neither exigent nor emergency, your prompt review is requested.

Very truly yours,

CGA/sab
Attachments

**To the best of my knowledge and belief, the statements contained in this submittal are true.**

**SUBSCRIBED AND SWORN TO before me, a Notary Public in and for Pope County and the State of Arkansas, this 29th day of August, 2000.**

**Notary Public**
**My Commission Expires 12/15/2007**

"OFFICIAL SEAL"
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ATTACHMENT

TO

1CAN080005

PROPOSED TECHNICAL SPECIFICATION

AND

RESPECTIVE SAFETY ANALYSES

IN THE MATTER OF AMENDING

LICENSE NO. DPR-51

ENTERGY OPERATIONS, INC.

ARKANSAS NUCLEAR ONE, UNIT ONE

DOCKET NO. 50-313

## DESCRIPTION OF PROPOSED CHANGES

The proposed changes to the Arkansas Nuclear One, Unit 1 (ANO-1) Technical Specifications (TS) provide for the application of the volumetric outer diameter intergranular attack (ODIGA) alternate repair criteria (ARC). Amendment 202, dated October 4, 1999, provided alternate repair criteria that applied only to the ANO-1 operating Cycle 16. The proposed change contained herein justifies continued operation beyond Cycle 16 for ANO-1 while leaving once-through steam generator (OTSG) tubes having ODIGA indications that are located in a defined area of the upper tube sheet in service.

Additions, revisions, and deletions are proposed as indicated below to provide for the implementation of the ODIGA ARC applicable to future operating cycles at ANO-1.

- A change to the referenced report in specification 4.18.3.a.5, from topical report BAW-10235p, Revision 1, "*Deterministic Management Program For Volumetric Outer Diameter Intergranular Attack In The Tubesheets Of Once-Through Steam Generators*" to ANO Engineering Report No. 00-R-1005-01 "*Management Program For Volumetric Outer Diameter Intergranular Attack In The Upper Tubesheets Of Once-Through Steam Generators At Arkansas Nuclear One – Unit One*". The ANO Engineering Report provides the site specific justification from a deterministic application for allowing ODIGA flaws to remain inservice.

- The first paragraph of 4.18.5.a.7 is being modified to remove the cycle specific limitation to allow ODIGA flaws to remain inservice. A change from the referenced FTI topical report for ODIGA similar to 4.18.3.a.5 is being proposed.

- The second paragraph of 4.18.5.b is being deleted which allowed tube 110/60 to remain inservice since the operating cycle where it is allowed will expire at 1R16. This change was approved in Operating License Amendment 203. No additional discussion will be provided on this proposed change.

- The wording to the second paragraph of the bases is revised to reference the ANO Engineering Report No. 00-R-1005-01 instead of the previously referenced FTI topical report for ODIGA, similar to 4.18.3.a.5.

## BACKGROUND

ANO-1 utilizes two model 177FA OTSGs. The OTSG is a straight-tube, vertical, counter-flow, once-through heat exchanger with shell-side boiling. Primary fluid from the reactor enters through an inlet nozzle in the top head, flows down through the tubes, is collected in the bottom head, and exits through two primary outlet nozzles. The feedwater enters through a series of spray nozzles near the top of the annular feedwater-heating chamber. Here the feedwater is heated to saturation temperature by direct contact with high-quality or slightly

superheated bleed steam. The resulting saturated feedwater enters the tube bundle through ports near the bottom of the tube bundle. Nucleate boiling starts immediately upon contact with the hot tubes. Steam quality increases as the secondary fluid flows upward between the tubes in counter-flow to the primary fluid inside the tubes. The departure from nucleate boiling occurs at about the 25-foot level at design conditions. The mode of heat transfer then changes from nucleate to film boiling. Steam quality continues to increase, but at a slower rate. After 100% quality is reached, the steam becomes superheated, leaves the tube bundle at the upper tubesheet, flows down the steam annulus, and exits through two steam outlet nozzles.

The more than 15,000 alloy 600 tubes employed in each OTSG are 5/8 inch OD x 0.037 inch nominal wall x 52 feet long. All are partially roll expanded and attached to the upper and lower tubesheets by fillet welds. The use of straight tubes results in almost pure counter-flow properties. This design along with the fact that alloy 600 tubes have a thermal coefficient of expansion slightly greater than that of the carbon steel shell, provide for compressive loading of the tubes during normal operating conditions. Compressive loading tends to inhibit the initiation and propagation of stress related damage mechanisms. As a result of being both sensitized and stress relieved during manufacturing, the tubes illustrate an improved resistance to stress corrosion cracking, but a susceptibility to intergranular attack.

Examination of a tube removed from the A OTSG in 1978 revealed deposits and a corrosion film containing elevated levels of sulfur and silicon, with trace amounts of chlorine and other contaminants. Such contamination was believed to have caused intergranular attack of the tubes secondary-side surface. This was further confirmed in 1982 during the examination of two OTSG B tubes. Sulfur and chlorine contaminants were again disclosed during the examination, and evidence of ODIGA was noted. One of these tubes indicated an ODIGA induced degradation penetrating approximately 50% through-wall (TW).

After further study, changes to the secondary system chemical controls at ANO-1 were implemented to minimize the ingress of sulfur and chlorides to the OTSGs. Results of tube examinations after 1984 indicated sulfur, chloride, and silicon contaminate levels were no longer elevated. Based on all available results to date, the damage mechanism appears to be dormant.

Through 1R13, ODIGA indications were sized and left in service if measured bobbin coil extents were <40% TW. Testing performed on selected ANO-1 OTSG tubes removed during the 1R13 outage, revealed that actual ODIGA through-wall (TW) depths were not consistent with the results of eddy current testing performed on the tubes during 1R13. By this observation, it became apparent that ODIGA affected tubes having >40%TW depths may have been left in service. Upon determination of non-compliance, ANO-1 promptly sought and was granted enforcement discretion. ANO-1 then began efforts to follow-up with an amendment to its TSs.

Entergy Operations submitted an exigent TS change on April 11, 1997 (1CAN049703), to allow a one time exception to the surveillance requirements of Specification 4.18.5.b. This

exception allowed tubes with ODIGA indications within the upper tube sheet with potential through-wall depths greater than the plugging limit to remain in service for the remainder of Cycle 14. The April 11, 1997, submittal was supplemented on May 2, 1997, by letter 1CAN059702 which reduced the leakage limit through the OTSG tubes from 500 gallons per day (gpd) to 144 gpd for the remainder of Cycle 14. In response to this request, the NRC issued Amendment No. 189 to the ANO-1 license dated May 7, 1997. This amendment allowed the unit to continue operation through the remainder of Cycle 14 with tubes that had potential through-wall defects in excess of the 40% plugging limit.

The Babcock and Wilcox Owners Group (B&WOG) had previously been developing alternate repair criteria for freespan and tubesheet volumetric ODIGA flaws. Because of the number of ODIGA indications detected in the upper tubesheet (UTS) regions of the ANO-1 OTSGs and due to inconsistencies in sizing ODIGA depths within the UTS, it was decided to focus efforts solely on the UTS region. Without verification of specific TW depth, each indication is conservatively considered to be above the current plugging criteria of 40%TW. Therefore, the B&WOG began immediate evaluation of an alternate repair criteria for ODIGA indications located in the UTS region only. Although topical report BAW-10226P was prepared and submitted prior to 1R14, insufficient time prevented resolution of all outstanding issues. Therefore, based on the information available, ANO-1 submitted a second amendment request to allow continued operation through Cycle 15.

In letter 1CAN049803, dated April 1, 1998, ANO-1 proposed an amendment providing discussion and technical bases supporting the treatment of ODIGA affected OTSG tubes within the UTS as unique in comparison to other tube defects. The proposed amendment was approved by the NRC on April 10, 1998, allowing ODIGA affected tubes in the UTS region to remain in service during ANO-1's Cycle 15. As part of Amendment No. 191 to the ANO-1 TS, five requirements were included: a 100% bobbin coil inspection of the upper tubesheet region would be performed in 1R14, a rotating pancake coil would be used to confirm ODIGA indications, 1R14 voltages would be compared with data from 1R13, an upper limit was placed on flaw extents and allowed growth, and 1R14 in-situ tests would verify that potential leakage from ODIGA affected tubes in the UTS region would remain ≤ 50% of the primary-to-secondary leak rate limits assumed in the accident analysis for the associated cycle.

Experiments discussed in EPRI Report 6864-L indicated burst pressures of the portion of OTSG tubes located within an enclosure are not impacted by flaws, provided the clearance between the outer tube wall and the enclosure is less than approximately 0.030 inches. The diametral gap in the UTS of ANO-1 OTSG tubes is 0.021 inches. All tests performed where defective tubes were confined within a tubesheet illustrated failure pressures consistent with that of tubes containing no flaws and all failures occurred outside the tubesheet, typically 1.5 inches or more away from the tubesheet face. It is important to note that volumetric ODIGA does not involve a loss of wall thickness and has very little effect on the structural integrity of the tubing.

Tensile stresses are by nature associated with certain cooldown transients. Values were previously provided in topical report BAW-10235P, Revision 0, by letter dated May 14, 1999

indicate the limiting tensile load for ANO-1 is 2097 lbs, based on a postulated SBLOCA event. A safety factor of 1/0.7 was considered with a resulting load of 2996 lbs. used in the evaluation. The same report provides test results indicating tube structural integrity to be maintained by tubes with ODIGA flaws of 100% TW and a circumferential range of 140°. The typical "thumbnail" shaped cross-section of ANO-1 ODIGA indications have previously shown maximum circumferential extents of ~80°. Therefore, tensile stresses are not expected to have an appreciable effect on UTS ODIGA indications at ANO-1.

Fatigue loading may be high-cycle or low-cycle. High-cycle fatigue is believed to develop from flaws initiated at sites of localized corrosion or wear that propagates into fatigue cracks by flow induced vibration associated with high cross flow. This phenomenon is generally associated with the open tube lane area of the ANO-1 OTSGs. High cycle fatigue has been successfully addressed in the ANO-1 OTSGs by preventatively sleeving susceptible tubes through the UTS and top span of the OTSGs. Low-cycle fatigue results primarily from mechanical, thermal, and pressure cycling during normal plant operation. Such indications would be evidenced during eddy current inspections of the OTSG tubes and, if necessary, the tubes would be removed from service at that time. In the case of either type of fatigue loading, any resulting effects are not adversely impacted by the ODIGA alternate repair criteria proposal.

During the 1R14 outage, 36 ODIGA patches of various depths and lengths were in-situ tested at normal operating differential pressure of 1500 psi and the accident pressure of 2900 psi (safety valve lift including 3% tolerance and thermal uncertainty factors) while applying an axial load of 1402 lbs. No leakage was evidenced from any of the tubes tested. In addition, three ODIGA flawed tubes with four indications were pressurized to 4400 psi and 6500 psi and again indicated no leakage. Similar hot leak tests were performed in the laboratory under near-normal operating temperatures and accident pressure, with like results of no leakage. For the purpose of postulating leakage, then, it is therefore assumed that the ODIGA must form a crack in order to develop a potential for leakage. However, this would indicate that the characteristics of ODIGA have taken on a mixed mode form where axial or circumferential cracks have developed which would be repaired upon detection.

In order to effectively implement the proposed changes, not only is an evaluation of tube integrity required, but a method of evaluating the growth of ODIGA indications is also necessary. As mentioned previously, the improved chemistry control at ANO-1 has had the effect of removing the mechanism that is believed to have caused the existing defects associated with ODIGA to grow or for new defects to form. This is supported by available eddy current information. The mean population voltage for bobbin testing performed over the period of 1993-1998 on more than 100 indications illustrated no appreciable increase in overall size of the ODIGA defects. In addition, OTSG bubble tests, in-situ pressure tests, tube pulls, and in-service leakage monitoring have not identified any 100%TW ODIGA indications or primary-to-secondary leakage attributed to ODIGA indications. Nevertheless, monitoring for growth is conservative and is discussed in length later in this submittal.

A further license amendment request was made on May 14, 1999 for cycle 16 operations with leaving ODIGA flaws in place under the basis of BAW-10235P, Revision 0, *"Deterministic Management Program for Volumetric Outer Diameter Intergranular Attack in the Upper Tubesheets of Once-Through Steam Generators"*. The evaluations of topical report BAW-10235P, Revision 0, showed that the volumetric ODIGA, due to its limited size, has very little effect on the structural performance or leakage potential of the tubing. That portion of the tube within the defined region of the UTS are constrained by the presence of the tubesheet, thus preventing the tube burst due to the existence of ODIGA flaws. Tensile rupture of tubes with ODIGA is highly improbable based on the results of tensile testing OTSG tubes with uniform thinning and 100%TW holes. The potential consequences of fatigue are mitigated by preventative sleeving and evaluating ODIGA for growth. Evaluations have also illustrated that this type of damage mechanism, along with its typically small size, make it a very unlikely candidate for primary-to-secondary leakage. Any potential effect of cross-flow loads during a MSLB condition were addressed and were considered negligible within the UTS.

On October 4, 1999, the NRC Staff issued license amendment 202 to the ANO-1 operating license. However, the staff found that implementation of the proposed ODIGA repair criteria was only acceptable for cycle 16 operation. The staff independently assessed the ODIGA inspection results obtained during the current outage and concurred with ANO's finding that the subject ODIGA indications were not experiencing any significant growth. The Staff's conclusion was based on the absence of significant growth, the in-situ pressure tests performed during the 1R14 outage that indicate that the licensee's estimate of the number of ODIGA indications that may potentially leak during postulated accidents was conservative, and that ANO's estimate of total accident-induced leak rate was conservative.

However, the Staff's evaluation concluded that the proposed change for a permanent ODIGA repair criteria could not be granted in that potential accident-induced leak rates was not addressed sufficiently. The staff believed that there was uncertainty associated with these estimates that had not been adequately evaluated and requested that future submittals address this concern.

## DISCUSSION OF CHANGE

Based on the NRC Staff's concern on the methodology for predicting growth and accident leakage determination, Entergy Operations has modified the information contained in BAW-10235 and developed a new ANO Engineering Report No. 00-R-1005-01. This report further addresses the issues raised by the Staff in their October 4, 1999 safety evaluation. Section 7.0 of the engineering report describes a revised procedure for assessing the statistical significance of apparent changes in the IGA flaws. This new procedure provides greater sensitivity to detecting changes in the overall distribution of IGA flaws. More importantly, it requires that the largest growth values observed be consistent with previous historical extremes. Additional new information is presented in this section from an evaluation of ANO-1 analyst-to-analyst variability for sizing these types of flaws. This NDE uncertainty information is required to separate analyst variability from the variability of the apparent growth rates that are obtained directly from the field measurements. Section 8.0 of the attached engineering

report provides the process for monitoring of ODIGA growth. The revised process uses a multi-step process starting with simple statistical tests to detect changes in the apparent growth distributions. The previously proposed 2-out-3 t-Tests are replaced by a generalized test to detect changes in the mean and a new extreme value test that will identify changes in the "tail" of the distribution.

The first step consists of two tests: (1) a single test (based on +Point voltage and axial length only) to detect changes in means and (2) a test to identify statistically significant changes in the largest growth measurement. If the results of the first step indicate no significant changes, this step is successful and no further action is required. If the first step is unsuccessful, a second step allows alternative tests where the assumption of underlying normality is relaxed. The second step provides some alternative and equivalent methods to confirm that the populations have not changed. If the results of the second step indicate no significant changes then one proceeds to calculate the (axial length) growth allowance for operational assessments as above. If the first two steps are unsuccessful, then there is evidence in the apparent growth data that the population has changed. At this point, a third step calls for the development of a cycle-specific growth model and additional calculations are required to develop an allowance for growth for operational assessment.

In addition to the improvements made in the modeling of leakage due to ODIGA, this amendment request is applying a risk-informed request based on the inability to burst the tubes due to ODIGA since all indications that would be left in operation will be restricted to the upper tubesheet. Therefore, leaving the ODIGA patches in the upper tube sheet unplugged will not significantly increase the CDF or LERF resulting from spontaneous SGTR, pressure induced SGTR or core damage induced SGTR.

**Severe Accident Consideration**

The proposed TS change will be applied only to ODIGA flaws within the defined region of the UTS at ANO-1. Based on structural testing described above and in topical report BAW-10235P, Revision 0, it was concluded that burst within the tubesheet is not possible due to the tight diametral clearance between the tube and tubesheet. Conditions associated with a postulated severe accident do not affect this conclusion. Therefore, the probability of tube rupture does not increase. Because burst will not occur within this defined region of the UTS, thermal challenges associated with a severe accident cannot increase the probability of tube burst within this location. Furthermore, application of the ODIGA alternate repair criteria has no effect on the remaining containment structures, or on any plant process or procedure that would increase the likelihood or consequences of any accident.

In regard to core damage induced steam generator tube ruptures, the conclusions made by the NRC in NUREG-1570, *Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture,* are that severe accident thermal challenges to steam generator tubes are not a concern for the B&W design. In addition to the above, preliminary results from an EPRI study indicate that B&W plants are not susceptible to the hot leg counter-current natural circulation phenomenon that presents a challenge to the steam generator tubes in other PWR

designs. The B&W OTSG design is inherently protected against this natural circulation process because of the vertical orientation of the hot legs.

At the high differential pressures following an ATWS or MSLB, if the ODIGA patches leak, the leakage would be less than the normal makeup capacity. The maximum leakage expected from these indications, at MSLB pressures, is 0.1 gpm. The calculation uses ¼ of the axial extent of each indication. If the entire measured length of the flaw is used and it is assumed that all of the flaws confirmed in the bounding steam generator leak (291 in the "A" OTSG), the total leakage would be approximately 23 gpm. This value is within the normal makeup capacity (70 gpm from Table 14-22 of the ANO-1 Safety Analysis Report).

The steam generator tubes with ODIGA in the upper tube sheet will not rupture because they are contained within the tube sheet. Therefore, the presence of unplugged ODIGA patches in the upper tubesheet does not increase the frequency of core damage induced SGTR. This concludes that the delta CDF is unaffected and is clearly in Region III as shown on the Figure 1.

Existing evidence demonstrates that, during a severe accident, flows of superheated gas are not expected to reach steam generator tube bundles in the Babcock & Wilcox OTSG designs, (*NUREG-1570*). Consideration of the OTSG design has excluded them from the NRC's risk assessment of core damage induced SGTR. An ODIGA condition that would cause all early core-melt pressure transient sequences to result in primary-to-secondary leakage (sufficient to place all of these sequences in the large LERF category) would only increase LERF by 3.744E-08/Rx-yr. In other words, all ODIGA flaws would have to result in leakage like that seen during a steam generator tube rupture (435 gpm from Table 14-22 of the ANO-1 Safety Analysis Report) to increase LERF by 3.744E-08/Rx-yr. (See Figure 2). Since the maximum possible leakage from the flaws has been determined to be approximately 23 gpm. This supports the approach that the LERF analysis, which applies a hypothetical worst case assumption to place all of the high-pressure events in the LERF bins, since it still results in an acceptable increase in the LERF.

## Steam Generator Upper Tube Sheet Intergranular Attack Sensitivity Analysis

**Figure 1 ANO-1 Delta CDF Due to ODIGA**

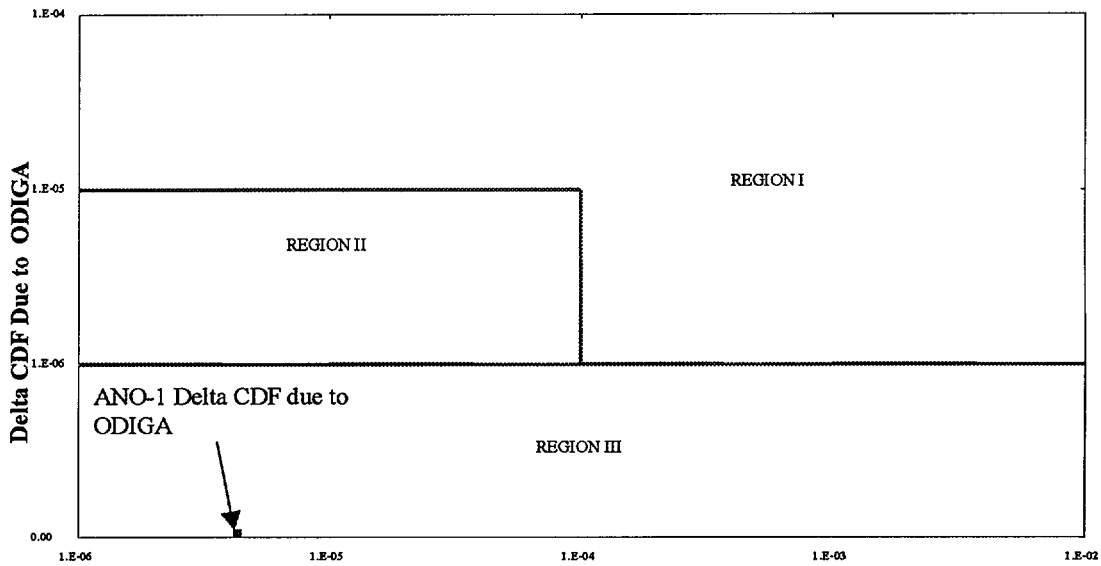
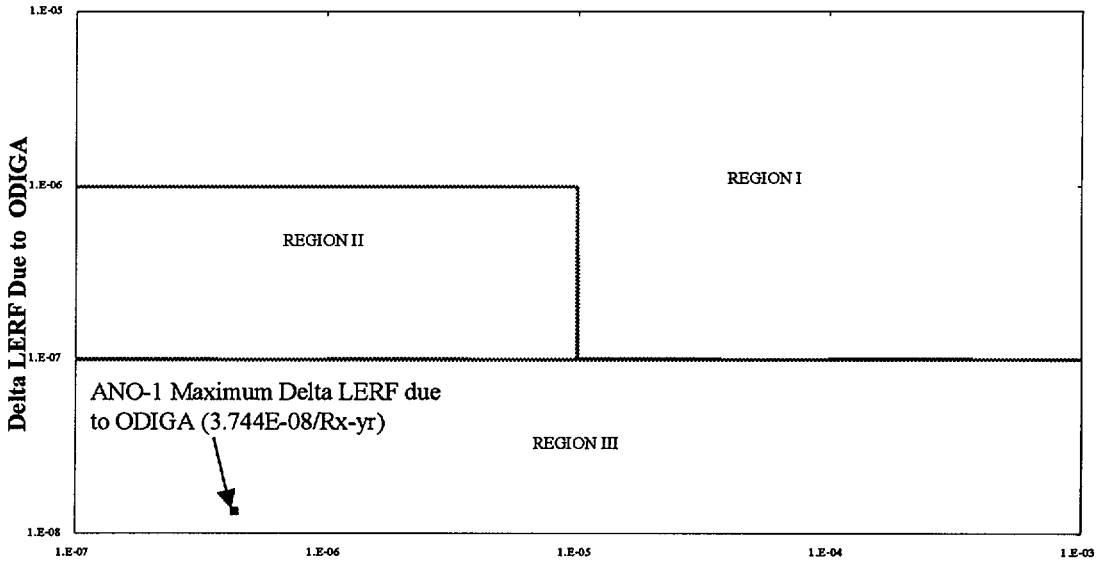



**Figure 2 ANO-1 Delta LERF Due to ODIGA**



Regulatory Guide 1.174 states that when the calculated increase in CDF is:

- less than $10^{-6}$ per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF (Region III),
- in the range of $10^{-6}$ per reactor year to $10^{-5}$ per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than $10^{-4}$ per reactor year (Region II), and,
- above $10^{-5}$ per reactor year (Region I), the application would not normally be considered.

When the calculated increase in LERF is

- less than $10^{-7}$ per reactor year, the change will be considered regardless of whether there is a calculation of the total LERF (Region III),
- in the range of $10^{-7}$ per reactor year to $10^{-6}$ per reactor year, applications will be considered only if it can be reasonably shown that the total LERF is less than $10^{-5}$ per reactor year (Region II), and,
- above $10^{-6}$ per reactor year (Region I) the application would not normally be considered.

Therefore, leaving the ODIGA patches in the upper tube sheet unplugged is clearly within Region III of the delta CDF and delta LERF graphs and will not increase the CDF or LERF consequences.

RG 1.174 provides five principles for risk-informed decision making. Each of these principles is addressed below for the proposed change to the ANO-2 licensing basis.

1) <u>Proposed Change Meets The Current Regulations</u>

The testing and analysis requirements described in ANO Steam Generator Integrity Program ensures that the deterministic structural and leakage integrity criteria of the plant's current licensing basis are satisfied. The appropriate structural margins for failure under normal operating conditions and postulated accidents established in Regulatory Guide 1.121 have also been met. In addition, the impact on postulated leakage during a design basis accident has been assessed, and it has been shown that the leakage will be less than the limit established to satisfy 10CFR100 limits for off-site dose defined in the plant's licensing documents. The ANO technical specifications require that the postulated accident induced end of cycle leakage value from all damage mechanisms, including upper tubesheet ODIGA be less than 1 gpm. The approach taken to conservatively quantify the leakage is similar to the methodology outlined in NRC Generic Letter 95-05, which established an acceptable framework for submittal of alternate repair criteria which could result in leaving tubes with known through-wall degradation in service. Therefore, the current ANO-1 steam generator integrity program meets all current regulations set forth for implementation of a risk-informed approach for allowing the ODIGA to remain in service.

2) Proposed Change Is Consistent With The Defense-In-Depth Policy

The proposed ARC will allow ODIGA with depths that are greater than 40% through-wall to remain in service. However, the structural integrity of the tubes will be maintained under application of this ARC, thus preventing rupture of the boundary. Leakage that could be attributed to these indications during a design basis accident has been conservatively estimated and shown to be less than the plant acceptance criteria. This evaluation will continue to be required after each inspection as part of the ANO-1 steam generator integrity program. Furthermore, leaving upper tubesheet ODIGA in service has no effect on the remaining containment structures or on any plant process or procedure that would increase the likelihood or consequences of any accident. Therefore, the defense-in-depth design attributes are satisfactorily maintained. In addition, primary-to-secondary leakage monitoring during normal operation ensures that the tubes are not degrading at a rate significantly higher than assumed in this application.

3) Proposed Change Maintains Sufficient Safety Margins

Indications managed by this risk-informed approach cannot burst due to the support provided by the tubesheet. At the high differential pressures following an ATWS or MSLB, if the ODIGA patches leak, the leakage would be less than the normal makeup capacity of the reactor coolant system. Therefore, safety margins consistent with the design basis of the plant have been maintained.

4) Proposed Increase In Risk Is Small And Consistent With The Commission's Safety Goal Policy Statement

This risk-informed approach for managing ODIGA will be applied only to indications located in the portion of tubing within the upper tubesheet. Burst of the tubing at these locations is not possible due to the constraint provided by the tubesheet, so the thermal challenge conditions associated with a severe accident do not affect the probability of tube burst at this location. Therefore, application of this approach will not increase the probability of tube rupture. Sensitivity analyses show that the potential impact on the CDF and LERF is very small, consistent with the commission's safety goal policy statement. (See Figures 1 and 2).

5) Impact Of Proposed Change Should Be Monitored Using Performance Measurement Strategies

All indications remaining in service as a result of this risk-informed approach will be inspected in each planned future inspection outage to ensure that performance criteria are satisfied. The ODIGA required surveillance inspections will include meeting the requirements contained in the EPRI Steam Generator Examination Guidelines. In addition, primary-to-secondary leakage monitoring during normal operation ensures that the tubes are not degrading at a rate significantly higher than assumed in this

application. Therefore, sufficient monitoring measures are in place to ensure the continued satisfactory performance of any tubes with indications left in service as a result of this risk-informed approach.

In summation, the studies and evaluations performed indicate that ODIGA affected tubes within the defined area of the UTS do not pose an appreciable threat to safe plant operation or to the health and safety of the public. The proposed changes to the ANO-1 TS are consistent with the principles set forth by the NRC for risk informed decision making. Current regulation is met based on the maintenance of structural integrity and leak rate limits assessed in this program. Because the structural integrity and leak rate limits are maintained, no change to the defense-in-depth philosophy is evident. Safety margins consistent with the design bases for ANO-1 are maintained considering the tubes have been shown to not burst within the defined region and leak rates are again maintained within limits. Based on these same criteria, no effect on core damage frequency, the consequences of a severe accident, or large early release frequencies is evident for ANO-1. Finally, a satisfactory performance monitoring program is established that both assesses current conditions and projects future conditions of tubes associated with ODIGA. Therefore, because identification, testing, monitoring, and reportability associated with ODIGA affected tubes within the defined region of the UTS have been adequately addressed, ANO-1 requests that the aforementioned changes to its technical specifications be approved.

## DETERMINATION OF NO SIGNIFICANT HAZARDS CONSIDERATION

Entergy Operations, Inc. is proposing that the Arkansas Nuclear One, Unit 1 (ANO-1) Operating License be amended to revise the requirements associated with the inspection, testing, and reporting of once-through steam generator (OTSG) tubes affected specifically by volumetric outer diameter intergranular attack (ODIGA) within the defined regions of the upper tubesheet. Current standards do not consider tube burst probability for ODIGA indications within the defined region of the upper tubesheet (UTS), or the improbability for leakage to occur from an ODIGA affected tube in this region. The proposed change is necessary to prevent removing OTSG tubes from service that are functionally evaluated to provide a protective barrier for radiation release to the public without increasing the likelihood of an accident or inhibiting the ability to mitigate accidents. The proposed changes are consistent with the recommendations of ANO Engineering Report No. 00-R-1005-01, "*Management Program for Volumetric Outer Diameter Intergranular Attack in the Tubesheets of Once-Through Steam Generators.*"

An evaluation of the proposed change has been performed in accordance with 10CFR50.91(a)(1) regarding no significant hazards considerations using the criteria in 10CFR50.92(c). A discussion of these criteria as they relate to this amendment request follows:

**Criterion 1 - Does Not Involve a Significant Increase in the Probability or Consequences of an Accident Previously Evaluated.**

The purpose of the periodic surveillance performed on the OTSGs in accordance with ANO-1 Technical Specification (TS) 4.18 is to ensure that the structural integrity of this portion of the reactor coolant system will be maintained. The TS plugging limit of 40% of the nominal tube wall thickness requires tubes to be repaired or removed from service because the tube may become unserviceable prior to the next inspection. Unserviceable is defined in the TS as the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an operating basis earthquake, a loss-of-coolant accident, or a steam line or feedwater line break. The proposed TS change allows OTSG tubes with ODIGA indications contained within a defined area of the UTS to remain in service with existing degradation exceeding the existing 40% through-wall (TW) plugging limit.

Extensive testing and plant experience has illustrated that ODIGA flaws confined to this area within the OTSG will not result in tube burst and tube leakage is unlikely. Therefore, allowing ODIGA flaws in this specific region to remain in service will not alter the conditions assumed in the current ANO-1 accident analysis for OTSG tube failures under postulated accident conditions. In addition, the condition of the OTSG tubes in this region are monitored during regular inspection intervals to assess for evidence of growth. Any growth noted will be addressed through testing and the operational assessment. Therefore, ANO-1 has determined that the identification, testing, monitoring, assessment, and corrective action programs provided in ANO Engineering Report No. 00-R-1005-01, sufficiently supports this change request.

