Entergy

Entergy Operations, Inc.
1448 S.R. 333
Russellville, AR 72802
Tel 501 858 5000

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1CAN030101

U. S. Nuclear Regulatory Commission
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Washington, DC 20555

Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
Response To NRC Requests For Additional Information On ANO-1 Steam Generator ODIGA

Gentlemen:

On August 29, 2000 (1CAN080005), Entergy submitted a request for an Operating License Amendment associated with the Arkansas Nuclear One, Unit 1 (ANO-1) steam generator outer diameter intergranular attack (ODIGA). The proposed amendment modified the 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 ODIGA within the upper tubesheet. The proposed alternate repair criteria (ARC) for ODIGA are necessary to allow continued operation of ANO-1 for 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. 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. As a result, information was presented that assumes if 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 proposed that the amendment request be reviewed under the guidelines of Regulatory Guide 1.174 as a risk informed amendment.

A public meeting was held between Entergy and representatives of the NRC Staff on January 22, 2001 to discuss the Entergy request for amendment regarding the ANO-1 OTSG ODIGA. At this meeting, initial responses to questions by members of the Staff were discussed. A subsequent telephone call was conducted on February 2, 2001 to address additional questions from the NRC Staff. The formal requests for additional information (RAIs) were received from the NRC on February 20, 2001. This submittal provides the ANO-1 response to these RAIs.

A001

Entergy has modified 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*" to further support the ODIGA growth projection uncertainty. Specifically, Section 8.3.4 has been modified to add the following statement:

> Any growth analysis performed using the Cycle Specific Growth Model described here will require a revision to this report to include information substantiating the growth conclusions reached and the basis for the conclusions. The revised report will be submitted in a license amendment to the NRC well ahead of the subsequent refueling outage with any actions to address potential growth.

In addition, based on the attached response to the NRC RAIs, Entergy is also replacing the generalized t-test with a combination of a sign test, a paired t-test and an extreme value test for potential ODIGA growth assessment. The attached engineering report has been appropriately modified to reflect this application.

A copy of Engineering Report No. 00-R-1005-01 is enclosed as Revision 1. Entergy has also modified the previously proposed TS 4.18.5.7 (TS page 110m) to add "Revision 1" to the referenced ANO Engineering Report 00-R-1005-01. The no significant hazards considerations contained in our August 29, 2000 letter are unchanged as a result of this proposed modification to the TSs.

As discussed above, Entergy had proposed that the amendment request be reviewed as a risk informed amendment. However, the NRC has determined that a risk-informed approach is not required in order to approve the ODIGA ARC. Therefore, Entergy is withdrawing the risk-informed portion from our amendment request. We request to have the ARC proposed by this amendment request approved for the upcoming 1R16 refueling outage currently scheduled to begin on March 16, 2001. The above growth analysis statement will not be tracked as a separate commitment since it is an integral part of Engineering Report No. 00-R-1005-01.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 2, 2001.

Very truly yours,

Jimmy D. Vandergrift
Director, Nuclear Safety Assurance

JDV/sab
Attachment

cc: Mr. Ellis W. Merschoff
Regional Administrator
U. S. Nuclear Regulatory Commission
Region IV
611 Ryan Plaza Drive, Suite 400
Arlington, TX 76011-8064

NRC Senior Resident Inspector
Arkansas Nuclear One
P.O. Box 310
London, AR 72847

Mr. William Reckley
NRR Project Manager Region IV/ANO-1
U. S. Nuclear Regulatory Commission
NRR Mail Stop O-7 D1
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

ANO-1 Requests for Additional Information to the ODIGA Amendment Request Dated August 29, 2000

NRC RAI 1:

What was the population size for outer diameter intergranular attack (ODIGA) detected in the upper tubesheet in each SG for 1R14 (and 1R13), compared with 1R15?

ANO-1 Response to RAI 1:

The following table represents the total tubes detected having upper tubesheet (UTS) ODIGA indications and the total number of indications detected (some tubes have multiple indications):

S/G	1R14 Outage[1] (Tubes/Indications)	1R15 Outage[2] (Tubes/Indications)
A	280/332	291/332
B	137/173	145/209

1 - The 1R14 information was submitted under letter 1CAN069806, dated June 15, 1998.
2 - The 1R15 information was submitted under letter 1CAN010001, dated January 3, 2000.

The data between 1R14 and 1R15 is considered to compare favorably within the uncertainty of detection. The B SG tubes and indications, on first glance, appear to have increased. However, with consideration of such factors as detection repeatability of smaller indications within the probability of detection and analyst variability, these differences are still considered to be acceptable. A review of the 1R15 data confirmed that the additional indications were generally small amplitude indications, which would provide a lower detection capability (i.e. < 0.3 V).