Application of the ODIGA alternate repair criteria will allow leaving tubes with ODIGA indications found in the defined area of the UTS in service while ensuring safe operation by monitoring and assessing the present and future conditions of the tubes. ANO-1 has operated since 1984 with ODIGA affected tubes in service with no appreciable effect on structural integrity or indications of tube leakage from ODIGA sources within the UTS. Through the inspection, testing, monitoring, and assessment program previously mentioned, and the on-line leak detection capabilities available during plant operation, continued safe operation of ANO-1 is reasonably assured.

Therefore, the application of the ODIGA alternate repair criteria does <u>not</u> involve a significant increase in the probability or consequences of any accident previously evaluated.

**Criterion 2 - Does Not Create the Possibility of a New or Different Kind of Accident from any Previously Evaluated.**

The implementation of the ODIGA alternate repair criteria will not result in any failure mode not previously analyzed. The OTSGs are passive components. The intent of the TS surveillance requirements are being met by these proposed changes in that

adequate structural and leak integrity will be maintained. Additionally, the proposed change does not introduce any new modes of plant operation.

Therefore, this change does not create the possibility of a new or different kind of accident from any previously evaluated.

**Criterion 3 - Does Not Involve a Significant Reduction in the Margin of Safety.**

The application of an alternate repair criteria for ODIGA provides adequate assurance with margin that ANO-1 steam generator tubes will retain their integrity under normal and accident conditions. The structural requirements of ODIGA affected tubes have been evaluated satisfactorily and meet or exceed regulatory requirements. Leakage rates for these tubes within the defined region of the upper tubesheet are essentially zero and are reasonably assured to remain within the assumptions of the accident analysis by proper application of the ODIGA alternate repair criteria program. Assuming high differential pressures following an ATWS or MSLB, if the ODIGA patches leak, the leakage would be less than the normal makeup capacity of the reactor coolant system. Since no appreciable impact is evidenced on the tubes structural integrity or its resulting leak rate, the margin to safety remains effectively unaltered.

Therefore, this change does not involve a significant reduction in the margin of safety.

Therefore, based upon the reasoning presented above and the previous discussion of the amendment request, Entergy Operations has determined that the requested change does not involve a significant hazards consideration.

## ENVIRONMENTAL IMPACT EVALUATION

10 CFR 51.22(c) provides criteria for and identification of licensing and regulatory actions eligible for categorical exclusion from performing an environmental assessment. A proposed amendment to an operating license for a facility requires no environmental assessment if operation of the facility in accordance with the proposed amendment would not: (1) involve a significant hazards consideration, (2) result in a significant change in the types or significant increase in the amounts of any effluents that may be released off-site, or (3) result in a significant increase in individual or cumulative occupational radiation exposure. Entergy Operations, Inc. has reviewed this license amendment and has determined that it meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of the proposed license amendment. The basis for this determination is as follows:

1. The proposed license amendment does not involve a significant hazards consideration as described previously in the evaluation.

2. As discussed in the significant hazards evaluation, this change does not result in a significant change or significant increase in the radiological doses for any Design Basis Accident. The proposed license amendment does not result in a significant change in the types or a significant increase in the amounts of any effluents that may be released off-site.

3. The proposed license amendment does not result in a significant increase to the individual or cumulative occupational radiation exposure because this change involves an alternate approach to addressing steam generator tubes with Outer Diameter Intergranular Attack.

# PROPOSED TECHNICAL SPECIFICATION CHANGES

a. The first sample inspection during each inservice inspection (subsequent to the baseline inspection) of each steam generator shall include:

1. All nonplugged tubes that previously had detectable wall penetrations (>20%), except tubes in which the wall penetration has been spanned by a sleeve, and

2. At least 50% of the tubes inspected shall be in those areas where experience has indicated potential problems, except where specific groups are inspected per Specification 4.18.3.a.3.

   A tube inspection (pursuant to Specification 4.18.5.a.9) shall be performed on each selected tube. If any selected tube does not permit the passage of the eddy current probe for a tube inspection, this shall be recorded and an adjacent tube shall be selected and subjected to a tube inspection.

3. Tubes in the following groups may be excluded from the first random sample if all tubes in a group in both steam generators are inspected. The inspection may be concentrated on those portions of the tubes where imperfections were previously found. No credit will be taken for these tubes in meeting minimum sample size requirements. Where only a portion of the tube is inspected, the remainder of the tube will be subjected to the random inspection.

   (1) Group A-1: Tubes within one, two or three rows of the open inspection lane.

   (2) Group A-2: Unplugged tubes with sleeves installed.

   (3) Group A-3: Tubes in the wedge-shaped group on either side of the lane region (Group A-1) as defined by Figure 4.18.1.

4. Tubes with axially-oriented tube end cracks (TEC) which have been left inservice for the previous cycle shall be inspected with a rotating coil eddy current technique in the area of the TEC and characterized in accordance with topical report BAW-2346P, Rev.0, during all subsequent SG inspection intervals pursuant to 4.18.4. The results of this examination may be excluded from the first random sample. Tubes with axial TECs identified during previous inspections which meet the criteria to remain in service will not be included when calculating the inspection category of the OTSG.

5. Implementation of the upper tubesheet ODIGA alternate repair criteria requires a 100% bobbin coil inspection of the non-plugged and non-sleeved tubes, spanning the defined region of the upper tubesheet, during all subsequent SG inspection intervals pursuant to 4.18.4. Tubes with ODIGA identified during previous inspections which meet the criteria to remain in service will not be included when calculating the inspection category for the OTSG. The defined region begins one inch above the upper tubesheet secondary face and ends at the nearest tube roll transition. ODIGA indications detected by the bobbin coil probe shall be characterized using rotating coil probes in accordance with ANO Engineering Report No. 00-R-1005-01.

4.18.5 Acceptance Criteria

a. As used in this specification:

1. Tubing or Tube means that portion of the tube or sleeve which forms the primary system to secondary system pressure boundary.

2. Imperfection means an exception to the dimensions, finish or contour of a tube from that required by fabrication drawings or specifications. Eddy current testing indications below 20% of the nominal tube wall thickness, if detectable, may be considered as imperfections.

3. Degradation means a service-induced cracking, wastage, wear or general corrosion occurring on either the inside or outside of a tube.

4. Degraded Tube means a tube containing imperfections ≥ 20% of the nominal wall thickness caused by degradation, except where all degradation has been spanned by the installation of a sleeve.

5. % Degradation means the percentage of the tube wall thickness affected or removed by degradation.

6. Defect means an imperfection of such severity that it exceeds the plugging limit except where the imperfection has been spanned by the installation of a sleeve. A tube containing a defect in its pressure boundary is defective.

7. Plugging Limit means the imperfection depth at or beyond 40% of the nominal tube wall thickness for which the tube shall be sleeved, rerolled, or removed from service because it may become unserviceable prior to the next inspection. This does not apply to ODIGA indications within the defined region of the upper tubesheet. These indications shall be assessed for continued plant operation in accordance with ANO Engineering Report No. 00-R-1005-01.

   Axially-oriented TEC indications in the tube that do not extend beyond the adjacent cladding portion of the tube sheet into the carbon steel portion are not included in this definition. These indications shall be assessed for continued plant operation in accordance with topical report BAW-2346P, Rev. 0.

   The reroll repair process will only be used to repair tubes with defects in the upper tubesheet area. The reroll repair process will be performed only once per steam generator tube using a 1 inch roll length. The new roll area must be free of detectable degradation in order for the repair to be considered acceptable. The reroll repair process is described in the topical report, BAW-10232P, Revision 00.

8. Unserviceable describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an Operating Basis Earthquake, a loss-of-coolant accident, or a steam line or feedwater line break as specified in Specification 4.18.4.c.

9. Tube Inspection means an inspection of the steam generator tube from the point of entry completely to the point of exit. For tubes that have been repaired by the reroll process within the upper tubesheet, that portion of the tube above the new roll can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed.

b. The steam generator shall be determined operable after completing the corresponding actions (plug, reroll, or sleeve all tubes exceeding the plugging limit and all tubes containing non-TEC through-wall cracks) required by Table 4.18-2.

4.18.6 Reports

Following each inservice inspection of steam generator tubes, the complete results of the inspection shall be reported to the NRC. This report, to be submitted within 90 days of inspection completion, shall include:

a. Number and extent of tubes inspected;

b. Location and percent of wall-thickness penetration for each indication of an imperfection;

c. Identification of tubes plugged and tubes sleeved;

d. Number of tubes repaired by rerolling and number of indications detected in the new roll area of the repaired tubes;

e. Summary of the condition monitoring and operational assessment results when applying TEC alternate repair criteria; and

f. Summary of the condition monitoring and the operational assessment results (including growth) when applying the upper tubesheet ODIGA alternate repair criteria.

This report shall be in addition to a Special Report (per Specification 6.12.5.d) required for the results of steam generator tube inspections which fall into Category C-3 as denoted in Table 4.18-2. The Commission shall be notified of the results of steam generator tube inspections which fall into Category C-3 prior to resumption of plant operation. The written Special Report shall provide a description of investigations conducted to determine cause of the tube degradation and corrective measures taken to prevent recurrence.

Bases

The surveillance requirements for inspection of the steam generator tubes ensure that the structural integrity of this portion of the RCS will be maintained. The program for inservice inspection of steam generator tubes is based on a modification of Regulatory Guide 1.83, Revision 1. Inservice inspection of steam generator tubing is essential in order to maintain surveillance of the conditions of the tubes in the event that there is evidence of mechanical damage or progressive degradation due to design, manufacturing errors, or inservice conditions that lead to corrosion. Inservice inspection of steam generator tubing also provides a means of characterizing the nature and cause of any tube degradation so that corrective measures can be taken.

In general, steam generator tubes that are degraded beyond the repair limit can either be plugged, sleeved, or rerolled. The steam generator (SG) tubes that are plugged are removed from service by the installation of plugs at both ends of the associated tube and thus completely removing the tube from service. When the tube end cracking (TEC) alternate repair criteria is applied, axially-oriented indications found not to extend from the tube sheet cladding region into the carbon steel region may be left in service under the guidelines of topical report BAW-2346P, Rev. 0. When the upper tubesheet outer diameter intergranular attack (ODIGA) alternate repair criteria is applied, indications found within the defined region of the upper tubesheet may be left in service under the guidelines of ANO Engineering Report No. 00-R-1005-01. The defined region begins one inch above the upper tubesheet secondary face and ends at the nearest tube roll transition. Following a SG inspection, an operational assessment is performed to ensure primary-to-secondary leak rates will be maintained within the assumptions of the accident analysis.

Degraded steam generator tubes can also be repaired by the installation of sleeves which span the area of degradation and serve as a replacement pressure boundary for the degraded portion of the tube, thus permitting the tube to remain in service.

Degraded steam generator tubes can also be repaired by the rerolling of the tube in the upper tubesheet to create a new roll area and pressure boundary for the tube. The rerolling methodology establishes a new pressure boundary below the degradation, thus permitting the tube to remain in service. The degraded tube above the new roll area can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed in the upper tubesheet. The rerolling repair process will only be used to repair defects in the upper tubesheet in accordance with BAW-10232P, Revision 00.

All tubes which have been repaired using the reroll process will have the new roll area inspected during future inservice inspections. Defective or degraded tube indications found in the new roll and any indications found in the original roll need not be included in determining the Inspection Results Category for the generator inspection.

The reroll repair process will only be used to repair tubes with defects in the upper tubesheet area. The reroll repair process will be performed only once per steam generator tube using a 1 inch roll length. Thus, multiple applications of the reroll process to any individual tube is not acceptable. The new roll area must be free of detectable degradation in order for the repair to be considered acceptable. After the new roll area is initially deemed acceptable, future degradation in the new roll area will be analyzed to determine if the tube is defective and needs to be removed from service. The reroll repair process is described in the topical report, BAW-10232P, Revision 00.

MARKUP OF CURRENT ANO-1 TECHNICAL SPECIFICATIONS

(FOR INFO ONLY)

a. The first sample inspection during each inservice inspection (subsequent to the baseline inspection) of each steam generator shall include:

1. All nonplugged tubes that previously had detectable wall penetrations (>20%), except tubes in which the wall penetration has been spanned by a sleeve, and

2. At least 50% of the tubes inspected shall be in those areas where experience has indicated potential problems, except where specific groups are inspected per Specification 4.18.3.a.3.

   A tube inspection (pursuant to Specification 4.18.5.a.9) shall be performed on each selected tube. If any selected tube does not permit the passage of the eddy current probe for a tube inspection, this shall be recorded and an adjacent tube shall be selected and subjected to a tube inspection.

3. Tubes in the following groups may be excluded from the first random sample if all tubes in a group in both steam generators are inspected. The inspection may be concentrated on those portions of the tubes where imperfections were previously found. No credit will be taken for these tubes in meeting minimum sample size requirements. Where only a portion of the tube is inspected, the remainder of the tube will be subjected to the random inspection.

   (1) Group A-1: Tubes within one, two or three rows of the open inspection lane.

   (2) Group A-2: Unplugged tubes with sleeves installed.

   (3) Group A-3: Tubes in the wedge-shaped group on either side of the lane region (Group A-1) as defined by Figure 4.18.1.

4. Tubes with axially-oriented tube end cracks (TEC) which have been left inservice for the previous cycle shall be inspected with a rotating coil eddy current technique in the area of the TEC and characterized in accordance with topical report BAW-2346P, Rev.0, during all subsequent SG inspection intervals pursuant to 4.18.4. The results of this examination may be excluded from the first random sample. Tubes with axial TECs identified during previous inspections which meet the criteria to remain in service will not be included when calculating the inspection category of the OTSG.

5. Implementation of the upper tubesheet ODIGA alternate repair criteria requires a 100% bobbin coil inspection of the non-plugged and non-sleeved tubes, spanning the defined region of the upper tubesheet, during all subsequent SG inspection intervals pursuant to 4.18.4. Tubes with ODIGA identified during previous inspections which meet the criteria to remain in service will not be included when calculating the inspection category for the OTSG. The defined region begins one inch above the upper tubesheet secondary face and ends at the nearest tube roll transition. ODIGA indications detected by the bobbin coil probe shall be characterized using rotating coil probes in accordance with ~~topical report BAW-10235P, Revision 1~~ANO Engineering Report No. 00-R-1005-01.

4.18.5 Acceptance Criteria

a. As used in this specification:

1. Tubing or Tube means that portion of the tube or sleeve which forms the primary system to secondary system pressure boundary.

2. Imperfection means an exception to the dimensions, finish or contour of a tube from that required by fabrication drawings or specifications. Eddy current testing indications below 20% of the nominal tube wall thickness, if detectable, may be considered as imperfections.

3. Degradation means a service-induced cracking, wastage, wear or general corrosion occurring on either the inside or outside of a tube.

4. Degraded Tube means a tube containing imperfections ≥ 20% of the nominal wall thickness caused by degradation, except where all degradation has been spanned by the installation of a sleeve.

5. % Degradation means the percentage of the tube wall thickness affected or removed by degradation.

6. Defect means an imperfection of such severity that it exceeds the plugging limit except where the imperfection has been spanned by the installation of a sleeve. A tube containing a defect in its pressure boundary is defective.

7. Plugging Limit means the imperfection depth at or beyond 40% of the nominal tube wall thickness for which the tube shall be sleeved, rerolled, or removed from service because it may become unserviceable prior to the next inspection. This does not apply ~~during Cycle 16~~ to ODIGA indications within the defined region of the upper tubesheet. These indications shall be assessed for continued plant operation in accordance with ~~topical report BAW-10235P, Revision 1~~ ANO Engineering Report No. 00-R-1005-01.

Axially-oriented TEC indications in the tube that do not extend beyond the adjacent cladding portion of the tube sheet into the carbon steel portion are not included in this definition. These indications shall be assessed for continued plant operation in accordance with topical report BAW-2346P, Rev. 0.

The reroll repair process will only be used to repair tubes with defects in the upper tubesheet area. The reroll repair process will be performed only once per steam generator tube using a 1 inch roll length. The new roll area must be free of detectable degradation in order for the repair to be considered acceptable. The reroll repair process is described in the topical report, BAW-10232P, Revision 00.

8. Unserviceable describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an Operating Basis Earthquake, a loss-of-coolant accident, or a steam line or feedwater line break as specified in Specification 4.18.4.c.

9. Tube Inspection means an inspection of the steam generator tube from the point of entry completely to the point of exit. For tubes that have been repaired by the reroll process within the upper tubesheet, that portion of the tube above the new roll can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed.

b. The steam generator shall be determined operable after completing the corresponding actions (plug, reroll, or sleeve all tubes exceeding the plugging limit and all tubes containing non-TEC through-wall cracks) required by Table 4.18-2.

~~Tube 110/60 in the "A" steam generator contains indications in the upper roll transition that exceed the plugging limit. Tube 110/60 may remain in service with these indications for the duration of cycle 16 without rendering the "A" steam generator inoperable.~~

4.18.6 Reports

Following each inservice inspection of steam generator tubes, the complete results of the inspection shall be reported to the NRC. This report, to be submitted within 90 days of inspection completion, shall include:

a. Number and extent of tubes inspected;

b. Location and percent of wall-thickness penetration for each indication of an imperfection;

c. Identification of tubes plugged and tubes sleeved;

d. Number of tubes repaired by rerolling and number of indications detected in the new roll area of the repaired tubes;

e. Summary of the condition monitoring and operational assessment results when applying TEC alternate repair criteria; and

f. Summary of the condition monitoring and the operational assessment results (including growth) when applying the upper tubesheet ODIGA alternate repair criteria.

This report shall be in addition to a Special Report (per Specification 6.12.5.d) required for the results of steam generator tube inspections which fall into Category C-3 as denoted in Table 4.18-2. The Commission shall be notified of the results of steam generator tube inspections which fall into Category C-3 prior to resumption of plant operation. The written Special Report shall provide a description of investigations conducted to determine cause of the tube degradation and corrective measures taken to prevent recurrence.

Bases

The surveillance requirements for inspection of the steam generator tubes ensure that the structural integrity of this portion of the RCS will be maintained. The program for inservice inspection of steam generator tubes is based on a modification of Regulatory Guide 1.83, Revision 1. Inservice inspection of steam generator tubing is essential in order to maintain surveillance of the conditions of the tubes in the event that there is evidence of mechanical damage or progressive degradation due to design, manufacturing errors, or inservice conditions that lead to corrosion. Inservice inspection of steam generator tubing also provides a means of characterizing the nature and cause of any tube degradation so that corrective measures can be taken.

In general, steam generator tubes that are degraded beyond the repair limit can either be plugged, sleeved, or rerolled. The steam generator (SG) tubes that are plugged are removed from service by the installation of plugs at both ends of the associated tube and thus completely removing the tube from service. When the tube end cracking (TEC) alternate repair criteria is applied, axially-oriented indications found not to extend from the tube sheet cladding region into the carbon steel region may be left in service under the guidelines of topical report BAW-2346P, Rev. 0. When the upper tubesheet outer diameter intergranular attack (ODIGA) alternate repair criteria is applied, indications found within the defined region of the upper tubesheet may be left in service under the guidelines of ~~topical report BAW-10235P, Revision 1~~ANO Engineering Report No. 00-R-1005-01. The defined region begins one inch above the upper tubesheet secondary face and ends at the nearest tube roll transition. Following a SG inspection, an operational assessment is performed to ensure primary-to-secondary leak rates will be maintained within the assumptions of the accident analysis.

Degraded steam generator tubes can also be repaired by the installation of sleeves which span the area of degradation and serve as a replacement pressure boundary for the degraded portion of the tube, thus permitting the tube to remain in service.

Degraded steam generator tubes can also be repaired by the rerolling of the tube in the upper tubesheet to create a new roll area and pressure boundary for the tube. The rerolling methodology establishes a new pressure boundary below the degradation, thus permitting the tube to remain in service. The degraded tube above the new roll area can be excluded from future periodic inspection requirements because it is no longer part of the pressure boundary once the repair roll is installed in the upper tubesheet. The rerolling repair process will only be used to repair defects in the upper tubesheet in accordance with BAW-10232P, Revision 00.

All tubes which have been repaired using the reroll process will have the new roll area inspected during future inservice inspections. Defective or degraded tube indications found in the new roll and any indications found in the original roll need not be included in determining the Inspection Results Category for the generator inspection.

The reroll repair process will only be used to repair tubes with defects in the upper tubesheet area. The reroll repair process will be performed only once per steam generator tube using a 1 inch roll length. Thus, multiple applications of the reroll process to any individual tube is not acceptable. The new roll area must be free of detectable degradation in order for the repair to be considered acceptable. After the new roll area is initially deemed acceptable, future degradation in the new roll area will be analyzed to determine if the tube is defective and needs to be removed from service. The reroll repair process is described in the topical report, BAW-10232P, Revision 00.

# ENCLOSURE 1

## ANO Engineering Report No. 00-R-1005-01

## Management Program for Volumetric Outer Diameter Intergranular Attack in the Tubesheets of Once-Through Steam Generators

August 2000

This Document contains 1 Page.

DOCUMENT RECORD TYPE (Refer to Procedure 5010.005):

☒ Quality Assurance Record

☐ NOT a Quality Assurance Record

SYSTEM / COMPONENT CLASSIFICATION:

☒ Q

☐ NON-Q

# ENGINEERING REPORT
# FOR
# ARKANSAS NUCLEAR ONE
# RUSSELLVILLE, ARKANSAS

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| **TITLE:** | **REPORT NO:** |
|---|---|
| **Management Program for Volumetric Outer Diameter Intergranular Attack in the Upper Tubesheets of Once-Through Steam Generators at Arkansas Nuclear One - Unit One** | **00-R-1005-01** |

## DESCRIPTION OF PROPOSED CHANGE

During the last two operating cycles ANO-1 has used an NRC approved one-cycle alternate repair criteria (ARC) to mange the ODIGA contained in the upper tubesheet. Entergy Operations personnel met with the NRC on February 16, 2000 to discuss a permanent ARC to manage the ODIGA program. During that meeting the NRC expressed a concern with the approach used to measure growth rate.

To address the NRC staff concerns, Entergy has developed an Engineering Report that includes some of the work previously accomplished by topical report BAW-10235P and also includes a new approach to help determine growth in the ODIGA population identified in the upper tubesheet.

This report documents how ANO will manage the ODIGA flaws deterministically to ensure all SG damage mechanisms do not leak above the 1 gpm licensing basis limit.

# EXECUTIVE SUMMARY

This report documents the technical justification to implement a permanent steam generator defect-specific management program for volumetric outer diameter intergranular attack (ODIGA) in the tubesheet regions of the ANO-1 Once Through Steam Generators (OTSGs). Even though the intent of this licensing change is invoke a permanent change to the way the ODIGA in the upper tubesheet is managed, ANO will continue to adhere to a strict deterministic type approach when determining possible growth, end of cycle leakage, and in-situ pressure candidates.

Volumetric ODIGA is defined as three-dimensional grain boundary corrosion, which initiates from the outside of the tube. Volumetric ODIGA has been present in the upper tubesheet region of the ANO-1 OTSGs since the late 1970's. The cause of the ODIGA is determined to be related to the intrusion of sulfur into the secondary system. Over the years, a large amount of research and development has been performed in an attempt to develop an eddy current (EC) sizing technique for ODIGA. While these projects did not result in a qualified EC sizing technique, the resulting analytical and experimental data is sufficient to develop a management program based on performing specific EC inspection and in-situ leak testing.

The structural evaluation of the volumetric ODIGA included an assessment of all limiting loading conditions. The resulting structural performance criteria includes limiting the circumferential extent of the ODIGA in order to prevent tensile rupture of the tube. Additionally, an inspection of the defined region is required each outage to monitor for low cycle fatigue. The performance criteria for tube rupture is met due to the constraint of the upper tubesheet. Therefore, leaving tubes with volumetric ODIGA does not result in any significant reduction in the structural integrity of the ANO-1 steam generator tubes.

The leakage performance criteria consists of limiting the steam generator (SG) primary-to-secondary leakage rate to 1 GPM under a MSLB condition. The results of leak testing volumetric defects that bound the sizes of volumetric ODIGA in the ANO-1 steam generators resulted in no primary-to-secondary leakage under simulated accident conditions. Even very deep (95%TW) defects did not develop leaks at bounding accident condition differential pressures and tensile loads. Therefore, leaving tubes with volumetric ODIGA does not result in a significant increase in the probability of leakage during normal operating or accident conditions.

The volumetric ODIGA management program is designed to ensure that OTSG tubes with volumetric ODIGA meet the structural and leakage performance criteria both at the time of inspection and at the end of the next cycle of operation. The assessment process involves performing EC inspections of the defined region and then performing EC sizing of the indications characterized as volumetric ODIGA. The number of allowable leaking indications is determined through statistical analysis based on postulated leakage rates using the EC sizing information and growth considerations. Based on the number of allowable leaking indications, the required number of indications that must be in-situ leak tested is calculated for each OTSG. In-situ leak testing is then performed as necessary on the limiting SG to demonstrate compliance with the accident condition performance criteria of 1gpm.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ANO-1 | Arkansas Nuclear One – Unit 1 |
| ARC | alternate repair criteria |
| ASTM | American Society for Testing and Materials |
| B&W | Babcock & Wilcox |
| BOC | beginning of cycle |
| CFR | Code of Federal Regulations |
| CMTR | certified material test report |
| CSA | cross sectional area |
| DE | destructive examination |
| DNB | departure from nucleate boiling |
| EC | eddy-current |
| EDM | electrical discharge machining |
| EFPY | effective full power years |
| EOC | end of cycle |
| EPRI | Electric Power Research Institute |
| FS | free span (tube is not surrounded by tubesheet or tube support plate) |
| FTI | Framatome Technologies Incorporated |
| GPM | gallons per minute |
| ID | inner diameter |
| IGA | intergranular attack |
| IGP | intergranular penetration |
| IGSCC | intergranular stress corrosion cracking |
| LTE | lower tube end |
| LTL | lower tolerance limit |
| LTS | lower tubesheet secondary face or lower tubesheet |
| MSLB | main steam line break |
| NDE | non-destructive examination |
| NQI | non-quantifiable indication |
| NRC | Nuclear Regulatory Commission |
| OD | outer diameter |
| ODIGA | outer diameter intergranular attack |
| ONS | Oconee Nuclear Station |
| OTSG | once-through steam generator |
| POD | probability of detection |
| RC | rotating coil technology, such as RPC or Plus-Point coil |
| RPC | rotating pancake coil |
| RSG | recirculating steam generator |
| SBLOCA | small break loss of coolant accident |
| SCC | stress corrosion cracking |
| SEM | scanning electron microscopy |
| SG | steam generator |
| SGDSM | steam generator defect-specific management |
| TPD | Tubular Products Division |
| TS | tubesheet |
| TSP | tube support plate |
| TW | through-wall |
| UTE | upper tube end |

| | |
|---|---|
| UTS | depending upon context, upper tubesheet secondary face or ultimate tensile strength |
| YS | yield strength |

## DEFINITIONS

The following definitions are adapted from reference 2.2.

**accident leakage rate** is the primary-to-secondary leakage rate occurring during postulated accidents other than a steam generator tube rupture. This includes the primary-to-secondary leakage rate existing immediately before the accident plus additional primary-to-secondary leakage induced during the accident. The limiting accident leakage rate condition for the OTSG is the MSLB.

**active degradation mechanisms** and **active defect types** means that new indications associated with these mechanisms and defect types have been identified during in-service inspection or that previously identified indications associated with these defect types have exhibited growth since the previous inspection of the subject tubes.

**alternative repair criteria** (ARC) means tube repair criteria which may be implemented for a specific defect type as part of an SGDSM program in lieu of the generally applicable depth-based criterion (which is 40% of the initial tube wall thickness at most plants).

**burst** means gross structural failure of the tube wall. Analytically this corresponds to a condition in which a critical parameter for unstable crack propagation e.g., limit load, is exceeded. Experimentally, it corresponds to unstable crack propagation limited only by testing considerations e.g., loss of bladder or depletion of the pressure reservoir.

**condition monitoring** means an assessment of the "as found" condition of the tubing with respect to the performance criteria. The "as found" condition refers to the condition of the tubing during an SG inspection outage, as determined from the in-service inspection results or by other means, prior to the plugging or repair of tubes.

**defect size** means the actual physical dimensions of the defect. For this application, defect size is expressed in terms of multiple parameters (depth, length, width as measured by NDE).

**defect size measurement** (or measured defect size) refers to defect size as measured during an NDE tube inspection.

**defect type** refers to a degradation mechanism and an associated set of general circumstances which affect determination of appropriate NDE techniques for flaw detection and sizing, flaw growth rates, and analytical models for determining structural and leakage performance. General circumstances include tube size, tube material, defect orientation, whether the defect initiates from the tube primary side or secondary side, and defect location within the tube (e.g., in straight freespan, in u-bend, at tube support plate, at expansion transition). A degradation mechanism may include several defect types.

**defined region** for a specific defect type means the portion of the tube where the SGDSM is to be applied.

**degradation mechanism** refers to a general defect morphology and its associated causes; e.g., wear induced thinning of the tube wall caused by adjacent support structures, high cycle

fatigue cracking due to flow induced vibration of the tube, intergranular stress corrosion cracking caused by stress, material susceptibility, and environment.

**departure from nucleate boiling (DNB)** is that point at which the tubes are no longer wetted by the secondary water.

**film boiling** is the conversion of water to steam in a zone where the tube is dry but not all of the water has evaporated. It is characterized by greatly reduced rates of heat transfer relative to nucleate boiling.

**indication** means the NDE signal response to a defect or condition which is present in the tube. An indication may or may not be measurable relative to the applicable tube repair criteria.

**indication size** or **indication measurement** refers to defect size measurement or to the voltage amplitude of the NDE signal response to a defect.

**lane region** refers to the tubes surrounding the lane of the OTSG. The lane is the untubed group of tubes beginning at the periphery and ending at the center of the SG. The untubed row number is 76 in the OTSG tube numbering system.

**NDE technique** refers to specific data acquisition equipment and instrumentation, data acquisition procedures, and data analysis methods and procedures. "NDE technique" in this context includes the summation of techniques directed at each degradation mechanism. For example, the use of bobbin probes for performing an initial screening inspection followed by a rotating pancake coil (RPC) inspection to confirm and characterize possible indications found by the bobbin would constitute a single NDE technique for detection purposes.

**nucleate boiling** is the conversion from liquid to vapor state, in a zone where the tubes are wetted by secondary water. This region is characterized by very high heat transfer rates.

**operational assessment** means an assessment to ensure that the tubes will continue to satisfy the performance criteria until the next scheduled inspection.

**performance criteria** means criteria that provide reasonable assurance that tube integrity is being maintained consistent with the licensing basis.

**qualified for detection** means that NDE techniques and personnel have undergone performance demonstration for a given defect type and have been shown capable of reliably detecting flaws associated with the defect type before these flaws are of sufficient size to cause the performance criteria to be exceeded.

**rupture** means perforation of the tube wall such that primary-to-secondary leak rate exceeds the normal charging pump capacity of the primary coolant system.