The ODIGA data for 1R13 resulted in 321 tubes with a total of 349 indications in the A SG and 204 tubes with 240 indications in the B SG which was based on only bobbin data. However, a direct comparison to 1R13 data cannot be made since only a limited MRPC exam of the bobbin calls in the UTS was accomplished. The probe used was a 3-coil MRPC (pancake, axial, and circ directed coil) probe. The plus-point was used for the first time during 1R14, which gave the analyst the ability to better characterize the indications in the UTS.

NRC RAI 2:

From the 10/4/99 NRC safety evaluation (SE) for License Amendment 202, approving the one-cycle alternate repair criteria for flawed tubes that have experienced ODIGA, the following statement was made:

> "The staff notes that the leakage through ODIGA degradation is calculated using a computer code that has not been reviewed and approved for use by the NRC. In particular, the code needs to be benchmarked against actual leakage data for flawed test specimens representative of the ODIGA flaws at ANO-1. Therefore, uncertainties associated with the leak rate estimates need to be quantified and taken into consideration to ensure they are conservative."

How was the computer code used for calculating leakage benchmarked against actual leakage data for ODIGA flaws, and how are associated uncertainties treated?

ANO-1 Response to RAI 2:

The code used to estimate the leakrates (KRACKFLO3) is a certified code that has been compared with PICEP as part of the certification. The temperatures, pressures and material properties will affect the leak rate results. The calculations used in KRACKFLO3 are based on the maximum achievable MSLB primary-to-secondary pressure differential and take no credit for any ligaments or turns. The same input information used in the KRACKFLO3 code was also used in PICEP code and similar results were obtained.

Uncertainties in the leak rates include:

Crack Dimensions – RPC typically overestimates the dimensions of ODIGA indications; therefore, the crack dimensions would typically be overestimated;

Indication Depth – All indications are assumed to develop a 100% TW crack over 25% of the axial extent of the ODIGA indication. Though there is no qualified depth-sizing technique, the assumption that every indication has some 100% TW component is conservative, based on pulled tube evaluations and insitu pressure tests.

Ligament and Turns with the Postulated Crack – The leak rates were developed assuming no ligaments are present and no turns in the flow path are present, which results in a conservative leak rate, compared to actual cracks in the OTSG tubing where the flow path would typically be more tortuous.

NRC RAI 3:

In the 10/4/99 SE for License Amendment 202, the staff stated that the licensee had evaluated the data per the proposed growth rate criteria and concluded that growth was not occurring. If small ODIGA patches not detected by eddy current testing are present in the areas of the tube selected for possible rerolls, how will the growth of the ODIGA patches be affected by reroll operations?

ANO-1 Response to RAI 3:

In ANO letter dated February 19, 2001, we discussed testing that was performed on ODIGA where it had been roller expanded. ODIGA was produced in the laboratory in tubes which subsequently had sleeves installed and expanded into the tube. No increase ODIGA penetration depth was observed. No evidence of either intergranular or transgranular cracking due to rolling was found and penetration depths were found to be in the same range before and after the rolling tests. In addition, corrosion tests were performed on rolled joints containing ODIGA. An accelerated corrosion test was performed in an autoclave using a prototype free span rolled joint made from an actual OTSG tube. The tube material used in that test was from tubing actually removed from an ANO-1 OTSG and it had actual service-induced ODIGA. In general, the ODIGA found on the corrosion specimens after testing was the same as the ODIGA on the control specimens. Thus, the shallow ODIGA observed in the specimens prior to the corrosion test remained as shallow ODIGA after the test. There was not a general shift toward deeper ODIGA. The corrosion test did not indicate any propagation of ODIGA beyond the range observed in tubes pulled from the OTSG. Based on this testing, it is not expected that ODIGA growth will be affected by the rerolling operations. It is also noted that all rerolls are tested each outage with the Plus Point probe. It should also be noted that all rerolls are tested following installation and each following outage with the bobbin and plus point probe. Any indication of ODIGA or any other damage mechanism within the one-inch effective roll will be repaired.

NRC RAI 4:

Page 25 of the 8/29/00 Entergy submittal (Proposed Risk Informed Technical Specification Change Regarding Steam Generator Outer Diameter Intergranular Attack within the Upper Tubesheet) stated that ". . and any patch of ODIGA with crack-like characteristics are repaired." Please provide details of ANO-1 experience with crack-like characteristics in ODIGA patches.

ANO-1 Response to RAI 4:

No crack-like ODIGA patches have been detected to date. Even though the ODIGA patches exhibit an elliptical pattern having both an axial and circumferential extent, they do not exhibit crack-like features. As discussed in the Entergy Engineering Report, ODIGA affects the grain boundary, but not the grain themselves. It is expected that the through wall depth would have to approach a 100% throughwall extent to become crack-like. However, no ODIGA patches have been experienced that would approach this condition. It should also be recognized that ANO has never experienced leakage through an ODIGA patch.

NRC RAI 5:

On page 6 of Entergy's 10/4/99 report, 1CAN109905, Entergy discussed their 1R15 inspection findings in the rerolls performed during 1R14. Both volumetric and axial/mixed mode indications were detected. The report stated that the volumetric indications were likely small ODIGA patches. Please discuss your ability to detect ODIGA in areas of the tube selected for possible rerolls, post-reroll inspection methodology, and disposition of tubes with ODIGA found in the rerolls during post-reroll inspections.

ANO-1 Response to RAI 5:

The areas selected for reroll are straight tube portions located within the upper tubesheet. In this area the bobbin coil is qualified for detection. The POD curve is Figure 25 on page 56 of the August 29, 2000 submittal. If a tube is selected for reroll, bobbin data of the area of the tube to be rolled is reviewed to determine if a detectable flaw is present. If an indication is detected, then the roll area is moved to below the defect area. If no defect is detectable, the area is rolled. Post roll NDE is acquired on the roll area. Both bobbin and Plus Point data is collected. If any degradation is identified in the one-inch effective roll area or the lower transition, then the tube would have to be either further rerolled or plugged. Thus, the Plus Point probe will be the final determination for detection of ODIGA to be used for rolls left in service. The Plus Point probe is the best process for sizing of ODIGA.

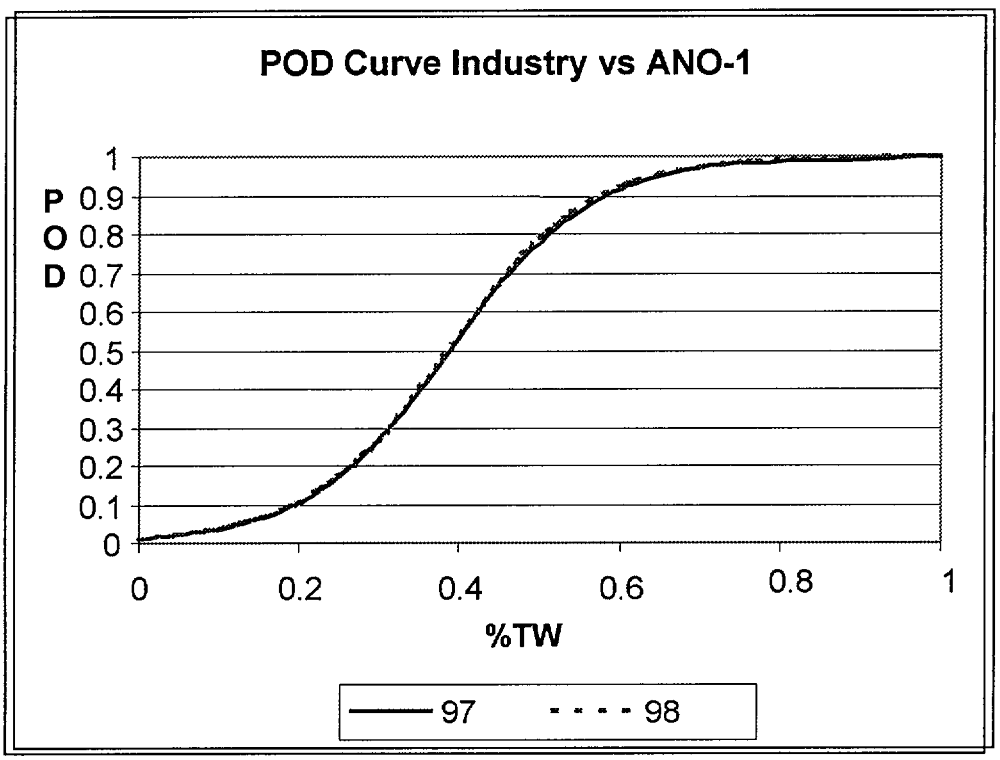
NRC RAI 6:

In the 8/29/00 Entergy submittal, 1CAN080005, a probability of detection (POD) curve for ODIGA is provided as Figure 25 on page 56. It appears that this is the same POD curve presented in the Entergy 9/7/99 submittal, 1CAN099901 (BAW-10235P, Rev. 1). The 9/7/99 report states that the POD is based solely on ODIGA defects in tubes removed from various once-through steam generator (OTSG) plants. How does the POD for

ODIGA detected at ANO-1 compare with that from the other OTSG plants represented in this analysis?