**steam generator defect-specific management** (SGDSM) means an integrated strategy applicable to a given defect type for ensuring that the performance criteria will be satisfied. SGDSM strategies include a specific program for conducting in-service

inspection (including specified NDE technique and frequency and level of sampling) and specific methodologies for conducting condition monitoring and operational assessments. SGDSM strategies may also include alternative repair criteria.

**structural limit** means the calculated maximum allowable flaw size or indication size consistent with the performance criteria.

**superheating** is the elevation of the steam temperature by continuous addition of heat.

**tube repair criteria** is the NDE measured flaw depth and/or length, or indication voltage amplitude at or beyond which the subject tube must be repaired or removed from service by plugging.

**validated for detection** means that NDE techniques and personnel have undergone supplemental performance demonstration for a given defect type as necessary to quantify defect detection performance (e.g., probability of detection (POD) of a given defect) expected under field conditions.

**validated for sizing** means that NDE techniques and personnel have undergone supplemental performance demonstration for a given defect type as necessary to quantify the potential error or variability of indication size measurements (e.g., measured defect depth, measured defect length, and/or measured voltage response to defect) expected under field conditions.

**variability** refers to the repeatability of indication size measurements for a given defect.

# 1.0 INTRODUCTION

The steam generator tubes in pressurized water reactors are an integral part of the reactor coolant pressure boundary. In order to ensure that the tubes are capable of performing their intended safety functions, the effects of degradation mechanisms on SG tube integrity must be addressed. Steam generator defect-specific management (SGDSM) is an integrated strategy designed to ensure that tubes degraded by a specific damage mechanism will continue to meet established performance criteria. The performance criteria used to measure acceptance is contained in the industry Steam Generator Program Guidelines, NEI 97-06 (reference 2.1) and include a peak accident pressure cumulative Once Through Steam Generator (OTSG) leakage limit of 1 gpm, a normal operating leakage limit of 150 gpd, along with structural limits. SGDSM strategies include a program for conducting in-service inspections and methodologies for conducting condition monitoring and operational assessments against repair criteria.

Although the cumulative effect of the various degradation mechanisms in the Once Through Steam Generators (OTSGs) must be considered, this report specifically addresses the effects of Outside Diameter Intergranular Attack (ODIGA) located in the upper tubesheets and provides the methodology for performing the operational assessments.

## 1.1 Purpose

The purpose of this engineering report is to present a permanent SGDSM program for volumetric IGA in the upper tubesheet region of the ANO-1 OTSGs. This program includes an alternative repair criteria (ARC) to the Technical Specification limit of 40% through wall (TW). The ARC ensures that the performance criteria are maintained and is based on the use of Eddy Current (EC) inspections, growth evaluations, and in-situ leak testing.

## 1.2 Background

Volumetric ODIGA is defined as three-dimensional grain boundary corrosion which initiates from the outside of the tube. Volumetric ODIGA has been present in the upper tubesheet region of the ANO-1 OTSGs since the late 1970's. The cause of the ODIGA is determined to be related to the intrusion of sulfur into the secondary system.

The ODIGA has been dispositioned several different ways throughout the ANO-1 operating history, mainly using EC data to depth size the flaws. Over the past several years the industry has evolved in the area of qualifying depth sizing techniques. As a result, a multiple linear regression depth sizing technique was developed and implemented during the 1R13 outage (September 1996) for the upper tubesheet ODIGA. Subsequent pulled tube destructive test results demonstrated the technique did not produce acceptable results. This prompted additional attempts to develop an accurate depth sizing technique, which given the inconsistent morphology of the ODIGA, produced unacceptable results. As of the latest inspection (1R15 – September 1999) there are 541 ODIGA indications in 436 tubes identified in the OTSGs.

A one cycle ARC was implemented during 1R14 (March 1998) using a bobbin voltage individual flaw growth and size criteria coupled with in-situ pressure testing. Significant work was performed between 1R14 and 1R15 which led to the development of another one cycle ARC (reference 2.2). This report contains the data and developed information from the BAW-10235P topical report along

with the growth, leakage and program implementation changes that address specific comments contained in the NRC Safety Evaluation Report, reference 2.3.

This Engineering Report documents a continued approach in developing the latest inspection techniques along with OTSG bubble tests, in-situ pressure tests, and using the latest statistical models to ensure the UTS IGA is proven to be dormant.

## 2.0 REFERENCES


2.1 NEI 97-06, Steam Generator Program Guidelines

2.2 BAW-10235P Rev. 1, "Management Program for Volumetric Outer Diameter Intergranular Attack in the Tubesheets of Once-Through Steam Generators"

2.3 Safety Evaluation by the Office of Nuclear Regulatory Regulation Related to Amendment No. 202 to Facility Operating License No. DPR-51 Entergy Operations, Inc. Arkansas Nuclear One, Unit No. 1 Docket No. 50-313.

2.4 "Bases for Plugging Degraded PWR Steam Generator Tubes," NRC Regulatory Guide 1.121, August 1976.

2.5 "Steam Generator Tube Integrity," NRC Draft Regulatory Guide DG-1074, December 1998.

2.6 "PWR Steam Generator Tube Repair Limits: PWSCC in the Roll Transition," EPRI Report 6864-L, June 1993.

2.7 "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis," NRC Regulatory Guide 1.174 July 1998.

2.8 Erdogan, F. "Ductile Fracture Theories for Pressure Riser Pipes and Containers," International Journal of Pressure Vessels and Piping, Volume 4, 1976.

2.9 "1R15 Steam Generator Condition Monitoring and 90 Day Operational Assessment", Entergy Operations Arkansas Nuclear One – Unit One Report ER-981220-E101, Rev. 0

2.10 W.A. Fuller, *Measurement Error Models*, John Wiley and Sons, 1987.

2.11 A. Hald, *Statistical Theory with Engineering Applications*, John Wiley & Sons, 1952.

2.12 G.J. Hahn and S.S. Shapiro, *Statistical Models in Engineering*, John Wiley & Sons, 1967.

2.13 M. Hollander and D.A. Wolfe, *Nonparametric Statistical Methods*, John Wiley and Sons, 1973.

2.14 W.J. Conover, *Practical Nonparametric Statistics*, 2nd Edition, John Wiley & Sons, 1980.

2.15 N.L. Johnson, S. Kotz and N. Balakrishnan, *Continuous Univariate Distributions: Volume 2*, 2nd Edition, John Wiley & Sons, 1995.

2.16 G.J. Hahn and W.Q. Meeker, *Statistical Intervals: A Guide for Practitioners*, John Wiley & Sons, 1991.

2.17 M.G. Natrella, *Experimental Statistics*, National Bureau of Standards Handbook 63, 1962.

# 3.0 DESCRIPTION OF OTSG

The ANO-1 nuclear power plant contains two Babcock and Wilcox model 177FA OTSG's. The plant began commercial operation in 1974.

## 3.1 Functional Description

The OTSG is a straight-tube, straight-shell, vertical, counter-flow, once-through heat exchanger with shell-side boiling. By nature of its design, the OTSG eliminates the need for steam separating equipment.

In the OTSG, shown in Figure 1, primary fluid from the reactor enters through an inlet nozzle in the top head, flows down through the tubes, is collected in the bottom head and exits through two primary outlet nozzles. The feedwater enters through a series of spray nozzles near the top of the annular feedwater heating chamber. Here the feedwater is heated to saturation temperature by direct contact with high-quality or slightly superheated "bleed" steam. The resulting saturated feedwater enters the tube bundle through ports near the bottom of the tube bundle. Nucleate boiling starts immediately upon contact with the hot tubes. Steam quality increases as the secondary fluid flows upward between the tubes in counterflow to the primary fluid inside the tubes. The departure from nucleate boiling occurs at about the 348-inch level at design conditions. The mode of heat transfer then changes from nucleate to film boiling. Steam quality continues to increase but at a slower rate. After 100% quality is reached, the steam becomes superheated, leaves the tube bundle at the upper tubesheet, flows down the steam annulus, and exits through two steam outlet nozzles.

## 3.2 Design Information

The units weigh approximately 570 tons and have an outer diameter of 150 inches and overall height of 878.5 inches. Each steam generator has 15,531 triangularly spaced alloy 600 tubes. These tubes are 0.625 inch OD x 0.037 inch nominal wall x 674.375 inches long. They are partially roll expanded (1 inch minimum) and attached to the upper and lower tubesheets by fillet welds. The use of straight tubes results in almost pure counterflow with resulting improved secondary flow distribution and primary-to-secondary temperature differentials. This design also has the benefit of placing the tubes in compression during normal operating conditions. This is mainly due to the fact that the alloy 600 tubes have a thermal coefficient of expansion slightly greater than that of the carbon steel shell. This compressive load tends to inhibit the initiation and propagation of stress related damage mechanisms.

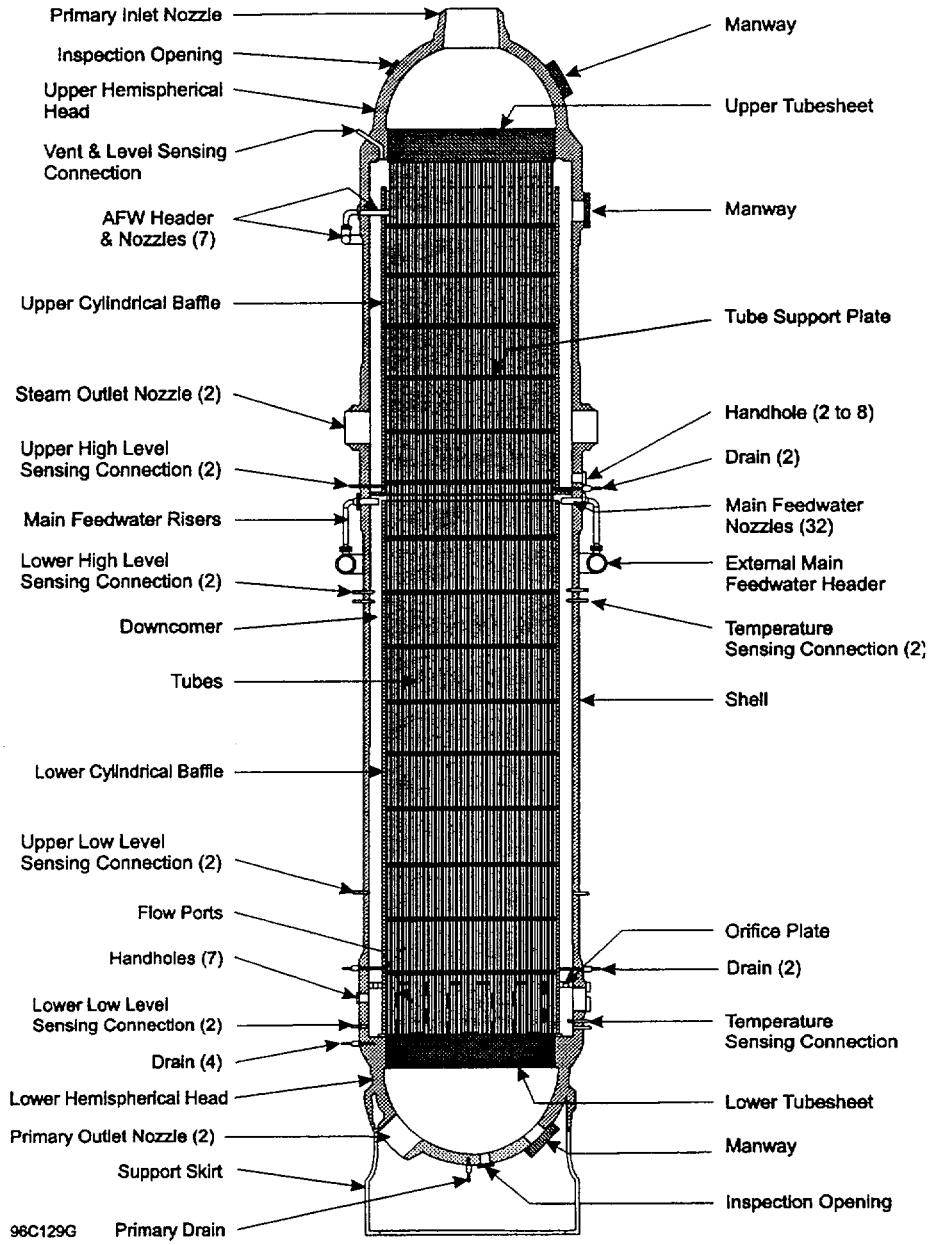
Proper lateral spacing of the tubes is maintained by 15 tube support plates. They are fabricated from 1-1/2 inch thick carbon steel plate, drilled and broached to provide surface contact and support along three axes for each tube at each tube support plate. An exception is the 15th TSP periphery rows, which are not broached. The support plates are non-uniformly spaced axially to prevent resonant vibrations along the tube length, thus providing the highest possible damping factor.

### 3.3 Tube Material Properties

The OTSG tube material is alloy 600 (ASTM SB163). The raw materials were both melted into the alloy 600 ingots and fabricated into hollow rounds by B&W Tubular Products Division (TPD) for the OTSG tubing. The tube finishing processes (tube drawing, etc.) were performed by TPD and two outside vendors. The tube material was later thermally treated at 1100°F to 1150°F for a minimum of 11 hours during full furnace stress relief of the completed steam generator. As a result, the installed tubes are both sensitized and stress relieved. This results in improved resistance to stress corrosion cracking, but susceptibility to intergranular attack.

# Figure 1 OTSG

## Longitudinal Section



## 4.0 DEFINITION OF VOLUMETRIC ODIGA

This section details the morphology and EC characteristics of ODIGA and defines the region of the upper tubesheet where the SGDSM will be applied. Limited volumetric ODIGA has been found in other regions of the ANO-1 OTSGs, but this SGDSM will only be applied to the defined region as specified in section 4.4.

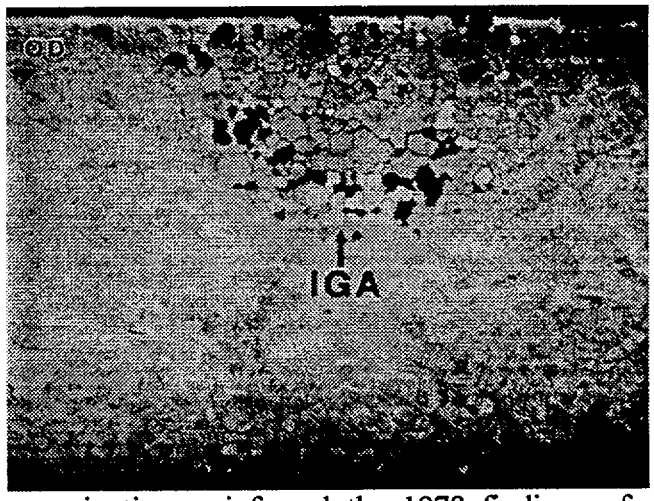
### 4.1 Operating History

In 1978, an indication was detected at the secondary face of the upper tubesheet in lane tube 77-17 during EC inspection of "A" OTSG. A portion of this tube was removed and destructively examined. The deposits and corrosion films on the tube OD contained elevated levels of sulfur (1-3 wt%) and silicon (1-7 wt%), and trace amounts of chlorine and other contaminants. The flaw characteristics were consistent with intergranular attack, and it was concluded that stress and fatigue were not significant contributors to this damage.

It was theorized that the indication was caused by sulfur transported up the open lane in water droplets during operation and deposited on the tube OD. The significance of the tube examination is, therefore, that intergranular attack was first confirmed in 1978 and was linked to secondary side sulfur contamination.

In November of 1982, EC examinations of "B" OTSG resulted in the removal and inspection of lane tube 73-8 and tube 112-19. As with tube 77-17, the deposits and corrosion films showed significant levels of sulfur (> 2 wt%) and chlorine (~1.2 wt%), as well as trace levels of other contaminants. Destructive examination of these tubes confirmed the presence of volumetric ODIGA and general surface intergranular attack. Figure 2 shows a micrograph of a 50%TW IGA patch located 6 inches above the secondary face of the UTS in tube 73-8. This patch, made visible by bending the tube, exemplifies the typical "thumbnail" cross section of volumetric ODIGA. It is noted that the grain dropout visible in the micrograph is attributed to bending the sample.

**Figure 2 Micrograph from 1982 Tube Pull**




This second set of tube examinations reinforced the 1978 findings of a sulfur induced damage mechanism at work. It was noted that the elevated amounts of chlorine may have helped to create a locally acidic environment. Also, re-examination of tube 77-17, showed that general surface intergranular attack was not present on that tube. The presence of general intergranular surface attack

on the tubes removed in 1982 but not present on the tube removed in 1978 aids in understanding the timeline for start of this damage mechanism.

In conjunction with the 1982 tube removals, a task group was convened to review the steam generator tube examination results and other technical data, and to assess the impact of the tube damage on ANO-1 operations. The proposed tube damage scenario was sulfur-induced IGA. The sulfur species were believed to have been introduced into the steam generator in the form of ammonium sulfate from regeneration/rinsing of the condensate polishers since sulfuric acid was used as the cation regenerant.

The task group concluded that the general surface IGA ceased as the available sulfur was converted to a less aggressive form in the reaction process or as the result of the conditions present in the upper regions of the steam generators. The group further concluded that the general surface IGA, which exists in the upper regions of the steam generator, could provide initiation sites for continued attack in susceptible areas during subsequent operation. The most susceptible area, based on thermal-hydraulic conditions and measured deposit levels, was determined to be the upper tubesheet region of tubes adjacent to the lane.

The task group recommended changes in plant chemistry and operating procedures. The changes were aimed at minimizing the effect of existing contaminants on tube integrity and preventing the ingress of future contaminants.

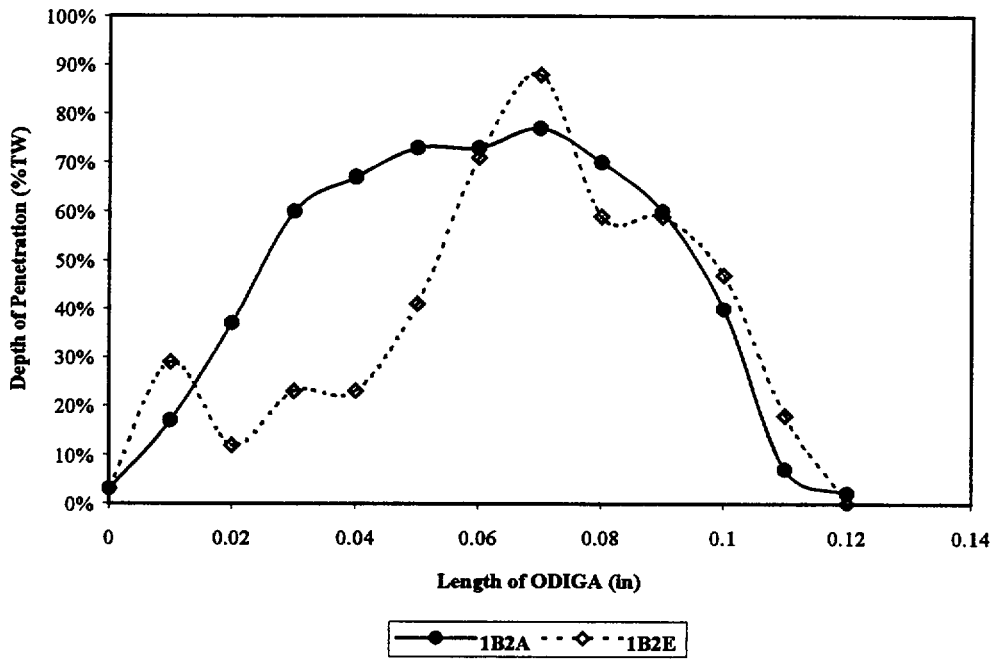
In 1984, lane tube 77-34 was removed from SG A and destructively examined. This tube supported the hypothesis that the lane region would remain susceptible, having developed intergranular attack at the upper tubesheet secondary face.

Since 1984, tubes adjacent to the lane have been preventively sleeved. This preventive sleeving was performed in response to another damage mechanism (high cycle fatigue), but effectively addressed the tubes most susceptible to intergranular attack. Furthermore, continued improvements to plant operating procedures and secondary side chemistry have been made.

The effect of these improvements is apparent in the results of the destructive examinations performed on three tubes (79-63, 80-18, and 83-47) removed from "B" OTSG in 1996 to monitor the condition of the ODIGA. The deposits and corrosion films no longer have elevated sulfur, silicon, or chloride contaminant levels. In fact, the chromium/nickel ratios were close to that of alloy 600, suggesting a near neutral chemistry.

The results of the destructive exams showed the same typical "thumbnail" cross section as found in tube 73-8. In some cases, the penetration through-wall was not uniform, suggesting that either two small, closely spaced patches of IGA had merged or intergranular penetrations (IGP) had extended deeper than the general depth of attack. Figure 3 shows a comparison of the depth profiles of two patches of ODIGA in tube 79-63. The first, specimen 1B2A, has a similar elliptical ("thumbnail") shape as the IGA patch in Figure 2. On the other hand, the shape of specimen 1B2E seems to indicate two overlapping patches, the first from 0 to 0.02 inches and the second from 0.02 to 0.12 inches, with a slightly deeper intergranular penetration from 0.05 to 0.08 inches.

**Figure 3 SEM Fractographic Data From 1996 Tube Pull**




## 4.2 Morphology

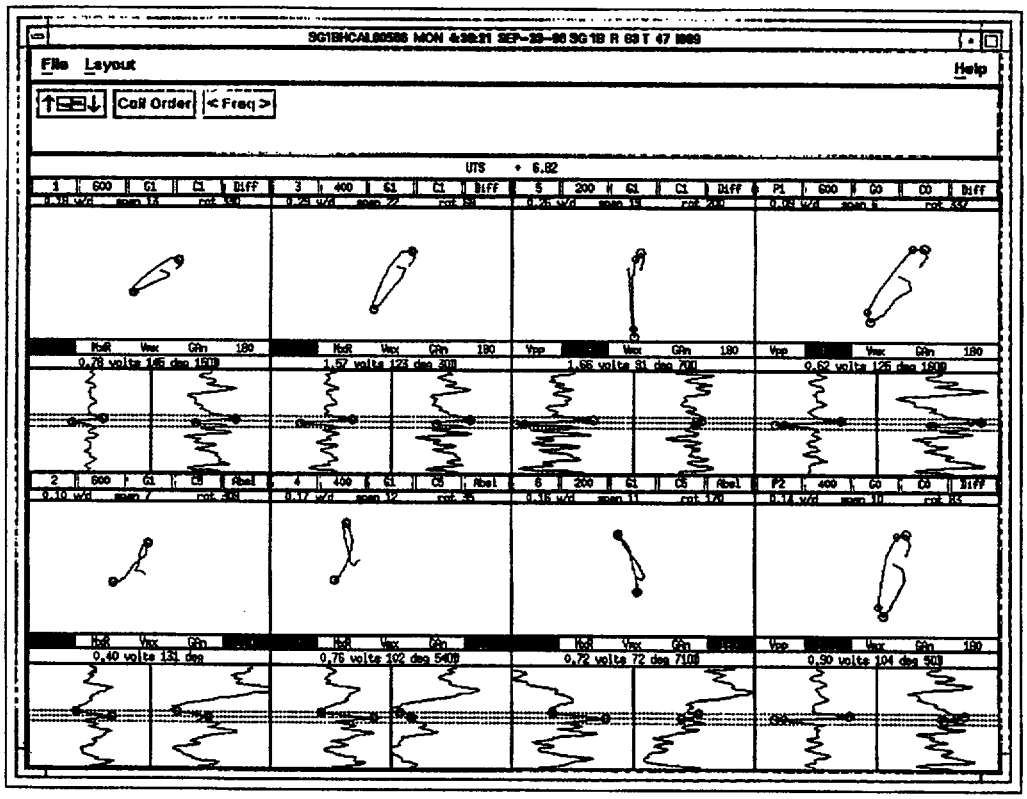
The information discussed in the operating history was utilized to define the morphology of the volumetric ODIGA. Volumetric ODIGA is defined as three-dimensional grain boundary corrosion initiating from the outside surface of the tube. The ODIGA can occur in isolated patches or at multiple initiation sites encompassing a given area. Typically, the ODIGA exhibits a thumbnail profile. In some cases, localized fingers of grain boundary attack may extend below a layer of general ODIGA. These fingers are referred to as intergranular penetrations (IGP). Based on all available information, this damage mechanism appears to be inactive.

## 4.3 Eddy-Current Characteristics

During in-service tube inspections, bobbin examinations are performed to detect potential ODIGA indications. These indications are then examined with a rotating coil to characterize the indication as a specific type of indication (ODIGA, stress corrosion cracking (SCC), etc). In other words, the bobbin examination screens the tubes for potential ODIGA indications. The rotating coil examination is then used to determine the size of the flaw and whether or not the indication is volumetric ODIGA.

The volumetric ODIGA typically has bobbin voltage amplitude (400 kHz peak-to-peak differential on Mid-Range bobbin probe) less than 2 volts. Figure 4 shows a typical plot of an ODIGA indication detected by the mid-range bobbin probe.

**Figure 4 MR Bobbin Mix Channel Detection**




A rotating coil examination is then performed to confirm and characterize the indication as volumetric ODIGA. Figure 5 shows a typical pancake coil response to ODIGA and Figure 6 shows a typical Plus-Point coil response to ODIGA. When confirming ODIGA with the pancake coil, the analyst looks for the cone shaped or "volcano" response. As shown in Figure 5 there is no preferential orientation or linear characteristic in the circumferential or axial direction. A preferential orientation is indicative of SCC. When confirming ODIGA with the Plus-point coil, the analyst looks for a similar response amplitude on either side of the balance point, as shown in Figure 6. The data is then reviewed to confirm that the indication has no crack-like features.

**Figure 5 Typical RPC Terrain Plot ODIGA Response**

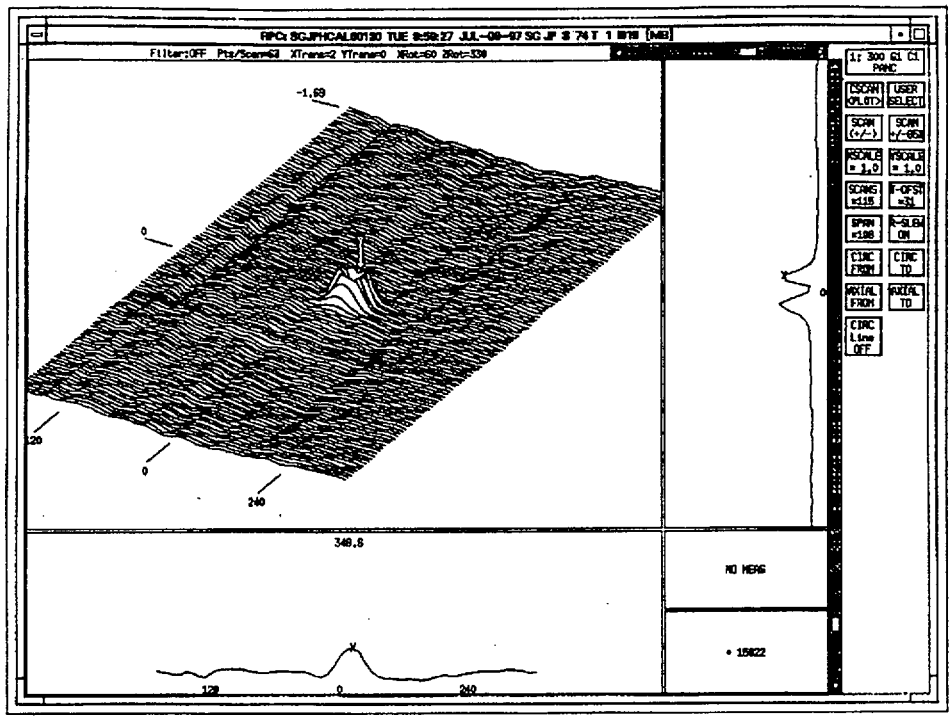
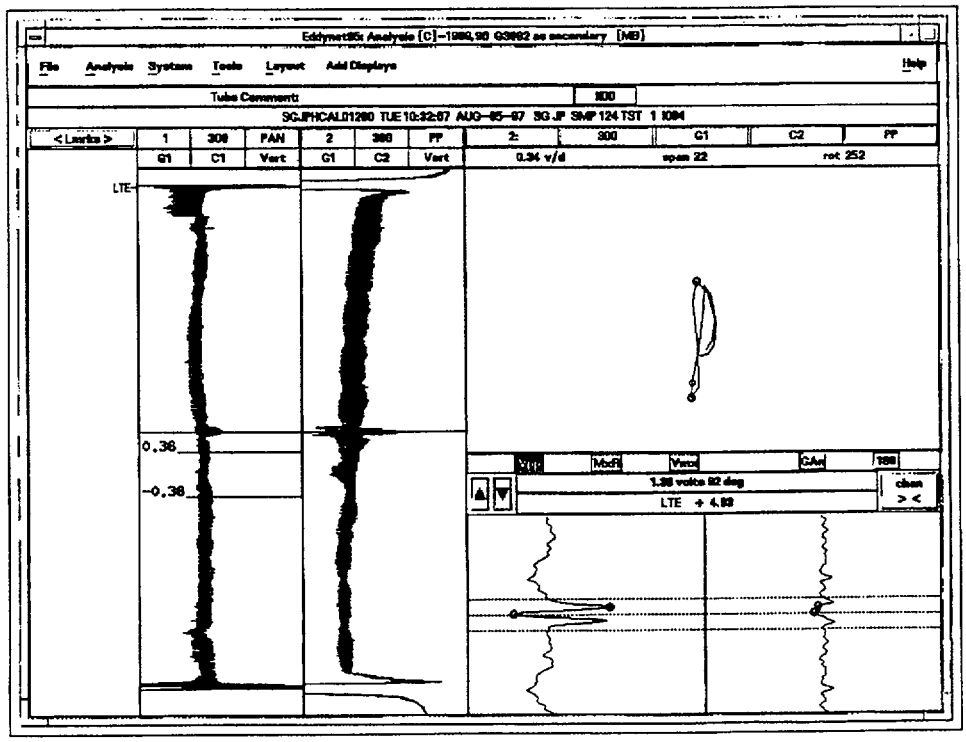



**Figure 6 Typical Plus-Point Strip Chart ODIGA Response**



## 4.4 Defined Region

This program is limited to ODIGA indications located in the upper tubesheet tube span beginning at (but not including) the nearest roll transition and ending 1 inch from the secondary face of the upper tubesheet. Indications located in the upper roll or upper re-roll transitions are not addressed due to differences in the tube condition and EC response in this area. Indications located in the portion of tube not enclosed by the tubesheet are not precluded from tube burst and therefore not addressed at this time.

This program does not address indications located in the upper tubesheet within 1 inch of the secondary face in order to establish a buffer region from the secondary face of the upper tubesheet. The reason for this buffer region is to ensure that edge effects caused by the tubesheet face do not inhibit the proper characterization of indications detected by the bobbin coil examination. This will also reduce the possibility of tube pullout under maximum tensile loading which could occur accident conditions.

# 5.0 STRUCTURAL EVALUATION

Structural evaluations were performed to determine the impact of bounding design bases conditions on tubes containing volumetric ODIGA. Due to the unique design of the OTSG, tensile loads can be developed within the tubes during certain accident and cool-down events. The effect of the ODIGA on the ability of the tube to carry these loads was also evaluated.

## 5.1 Loading Conditions

The two conditions that are of concern for the structural evaluation are the limiting normal operating conditions and the limiting accident conditions. The limiting 100% power steady state and accident conditions are discussed in this section.

### 5.1.1 Limiting Pressure Differentials

The limiting primary-to-secondary pressure differential associated with 100% steady state power conditions is the design limit of 1350 psi. Application of the safety factor of three (reference 2.4) results in a limiting primary-to-secondary pressure differential of 4050 psi.

The limiting primary-to-secondary pressure differential associated with accident conditions is the safety relief valve setpoint of 2575 psi. This condition is associated with a MSLB condition and includes a 3% allowance for setpoint tolerance. Application of the safety factor of 1/0.7 (reference 2.4) results in a limiting primary-to-secondary pressure differential of 3679 psi.

### 5.1.2 Limiting Tensile Tube Loads

Tensile tube loads develop in the OTSG during cool-down events. During these events, the tubes cool faster than the surrounding shell, resulting in tensile tube loads. The primary component of these tube loads are thermal loads, which are displacement limited. This results in the majority of the tensile load being associated with secondary stresses that do not require the ASME faulted condition safety factor of 1/0.7.

The limiting tensile tube load for the ANO-1 steam generators is associated with the small break loss of coolant accident (SBLOCA). This includes evaluation of normal operating design transients and postulated accident transients such as MSLB and SBLOCA. Leak before break was credited for a LBLOCA event and; therefore, not analyzed. The maximum postulated tensile load associated is 2,097 lbs. Even though this load is mainly a thermal load and therefore not considered a primary stress, the accident condition safety factor of 1/0.7 is conservatively applied. This results in a limiting accident condition tensile of 2,996 lbs.

### 5.1.3 Limiting Cross Flow Loading

Cross flow loads occur in the top and bottom spans of an OTSG due to the radial flow of water and steam in these regions. The limiting case for cross flow loading is the MSLB, and the amount of cross flow is related to the size and location of the break in the steam pipe. The analyses performed for determining the cross flow bounded the worst case for these conditions.

The MSLB transient initiates with the severance of the steam line. This causes a large pressure differential between the OTSG secondary side and the downstream steam line break. The resulting

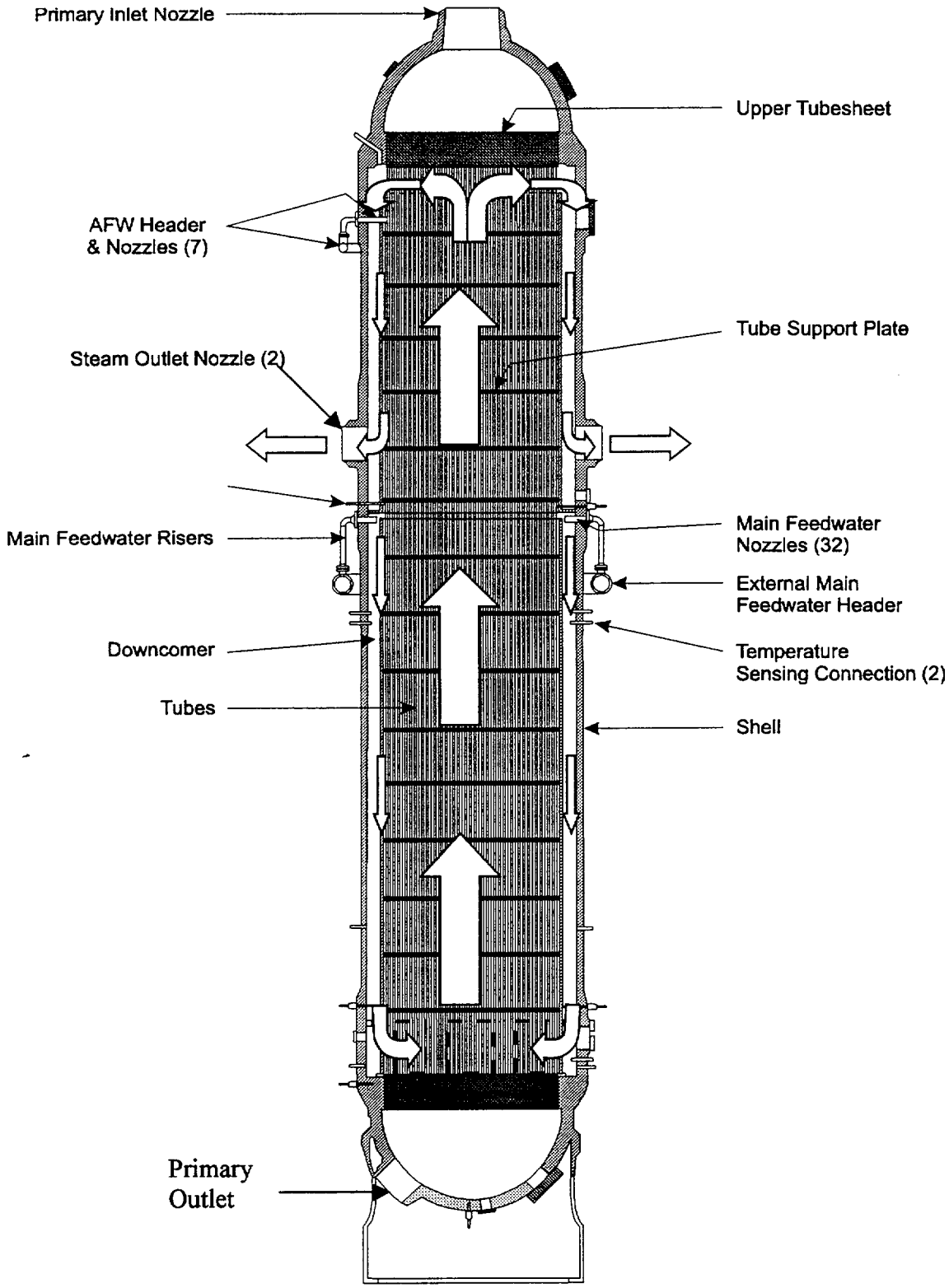
accelerated flow of water and steam impose cross flow loads on tubes in the top and bottom spans (see Figure 7). These loads last for the first few seconds of the transient, when the primary-to-secondary pressure differential is approximately that of normal operating conditions, and the tubes are under a small compressive axial load. These loads produce bending moments on the tubes due to the lateral restraint of the tubesheets and tube support plates. The magnitude of the moment varies with elevation (because the cross flow load varies with elevation) and the condition of the tube.

The most limiting moment is located at the secondary face of the upper tubesheet. The more degraded this region is, the more plastic deformation the region could experience due to the bending moment. Analyses were conducted to determine the relationship between the lateral load, the bending moment, and location within the OTSG. The results of the analysis were then used to determine how far to deflect tube samples with ODIGA in order to simulate the worst case stress condition.

Two sets of leak and burst testing were performed to address any potential effects that volumetric ODIGA might have on the structural and leakage integrity of the OTSG tubes. The first set of tests utilized straight tube samples with ODIGA subjected conditions that bound the limiting tube loads and pressure discussed in sections 5.1.1 and 5.1.2. These samples are representative of tubes with ODIGA located away from the secondary face of the tubesheet. Stress calculations show this testing is applicable to ODIGA located at least 2.50 inches above the secondary face of the tubesheet. The second set of testing involved bending the samples to apply the greatest stress at the ODIGA defect. This preconditioning simulates the effects of cross flow loads. Leak and burst tests were then performed in the same manner as the unbent samples.

The test results show that for the ODIGA tested, which bounds the sizes of ODIGA detected in the ANO-1 OTSGs, the cross flow loads had no measurable effect on the structural integrity of the tube. This is concluded based on comparing the burst test results and the fact that no leakage resulted from testing either set of samples. There is, therefore, no performance criteria limitations associated with cross flow loads.

**Figure 7 MSLB Cross Flow Loads**



## 5.2 Tube Rupture Evaluation

The tube rupture evaluation is presented in two parts. The first part evaluates the burst probability of volumetric defects constrained by the tubesheet. The second part evaluates the burst pressure associated with ODIGA not constrained by the tubesheet.

### 5.2.1 Probability of Burst in Tubesheet

Experiments have been performed to determine the burst pressures for tubes having outer diameter initiated axial cracks that are contained within a support with relatively small annular distances [reference 2.6]. The results from these EPRI experiments show that flawed tube burst below the burst pressure for an unflawed tube is precluded by the constraint of the tube radial displacement when the cracked section of the tube remains within the tubesheet and the diametrical gap is less than approximately 0.030".

The bounding tube-to-tubesheet diametrical difference for ANO-1 is computed by assuming the minimum tube OD (0.625") and the maximum tubesheet bore ID (0.646"), resulting in a diametrical gap of 0.021". Based upon the results of the EPRI testing discussed above, this gap is not sufficient to allow burst of an axially cracked tube within the tubesheet.

Burst testing of machined 100%TW defects confined within a tubesheet was performed to confirm that this assumption is also applicable to volumetric defects. Each defect specimen had a transverse through-wall hole machined through one wall at the approximate midspan to conservatively simulate volumetric ODIGA. The removed material was placed back in the hole to represent tube material which has suffered from intergranular attack and has no tensile strength but fills the cavity and provides only bearing strength. A split steel block with a bore ID of 0.646" surrounded the simulated ODIGA to represent the tubesheet.

Results of the burst testing showed no decrease in burst strength relative to the unflawed tube, as all tube ruptures occurred in the freespan portion of the tubing, typically 1.5 inches or more away from the tubesheet. These test results demonstrate that volumetric ODIGA, which is located within the tubesheet, is precluded from burst. This SGDSM ensures that the indications are located within the tubesheet by virtue of the defined region (section 4.4). This eliminates the need to determine a volumetric ODIGA structural limit based on burst pressure.

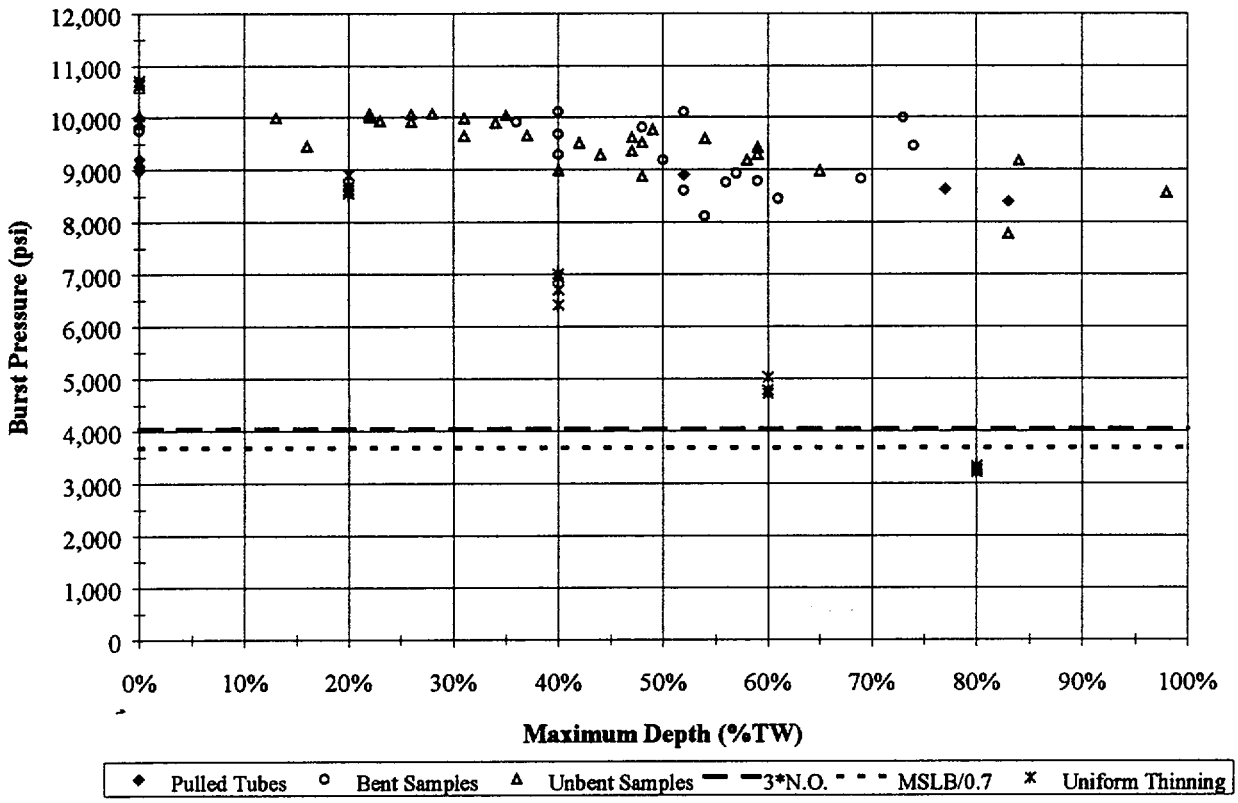
### 5.2.2 Unsupported Burst Strength

While it has already been demonstrated that the volumetric ODIGA cannot burst due to the structural reinforcement provided by the tubesheet, it is worthwhile to show the minimal impact that the volumetric ODIGA has on the structural strength of the tubing. The room temperature burst pressures associated with the pulled tubes and laboratory ODIGA are presented in Table 23 and 25 at the end of this report. These burst pressures were normalized to the 95/95 lower tolerance limit (LTL) flow stress at 600°F and then plotted in Figure 8. This figure shows that the depth of the ODIGA has very little effect on burst pressure for the axial and circumferential extents tested. In fact, all the ODIGA tested had burst pressures more than 3,000 psi greater than 4,050 psi (three times the 100% power steady state pressure differential).

For comparison purposes, burst test results from testing 360° uniform thinning samples are also presented. The uniform thinning data shows that 360° volumetric defects must be at least 70%TW

before burst pressure margins are challenged. When it is considered that most of the ODIGA in the ANO-1 OTSGs has been sized as less than 0.30 inches (55°) in circumferential extent by EC, the insignificant impact that the ODIGA has on the structural integrity of the tubing becomes apparent.

**Figure 8 ODIGA Unsupported Burst Pressures**



## 5.3 Tensile Rupture Evaluation

As discussed earlier in this section, the presence of the tubesheet precludes the volumetric ODIGA from burst failure. This results in the structural integrity being determined by the tensile rupture load. Tensile rupture is defined as the complete severance of the tube due to tensile loads and is equivalent to the ultimate tensile strength of the tube. The OTSG tubes are subjected to tensile loads during certain cool-down transients and accident scenarios. To develop a performance criteria for tensile rupture, the tensile failure load of OTSG tube samples with volumetric degradation is correlated to the remaining cross-sectional area. The remaining cross-sectional area is then correlated to an allowable circumferential extent assuming the defect is 100%TW. These two relationships are then used to determine the maximum allowable circumferential extent of a 100%TW volumetric defect that will not result in tensile rupture of the tube under the limiting accident condition axial tube loads with the appropriate safety margins. The tensile test data consists of OTSG tubing with 100%TW EDM holes and 360° uniform thinning. The sample data is summarized in Table 1 and Table 2.

**Table 1 Tubing Information**

| Heat | Tube O.D. (inches) | Tube wall thickness (inches) | RT YS (psi) (See Note 1) | RT UTS (psi) (See Note 1) |
|---|---|---|---|---|
| 93542 | 0.6285 | 0.0388 | 45,461 | 96,662 |
| M5442 | 0.628 | 0.038 | 44,403 | 98,651 |

Note 1: Yield (YS) and ultimate strength (UTS) based on average of room temperature (RT) test results.

**Table 2 Sample Information**

| | | Defect Geometry | | | | |
|---|---|---|---|---|---|---|
| Sample No. | Heat No. | Axial Extent (inches) | Circ. Extent (inches) | %TW | CSA (inches$^2$) | Ultimate Load (lbs) |
| 1 | 93542 | 0 | 0 | 0% | 0.0719 | 7,017 |
| 2 | 93542 | 0 | 0 | 0% | 0.0719 | 6,923 |
| 3 | 93542 | 0 | 0 | 0% | 0.0719 | 6,910 |
| 4 | 93542 | 0.5 | 0.5 | 100% | 0.0481 | 4,021 |
| 5 | 93542 | 0.5 | 0.5 | 100% | 0.0477 | 4,126 |
| 6 | 93542 | 0.75 | 0.75 | 100% | 0.0411 | 4,013 |
| 7 | 93542 | 0.75 | 0.75 | 100% | 0.0422 | 3,942 |
| 8 | 93542 | 0.75 | 0.75 | 100% | 0.0415 | 3,960 |
| 9 | 93542 | 0.98 | 0.98 | 100% | 0.0363 | 3,463 |
| 10 | 93542 | 0.98 | 0.98 | 100% | 0.0365 | 3,464 |
| 11 | 93542 | 0.98 | 0.98 | 100% | 0.0360 | 3,430 |
| 12 | M5442 | 0 | 0 | 0% | 0.0704 | 6,945 |
| 13 | M5442 | 0.5 | 1.973 | 25% | 0.0520 | 5,080 |
| 14 | M5442 | 0.5 | 1.973 | 50% | 0.0341 | 3,240 |
| 15 | M5442 | 0.5 | 1.973 | 70% | 0.0202 | 1,340 |

Note 1: CSA = cross sectional area remaining in defect region

As shown in Table 1, the tubes are not of the same heat of material and therefore do not have the same ultimate tensile strength. Furthermore, review of the ANO-1 CMTRs shows a 1-sided 95/95 LTL room temperature ultimate tensile strength of 94,000 psi, or 89,300 psi when corrected to 600°F.

The ultimate load data will therefore be normalized to an ultimate tensile strength of 89,300 psi to provide a conservative predictor of tensile rupture load.

**Table 3 Normalized Tensile Rupture Data**

| Sample No. | CSA (inches$^2$) | Ultimate Load (lbs) | Normalized Load (lbs) |
|---|---|---|---|
| 1 | 0.0719 | 7,017 | 6,456 |
| 2 | 0.0719 | 6,923 | 6,369 |
| 3 | 0.0719 | 6,910 | 6,357 |
| 4 | 0.0481 | 4,021 | 3,699 |
| 5 | 0.0477 | 4,126 | 3,796 |
| 6 | 0.0411 | 4,013 | 3,692 |
| 7 | 0.0422 | 3,942 | 3,627 |
| 8 | 0.0415 | 3,960 | 3,643 |
| 9 | 0.0363 | 3,463 | 3,186 |
| 10 | 0.0365 | 3,464 | 3,187 |
| 11 | 0.0360 | 3,430 | 3,156 |
| 12 | 0.0704 | 6,945 | 6,320 |
| 13 | 0.0520 | 5,080 | 4,623 |
| 14 | 0.0341 | 3,240 | 2,948 |
| 15 | 0.0202 | 1,340 | 1,219 |

The normalized ultimate loads are plotted as a function of remaining cross sectional area in Figure 9. The 95/95 LTL for the normalized loads and the limiting accident condition tube load are also displayed. The limiting accident condition tube load is the SBLOCA condition with a postulated maximum load of 2,097 lbs. With a safety margin of 1/0.7, the limiting load becomes 2,996 lbs (section 5.1.2). This load correlates to a minimum allowable cross sectional area of 0.0417 in$^2$.

A nominal OTSG tube has an outer diameter of 0.625 inches and a wall thickness of 0.037 inches. This results in an unflawed tube cross sectional area of 0.0683 in$^2$. To estimate the allowable circumferential extent that will result in at least 0.0417 in$^2$ of remaining cross sectional area, it will be conservatively assumed that the ODIGA is 100%TW. Figure 10 shows the relationship between remaining cross sectional area and allowable circumferential extent. This figure shows that a 100%TW hole with a circumferential extent of 140° has at least 0.0417 in$^2$ of remaining cross sectional area. Therefore, an ODIGA patch that has a circumferential extent of 140° can be concluded to have enough cross sectional area to carry the limiting accident condition tube loads with the required margin of safety. This evaluation is considered to be quite conservative because the ANO-1 ODIGA is less than 100%TW and has a "thumbnail" shaped cross section (see section 4.1), which results in quite a bit more remaining cross sectional area for a given circumferential extent.

**Figure 9 Tensile Rupture Load vs Remaining Cross Sectional Area**

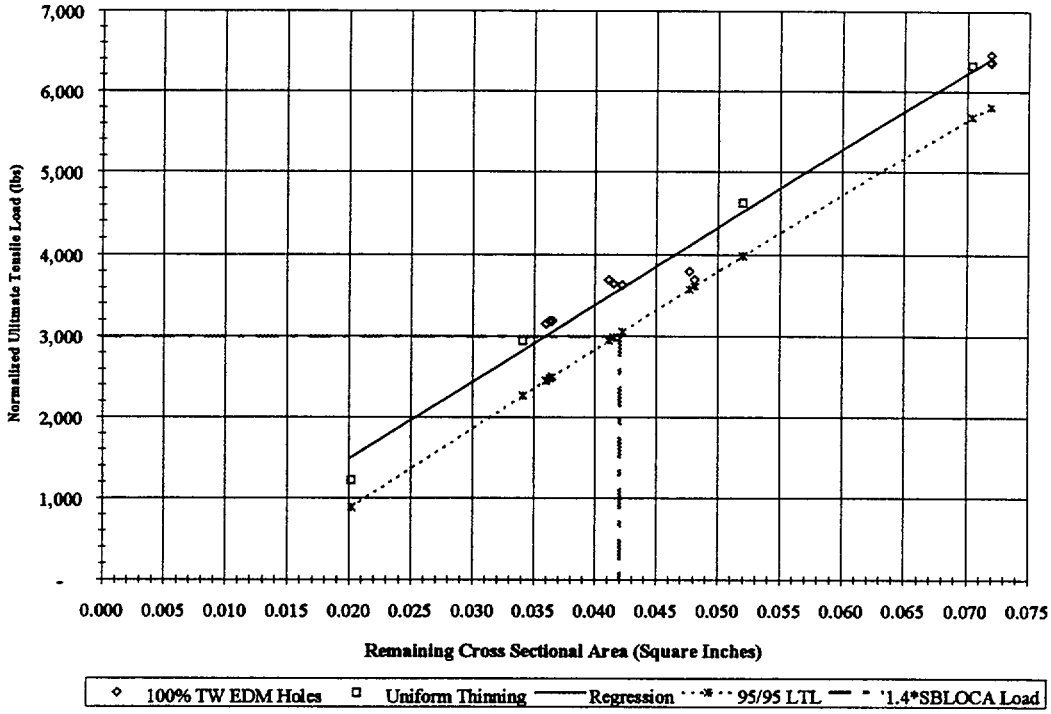
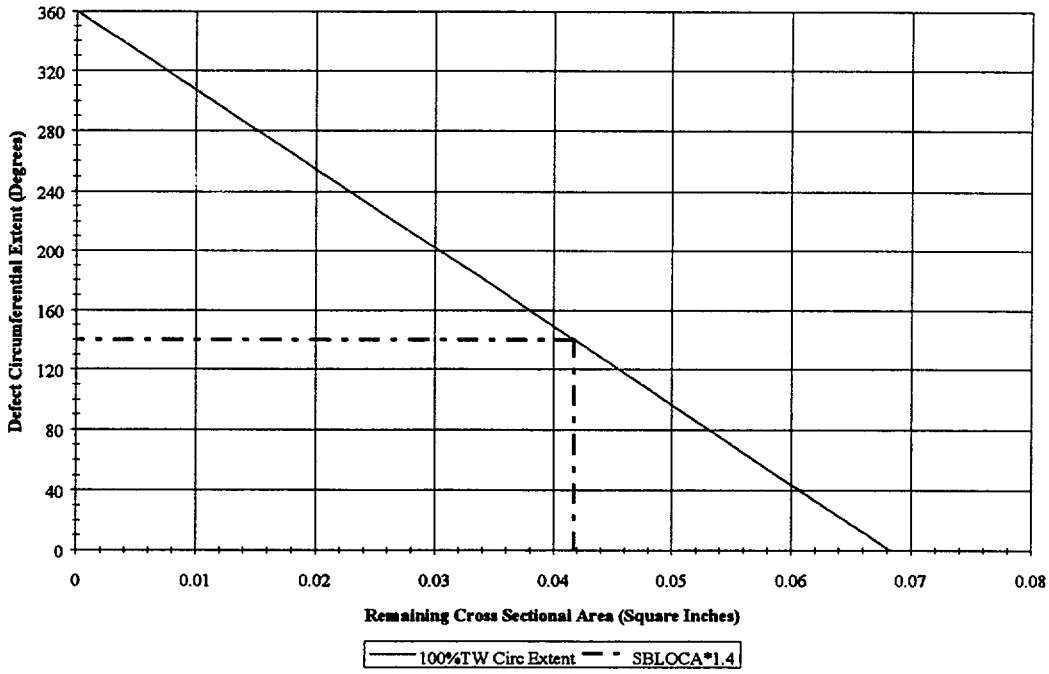



**Figure 10 Maximum Allowable Circumferential Extent vs Remaining CSA**



## 5.4 Fatigue Evaluation

Fatigue loading on OTSG tubes can be classified as either high-cycle or low cycle. Tube degradation due to high cycle fatigue has been observed in OTSGs at the 15th (uppermost) TSP and at the secondary face of the upper tubesheet. The resulting flaw morphology is a circumferential fatigue crack that propagates rapidly around the tube once initiated. The affected tubes are located adjacent to the open tube lane, where secondary side cross flow is high. This damage mechanism was first identified in the late 1970's and confirmed through examinations of tube pull samples from the Oconee Nuclear Station (ONS) plants. It was concluded that the flaws were initiated at sites of localized corrosion, and then were propagated into a fatigue crack by flow induced vibration associated with the high cross flow.

High cycle fatigue has been addressed in OTSGs by preventively sleeving the susceptible tubes. The lack of tube leaks attributed to fatigue in recent years supports the adequacy of the defined sleeving zone in bounding the susceptible area. The installed sleeves span the entire upper tubesheet and top span of the generator, so the program will not be applied to the susceptible area of these tubes. Addressing the effects of high cycle fatigue is therefore not necessary.

Fatigue due to low cycle loading results primarily from mechanical, thermal, and pressure cycling during normal plant operation. If flaws were to propagate due to low cycle fatigue, this would be evident as a change in the EC response of the flaw from one cycle to the next. Therefore, performing an evaluation for potential growth addresses any historical effects of low cycle fatigue on tubesheet OD IGA. Since the growth will be regularly monitored during implementation of the program, and flaws will be repaired prior to becoming a leakage or structural concern, a separate repair limit for low cycle fatigue is not necessary.

## 5.5 Structural Performance Criteria

The structural performance criteria are the result of the evaluations described in sections 5.2 through 5.4, and are presented in Table 4. The evaluations show that the volumetric ODIGA, due to its limited size, has very little effect on the structural performance of the tubing. Tubes with ODIGA in the defined region are constrained by the presence of the tubesheet, thus preventing the burst rupture of ODIGA. Tensile rupture of tubes with ODIGA is highly improbable based on the results of tensile testing OTSG tubes with uniform thinning and 100%TW holes. Preventive sleeving and evaluating ODIGA for growth mitigates the potential consequences of fatigue. Finally, any potential effects of cross flow loads during a MSLB conditions have been addressed through leakage and burst testing.

**Table 4 Structural Performance Criteria**

| Condition | Performance Criteria | Comments |
|---|---|---|
| Burst Rupture | none | not possible due to tubesheet constraint |
| Tensile Rupture | EC measured Circumferential extent $\leq 140°$ | conservatively assumes 100%TW and bounds all loads (including safety factors) |
| High Cycle Fatigue | none | addressed through preventive sleeving |
| Low Cycle Fatigue | none | addressed through flaw characterization and growth monitoring |
| Cross Flow Loads | none | testing showed no structural impact for this damage mechanism |

# 6.0 LEAKAGE EVALUATION

At the present time, a qualified EC depth sizing technique does not exist for ODIGA. In the absence of being able to verify no leakage based on an EC depth measurement, a combination of in-situ leak testing and hot leak testing of laboratory ODIGA and EDM holes is utilized to evaluate the leakage integrity of tubes with ODIGA.

## 6.1 In-situ Leak Testing

As part of the 1R14 in-service tube examinations, 40 ODIGA indications were in-situ leak tested. This data is presented in Reference 2.2. The tubes were pressurized to a representative normal operating primary-to-secondary pressure (1500 psig) and a representative accident pressure differential (2900 psig). For 36 of the indications, the 2900 psig pressure was combined with an net axial load of 1402 lbs via an axial pull probe. All tests were conducted for the time recommended by the EPRI in-situ pressure testing guidelines. None of the indications tested under any of these conditions exhibited any leakage. In addition, the four remaining indications were subjected to pressure only tests up to 6500 psig. Even at this pressure, more than 2.5 times the accident pressure differential, the ODIGA indications did not exhibit any leakage.

## 6.2 Hot Leak Testing

High temperature leak testing was performed to establish expected leak rates for ODIGA. These conditions are given below in Table 5 and bound the conditions of section 5.1. The samples tested included 46 volumetric ODIGA samples made in a laboratory environment and 6 EDM holes.

**Table 5 Hot Leak Test Conditions**

| Primary Side Parameters | | Secondary Side Parameters | | Specimen Conditions |
|---|---|---|---|---|
| Pressure psig | Temp. °F | Pressure psig | Temp. °F | Axial Load lbs |
| 2750 ± 100 | 595 ± 20 | 90 ± 20 | 300 - 425 | 1402 + 50, -0<br>2376 + 50, -0 |

A summary of the range of tested flaw extents is presented in Table 6. The 52 samples tested resulted in no leakage under either axial loading condition. This is significant when one considers that sample 126 had a defect 98%TW and approximately 0.25 inches in diameter, and sample 110 had a defect 95%TW and 0.50 inches (~90°) in diameter. This leak testing, along with the tensile testing described in section 5.3, underscores the remaining structural strength of tubing degraded by this damage mechanism. Unlike damage mechanisms associated with cracking, where localized stress concentrations at the crack tip tend to drive the crack through-wall and open up the crack under large hoop or axial stresses, volumetric ODIGA is merely the corrosion of grain boundaries with no localized high stresses. This type of damage mechanism, along with its typically small size, makes it an unlikely candidate for primary-to-secondary leakage.

**Table 6 Leak Test Sample Geometry Summary**

| | Max Depth (%TW) | Axial Extent (Inches) | Circumferential Extent (inches) |
|---|---|---|---|
| Count | 52 | 52 | 52 |
| Minimum | 13% | 0.0490 | 0.0580 |
| Maximum | 98% | 0.5560 | 0.5000 |
| Average | 51% | 0.2731 | 0.2323 |

## 6.3 Predicted Leakage Condition

As discussed in the previous sections, no ODIGA patches leaked under any of the conditions tested. Based on the lack of any leakage and the following observations, it is concluded that ODIGA patches will not leak in their current state.