ANO-1 Response to RAI 6:

The POD curve submitted came from BWOG Report 77-1258722-00, Probability of Detection of Defects in Once-Through Steam Generators (Dec. 1997). The original POD curve contained pulled tube data from Crystal River, Oconee, and a small number of older samples from ANO-1 and Rancho Seco. In 1998 three pulled tubes from ANO-1, four from Oconee 3 and two from TMI were added to the database. The attached POD graph shows very little change from the 1997 data to 1998 data.



NRC RAI 7 & 8:

Re: Generalized t-test on P. 50 of 1CAN080005

7. Because the indications in the first and second inspections used in the t-test are matched, the sample sizes n_1 and n_2 should be equal. Why are the sample sizes denoted by n_1 and n_2 instead of a common n?

8. Why is the t-test used instead of the paired t-test or the sign test to test for differences between the first and second inspections? In particular, the sign test

does not assume that the data is normally distributed and it should be more sensitive to small differences which may be masked by the estimated variances used in the t-test.

ANO-1 Responses to RAIs 7 & 8:

The enclosed engineering report has been modified to replace the generalized t-test with a combination of the sign test, the paired t-test and the extreme value test for performing the initial ODIGA growth evaluation.

NRC RAI 9 & 10:

Re: Table 4-1 in 1CAN099901 (page 6 of 12)

9. What is the basis for using a second sample size of 13 if one leaker is found in the initial sample of 22? Although not explicitly stated, the decision rule for accepting the population of 130 as having no more than 15 leakers is apparently the following:

   (i) Take an initial sample of 22. If no leakers are found, accept the population.
   (ii) If one leaker is found, take a second sample of 13. Accept the population if no leakers are found in the second sample.

   If the population has 15 leakers, then the probability of acceptance using this decision rule is 0.079. Hence the confidence level is 92%, not 95% as claimed.

10. Columns 1 and 2 in Table indicate that there are 15 leakers in the population for the initial sample while Column 3 indicates that there are 21 leakers for the second sample. How can the assumed number of leakers increase from the first to the second sample?

ANO-1 Responses to RAIs 9 & 10:

The comment is correct regarding the probability of acceptance for the double sampling scheme cited. Table 4-1 previously contained in letter 1CAN099901 has been simplified as a Single Sampling Plan and a Multiple Sampling Plan. The minimum size initial sample is 23 for a multiple sample plan. The population is accepted with 0 leakers, rejected with 2, and resampled with 1 leaker. The second sample of size 15 is accepted only with 0 leakers. The probability of population acceptance for the least adverse unacceptable population [16 leakers] is 4.8%.

TABLE 4-1
(Modified from 1CAN099901)
Tested Sample Sizes

** Population Size equals 130*

	Single Sampling Plan	Multiple Sampling Plan	
		1st Sample	2nd Sample
Confidence	95%	95%	95%
Sample Size	33	23	15
Leakers in Samples	1	0	0
Leakers in Population	16	16	15
Reference Column	1	2	3

PROPOSED TECHNICAL SPECIFICATION CHANGES

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, Rev. 1.

   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.

ENCLOSURE 1

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

Revision 1

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

This Document contains 84 Pages.

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

1	2/01/01	Revised for editorial comments, added sign test, and paired t-test to statistical growth evaluation (Section 8.3)	RLG	DM	DM for DH.
REV	**DATE**	**REVISIONS**	**BY**	**CHECK**	**APPR**

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

FORM TITLE: CONFIGURATION CHECKLIST	FORM NO. 5010.004A	REV. 004-00-0

Note:
The Configuration Checklist may not be used instead of a 50.59 Review when a 50.59 Review is required by **Procedure 1000.131** or other governing procedures related to the affected documents.

Complete this form in accordance with the instructions provided in **Procedure 5010.004, Attachment 3**. For additional information, follow the "Configuration Checklist" link provided on EntergyNET's ANO Engineering home page.

AFFECTED?	LICENSING	DISPOSITION or BASIS FOR CONCLUSION
☒Yes[1] ☒No[2]	Any of the following: • Technical Specifications • Operating License • Confirmatory Orders • Safety Analysis Report / SAR Figures • Core Operating Limits Report • Fire Hazards Analysis • Tech Spec Bases • Technical Requirements Manual • NRC Safety Evaluation Reports • Ventilated Storage Cask Licensing Documents • Quality Assurance Program Manual • Emergency Plan	This Engineering Report will be submitted to the NRC in submittal 1CAN030101. The Tech.Specs will be changed accordingly.

[1] If "Yes," a 10CFR50.59 Determination is required in accordance with Procedure 1000.131 unless exempted by Procedure 1000.131.
[2] If "No," the basis for this conclusion must be documented (e.g., LRS search criteria, LBD sections/figures reviewed, etc.)

AFFECTED?	DESIGN/OTHER	DISPOSITION (If applicable)
☐Yes ☒No	Drawings/DRNs/DTS Database	
☐Yes ☒No	Component Database	
☐Yes ☒No	Vendor Tech Manuals / VTM Database	
☐Yes ☒No	Upper Level Documents (ULDs)	
☐Yes ☒No	Calculations / Code Stress Reports	
☐Yes ☒No	Specifications	
☐Yes ☒No	Engineering Reports	
☐Yes ☒No	EQ Documentation	
☐Yes ☒No	Piping Class Summary	
☐Yes ☒No	Fire Barrier Penetration Log	
☐Yes ☒No	Cable, Raceway or Equipment Numbers (PDMS)	
☐Yes ☒No	ER Responses / Mods (in-progress only)	
☐Yes ☒No	Procedures	
☐Yes ☒No	Engineering Standards	
☐Yes ☒No	Component Labels	
☐Yes ☒No	Fuse Lists	
☐Yes ☒No	Repetitive Task Database	
☐Yes ☒No	Preventive Maintenance Engineering Evaluations	
☐Yes ☒No	Simulator	
☐Yes ☒No	Training / System Training Manuals (STMs)	
☐Yes ☒No	MMIS	
☐Yes ☒No	Engineering Programs	
☐Yes ☒No	Lubrication Manual	

Completed By: Rocky L. Jones *RLJ* Date: 3/1/01

FORM TITLE: ENGINEERING REPORT DATA SHEET	FORM NO. 5010.017-ATT-2	REV. 001-03-0

This Document contains 1 Page.

Report No.: **Eng. Report 00-R-1005-01** Unit: 1 Category:

Report Title: Management Program for Volu Through

System(s):
Topic(s):

Component No(s):

Plt Area: Bldg. Elev. Room: Wall Coordinates:

Abstract (Included Purpose/Results):

Documents the management program for ODIGA in the upper tubesheet of the ANO-1 Steam Generators.

Revision No: 1

Config. Checklist (per 5010.004) completed? ☒ Yes ☐ No

Pages Revised and/or Added:

Purpose of Revision:

Revised the ANO-1 ODIGA management report to include editorial comments, addition of the sign test and paired t-test to the statistical growth evaluation section of the report.

Initiating Document(s)	Resulting Document(s)	Reference Document(s)
	1CAN030101	

Supersedes Report(s):

	(Print Name)	(Initials)	(Date)		(Print Name)	(Initials)	(Date)
By:	Rocky L. Jones	RLJ	2/1/01	Rvw'd:			
Chk'd:	Dan Meatheany	DM	2/2/01	Apv'd:	Darol Harrison	DM *	3-2-01

Check if Additional Revisions: ☐

* Dan Meatheany for Darol Harrison 3-2-01

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
EONC	end of next 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

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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.