1. Volumetric ODIGA is a three dimensional corroding of the grain boundaries, but not the grains themselves. As the ODIGA progresses deeper, it tends to increase in circumferential and axial extent. As the ODIGA approaches 100%TW, however, the local stresses in the remaining cross sectional area increase. During normal operating conditions the tube is subjected to a small compressive load and a primary-to-secondary pressure differential, resulting in a positive hoop stress. At some point before the ODIGA can progress 100%TW, the cross section of the degraded tube will reach the critical stress needed for crack initiation. This crack may then progress 100%TW, but this is now a mixed mode or linear form of degradation that must be repaired.

2. There is a considerable amount of experience in the generation of volumetric ODIGA in the laboratory. This experience has focused on the attempt to develop 100%TW ODIGA. The difficulty in achieving 100%TW ODIGA is that even with highly concentrated solutions, as the corrosion proceeds through the tube wall, the concentration of the contaminant decreases as a function of depth. This is true even though the solutions are replenished. The ODIGA reaches a certain depth and then stops. The only way to drive the ODIGA deeper is to increase the stress in the tube. The difficulty in this approach is that the required stress increases with depth of penetration, and results in initiation of a linear crack before a 100%TW penetration is reached. Under this program, the crack indications must be repaired.

### 6.3.1 Predicted Mode of Cracking

For purposes of postulating leakage, it is therefore assumed that the ODIGA must form a crack in order to have a potential for leakage. Evaluation of the normal operating conditions results in the conclusion that the initiation of an axial crack is more probable than formation of a circumferential crack. This is based on the fact that the OTSG tubes are in compression during steady-state operation, which inhibits the initiation of a circumferential crack, and that the hoop stresses caused by primary-to-secondary pressure differential favor the formation of an axial crack. If a volumetric ODIGA patch does not develop into a crack during normal operation, it is unlikely that it will crack under MSLB conditions for circumferential extents less than ~90° based on the leak testing discussed in section 6.2. This circumferential extent bounds the existing in-service ANO-1 volumetric ODIGA and is used to develop the acceptance criteria. Therefore, for purposes of estimating leakage, it is concluded that the most probable means of developing a through-wall flaw is by axial cracking during normal operation.

Additionally, recently performed OTSG transient analysis indicates that the MSLB axial tube loads are less than the axial tube loads experienced during cool down. This implies that if an IGA patch develops a preferential orientation or linear characteristics it would be expected during cool down as a result of the larger tube loads. At this time the OTSGs are inspected per Engineering Standard, HES-27 and any patch of IGA with crack-like characteristics are repaired.

### 6.3.2 Predicted Length of Leak Path

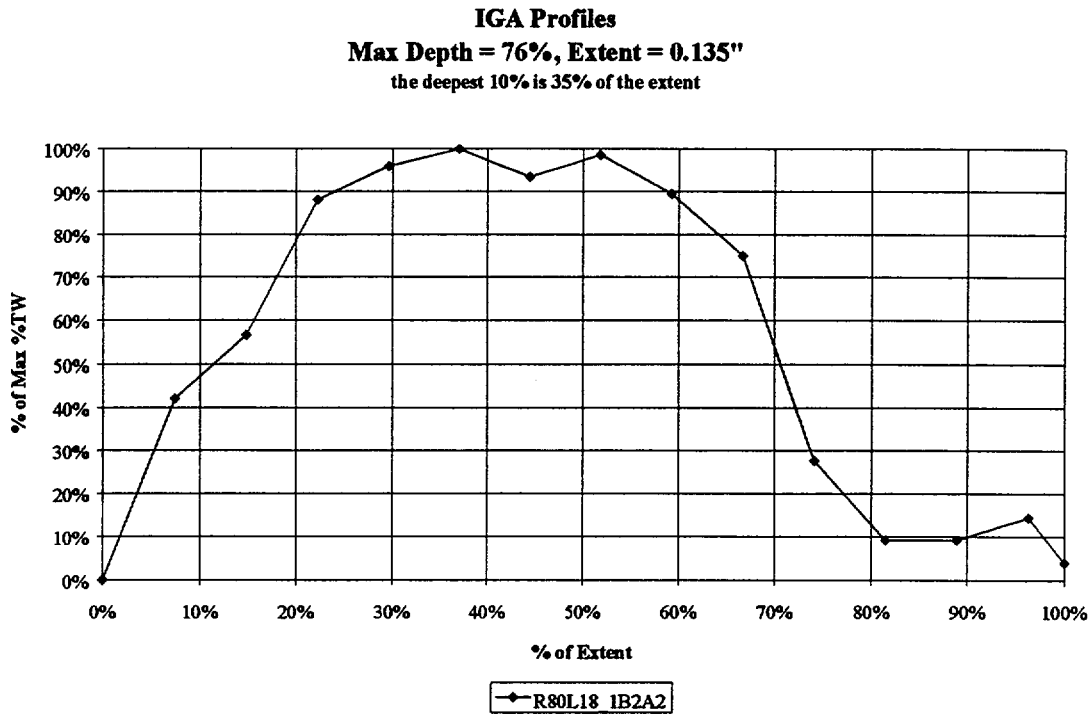
The axial depth profiles of ODIGA patches with maximum depths greater than 70%TW were evaluated in order to predict a representative leak path length. The 70%TW criteria was chosen in order to evaluate the shape of patches that had a more reasonable chance of developing a leak (note that patches up to 98%TW did not leak). This criteria resulted in evaluating four patches (Figure 11 - Figure 14) removed from the ANO-1 steam generators in 1996.

As described in section 4.2, the IGA has a generally elliptical profile as shown in Figure 11 and Figure 12. In other cases, the presence of small intergranular penetrations result in a maximum depth that extends over a much smaller percentage of the axial extent than if it were just an elliptical patch. This type of profile is exemplified in Figure 13 and Figure 14. In other words, the four patches are representative of the range of profile types expected to exist within the ANO-1 population.

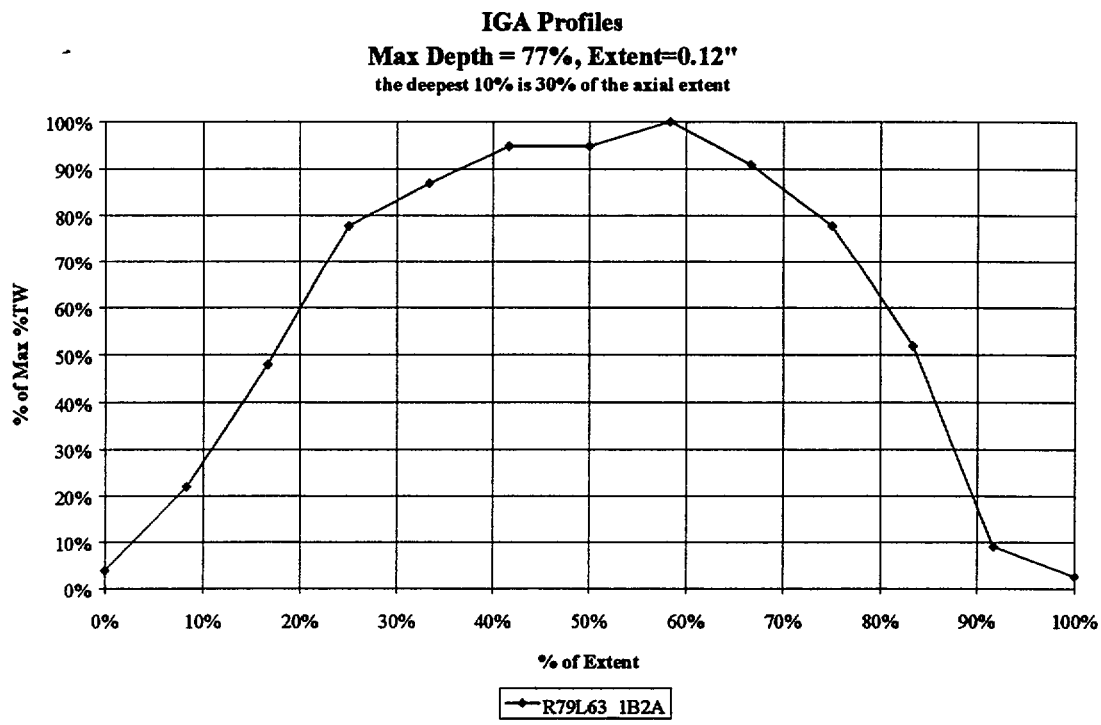
For purposes of predicting a leak path length, the four profiles are assumed to maintain the same profile and grow to a depth necessary to initiate an axial crack. It is further assumed that the crack will occur over the axial extent associated with the deepest 10% of the patch. For example, if a patch were 100%TW, then the crack would be predicted to span the extent of the patch which is greater than or equal to 90%TW. The plots show that based on these assumptions, the individual extent percentages are 35%, 30%, 10%, and less than 10%, respectively. This results in an average potential crack length equal to 21% of the axial extent of the patch. Therefore, when calculating population leak rates, the assumed individual leak rates will be conservatively calculated based on a 100%TW crack whose length is 25% of the total axial extent of the IGA patch.

Based on the lack of any leakage data from the leak testing discussed in sections 6.1 and 6.2, and lack of any significant reduction in structural strength as discussed in section 5, this approach is deemed conservative.

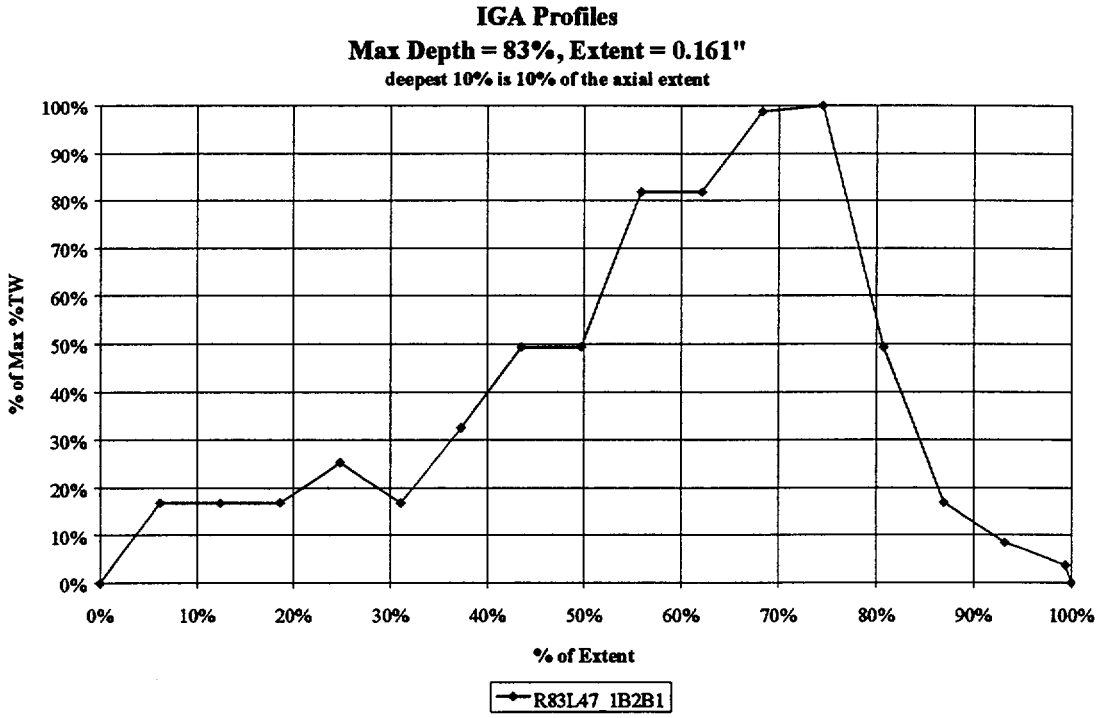
## Figure 11 ODIGA Profile of Tube 80-18, Section 1B2A2



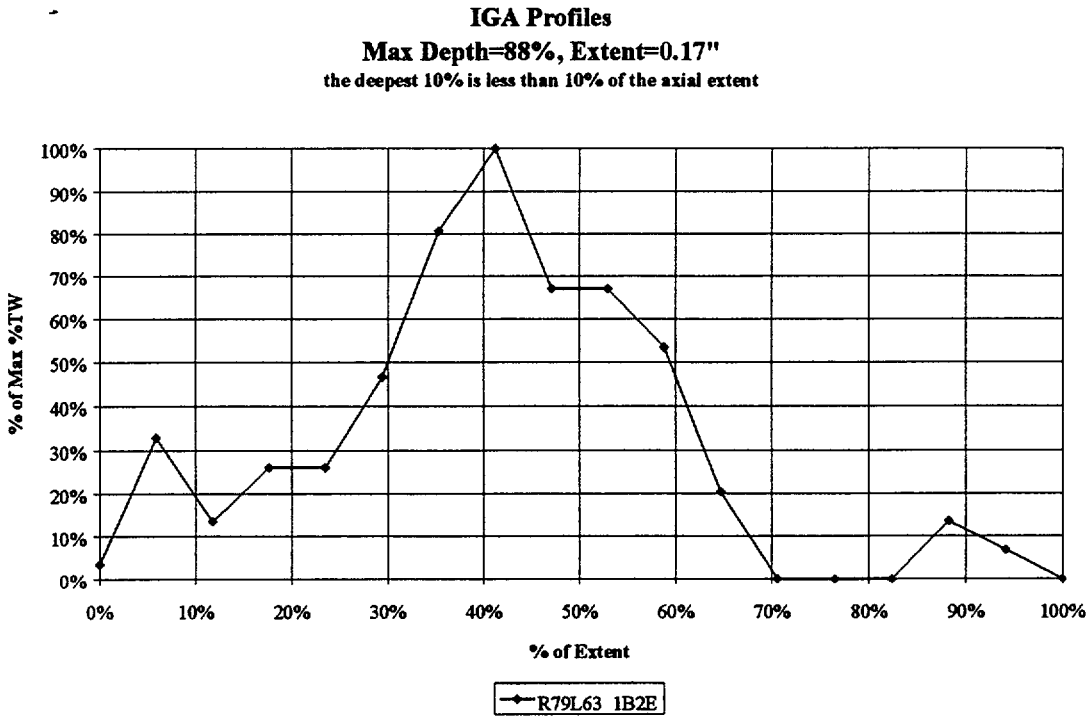

## Figure 12 ODIGA Profile of Tube 79-63, Section 1B2A



## Figure 13 ODIGA Profile of Tube 83-47, Section 1B2B1




## Figure 14 ODIGA Profile of Tube 79-63, Section 1B2E



## 6.4 Leakage Performance Criteria

As part of the licensing basis, ANO-1 must provide assurance that the potential primary-to-secondary leakage rate during the limiting accident condition for leakage (MSLB) does not exceed 1 gpm for the affected SG. This criteria will be met each outage through the SG program requirements/procedures. A portion of the 1 gpm limit is designated for the volumetric ODIGA. The other degradation mechanisms are addressed separately under the SG Program requirements and are combined with the IGA value to ensure the design requirements are met.

To provide a reasonable assurance that the leakage rate will not be exceeded, MSLB primary-to-secondary leak rates must be determined as a function of the axial extent of the assumed crack (see discussion in section 6.3). KRAKFLO, an FTI computer program, was used to calculate the fluid flow rates through axial cracks in OTSG tubes subjected to bounding MSLB conditions. The crack opening diameter was calculated based on the elastic-plastic method of Erdogan (reference 2.5). The effect of the tensile load, which would act to close the axial crack opening, is conservatively omitted in these calculations. The MSLB conditions assumed in this analysis are a primary-to-secondary pressure differential of 2575 psi, and the tube and primary fluid temperatures are assumed to be 540°F (which correspond to the temperatures at maximum pressure). Based on these conditions, the predicted leak rates are presented as a function of 100%TW crack length in Table 7. As shown in the table, the axial extent is based on the 0.115" pancake coil measurement. Due to the characteristics of EC, the indication associated with the IGA is "seen" before the coil actually passes over the ODIGA patch and is still "seen" after the coil has passed by the flaw. This is referred to as EC "look ahead" and "look behind" and results in consistently oversizing flaws. This fact is supported by the EC measurements of the pulled tube and laboratory ODIGA (see Tables 23 and Table 25) at the end of the report.

**Table 7 MSLB Leak Rate for Axial Cracks**

| ODIGA EC Axial Extent (inches) | 100%TW Crack Length (inches) | Flow Rate (lbm/sec) | Flow Rate (gpm) |
|---|---|---|---|
| 0.2 | 0.05 | 0.000031 | 0.00030 |
| 0.4 | 0.10 | 0.000278 | 0.0026 |
| 0.6 | 0.15 | 0.0016 | 0.0150 |
| 0.8 | 0.20 | 0.00516 | 0.0485 |
| 1.0 | 0.25 | 0.0151 | 0.1422 |
| 1.2 | 0.30 | 0.0363 | 0.3415 |
| 1.4 | 0.35 | 0.0710 | 0.6680 |

# 7.0 SPECIAL CONSIDERATIONS FOR PERFORMING ASSESSMENTS

Data from recent inspections (Ref. 2.9) of ANO-1 steam generator tubes support the conclusion that there are very small changes in the population of IGA flaws detected in the upper tubesheet region. Earlier efforts to evaluate these data in support of the continued application of an Alternate Repair Criteria for ANO-1 IGA flaws at the upper tube sheet (Ref. 2.2) applied a method based on the Student's t distribution for samples from normally distributed flaw features. The intention was to assess the statistical significance of these changes in the ANO-1 IGA flaw features. The existing procedure described in Ref. 2.2 was used to evaluate the statistical significance of apparent changes in an individual feature of the flaw (i.e. axial length, circumferential extent or Plus Point voltage) for condition monitoring and to calculate an allowance for use in ANO-1 operational assessments.

The conclusion presented in Reference 2.9 was that the Student t analysis indicated no apparent growth in the IGA flaws. That conclusion was based on the lower 95% confidence limit for two of the three variables (volts, axial length and circumferential extent) being less than zero.

This section of the report describes a revised procedure for assessing the statistical significance of apparent changes in the IGA flaws. This new procedure provides greater sensitivity to detecting changes in the overall distribution of IGA flaws and more importantly, requires that the largest growth values observed be consistent with previous historical extremes. Additional new information is presented here from a limited evaluation of ANO-1 analyst-to-analyst variability for sizing these types of flaws. This NDE uncertainty information is required to separate analyst variability from the variability of the apparent growth rates that are obtained directly from the field measurements. An example is also provided to illustrate application of the revised procedure to the most recent ANO-1 inspection results.

This work was developed specifically from information obtained from previous ANO-1 inspections and ANO-1 specific ECT uncertainty studies; no basis is provided for application of this method to UTS IGA at other B&W design steam generators.

## 7.1 Apparent Growth of ANO-1 ODIGA Flaws at the Upper Tubesheet

### 7.1.1 Introduction

Inspection data for ANO-1 IGA flaws characterizes their size and change in size in terms of Plus Point voltage and inferred crack length and circumferential extent. Apparent changes in a particular feature, for example axial crack length, is calculated from the difference in length measured at two inspections for each flaw. The resulting empirical distribution of change in the flaw feature provides an indication of how the entire population of detected flaws are behaving as they continue in service.

### 7.1.2 ANO-1 Field Measurements

Figures 15 through 17 provide related graphs of the cumulative probability of the 1R14 and 1R15 apparent growth of these IGA flaws for steam generators A and B. At ANO-1 and other units with B&W designed steam generators, these flaws occur predominantly at the upper tubesheet. The data presented in these Figures suggest that the IGA flaws at the upper tubesheet in each steam generator can be characterized by nearly identical distributions as evidenced by the small separation between their respective cumulative probabilities. The data from the two generators were pooled for use in this evaluation.

The median change calculated from the apparent growth data is consistent with no change (zero growth) as the most probable case. However, the extremes of apparent growth indicate the possibility of a small amount of change during an operating cycle. What is not evident from the apparent growth distributions is how much of the calculated change in the extremes is due to NDE uncertainty. NDE uncertainty includes: analyst-to-analyst variability, variability between NDE field size and ground truth from destructive examinations and variability due to true changes in flaw dimensions. This question has been investigated in significant detail in this evaluation.

Tables 8 through 10 provide summaries of basic descriptive statistics that were calculated for these (pooled) data. These descriptive statistics indicate that the apparent changes in the flaw feature populations are consistent with a zero mean change and relatively small variability. It is also clear that the axial length and circumferential extent dimensions are similar in magnitude and variability as evidenced by their similar mean values and standard deviations.

Section 8 of this report provides a revised procedure for assessing the statistical significance of apparent changes in the population of IGA flaws. This revised procedure provides guidance for Condition Monitoring; Section 9 provides a procedure for calculating a growth allowance for an individual flaw for use in Operational Assessments.

### 7.1.3 Components of Variability

The ANO-1 IGA flaw dimensions, particularly the axial extent, are short relative to typical axial stress corrosion cracks. Because of their small size, the relatively low amplitude of the +Point response and the inherent difficulties in establishing accurate sizes for small flaws, the apparent sizes reflect some unknown amount of NDE uncertainty. Section 7.1.4 describes the results of a study to estimate an important part of the NDE uncertainty that is attributable to analyst-to-analyst variability in sizing. Section 7.1.5 describes a method to estimate the component of variation attributable to actual growth variability.

The actual change in a particular flaw dimension, $d = y-x$, is not observable; the apparent change: $D = Y_{'99} - X_{'98}$ is the measured (apparent) change which includes the influence of NDE sizing uncertainties and analyst interpretation uncertainties.

The variance of the difference in apparent values for a flaw feature is therefore larger than the variance of the actual values; an effect that tends to over-estimate (in the conservative) direction the extremes of actual growth. The common appearance of negative values of growth are also indicative of this effect.

For the ANO-1 IGA flaws, a pooled estimate of the overall variance for the axial and circumferential dimensions, assuming that the true variability and measurement uncertainties are similar can be calculated by conventional methods; the portion of this overall variability that is attributable to NDE uncertainty is addressed in the following section.

### 7.1.4 Analyst-to-Analyst Sizing Uncertainty

The amount of variation in the ANO-1 IGA flaw growth that can be attributed to NDE uncertainty was determined by an independent evaluation. Entergy Operations had 3 QDA certified NDE analysts blindly re-evaluate the ODIGA flaws that were present in ANO-1 steam generator tubes that were pulled at the time of the 1R13 outage. Figures 18 through 20 provide the volts and sizes called by these three analysts. Tables 11 through 13 provide summaries of the variation between analysts for these data. These Figures and Tables indicate that while the analyst calls are similar, there exists a moderate amount of variability. This variability, that is present in the apparent growth data, is summarized in Tables 8 through 10.

Table 14 provides a comparison of the apparent variability from the field measurements with the analyst-to-analyst variability determined by this limited study. The results show striking similarity; this is further independent evidence that the bulk of the ANO-1 IGA flaw size variability is directly attributable to NDE uncertainty (and in particular, analyst-to-analyst variability). Most of the +Point and circumferential extent variability can be explained by analyst-to-analyst variability and about half of the variability in axial length can be attributed to the same source.

### 7.1.5 Variability of Actual IGA Growth Rates

As discussed previously, apparent growth rate variability consists of two components: actual variability in the changes in the flaw features and variability introduced by NDE uncertainties due to analyst-to-analyst variability and other factors. This section describes a method to determine the actual variability using data from the field (apparent growth rates) and the data from the analyst-to-analyst study. Of particular interest is the variability of the actual axial length as this variable has an important impact on leakage calculations that are performed as part of the Operational Assessment.

Using the results from the previous section to estimate the NDE component, the actual variability was directly obtained as reported in Figure 21 and 22. As a check on the value obtained, an independent method for estimating the components of the growth rate variability was applied to the ANO-1 IGA data. The NDE uncertainties implied by this alternate model correspond to 1-sigma values of about 17% for axial extent and 14% for circumferential extent, consistent with measurement uncertainties for other ECT techniques. The alternate model was used to predict the ANO-1 field measurements (X'98, Y'99) as a check on the consistency of the model with the field data. Close agreement between the model and the field data are indicated by Figures 21 and 22. The agreement is better for the case of change in axial extent than for the case of change in circumferential extent.

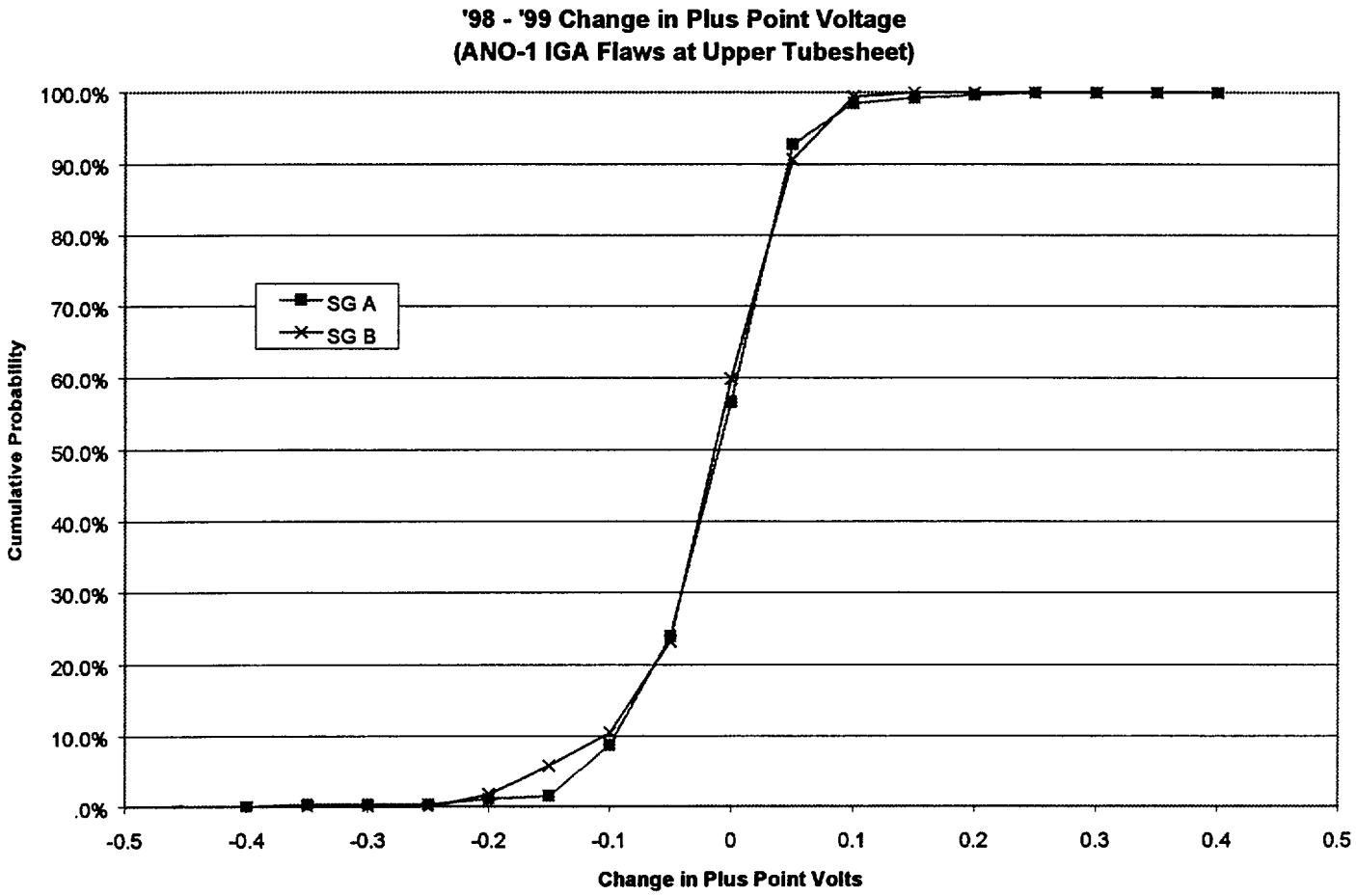



Figure 15. Apparent Change in ANO-1 UTS OD-IGA Plus Point Volts ('98 – '99)

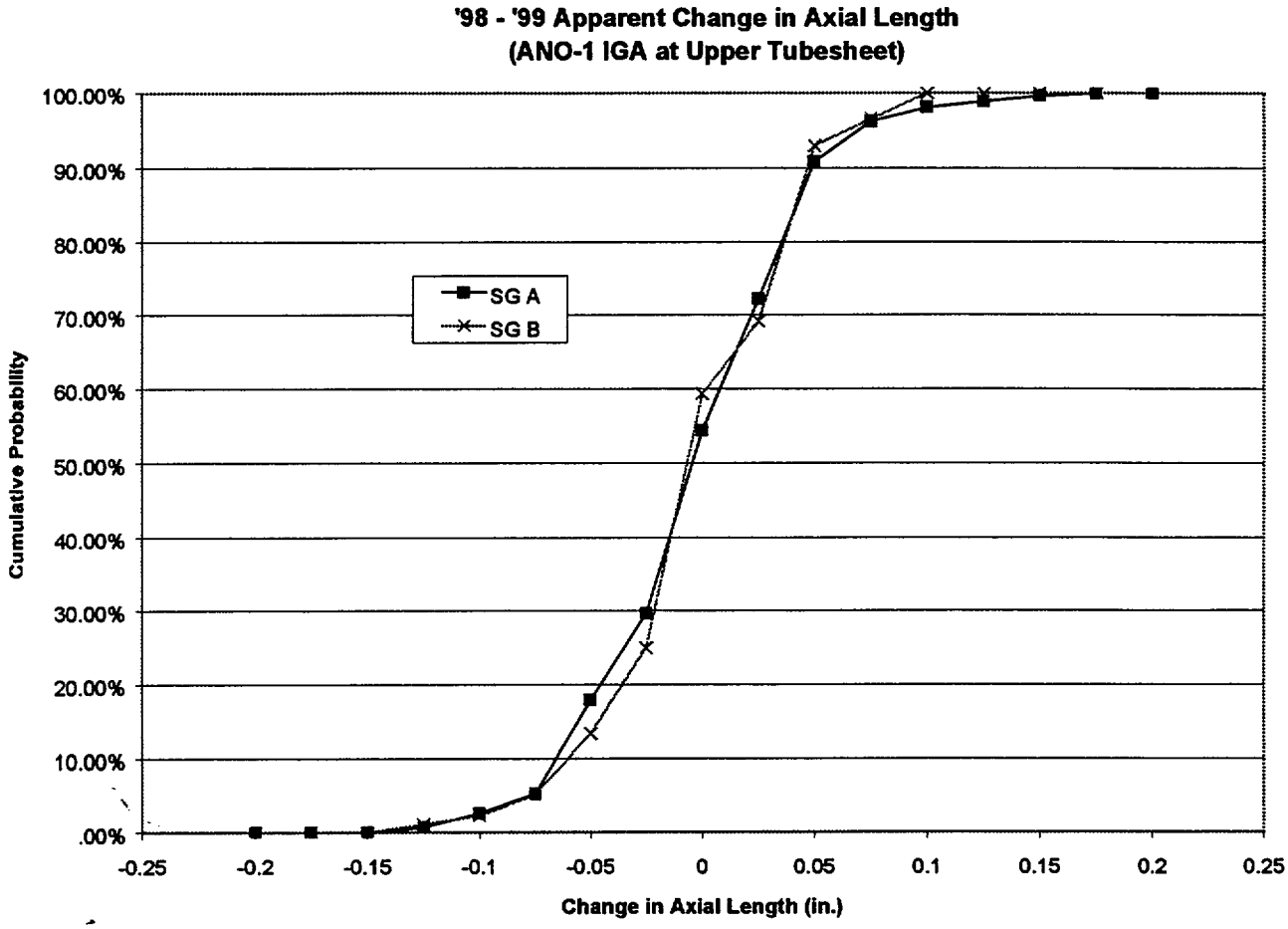



Figure 16. Apparent Change in ANO-1 UTS OD-IGA Axial Length ('98 – '99)