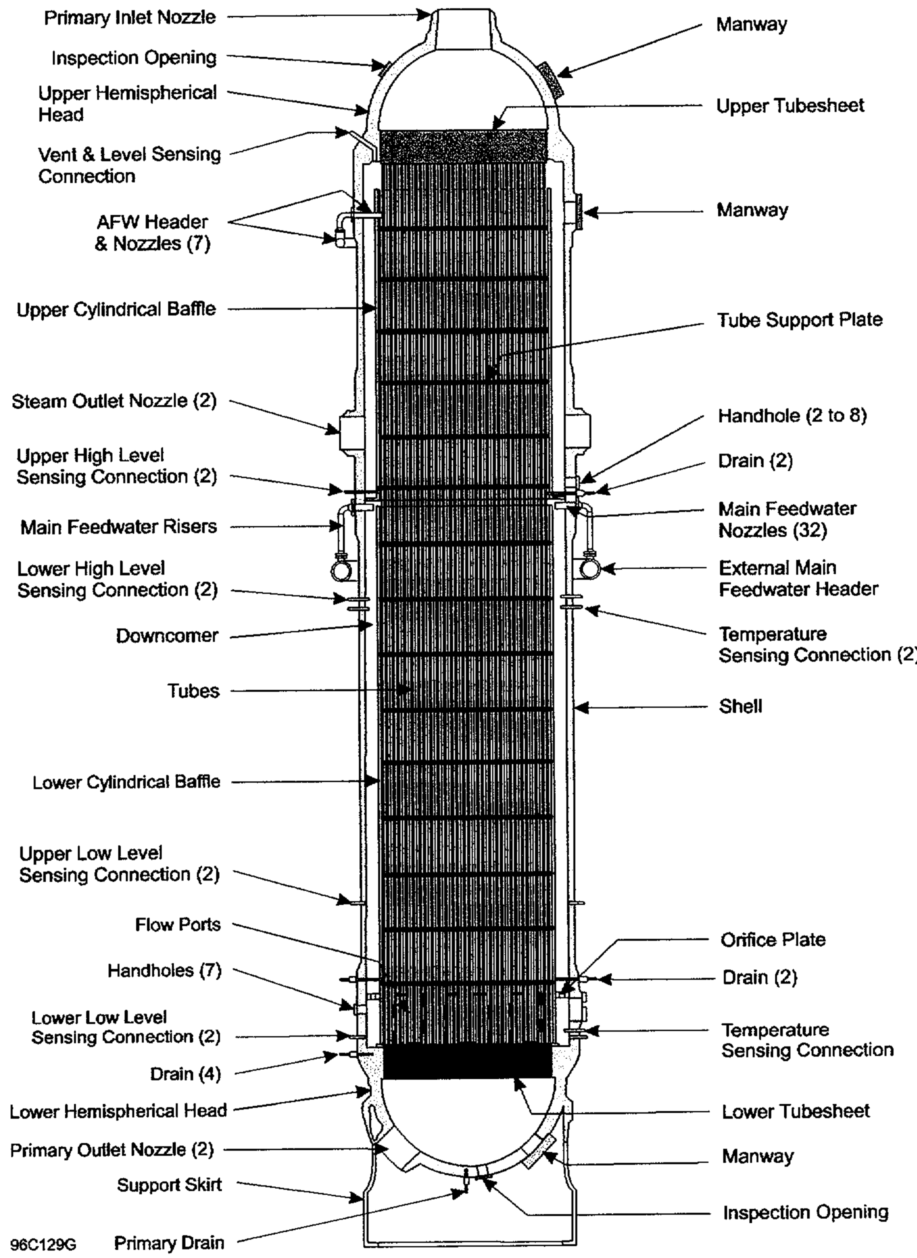
Proper lateral spacing of the tubes is maintained by 15 tube support plates. They are fabricated from 1-1/2 inch thick carbon steel plate, drilled and broached to provide surface contact and support along three axes for each tube at each tube support plate. An exception is the 15th TSP periphery rows, 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.

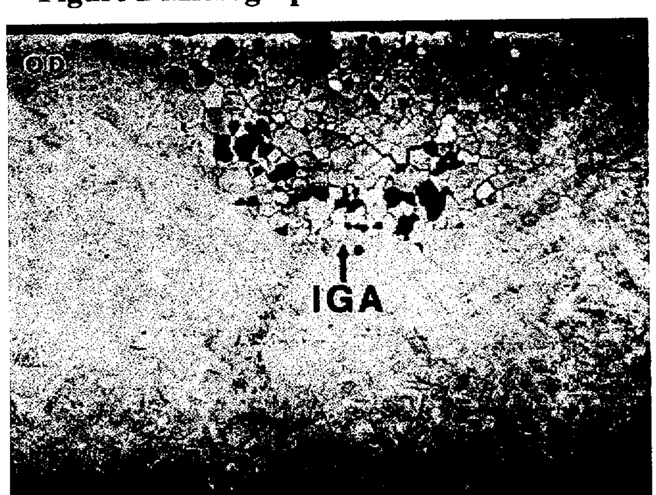
4.1 Operating History

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.

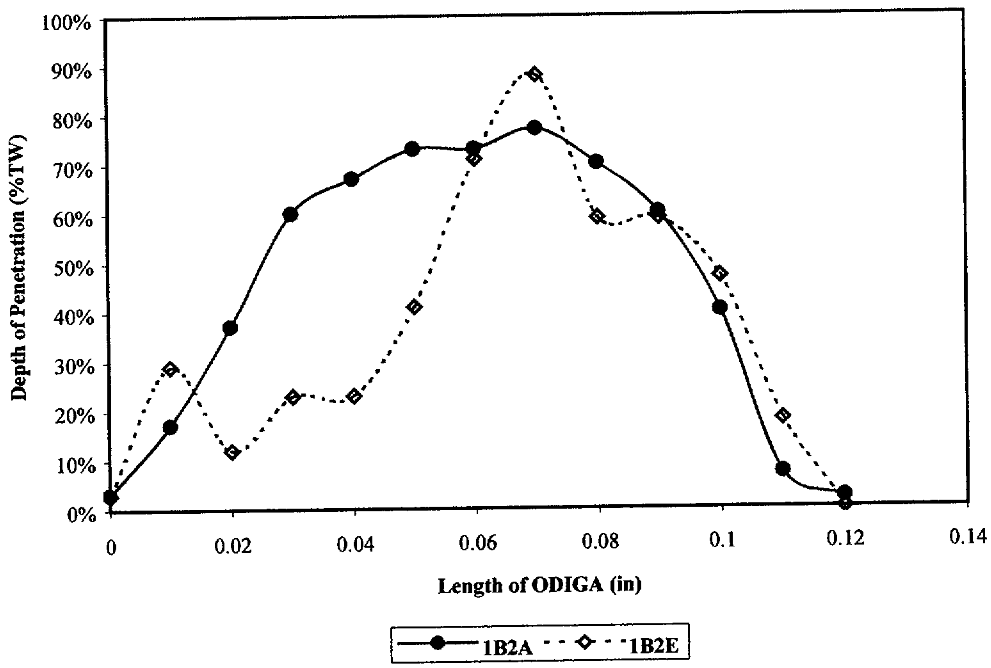
In 1984, lane tube 77-34 was removed from SG A and destructively examined. This tube supported the hypothesis that the lane region would remain susceptible, having developed intergranular attack at the upper tubesheet secondary face.

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

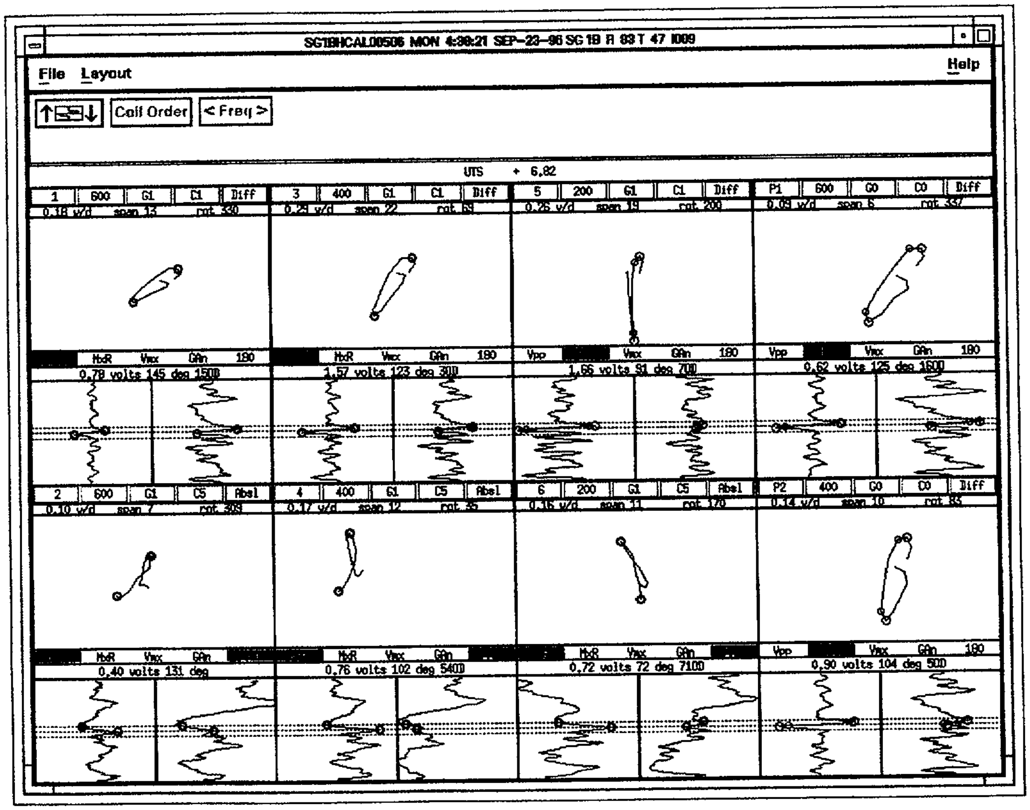
The information discussed in the operating history was utilized to define the morphology of the volumetric ODIGA. Volumetric ODIGA is defined as three-dimensional grain boundary corrosion initiating from the outside surface of the tube. The ODIGA can occur in isolated patches or at multiple initiation 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