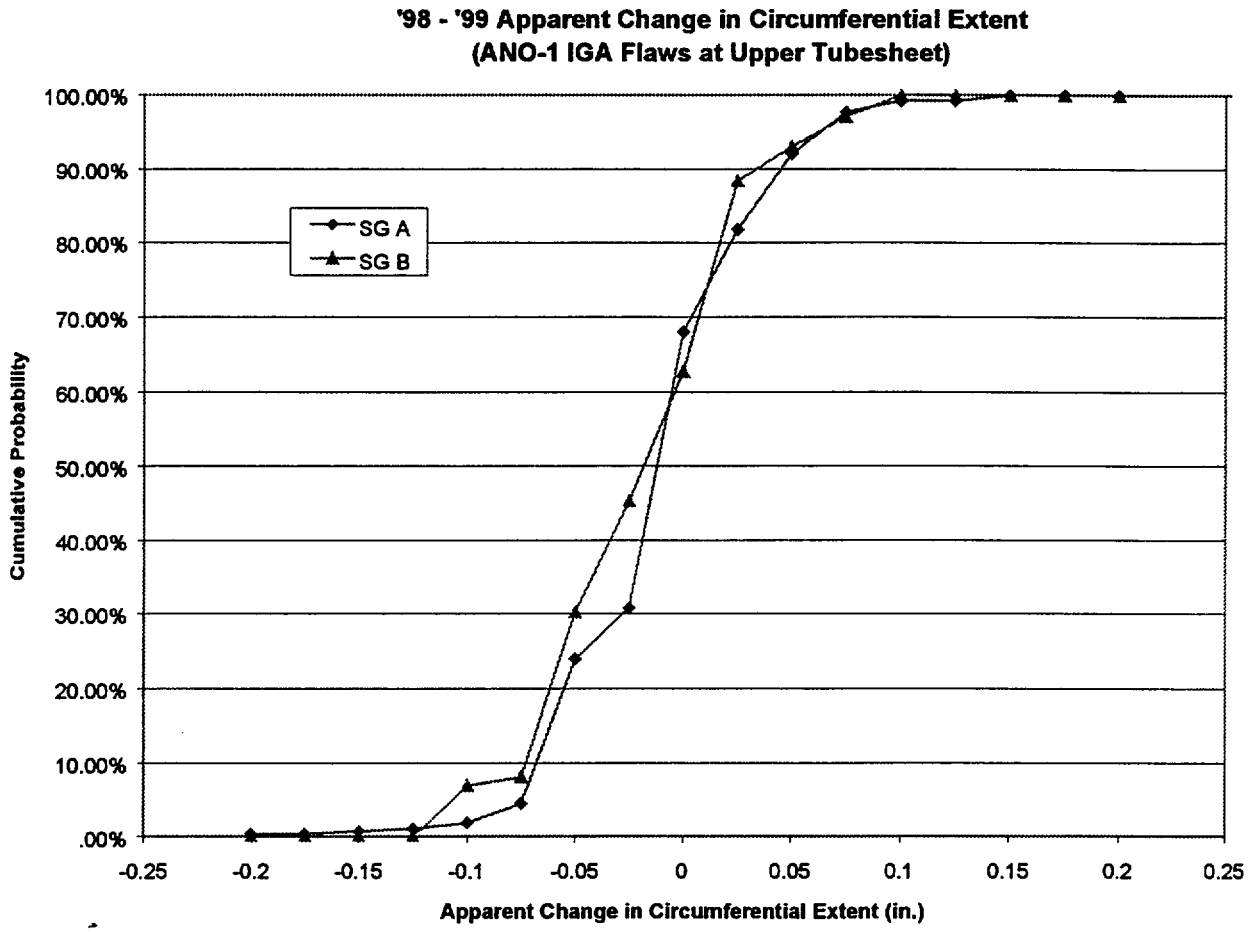



Figure 17. Apparent Change in ANO-1 UTS OD-IGA Circumferential Extent ('98 – '99)

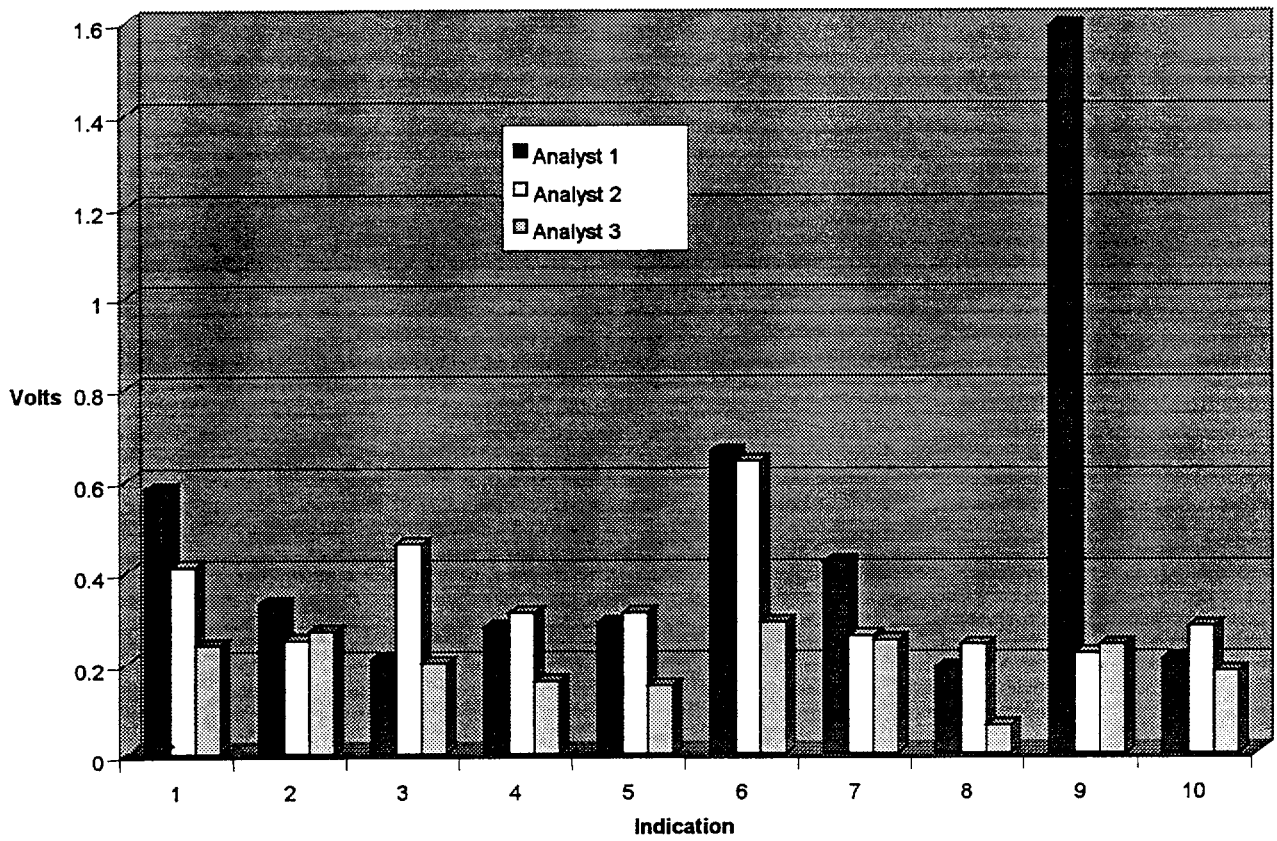



Figure 18. Volts for ANO-1 Pulled Tube IGA Flaws by Analyst

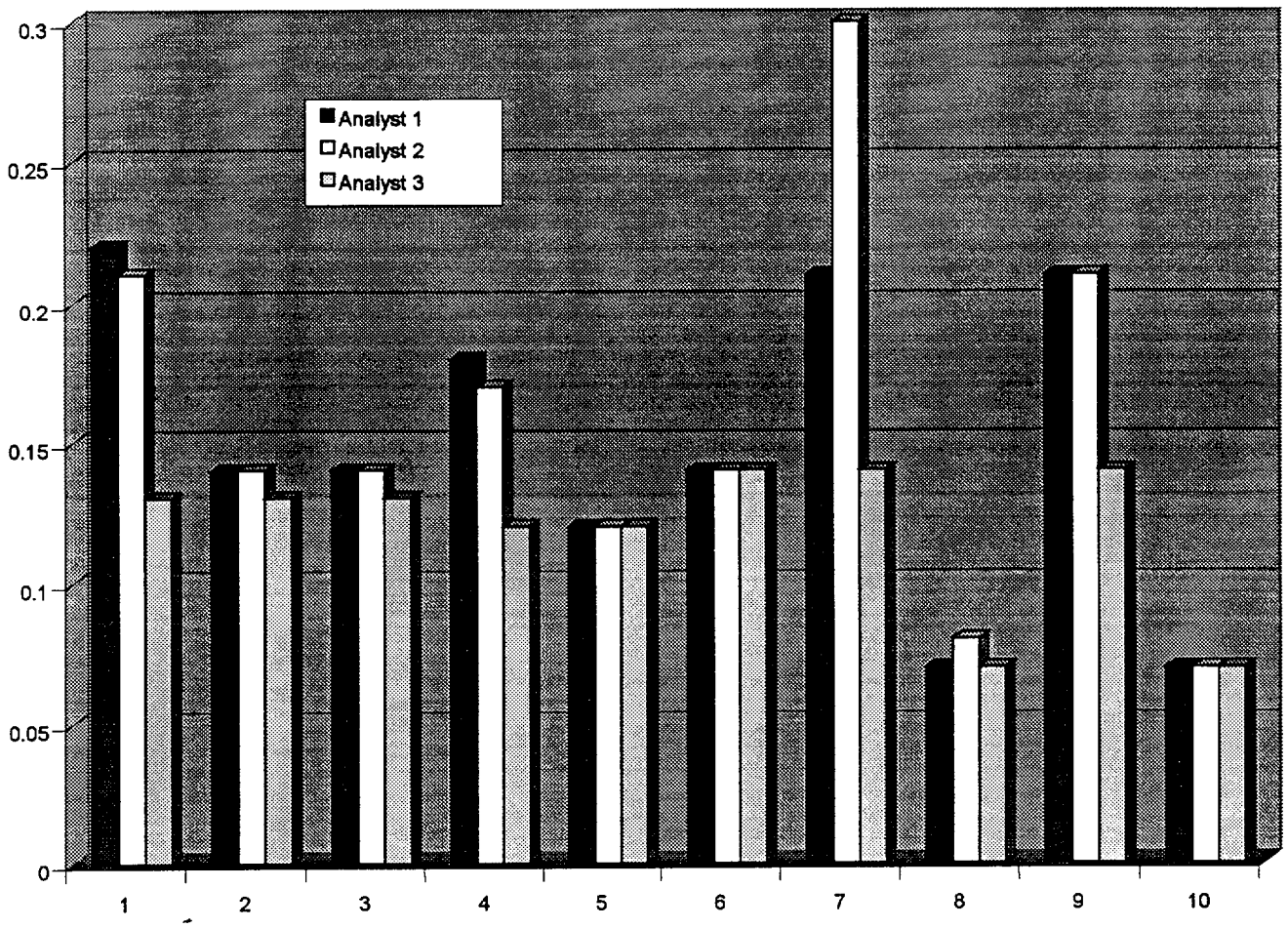



Figure 19. Axial Extents for ANO-1 Pulled Tube IGA Flaws by Analyst

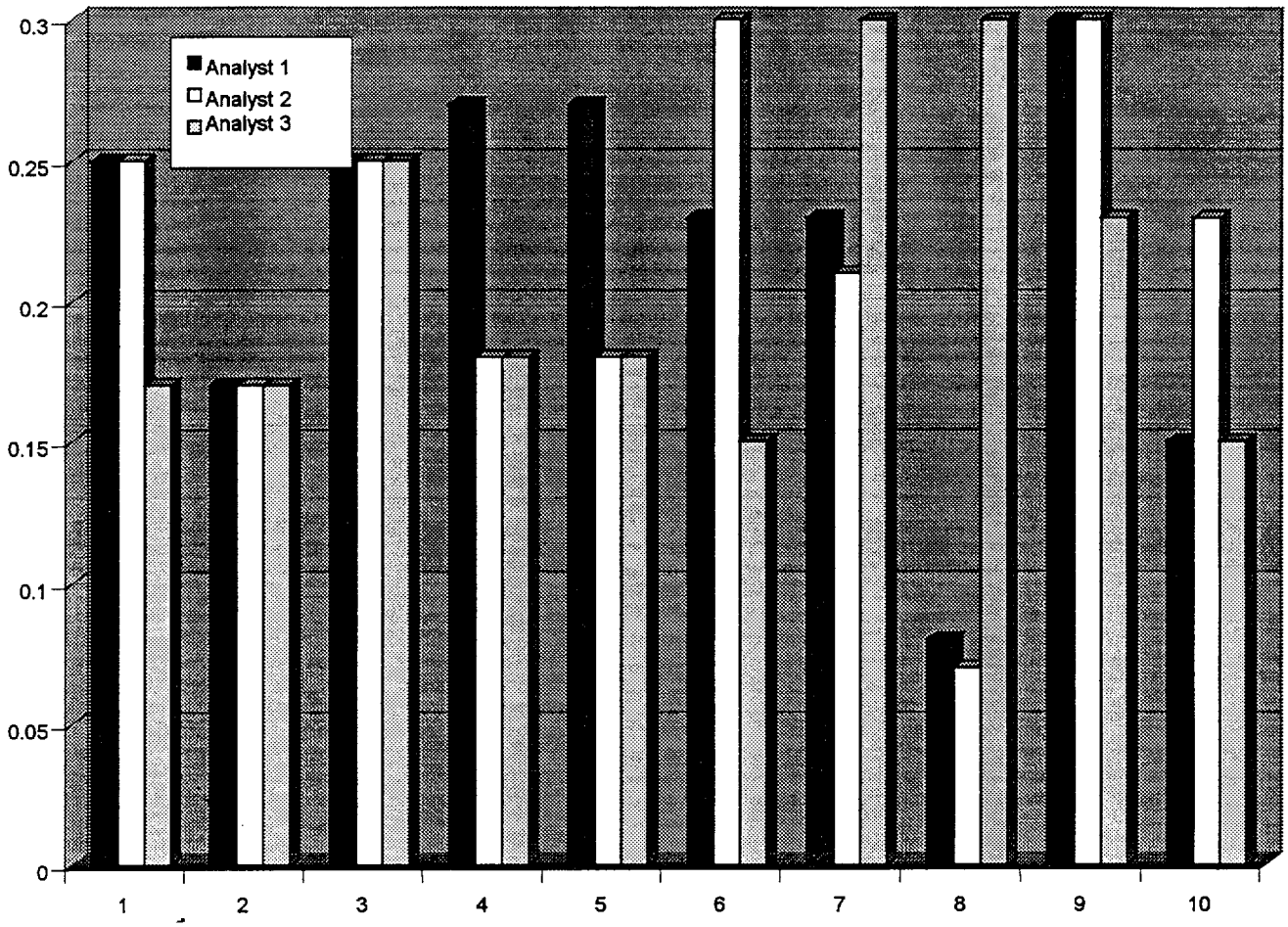



Figure 20. Circumferential Extents for ANO-1 Pulled Tube IGA Flaws by Analyst

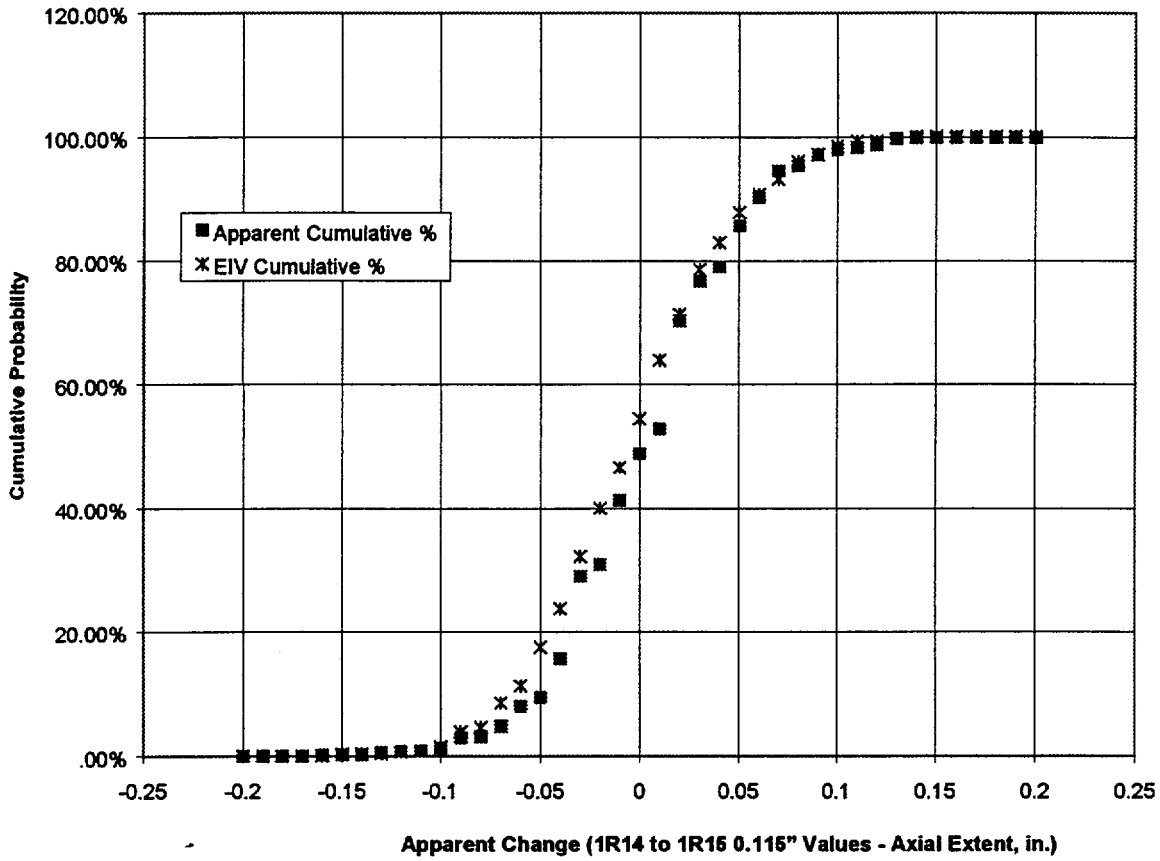



Figure 21. Apparent Change in Axial Length (Field Measurements vs. EIV Prediction)

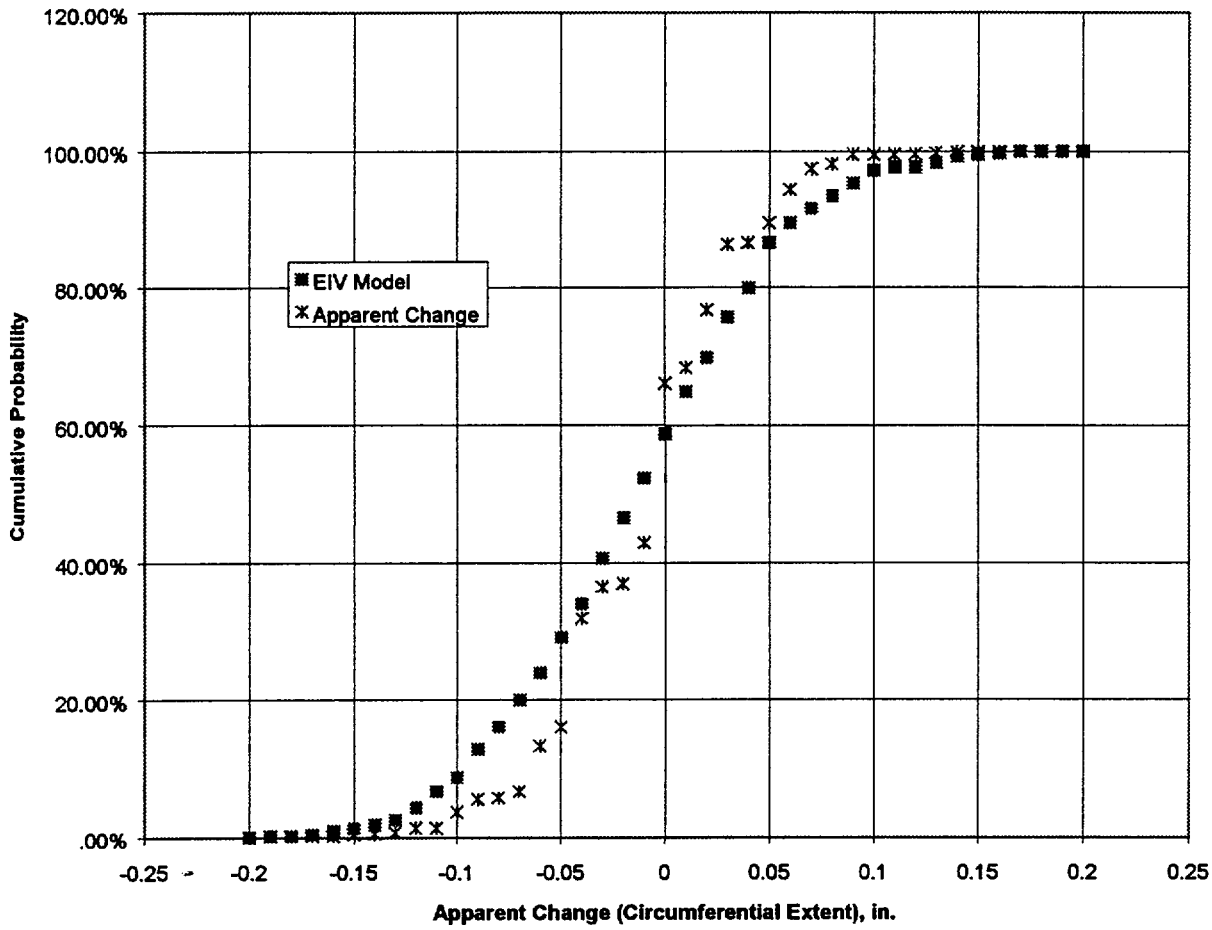



Figure 22. Apparent Change in Circumferential Extent (Field Measurements vs. EIV Model)

Table 8

Descriptive Statistics for Apparent Change in IGA Plus Point Volts

(Pooled Data from SG A and SG B)

| Statistic | Value |
|---|---|
| Mean | -0.014 |
| Standard Error | 0.003 |
| Median | -0.010 |
| Mode | 0.010 |
| Standard Deviation | 0.061 |
| Sample Variance | 0.004 |
| Kurtosis | 3.316 |
| Skewness | -0.885 |
| Range | 0.570 |
| Minimum | -0.360 |
| Maximum | 0.210 |
| Count | 435 |

Table 9

Descriptive Statistics for Apparent Change in IGA Axial Length

(Pooled Data from SG A and SG B)

| Statistic | Value |
|---|---|
| Mean | -0.003 |
| Standard Error | 0.002 |
| Median | -0.010 |
| Mode | -0.010 |
| Standard Deviation | 0.045 |
| Sample Variance | 0.002 |
| Kurtosis | 0.534 |
| Skewness | -0.058 |
| Range | 0.300 |
| Minimum | -0.140 |
| Maximum | 0.160 |
| Sample Size | 435 |

Table 10

Descriptive Statistics for Apparent Change in Circumferential Extent

(Pooled Data from SG A and SG B)

| Statistic | Value |
|---|---|
| Mean | -0.011 |
| Standard Error | 0.002 |
| Median | 0.000 |
| Mode | 0.000 |
| Standard Deviation | 0.045 |
| Sample Variance | 0.002 |
| Kurtosis | 0.777 |
| Skewness | -0.150 |
| Range | 0.340 |
| Minimum | -0.200 |
| Maximum | 0.140 |
| Sample Size | 435 |

Table 11

Results from Independent Assessment of Analyst-to-Analyst Variability

(IGA Flaws at Upper Tubesheet - Plus Point Volts)

| Indication | Analyst 1 | Analyst 2 | Analyst 3 | Avg of Analysts | Analyst-to-Analyst Std Dev |
|---|---|---|---|---|---|
| 1 | 0.58 | 0.41 | 0.24 | 0.41 | 0.17 |
| 2 | 0.33 | 0.25 | 0.27 | 0.28 | 0.04 |
| 3 | 0.21 | 0.46 | 0.2 | 0.29 | 0.15 |
| 4 | 0.28 | 0.31 | 0.16 | 0.25 | 0.08 |
| 5 | 0.29 | 0.31 | 0.15 | 0.25 | 0.09 |
| 6 | 0.66 | 0.64 | 0.29 | 0.53 | 0.21 |
| 7 | 0.42 | 0.26 | 0.25 | 0.31 | 0.10 |
| 8 | 0.19 | 0.24 | 0.06 | 0.16 | 0.09 |
| 9 | 1.59 | 0.22 | 0.24 | 0.68 | 0.79 |
| 10 | 0.21 | 0.28 | 0.18 | 0.22 | 0.05 |
| | | | Mean | 0.339 | 0.176 |

Table 12

Results from Independent Assessment of Analyst-to-Analyst Variability

(IGA Flaws at Upper Tubesheet – Axial Extent)

| Indication | Analyst 1 | Analyst 2 | Analyst 3 | Avg of Analysts | Analyst-to-Analyst Std Dev |
|---|---|---|---|---|---|
| 1 | 0.22 | 0.21 | 0.13 | 0.1867 | 0.0493 |
| 2 | 0.14 | 0.14 | 0.13 | 0.1367 | 0.0058 |
| 3 | 0.14 | 0.14 | 0.13 | 0.1367 | 0.0058 |
| 4 | 0.18 | 0.17 | 0.12 | 0.1567 | 0.0321 |
| 5 | 0.12 | 0.12 | 0.12 | 0.1200 | 0.0000 |
| 6 | 0.14 | 0.14 | 0.14 | 0.1400 | 0.0000 |
| 7 | 0.21 | 0.3 | 0.14 | 0.2167 | 0.0802 |
| 8 | 0.07 | 0.08 | 0.07 | 0.0733 | 0.0058 |
| 9 | 0.21 | 0.21 | 0.14 | 0.1867 | 0.0404 |
| 10 | 0.07 | 0.07 | 0.07 | 0.0700 | 0.0000 |
| | | | Mean | 0.142 | 0.022 |

Table 13

Results from Independent Assessment of Analyst-to-Analyst Variability

(IGA Flaws at Upper Tubesheet – Circumferential Extent)

| Indication | Analyst 1 | Analyst 2 | Analyst 3 | Avg of Analysts | Analyst-to-Analyst Std Dev |
|---|---|---|---|---|---|
| 1 | 0.25 | 0.25 | 0.17 | 0.2233 | 0.0462 |
| 2 | 0.17 | 0.17 | 0.17 | 0.1700 | 0.0000 |
| 3 | 0.25 | 0.25 | 0.25 | 0.2500 | 0.0000 |
| 4 | 0.27 | 0.18 | 0.18 | 0.2100 | 0.0520 |
| 5 | 0.27 | 0.18 | 0.18 | 0.2100 | 0.0520 |
| 6 | 0.23 | 0.3 | 0.15 | 0.2267 | 0.0751 |
| 7 | 0.23 | 0.21 | 0.3 | 0.2467 | 0.0473 |
| 8 | 0.08 | 0.07 | 0.3 | 0.1500 | 0.1300 |
| 9 | 0.3 | 0.3 | 0.23 | 0.2767 | 0.0404 |
| 10 | 0.15 | 0.23 | 0.15 | 0.1767 | 0.0462 |
| | | | Mean | 0.214 | 0.049 |

Table 14

Comparison of Analyst-to-Analyst Variability with Apparent Variability

(ANO-1 IGA Flaws at Upper Tubesheet)

| Statistic | +Point Volts | Axial Extent, in. | Circumferential Extent, in. |
|---|---|---|---|
| Field Sample Size, n | 435 | 435 | 435 |
| Analyst-to-Analyst Sample Size, m | 10 | 10 | 10 |
| Apparent Average | 0.335 | 0.186 | 0.214 |
| Average from Analyst-to-Analyst Study | 0.339 | 0.142 | 0.214 |
| Apparent Variability (Standard Deviation - from Field Data) | 0.160 | 0.045 | 0.049 |
| Analyst-to-Analyst Variability (Standard Deviation - from Study) | 0.159 | 0.022 | 0.049 |
| NDE Variability (Standard Deviation - EIV model) | N/A | 0.032 | 0.031 |

# 8.0 REVISED PROCEDURE FOR MONITORING ODIGA GROWTH

## 8.1 Introduction

This section provides a revised procedure for monitoring ODIGA growth. The new procedure is a multi-step process starting with simple statistical tests to detect changes in the apparent growth distributions. The existing 2-out-3 t-Tests are replaced by a generalized test to detect changes in the mean and a new extreme value test that will identify changes in the "tail" of the distribution. If an initial normality test indicates that the growth data are not sufficiently normal, or if the initial tests are unsuccessful, an alternative set of tests will be applied. These alternative tests do not require that the data be normally distributed as is the case for both the existing 2 out 3 t-Tests and the generalized t-Test. If the alternative tests are unsuccessful or in the interest of timeliness, a cycle-specific growth model is required. Since cycle-specific models typically must account for specific features of the field data, namely observed extremes, only general guidance is provided for such a circumstance.

The ODIGA population is assumed to remain constant (inactive degradation). By demonstrating "no change" in the population it allows the conclusion that the same population existed during previous outages, thus allowing credit to be taken for previous in-situ pressure testing. If application of the initial tests results in a statistically significant result (that is, that there is statistically significant evidence of growth based on normal distribution models of the IGA dimensions), passing the alternative test procedure will be sufficient to demonstrate that no growth in fact has occurred, provided that a suitable explanation can be developed to account for the results from the first test.

## 8.2 Capability of Existing Procedure to Detect a Change in Mean Growth

The existing procedure for condition monitoring of the population of ANO-1 IGA flaws is described in Ref. 2.2. It consists of demonstrating that the lower confidence limits for the population mean for at least 2 of the flaw features do not exceed 0. Such a procedure will not indicate a change in the mean until a significant portion of the population exhibits growth.

Any elementary text on statistical methods describes the classic Student's t test for paired samples (each of n measurements) from a normal (Gaussian) distribution. The test statistic is easy to calculate from the data and the hypothesis that the two samples were obtained from populations that have identical mean (median) is evaluated by comparing the test statistic with conventional quantiles from the Student t distribution function with n-1 degrees of freedom. The procedure for performing the test is as follows: If the value of the test statistic calculated from the measurements exceeds the one-sided critical value (conventionally the 5% significance level) then the hypothesis is rejected; that is, there exists less than a 5% chance of a difference between the means (medians) as large as was observed if the samples were in fact drawn from normal distributions with the same mean/median. This standard method for paired samples from normal distributions is included in many commercial software packages.

Differences in apparent growth of IGA at the upper tubesheet of ANO-1, while statistically significant, do not necessarily indicate actual growth of the flaws as they also reflect the substantial NDE uncertainties associated with sizing these relatively small flaws as discussed earlier in this report. The validity of classical tests for no growth depends strongly on the assumption that the data are normally distributed. Departures from normality such as excessive peakedness or skewness effect

the results of the tests and may lead to incorrect conclusions (for example, concluding that flaw dimensions have changed when, in actual fact, they have not). While generally similar to a normal distribution, the ANO-1 IGA field data do exhibit some deviations from the ideal shape of both the central portion of the distribution as well as the tails. Therefore, the shape of these distributions may adversely affect future assessments of changes in the flaw dimensions. For that reason, an alternative method is described in this report that does not require that the data have a normal distribution.

The following section describes a revision to the current procedure that results in a multi-step process where a conclusion of no growth may result at any intermediate stage, depending on the field measurements.

### 8.3 Revised Procedure for Assessing IGA Growth

A three-step procedure is proposed as a replacement for the existing procedure for assessing IGA growth. The first step consists of three tests: (1) a test to determine if the data is distributed normally (2) a single test (based on +Point voltage and axial length only) to detect changes in means and (3) tests to identify statistically significant changes in the largest growth measurement. If the results of the first step indicate no significant changes, Step I is successful and one proceeds directly to calculating the (axial length) growth allowance and determining the in-situ requirements for operational assessments as described in Section 9. Examples are provided in Section 10.

If the normality test is not satisfied or the other tests in Step I are not satisfied, an alternate step provides different tests where the assumption of underlying normality is not required. Therefore, Step II provides some alternative and equivalent methods to confirm that the populations have not changed. The primary decision at Step II will be an issue of ease of application. If the results of Step II indicate no significant changes in the population of IGA defects, an explanation for the unsuccessful results of the initial test should be prepared prior to (or in parallel with) proceeding with the calculation of the (axial length) growth allowance and determining the in-situ requirements for operational assessments as described in Section 9.

If Steps I and II are both unsuccessful, then there is significant evidence in the apparent growth data that the population of ODIGA has changed. At this point, Step III calls for the development of a cycle-specific growth model and credit cannot be taken for only previous in-situ pressure testing. In any event, additional calculations are required to develop an allowance for growth for operational assessment purposes; those calculations are described in Section 9.

An outline of the procedure steps are as follows:

Step I. Perform Parametric Tests for Change in Flaw Population
a. Normality test
b. Generalized T-Test for Change in IGA Population Mean
c. Extreme Value Test for Largest Growth Rates

Step II. Perform Nonparametric Tests for Change in Flaw Population
a. K-S Test for Change in IGA Population
b. Extreme Value Test for Largest Growth Rates

Step III. Develop Cycle-Specific Model for IGA Flaw Population

These steps in the procedure are described in the following sections. Figure 24 illustrates the overall logic of the revised approach for condition monitoring of the population of IGA flaws.

8.3.1 Step Ia. Generalized t-Test for Change in IGA Population

A simple test will be conducted to determine if the data is distributed normally then rather than perform multiple Student t tests as in the existing procedure, a single generalized Student's t test can be used to identify changes in the flaw population. Since +Point voltage has been shown to have the lowest standard deviation and axial length is the most significant variable for operational assessment purposes, the generalized t-Test will be applied to detect apparent changes indicated in those two measured dimensions. If the test result is significant (that is, the data indicate a change in either or both of the population means) the alternative procedures may be applied as described in Sections 8.3.2-8.3.4.

Designating +Point voltages at the first and second inspections by the variable $x_1$, $y_1$ and the axial lengths by the variables $x_2$, $y_2$, the generalized statistic, $T^2$ is calculated as described in Reference 2.11:

$$T^2 = \frac{\left(t_1^2 - 2rt_1t_2 + t_2^2\right)}{1-r^2}$$

$$t_1 = \frac{d_1}{S_{d_1}} = \frac{\bar{x}_1 - \bar{y}_1}{S_1\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$t_2 = \frac{d_2}{S_{d_2}} = \frac{\bar{x}_2 - \bar{y}_2}{S_2\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$r = \frac{S_{12}}{S_1S_2}$$

and where the variance components are calculated from the marginal distributions as:

$$S_1^2 = \frac{(n_1-1)S_{x_1}^2 + (n_2-1)S_{y_1}^2}{n_1+n_2-2}$$

$$S_2^2 = \frac{(n_1-1)S_{x_2}^2 + (n_2-1)S_{y_2}^2}{n_1+n_2-2}$$

$$S_{12} = \frac{(n_1-1)S_{x_1x_2} + (n_2-1)S_{y_1y_2}}{n_1+n_2-2}$$

The variable $T^2$ is related to the F distribution with $(2,n_1+n_2-3)$ degrees of freedom:

$$F = \frac{(n_1 + n_2 - 3)T^2}{2(n_1 + n_2 - 2)}$$

If the value of F is significant, ($d_1$, $d_2$) deviates from mean growths of (0,0). The test is then performed by comparing the value of $T^2$ with the critical value:

$$T_0^2 = 2F_{\alpha,2,n_1+n_2-3}\frac{n_1 + n_2 - 2}{n_1 + n_2 - 3}$$

If the calculated value from the measurement data exceeds the critical value, we reject the hypothesis of zero change in the means. This is a relatively simple calculation and can be readily performed in a spreadsheet. The data will then be reviewed per Section 8.3.2 to determine any extreme value as being statistically significant. An example of applying this method to ANO-1 IGA flaws is provided in Section 10.

8.3.2 Steps Ib, Ic. Extreme Value Test for Largest Growth Rates

Samples from normal distributions yield extreme (in our case maximum apparent growth) values that are described (for large sample sizes) by the so-called Type I Extreme Value distribution. Since the number of IGA flaws in the ANO-1 steam generators is large, the Type I distribution is expected to provide a good representation of the expected frequency of extreme growth values. This test is performed by comparing the largest observed growth value with the 5% critical value. If the largest growth value is less than the critical value, we conclude that the IGA growth data extreme value is not statistically significant. An example of the extreme value test is provided in Section 10. If this test is accomplished successfully the IGA flaws will then be reviewed per Section 9.0 to determine repair limits, POD adjustments, and condition monitoring requirements.

8.3.3 Step IIa. K-S Test for Change in IGA Population

In the event that the evaluations in Step I yield statistically significant changes in the IGA flaw populations, alternative non-parametric tests may be applied. One such test that is sensitive to both changes in the mean and the shape of a distribution is the Kolmogorov-Smirnov (K-S) test. If two samples are drawn from the same population, then as the number of samples is increased, the largest difference between the two sample cumulative distributions will get smaller. Details of this test are available in standard references on distribution-free methods. If this test is accomplished successfully the IGA flaws will then be reviewed per Section 9.0 to determine repair limits, POD adjustments, and condition monitoring requirements.

8.3.4 Step III. Develop Cycle Specific Growth Model

In the event that future ANO-1 IGA field data indicate a statistically significant change from the historical population of apparent growth as evidenced by the inability to demonstrate via the procedures in Step I and Step II statistically insignificant growth, it will be necessary to develop a cycle-specific model of growth for the operational assessment. It may also be necessary to perform additional in situ tests of the larger flaws. This growth model will characterize changes in the mean, variability and extremes of apparent growth and will be important as a basis for a cycle-specific growth allowance for operational assessments. It will be necessary to re-verify the analyst-to-analyst variability that is applicable to the field data at hand and to evaluate the components of variability so that an accurate model of actual growth can be obtained.

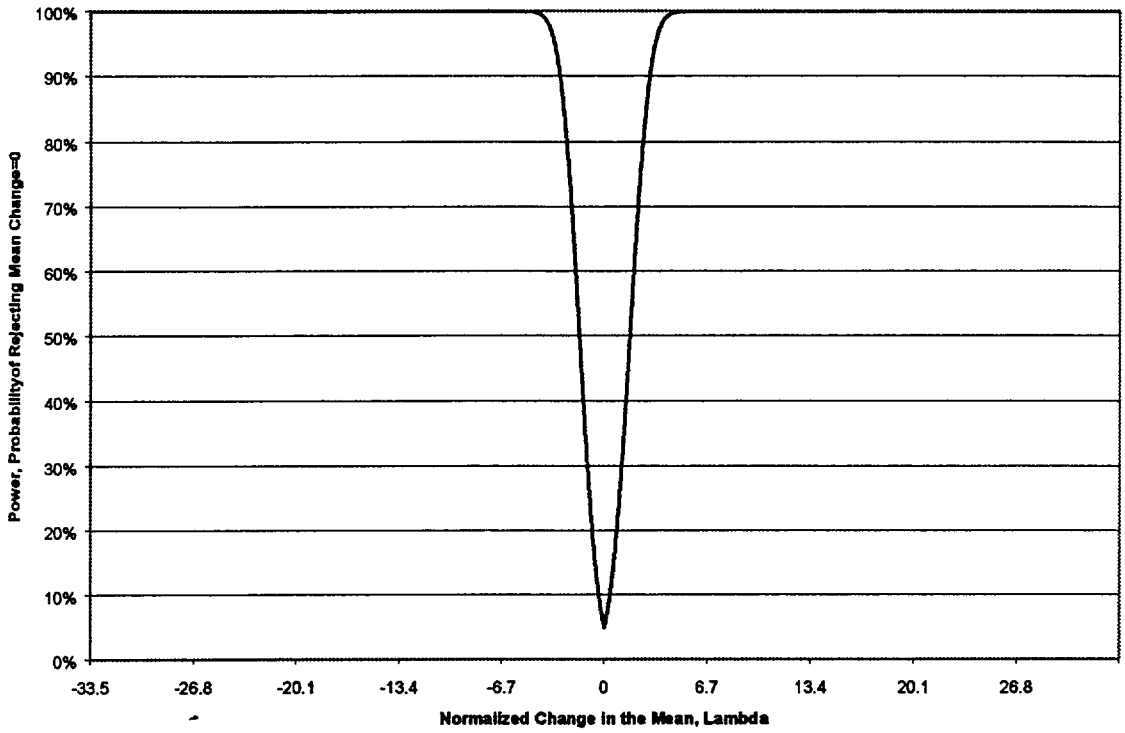



Figure 23. Capability of t-Test to Detect a Shift in the Mean

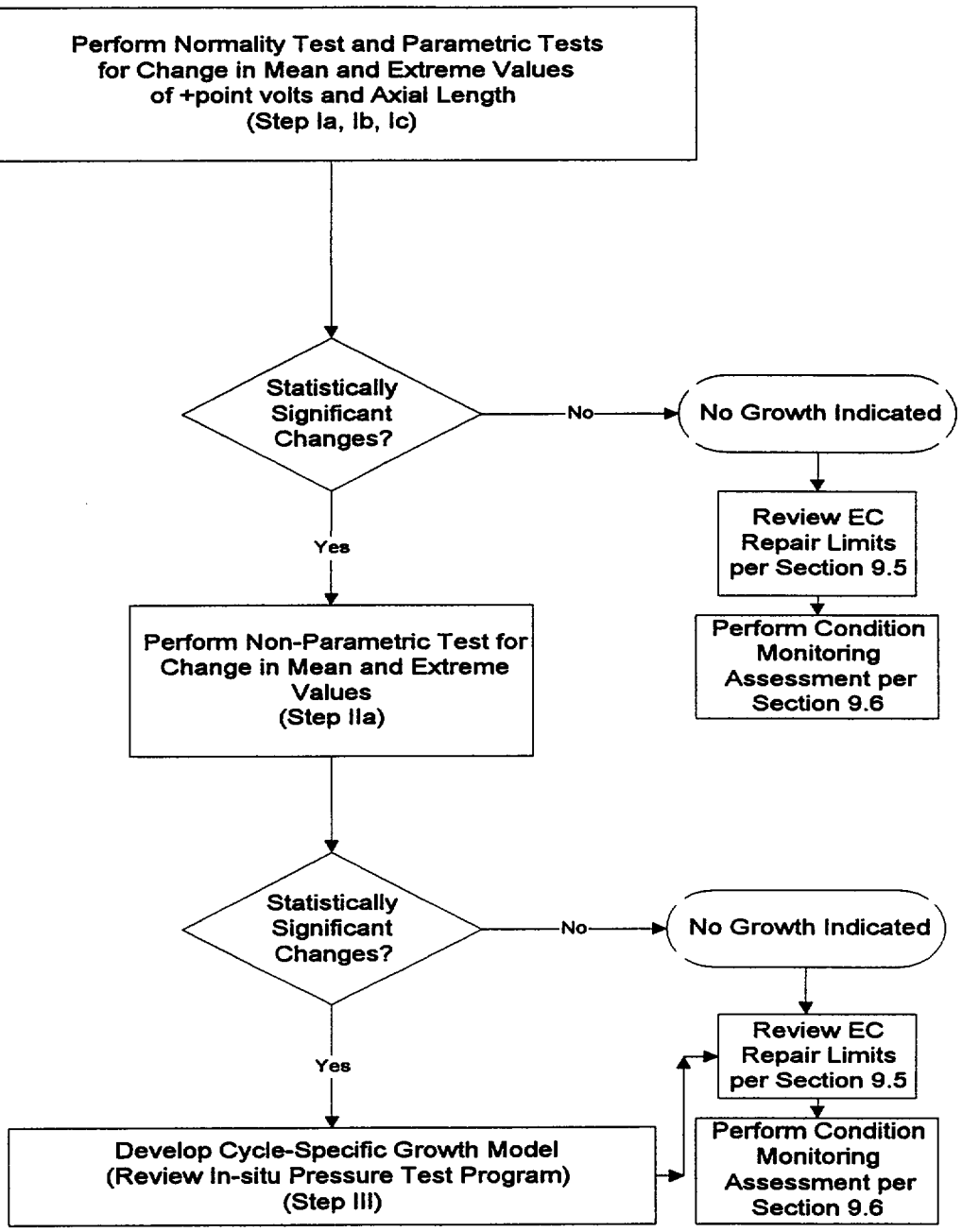



Figure 24. Revised Procedure for IGA Growth Condition Monitoring

# 9.0 UTS VOLUMETRIC ODIGA MANAGEMENT PROGRAM

The volumetric ODIGA management program is designed to ensure that OTSG tubes with volumetric ODIGA meet the structural performance criteria of section 5.5 and the leakage performance criteria of section 6.4 at the time of inspection and at the end of the next cycle of operation. The assessment process involves performing EC inspections of the defined region and then performing EC defect sizing of the indications characterized as volumetric ODIGA. The number of allowable leaking indications is determined based on postulated leak rates using the EC sizing information. Based on the number of allowable leaking indications, the required number of indications that must be in-situ leak tested is calculated for each SG and assessment. In-situ leak testing is then performed as necessary on the limiting SG to demonstrate compliance with the accident condition performance criteria.

## 9.1 SG Tube Inspection

During each outage in which the management program is utilized, a 100% bobbin coil inspection of the defined region (section 4.4) of in-service unsleeved tubes will be conducted in accordance with the requirements of the Entergy ANO-1 steam generator tube inspection guidelines. All OD indications reported as a result of this inspection will then be inspected with a RC. If the morphology is characterized as:

- ⇒ volumetric, then the indication will be treated as ODIGA.
- ⇒ mixed mode, (containing both volumetric characteristics of ODIGA and characteristics of crack initiation) then the indication will be treated as ODIGA that has developed a crack and will be repaired.
- ⇒ crack-like, (either axial or circumferential) then the indication will be treated as a crack and will be repaired.
- ⇒ no defect, if no indication is found then it will be assumed that the bobbin indication is not a defect.

The number of bobbin NQI indications that are confirmed volumetric plus any additional volumetric indications not reported by the bobbin examination but detected during the RC examination are considered to make up the detected population, $P_{det}$ for each steam generator.

## 9.2 Sizing of Volumetric ODIGA

All indications dispositioned as ODIGA will then be sized. Sizing includes determining a voltage amplitude, axial extent, and circumferential extent for each ODIGA patch. The NDE techniques used to perform these measurements, while not formally validated, are the best available methods and equipment available and also are chosen such that a viable comparison can be made with the previous inspection's EC data. For instance, based on extensive investigation, the best available correlation of EC voltage with ODIGA depth is the Plus-point coil. The Plus-point coil will therefore be utilized as the voltage amplitude comparison. The axial and circumferential extents shall be measured with the 0.115 inch pancake coil because it provides a more accurate measurement of axial and circumferential extent of ODIGA than the Plus-point coil.

If a new technique is used in an inspection, then the EC data from the previous inspection will be re-analyzed to provide an equivalent measurement comparison. If the new technique involves a different coil, or some other change that makes comparison with the previous outage impossible, then the current inspection's data will be re-analyzed in the manner utilized in the previous inspection and comparisons will be made using the old technique.

**Table 15 - EC Sizing Techniques and Notations**

| Sizing Parameter | EC Sizing Coil |
|---|---|
| Voltage | Plus-point |
| Axial Extent (inches) | 0.115 inch pancake |
| Circ. Extent (inches) | 0.115 inch pancake |

Note: As stated in text, the EC sizing coil is currently the best available technique and may be changed as new techniques become available.

## 9.3 Probability of Detection

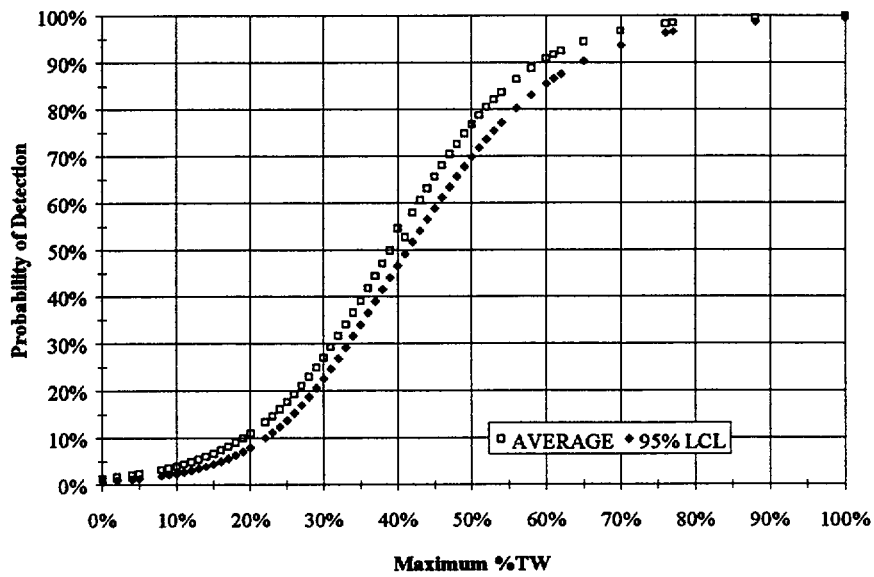
The purpose of POD is to quantify how reliably the ODIGA is detected. This probability is presented as a function of the maximum depth of the ODIGA. Quantifying the probability of detection is important when it is necessary to estimate the size of the ODIGA population based on the number of indications found during the EC examination.

For ODIGA, the performance criteria that requires estimating the population of the ODIGA is primary-to-secondary leakage (attributed to ODIGA) during a MSLB. The maximum depth of the ODIGA defect is the major determining factor when assessing the probability of leakage. For instance, a 10%TW ODIGA patch has almost no probability of leaking under MSLB conditions, but a 100%TW ODIGA patch has a high probability of leaking. As discussed in section 6.0, none of the defects that were tested under MSLB conditions leaked. That includes EDM holes up to 95%TW and 0.50 inches in diameter. This data supports the conclusion that for ODIGA to leak, it must be nearly 100%TW.

For purposes of this management program, the importance of POD is to increase the size of the population to account for indications with a reasonable probability of leaking under MSLB conditions. It will therefore be conservatively assumed that the maximum depth of ODIGA must be at least 70%TW for there to exist a reasonable probability of leakage. To determine the POD associated with ODIGA 70%TW or deeper, the validated bobbin POD logistic regression curve for ODIGA is utilized. This curve, shown in Figure 25, shows that the 95% lower confidence limit for detecting ODIGA 70%TW or deeper is greater than 90%. For this SGDSM, it is therefore assumed that 90% of the ODIGA defects with any chance of leaking will be found during an in-service inspection.

**Figure 25**

**POD for ODIGA**




Ideally, this POD value would be applied to the number of indications that are found during the in-service inspection and sized to be greater than or equal to 70%TW. This is not currently possible, however, because there is no qualified depth sizing technique. It will therefore be conservatively assumed that all the indications found are greater than 70%TW and the entire population will be increased by 10%. This will be done by first determining the potential number of indications not detected, $n$, by multiplying the number of ODIGA indications found by 0.10. The EC measured axial extents (this is the controlling parameter for conditional leak rate) of the indications found are then binned into 0.10-inch increments. Finally, each bin is increased by $n$ multiplied by the ratio of the bin size to the number of indications found. For instance, if 100 indications are found in OTSG A, then 10 indications are assumed to not be detected. The new amount is calculated in descending bin order, and fractions <1/2 are rounded down. Once the number of new indications is added, the process is stopped.

**Table 16 - Sample POD Adjustment**

| Axial Extent (inches) | Number of Indications Detected | Assumed Not Detected | ODIGA Population Size |
|---|---|---|---|
| 0.40 | 10 | 0.10*10=1 | 11 |
| 0.30 | 30 | 0.30*10=3 | 33 |
| 0.20 | 40 | 0.40*10=4 | 44 |
| 0.10 | 20 | 0.20*10=2 | 22 |

## 9.4 New Indications

As discussed in section 4.1, the volumetric ODIGA is believed to be attributed to sulfur ingress during the late 1970's and early 1980's. Consequently, no new indications are expected to be found. Given the small geometric sizes of the ODIGA, however, it is possible that as EC techniques and

equipment continue to improve, indications not previously reported are found. When an indication not previously reported is found, the EC inspection history will be reviewed to determine whether or not the indication was present. If it is determined that the new indication was present, then available EC data on that indication will be utilized in growth monitoring. If the indication is not located in the historical review, then the indication will be considered new. Newly identified ODIGA indications will be reviewed to determine if they meet the repair criteria, if not, they will be added to the database and tracked for growth.

## 9.5 EC Measurement Repair Limits

Repair limits are established in order to provide assurance that leak testing performed on volumetric ODIGA will bound indications that are left in-service based on this management program. Three EC measurements are performed on the volumetric ODIGA indications as discussed in section 8.2. These are the axial extent, circumferential extent, and voltage response.

The axial extent and circumferential extern repair limits are set at 0.50 inches based on the hot leak testing summarized in section 6.2. This testing included ODIGA and EDM samples with directly measured extents of approximately 0.50 inches and depths greater than 80%TW (refer to samples 112, 110, and 74 in Table 25). The 0.5 inch limit is considered conservative based on the fact that in application, the limit will be compared against an EC measurement which typically over-estimates the length.

The voltage repair limit is based on the Plus-Point 300 kHz voltage peak-to-peak response and is calibrated consistent with revision 5 of the EPRI PWR Steam Generator Examination Guidelines. The repair limit is set at 1.14 volts, which is the maximum in-situ test sample voltage of 1.26 (Table 24) minus 0.12 volts designated for EC variability.

**Table 17 - EC Measurement Repair Limits**

| Axial Extent (inches) | Circumferential Extent (inches) | Voltage |
|---|---|---|
| 0.50 | 0.50 | 1.14 |

In order to develop an appropriate allowance for Plus Point coil (and other coils) variability, a study was conducted. This study included the analysis of 6 independent acquisitions of 9 different laboratory ODIGA defects using the Plus Point, 0.115 inch pancake, and the axially wound and circumferentially wound coils. The samples were chosen to provide a range of depths for the study. The dimensional information can be found in Table 25. Two analysts using techniques consistent with revision 5 of the EPRI inspection guidelines performed the re-analysis.

The data is summarized by calculating the average and standard deviation for each sample and each coil utilized (Table 18). The numbers in bold italics note the coil that produced the greatest variability for that sample. The data shows that the pancake and circumferentially wound coils have the most variability for the samples evaluated. The maximum standard deviation of the Plus Point voltages is 0.06. A two-sided 95% confidence limit is approximated by twice the maximum standard deviation (0.12).

**Table 18 – Plus Point Voltage Variability**

| | Average Voltage | | | | Voltage Standard Deviation | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | Pancake | Plus Point | Axial | Circ. | Pancake | Plus Point | Axial | Circ. |
| 15 | 0.70 | 0.51 | 0.43 | 0.65 | **0.11** | 0.06 | 0.04 | 0.02 |
| 19 | 0.18 | 0.15 | 0.11 | 0.18 | **0.02** | 0.02 | 0.02 | 0.02 |
| 44 | 0.34 | 0.31 | 0.25 | 0.43 | **0.13** | 0.01 | 0.07 | 0.03 |
| 50 | 1.21 | 0.30 | 0.57 | 0.78 | 0.04 | 0.04 | 0.03 | **0.05** |
| 74 | 1.20 | 0.83 | 0.84 | 1.00 | **0.08** | 0.03 | 0.03 | 0.03 |
| 107 | 0.17 | 0.07 | 0.09 | 0.14 | 0.02 | 0.02 | 0.02 | **0.05** |
| 113 | 1.34 | 0.32 | 0.51 | 0.67 | **0.05** | 0.02 | 0.04 | 0.04 |
| 115 | 0.94 | 0.37 | 0.45 | 0.68 | 0.02 | 0.02 | 0.02 | **0.03** |
| 126 | 1.39 | 0.65 | 0.72 | 1.01 | **0.13** | 0.06 | 0.03 | 0.04 |

## 9.6 Condition Monitoring Assessment

Condition monitoring is the assessment of the "as found" condition of the tubing relative to the management program performance criteria. The "as found" condition refers to the condition of the tubes during a SG inspection outage, prior to any plugging or repair of tubes.

### 9.6.1 Apparent Growth Evaluation

The growth evaluation is performed for each SG using the process outlined in section 8.0 and is considered an "apparent" growth evaluation because it is based on the relative change in EC measurements as opposed to direct physical measurements. For each EC sizing parameter, the 95% confidence interval of the differences will be calculated. The number of indications includes all volumetric ODIGA indications detected and sized both at the beginning of the cycle (BOC) and the end of the cycle (EOC). Indications without BOC EC data are addressed by POD and are not included in the growth evaluation. The effects based on the outcome of this evaluation are discussed below.

If the assumption of "no growth" is supported, then it is assumed that the volumetric ODIGA is not changing. This allows the use of past tube destructive examination data and in-situ testing to be utilized. For instance, Table 23 and 24 show that 35 volumetric ODIGA defects in SG A and 20 volumetric ODIGA defects in SG B have been either destructively examined or in-situ leak tested. None have resulted in any leakage. This data is from the 1R13 and 1R14 in-service inspections. Growth evaluations performed during the 1R14 and 1R15 inspections supported "no growth" and therefore if "no growth" is again supported during future inspections, this data can be credited in the leakage assessments. The notation for previous test data is presented in Table 19.

**Table 19 - Previous Test Data Notation**

| Parameter (amount) | Notation | |
|---|---|---|
| | SG A | SG B |
| Samples Tested | $n_{Aprev}$ | $n_{Bprev}$ |
| Samples that Leaked | $X_{Aprev}$ | $X_{Bprev}$ |

9.6.2 Population Size Defined

The detected population is defined as all indications characterized by EC to be ODIGA during the current inspection (section 8.1). An additional number of indications is then included to account for limitations in the detection of indications. This adjustment for POD is made in accordance with section 7.2. If the conclusion of the apparent growth evaluation (section 8.3.1) is no growth, then previous testing data may be included in the population (section 8.3.2). In other words, if it is concluded that the population is not changing, testing performed during an earlier inspection may be treated as though it were being performed now. If it is concluded that the ODIGA indications are growing, then previous testing cannot be credited because the population is not the same and the previous testing term is set to zero. The notation for population size determination is presented in .

**Table 20 - Population Size Determination**

| | Population | |
|---|---|---|
| | SG A | SG B |
| Number of Detected Indications | $P_{Adet}$ | $P_{Bdet}$ |
| POD Adjustment | $+P_{Apod}$ | $+P_{Bpod}$ |
| Previous Testing Adjustment | $+n_{Aprev}$ | $+n_{Bprev}$ |
| Population | $P_A$ | $P_B$ |

9.6.3 Determination of Sample Size

Many repair criteria utilize a 40%TW repair limit. These criteria require a validated EC depth sizing technique. The limited structural impact that this damage mechanism has on the tube (for the axial and circumferential extents present in the steam generators), however, makes a 40%TW repair criteria overly conservative. To provide a more realistic assessment of the ODIGA, a program involving in-situ pressure testing will be utilized for monitoring the current condition of the tubes and assessing their future operability. Therefore, the next step in this assessment is to determine the number of ODIGA patches that must be tested to provide a high level of confidence (95% confidence level) that any primary-to-secondary leakage through ODIGA patches left in service is less than the amount allocated.

*9.6.3.1 Determine Allowable Number of Leaking Indications*

The first step is to define the allowable MSLB leakage rate for the population of ODIGA indications. The MSLB accident is considered the limiting accident condition for primary-to-secondary leakage, and the cumulative leakage rate from all leakage sources must be less than 1 gpm. Other potential sources of leakage include plugs, sleeves, other damage mechanisms, and repair rolls. Based on the condition of the generator, the allowed leakage rate for volumetric ODIGA may change from inspection to inspection and is therefore not set in this report.

The second step is to order the EC measured axial extents of the population from largest to smallest. Individual leak rates will be assigned to each indication according to the EC size bins of Table 7. (For example, all EC axial extents less than or equal to 0.20 inches are assigned a leakage rate of 0.0003 gpm.) The leakage rates are then summed from the largest axial extent to the smallest axial extent until the allowable MSLB leakage rate is met. This means that it is conservatively assumed that only the indications with the largest axial extents would leak. The variable $a$ is defined as the allowable number of leaking ODIGA indications in the SG.

*9.6.3.2 Hypergeometric Distribution*

The assessments make the conservative assumption that all ODIGA indications have an equal probability of leaking. The hypergeometric distribution involves sampling from a population without replacement. (Sampling with replacement would utilize the binomial distribution). The variables in the hypergeometric distribution are defined in Table 21 for each SG, but the derivation of the equations in this section uses the generic variable form.

**Table 21 - Hypergeometric Distribution Variables Defined**

| Variable | Section or Equation | | Description |
|---|---|---|---|
| | SG A | SG B | |
| $a$ | $a_A$, 8.3.3.1 | $a_B$, 8.3.3.1 | leaking indications in SG |
| $b$ | $b_A = P_A - a_A$ | $b_B = P_B - a_B$ | non-leaking indications in SG |
| $n$ | $n_A$, 8.3.3.2 | $n_B$, 8.3.3.2 | required sample from equation |
| $n_{test}$ | $n_{Atest} = n_A - n_{Aprev}$ | $n_{Btest} = n_B - n_{Bprev}$ | number of samples to test |
| $X_f$ | $X+X_{Aprev}$ | $X+X_{Bprev}$ | leaking indications in test sample |
| $P$ | $P_A$, 8.3.2 | $P_B$, 8.3.2 | number of indications in SG |

Note 1: initial assumption is no leaking indications will be found ($X$=0) in the tested sample size, so $X_f$ will always be zero unless previous test results ($X_{prev}$) are included and resulted in leakage.
Note 2: See section 9.3.1 for definition of $X_{Aprev}$, $X_{Bprev}$, $n_{Aprev}$, $n_{Bprev}$.

The hypergeometric distribution is defined as follows: Given a population with only two types of objects (indication leaks or doesn't leak), such that there are $a$ items of one kind (leaks) and $b$ items of another kind (doesn't leak) and $a+b$ equals the total population, the probability P(A) of selecting a sample size $n$ with $X_f$ items of type $a$ and $n$-$X_f$ items of type b is given in .

**Equation 1 Base Hypergeometric Distribution**

$$P(A) = \frac{{}_aC_{X_f} \times {}_bC_{n-X_f}}{{}_{(a+b)}C_n}$$

The above equation is the probability of having exactly $X_f$ leakers in a sample size of $n$. Based on this premise, if $X$ is set to zero and $X_{prev}$=0, then $P(A)$ is the probability of finding no leakers in a sample size of $n$. Therefore, 1-$P(A)$ is the probability of finding at least 1 leaker in the tested sample. This will serve as the basis for evaluating the condition of the tubes. Setting the probability that zero leakers will be found in the sample to 0.05 results in a 95% probability that at least one leaker will be found in the tested sample if a specific number of leakers exist in the population.

**Equation 2 Probability of at Least One Leaker**

$$1-P(0_leaks)=1-\frac{{}_aC_0\times{}_bC_n}{{}_{(a+b)}C_n}=0.95$$

Equation 2 is set up to determine the required sample size $n$ that must be tested to have a 95% confidence that no more than $a$ leakers are in the population because 0 leakers were found in the sample tested. It is reiterated at this point that this equation takes no credit for any knowledge of the EC sizing information, resulting in each indication being treated equally with respect to the probability of leakage. This is a conservative assumption because the allowable number of leaking indications is based on the assumption that the indications with the largest axial extents leak.

For the case where one or more leaking ODIGA patches is found in the tested sample, the cumulative sum of the probabilities is subtracted from one . Equation 3 represents the probability of finding $d$ leaks in a sample size $n$, given $a$ leaking patches in the population.

**Equation 3 Probability of "d" Leakers in Tested Sample**

$$P(d_leaks)=1-\sum_{X_f=0}^{d}\frac{{}_aC_{X_f}\times{}_bC_{n-X_f}}{{}_{(a+b)}C_n}=0.95$$

*9.6.3.3 Sample Size Defined*

The required sample size, $n$, is therefore determined by solving either Equation 2 or Equation 3 for $n$. For instance, assume that it is determined that an SG has an ODIGA population of 130 indications and that this population includes 35 indications that had previously been tested with no leaking indications found. Further assume that the allowable leakage rate is set to 0.2 gpm, resulting in an allowable number of leaking indications equal to 15. Solving Equation 2 for $n$ yields:

**Equation 4 Example of Sample Size Determination**

$$1-P(0_leaks)=1-\frac{{}_{15}C_0\times{}_{115}C_n}{{}_{(130)}C_n}=0.95$$

$$n=22, \text{ and}$$

$$n_{prev}=35, \text{ so}$$

$$n_{test}=n-n_{prev}<0$$

The final sample size to be tested is equal to the sample size $n$ minus the number of indications previously tested $n_{prev}$. In this example, comparing the number of indications previously tested (35) to the number required (22) shows that more than the required sample size has been tested, so further in-situ testing is not needed. If $n_{test}$ is greater than zero, then in-situ leak testing must be performed on the limiting SG. The limiting SG is the SG that has the larger required sample size to test.

9.6.4 In-Situ Leak Testing

The purpose of the in-situ pressure testing is to provide a means of validating the premise that leaving tubes with ODIGA in-service will not result in MSLB primary-to-secondary leakage rates in excess of the plant technical specification allowable. As discussed in section 6.3, the most probable cause of leakage is through the development of an axial crack in the ODIGA during plant operation. Leak

tests will therefore be conducted at MSLB pressure differential of 2575 psi without a specific axial load in order to maximize the hoop stress in the tube. If the indication leaks at this pressure, then the test will be repeated with the maximum axial load and the associated MSLB pressure differential.

Upon completion of the leak testing, the results are compared against the required sample size to ensure that enough indications were tested. If any indications leaked, then the required sample size must be recalculated using Equation 3, and more tests may have to be performed.

9.6.5 Reporting Requirements

The results of the inspection and assessment of tubes with volumetric ODIGA in the defined region shall be included in the in-service inspection report. This report shall include the number of detected ODIGA indications in each SG, the number of ODIGA indications left in service, and the total MSLB leakage predicted for the limiting SG.

## 9.7 Operational Assessment

The operational assessment is performed to ensure that the performance criteria will be maintained over the next scheduled steam generator in-service inspection interval. The length of the operating cycle prior to the next scheduled inspection is utilized to determine appropriate growth rates for the volumetric ODIGA. It is noted that although general procedure appears to be the same for both the condition monitoring and operational assessments, the specific requirements change due to assessing the predicted population at the end of the next cycle of operation.

9.7.1 Apparent Growth Evaluation

The growth evaluation is performed for each SG using the process outlined in section 7.1.2 and is considered an "apparent" growth evaluation because it is based on the relative change in EC measurements as opposed to direct physical measurements. For each EC sizing parameter, the 95% confidence interval of the differences will be calculated. The number of indications includes all volumetric ODIGA indications detected and sized both at the beginning of the cycle (BOC) and the end of the cycle (EOC). Indications without BOC EC data are addressed by POD and are not included in the growth evaluation. As stated in section 7.1, if two of the three parameters do not support the assumption of "no growth", then "no growth" cannot be assumed. The effects based on the outcome of this evaluation are discussed below.

*9.7.1.1 Credit for Previous Testing*

This portion of the assessment is the same for both assessments. Refer to section 8.3.1.

*9.7.1.2 Projected EOC Indication Sizes*

When performing the operability assessment for each SG, the EOC measurements used in the growth evaluation become the BOC measurements for the next cycle of operation. The operability assessment, however, is based on the projected EOC measurements for the next cycle. If the "no growth" assumption is not supported, the projected EOC measurements of axial and circumferential extents are estimated by increasing the BOC measurements by the upper 95% confidence value for growth. This growth term is determined by multiplying the upper 95% confidence value calculated in by the ratio of the next cycle's run time to the just completed cycle run time (in units of EFPY). If

the "no growth" assumption is supported, then the projected EOC measurements are simply the BOC measurements. The equations to calculate the projected EOC measurements are given in Equation 5 and Equation 6 .

**Equation 5 Projected EOC Axial Extent**

$$A_{EOC} = A_{BOC} + A_{\Delta 95} \times (\frac{EFPY_{projected}}{EFPY_{completed}})$$

**Equation 6 Project EOC Circumferential Extent**

$$C_{EOC} = C_{BOC} + C_{\Delta 95} \times (\frac{EFPY_{projected}}{EFPY_{completed}})$$

9.7.2 Tube Repairs

The operational assessment considers all indications that will be in-service during the next cycle of operation. Indications in tubes that will be repaired or taken out of service during the current inspection are therefore not considered in this assessment. As part of this management program, all tubes with volumetric ODIGA projected to have circumferential extents in excess of 90° at the end of the next cycle of operation must be repaired or removed from service. This extent limit is conservatively applied to ensure that the circumferential extents of the volumetric ODIGA remain bounded by what has been tested (section 6.2).

9.7.3 Population Size Defined

The detected population is defined as all indications characterized by EC to be ODIGA during the current inspection (section 9.1). All indications that are repaired or removed from service in accordance with section 9.5 are removed from consideration. An additional number of indications is then included to account for limitations in the detection of indications. This adjustment for POD is made in accordance with section 9.3. If the conclusion of the apparent growth evaluation (section 8.3) is no growth, then previous testing data may be included in the population. In other words, if it is concluded that the population is not changing, testing performed during an earlier inspection may be treated as though it were being performed now. If it is concluded that the ODIGA indications are growing, then previous testing cannot be credited because the population is not the same and the term is set to zero. The notation for population size determination is presented in .

**Table 22 - Population Size Determination**

| | Population | |
|---|---|---|
| | SG A | SG B |
| Number of Detected Indications | $P_{Adet}$ | $P_{Bdet}$ |
| Indications Repaired/Plugged | $P_{Arep}$ | $P_{Brep}$ |
| POD Adjustment | $+P_{Apod}$ | $+P_{Bpod}$ |
| Previous Testing Adjustment | $+n_{Aprev}$ | $+n_{Bprev}$ |
| Population | $P_A$ | $P_B$ |

**Table 23 - Pulled Tube Data Summary**

| Identification | | | | | Direct Measurement | | | |
|---|---|---|---|---|---|---|---|---|
| Type | OTSG | Row | Tube | Position | Max Depth (%TW) | Axial Extent (inches) | Circ. Extent (inches) | Burst Pressure (psi) |
| ODIGA | B | 73 | 8 | UTE - 18.00 | 50% | (2) | (2) | (2) |
| Unflawed | B | 79 | 63 | -- | (1) | (1) | (1) | 11,100 |
| ODIGA | B | 79 | 63 | UTE - 21.31 | 77% | 0.12 | (2) | 10,400 |
| ODIGA | B | 79 | 63 | UTE - 20.60 | 35% | (2) | (2) | (3) |
| ODIGA | B | 79 | 63 | UTE - 20.33 | 88% | 0.16 | (2) | (3) |
| ODIGA | B | 79 | 63 | UTE - 20.08 | 24% | 0.035 | (2) | (3) |
| ODIGA | B | 79 | 63 | UTE - 20.04 | 38% | 0.071 | (2) | (3) |
| ODIGA | B | 79 | 63 | UTE - 19.96 | 25% | 0.043 | (2) | (3) |
| ODIGA | B | 79 | 63 | UTE - 19.73 | 61% | 0.23 | (2) | (3) |
| Unflawed | B | 80 | 18 | -- | (1) | (1) | (1) | 11,200 |
| ODIGA | B | 80 | 18 | UTE - 18.00 | 76% | (2) | 0.1350 | (3) |
| ODIGA | B | 80 | 18 | UTE - 16.76 | 52% | 0.142 | (2) | 11,000 |
| ODIGA | B | 80 | 18 | UTE - 15.24 | 44% | 0.09 | (2) | (3) |
| ODIGA | B | 80 | 18 | UTE - 12.53 | 65% | 0.057 | 0.1830 | (3) |
| Unflawed | B | 83 | 47 | -- | (1) | (1) | (1) | 10,700 |
| ODIGA | B | 83 | 47 | UTE - 17.25 | 83% | 0.161 | (2) | 10,000 |
| ODIGA | B | 83 | 47 | UTE - 14.90 | 58% | 0.045 | (2) | (3) |
| ODIGA | B | 83 | 47 | UTE - 14.73 | 41% | 0.072 | (2) | (3) |
| ODIGA | B | 83 | 47 | UTE - 14.73 | 58% | 0.06 | (2) | (3) |

Notes:

(1) test not performed due to sample type
(2) data not available
(3) burst away from defect
(4) detected as one indication by EC

**Table 24 - In-Situ Pressure Testing Data Summary**

| Identification | | | | | EC Measurements | | | In-situ |
|---|---|---|---|---|---|---|---|---|
| Index No. | OTSG | Row | Tube | Position | Bobbin Voltage | RC Axial Extent (inches) | RC Circ. Extent (inches) | Test Condition Codes |
| 1 | A | 47 | 4 | UTE - 11.96 | 0.53 | 0.17 | 0.18 | 1 |
| 2 | A | 47 | 4 | UTE - 13.33 | 0.48 | 0.17 | 0.18 | 1 |
| 3 | A | 51 | 116 | UTE - 15.09 | 0.38 | 0.17 | 0.18 | 1 |
| 4 | A | 51 | 116 | UTE - 18.54 | 1.00 | 0.17 | 0.18 | 1 |
| 5 | A | 53 | 109 | UTE - 14.27 | 0.40 | 0.13 | 0.18 | 1 |
| 6 | A | 53 | 109 | UTE - 14.48 | 0.40 | 0.17 | 0.18 | 1 |
| 7 | A | 53 | 109 | UTE - 19.14 | 0.38 | 0.17 | 0.12 | 1 |
| 8 | A | 69 | 40 | UTE - 3.67 | 0.47 | 0.21 | 0.22 | 1 |
| 9 | A | 69 | 40 | UTE - 14.23 | 1.04 | 0.31 | 0.33 | 1 |
| 10 | A | 69 | 54 | UTE - 5.8 | 0.38 | 0.25 | 0.28 | 1 |
| 11 | A | 69 | 54 | UTE - 10.27 | 1.60 | 0.31 | 0.28 | 1 |
| 12 | A | 70 | 21 | UTE - 3.62 | 1.64 | 0.24 | 0.28 | 1 |
| 13 | A | 70 | 21 | UTE - 15.26 | 0.46 | 0.19 | 0.22 | 1 |
| 14 | A | 71 | 19 | UTE - 13.9 | 0.27 | 0.19 | 0.22 | 1 |
| 15 | A | 71 | 19 | UTE - 17.17 | 1.12 | 0.24 | 0.28 | 1 |
| 16 | A | 78 | 46 | UTE - 22.8 | 0.41 | 0.18 | 0.24 | 1 |
| 17 | A | 78 | 46 | UTE - 23.12 | 0.32 | 0.18 | 0.24 | 1 |
| 18 | A | 80 | 14 | UTE - 13.74 | 0.42 | 0.18 | 0.18 | 1 |
| 19 | A | 80 | 14 | UTE - 19.44 | 0.55 | 0.18 | 0.18 | 1 |
| 20 | A | 81 | 55 | UTE - 7.99 | 0.25 | 0.18 | 0.24 | 1 |
| 21 | A | 81 | 55 | UTE - 10.93 | 0.25 | 0.18 | 0.18 | 1 |
| 22 | A | 81 | 55 | UTE - 11.93 | 0.25 | 0.18 | 0.18 | 1 |
| 23 | A | 81 | 55 | UTE - 12.17 | 0.33 | 0.12 | 0.18 | 1 |
| 24 | A | 91 | 56 | UTE - 7.6 | 0.68 | 0.13 | 0.17 | 1 |
| 25 | A | 91 | 56 | UTE - 8.96 | 0.36 | 0.13 | 0.22 | 1 |
| 26 | A | 92 | 4 | UTE - 6.11 | 0.36 | 0.18 | 0.23 | 1 |
| 27 | A | 92 | 4 | UTE - 6.6 | 0.48 | 0.12 | 0.18 | 1 |
| 28 | A | 92 | 4 | UTE - 6.67 | 0.36 | 0.18 | 0.24 | 1 |
| 29 | A | 92 | 4 | UTE - 16.61 | 0.33 | 0.18 | 0.23 | 1 |
| 30 | A | 94 | 2 | UTE - 17.59 | 0.96 | 0.20 | 0.17 | 1 |
| 31 | A | 94 | 2 | UTE - 22.91 | 0.65 | 0.20 | 0.17 | 1 |
| 32 | A | 104 | 15 | UTE - 11.46 | 1.61 | 0.24 | 0.24 | 1,3 |
| 33 | A | 104 | 15 | UTE - 14.98 | 1.87 | 0.24 | 0.30 | 1,3 |

| Identification | | | | | EC Measurements | | | In-situ |
|---|---|---|---|---|---|---|---|---|
| Index No. | OTSG | Row | Tube | Position | Bobbin Voltage | RC Axial Extent (inches) | RC Circ. Extent (inches) | Test Condition Codes |
| 34 | A | 107 | 14 | UTE - 10.67 | 0.87 | 0.18 | 0.18 | 1 |
| 35 | A | 107 | 14 | UTE - 17.52 | 0.33 | 0.18 | 0.18 | 1 |
| 36 | B | 37 | 114 | UTE - 2.66 | 1.91 | 0.28 | 0.37 | 3 |
| 37 | B | 58 | 87 | UTE - 16.93 | 0.74 | 0.33 | 0.31 | 1 |
| 38 | B | 64 | 51 | UTE - 18.90 | 1.67 | 0.10 | 0.18 | 2 |
| 39 | B | 95 | 68 | UTE - 3.4 | 1.80 | 0.25 | 0.25 | 3 |
| 40 | B | 103 | 17 | UTE - 17.58 | 0.85 | 0.43 | 0.43 | 2 |

Test Conditions:

(1) Maximum pressure of 2900 psig and axial load of 1402 lbs.

(2) Maximum pressure of 2900 psig.

(3) Maximum pressure of 6500 psig.

**Table 25 - Unbent Lab Sample Data Summary**

| Identification | | Direct Measurement | | | | EC Measurements | | |
|---|---|---|---|---|---|---|---|---|
| Type | Sample Number | Max Depth (%TW) | Axial Extent (inches) | Circ. Extent (inches) | Burst Pressure (psi) | Bobbin Voltage | RC Axial Extent (inches) | RC Circ Extent (inches) |
| Unflawed | -- | (1) | (1) | (1) | 11,672 | (1) | (1) | (1) |
| EDM | 27 | 86% | 0.3000 | 0.3000 | (1) | (1) | (1) | (1) |
| EDM | 52 | 86% | 0.3000 | 0.3000 | (1) | (1) | (1) | (1) |
| EDM | 112 | 89% | 0.5000 | 0.5000 | (1) | (1) | (1) | (1) |
| EDM | 110 | 95% | 0.5000 | 0.5000 | (1) | (1) | (1) | (1) |
| ODIGA | 4 | 26% | 0.1900 | 0.1865 | 11,705 | 0.13 | 0.24 | 0.33 |
| ODIGA | 15 | 84% | 0.0790 | 0.0890 | 10,660 | 0.77 | 0.36 | 0.34 |
| ODIGA | 19 | 28% | 0.0620 | 0.2845 | 11,718 | 0.47 | 0.34 | 0.34 |
| ODIGA | 21 | 31% | 0.4700 | 0.2060 | 11,220 | 0.12 | NDF | NDF |
| ODIGA | 24 | 22% | 0.1165 | 0.1285 | 11,698 | 0.13 | NDF | NDF |
| ODIGA | 26 | 54% | 0.1225 | 0.1265 | 11,162 | 0.74 | 0.33 | 0.36 |
| ODIGA | 29 | 48% | 0.1125 | 0.2155 | 11,077 | 0.33 | 0.29 | 0.36 |
| ODIGA | 31 | 31% | 0.1445 | 0.1590 | 11,608 | 0.32 | 0.38 | 0.35 |
| ODIGA | 32 | 22% | 0.1105 | 0.2190 | 11,716 | 0.21 | 0.32 | 0.36 |
| ODIGA | 33 | 47% | 0.1305 | 0.1610 | 11,182 | 1.43 | 0.33 | 0.37 |
| ODIGA | 44 | 59% | 0.1485 | 0.1680 | 10,812 | 0.58 | 0.35 | 0.35 |
| ODIGA | 45 | 59% | 0.2260 | 0.2505 | 10,968 | 0.68 | 0.35 | 0.49 |
| ODIGA | 46 | 49% | 0.1800 | 0.2165 | 11,354 | 0.91 | 0.35 | 0.39 |
| ODIGA | 47 | 22% | 0.2445 | 0.1117 | 11,644 | 0.12 | 0.30 | 0.28 |
| ODIGA | 48 | 44% | 0.2350 | 0.1020 | 10,797 | 0.37 | 0.44 | 0.32 |
| ODIGA | 50 | 42% | 0.2290 | 0.2630 | 11,060 | 1.62 | 0.46 | 0.47 |
| ODIGA | 51 | 34% | 0.2405 | 0.2565 | 11,509 | 0.28 | 0.42 | 0.38 |
| ODIGA | 53 | 47% | 0.2345 | 0.0915 | 10,888 | 0.37 | 0.47 | 0.35 |
| ODIGA | 55 | 35% | 0.2175 | 0.3545 | 11,673 | 0.74 | 0.38 | 0.53 |
| ODIGA | 74 | 83% | 0.4945 | 0.2835 | 9,040 | 1.38 | 0.47 | 0.35 |
| ODIGA | 75 | 65% | 0.2325 | 0.0955 | 10,444 | 0.74 | 0.33 | 0.37 |
| ODIGA | 82 | 16% | 0.4940 | 0.2705 | 10,990 | 0.04 | NDF | NDF |
| ODIGA | 88 | 13% | 0.5115 | 0.2630 | 11,625 | NDD | NDF | NDF |
| ODIGA | 96 | 26% | 0.4585 | 0.4495 | 11,534 | 0.27 | NDF | NDF |
| ODIGA | 98 | 48% | 0.4260 | 0.0975 | 10,329 | 0.36 | 0.56 | 0.32 |
| ODIGA | 99 | 37% | 0.5075 | 0.2155 | 11,233 | 0.14 | NDF | NDF |
| ODIGA | 107 | 23% | 0.2960 | 0.2915 | 11,554 | 0.28 | 0.48 | 0.37 |
| ODIGA | 113 | 58% | 0.2630 | 0.2635 | 10,682 | 1.12 | 0.45 | 0.44 |
| ODIGA | 115 | 40% | 0.3210 | 0.1725 | 10,457 | 0.77 | 0.56 | 0.37 |
| ODIGA | 126 | 98% | 0.2720 | 0.2590 | 9,969 | 1.46 | 0.41 | 0.41 |

Notes:

(1) test not performed due to sample type

## 10.0 GROWTH ALLOWANCE FOR OPERATIONAL ASSESSMENTS

### 10.1 INTRODUCTION

Operational Assessments of steam generator tube integrity account for the possibility that tube degradation will progress during further plant operation at normal temperatures. Further degradation of existing flaws is characterized by growth of the flaw, with growth in the axial direction of particular concern. An allowance for individual flaw growth can be calculated from the statistics of apparent growth (conservative results) or from the models for actual growth (components of variance analysis or EIV model evaluations) which yield more realistic results. The mechanics for separating actual growth from NDE uncertainty were discussed in earlier sections of this report; refer to Sections 7.1.3 and 7.1.4 for details.

### 10.2 DETERMINISTIC ASSESSMENTS

A one-sided upper 95/95 limit provides a conventional level of probability/confidence for use in simplified deterministic operational assessments. This is the type of assessment that is typically used for steam generators where there has been no history of structurally challenging defects for the subject degradation mechanism. In instances where the type of degradation mechanism has yielded structurally challenging flaws (i.e. flaws that leaked excessively or burst when subject to in-situ burst/leak testing), probabilistic assessments have often been required to demonstrate confidence that the risk of tube rupture and leakage is within acceptable limits.

Two methods are standard for calculating 95/95 limits: a procedure that is derived from the non-central t distribution for samples from the normal distribution and a distribution-free method that is derived from the binomial distribution for samples from non-normal distributions. These two methods will be outlined in procedure form.

#### 10.2.1 95/95 Limits for Normal Distribution

The apparent growth of ANO-1 IGA flaws (+Point volts, axial length and circumferential extent) based on current field data is approximately normally distributed. Because there are a large number of ANO-1 IGA flaws inservice and standard statistical tests for normality are overly sensitive for large data sets, the recommended approach is to use a normal probability graph of the growth data to provide a qualitative assessment of their distribution. The point is to use the normal probability graph to identify gross departures from normality that will invalidate the 95/95 limits obtained by normal theory methods. In such a case, it is necessary to use the distribution-free method described in Section 10.2.2 to obtain an accurate 95/95 limit.

Figure 26 provides an example normal probability plot graph for the apparent growth in SGA axial lengths. Close agreement between the data and the expected probability for a normal distribution are evidenced by small departures from the theoretical line. Large differences, particularly in the high extremes, are indicative of data that are not well represented by a normal distribution.

An upper one-sided 95/95 limit provides a growth value such that at least a proportion, P=95%, of the population of flaws has a growth value less than the value of $\overline{X} + kS$ with 95% confidence. The so-called k-factor for a one-sided limit is available in tables (Ref. 9) and in some commercial software packages. For large sample sizes above 60, the 95% value of the normal distribution (1.645) provides a close approximation to k.

10.2.2 95/95 Limits by distribution-free Method

When the sample is not drawn from a normal distribution, 95/95 limits can be calculated by distribution-free methods. The 95/95 limit value for a sample of n growth values can be determined by ordering the values from lowest to highest. The one-sided upper 95/95 limit is then the $m^{th}$ largest value where values of the index m are provided in Table 26 (reproduced from Ref. 2.17).

## 10.3 PROBABILISTIC ASSESSMENTS

Probabilistic assessments typically incorporate more complete information about the distribution of growth for a particular degradation mechanism. Specifics of the growth model may vary, although they usually account for a number of factors, including:

- dependence/independence of growth on size
- separation of NDE uncertainties from actual growth
- statistical models/parameter estimation for variability of growth

Typically, the growth model is one variable that is incorporated in a Monte Carlo simulation evaluation of the probability of burst and accident leakage.

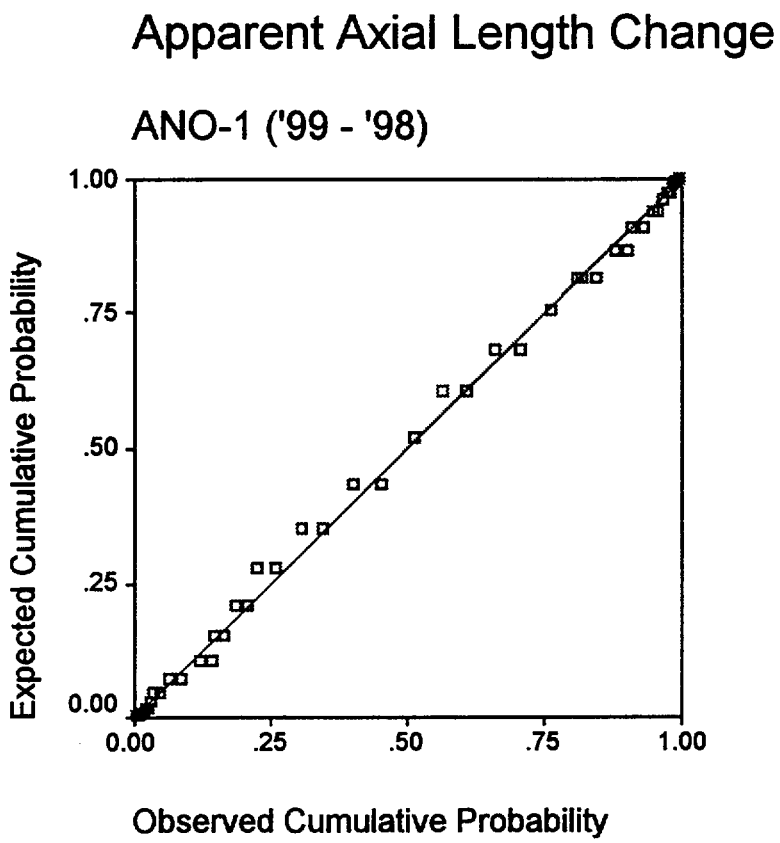



Figure 26. Normal Probability Plot

Table 26

One-Sided Distribution-Free Tolerance Limit Indices

| N | M |
|---|---|
| 50 | - |
| 55 | - |
| 60 | 1 |
| 65 | 1 |
| 70 | 1 |
| 75 | 1 |
| 80 | 1 |
| 85 | 1 |
| 90 | 1 |
| 95 | 2 |
| 100 | 2 |
| 110 | 2 |
| 120 | 2 |
| 130 | 3 |
| 140 | 3 |
| 150 | 3 |
| 170 | 4 |
| 200 | 5 |
| 300 | 9 |
| 400 | 13 |
| 500 | 17 |
| 600 | 21 |
| 700 | 26 |
| 800 | 30 |
| 900 | 35 |
| 1000 | 39 |

## 11.0 EXAMPLE APPLICATION TO ANO-1

The procedure described in Sections 9 and 10 was applied to the ANO-1 data from the most recent inspections. Results are provided in Sections 11.1 and 11.2 for the Step I evaluation of the ANO-1 IGA flaws from SG A.

### 11.1 EXAMPLE OF GENERALIZED TEST FOR CHANGE IN AXIAL LENGTH AND +POINT VOLTS

The +Point volts and axial length data from the '98 and '99 inspections of the SG A IGA flaws at the upper tube sheet were used to perform an example calculation of the generalized test. Table 27 summarizes the results. Since $T^2$ does not exceed the test statistic $\left(T_0^2\right)$, no statistically significant change in the two population is indicated from these large data sets.

### 11.2 EXAMPLE CALCULATION OF EXTREME VALUE TEST

The axial length data set was then evaluated with the extreme value test. Table 28 provides the results. Since the largest value does not exceed the 95% limit on the extreme value, no statistically significant difference in extreme value is indicated.

Since both the generalized test and the extreme value test results indicate that there is no significant change in the IGA flaws in SG A, Step I is satisfied and the Condition Monitoring procedure is complete as per Figure 24.

### 11.3 EXAMPLE CALCULATION OF 95/95 ALLOWANCES

The one-sided 95/95 limits for axial length growth were calculated for the case of the normal distribution. The results are provided in Table 29.

Table 27

EXAMPLE OF GENERALIZED TEST FOR AXIAL LENGTH, +POINT VOLTS

| Variable | Value |
|---|---|
| $d_1$ | -0.0023 |
| $d_2$ | -0.0118 |
| $S_{x_1}^2$ | 0.0020 |
| $S_{y_1}^2$ | 0.0021 |
| $S_{x_1y_1}$ | 0.0009 |
| $S_{x_2}^2$ | 0.0256 |
| $S_{y_2}^2$ | 0.0295 |
| $S_{x_2y_2}$ | 0.0257 |
| $S_1^2$ | 0.0020 |
| $S_2^2$ | 0.0276 |
| $S_{12}$ | 0.0133 |
| r | 1.7773 |
| $S_{d_1}$ | 0.0056 |
| $S_{d_2}$ | 0.0205 |
| $t_1$ | -0.4168 |
| $t_2$ | -0.5776 |
| $T^2$ | 0.1614 |
| $F_{.95,2,(n_1+n_2-3)}$ | 3.0129 |
| $T_0^2$ | 6.0374 |

Table 28

EXAMPLE OF EXTREME VALUE TEST FOR SG A AXIAL LENGTH

| Variable | Value |
|---|---|
| Largest Axial Length Change, in. | 0.160 |
| Extreme Value Model | |
| $\mu$ | 0.124 |
| $\sigma$ | 0.014 |
| 95% Value | 0.167 |

Table 29

EXAMPLE OF 95/95 LIMIT FOR SG A AXIAL LENGTH

| Variable | Value |
|---|---|
| Mean Growth, in. | -0.00232 |
| Standard Deviation, in. | 0.0468 |
| k | 1.645 |
| 95/95 Limit | 0.075 |