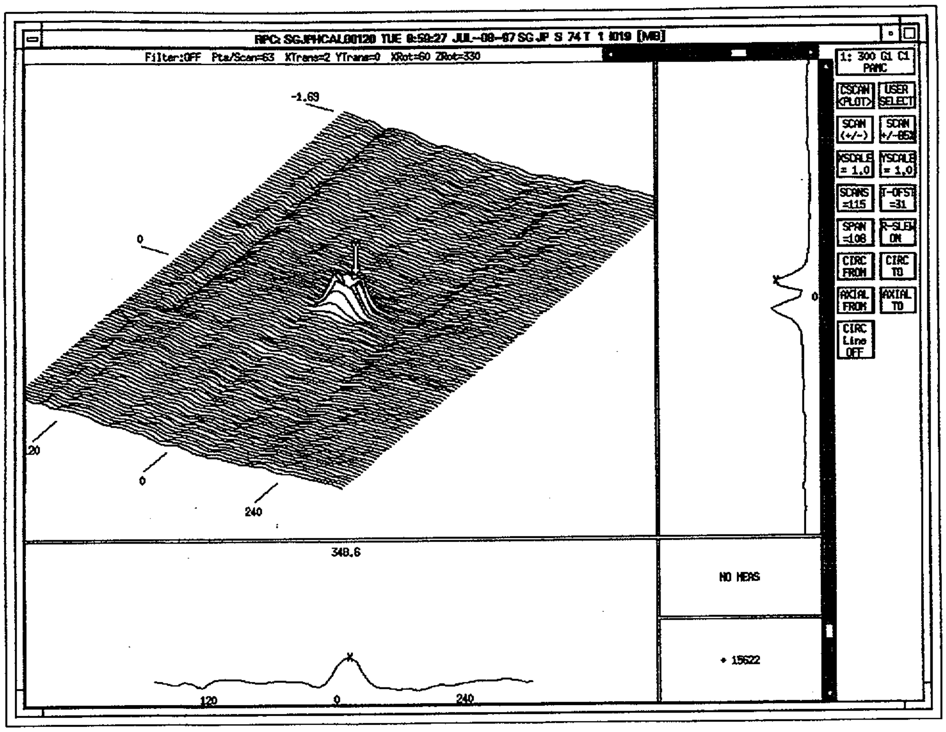
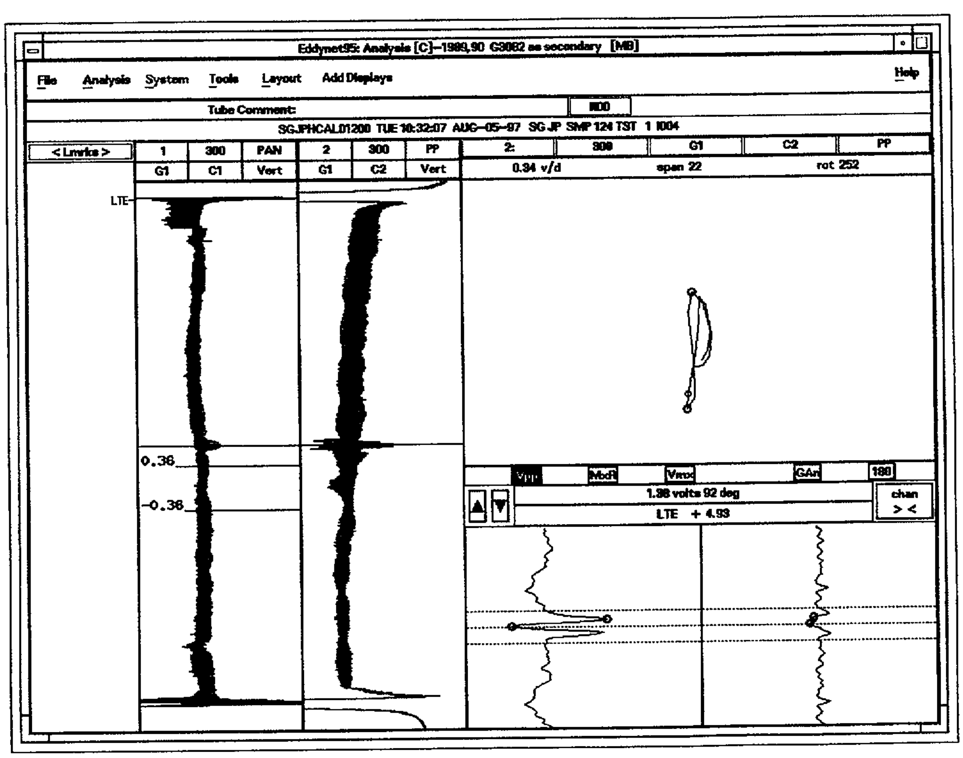


Figure 6 Typical Plus-Point Strip Chart ODIGA Response



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.

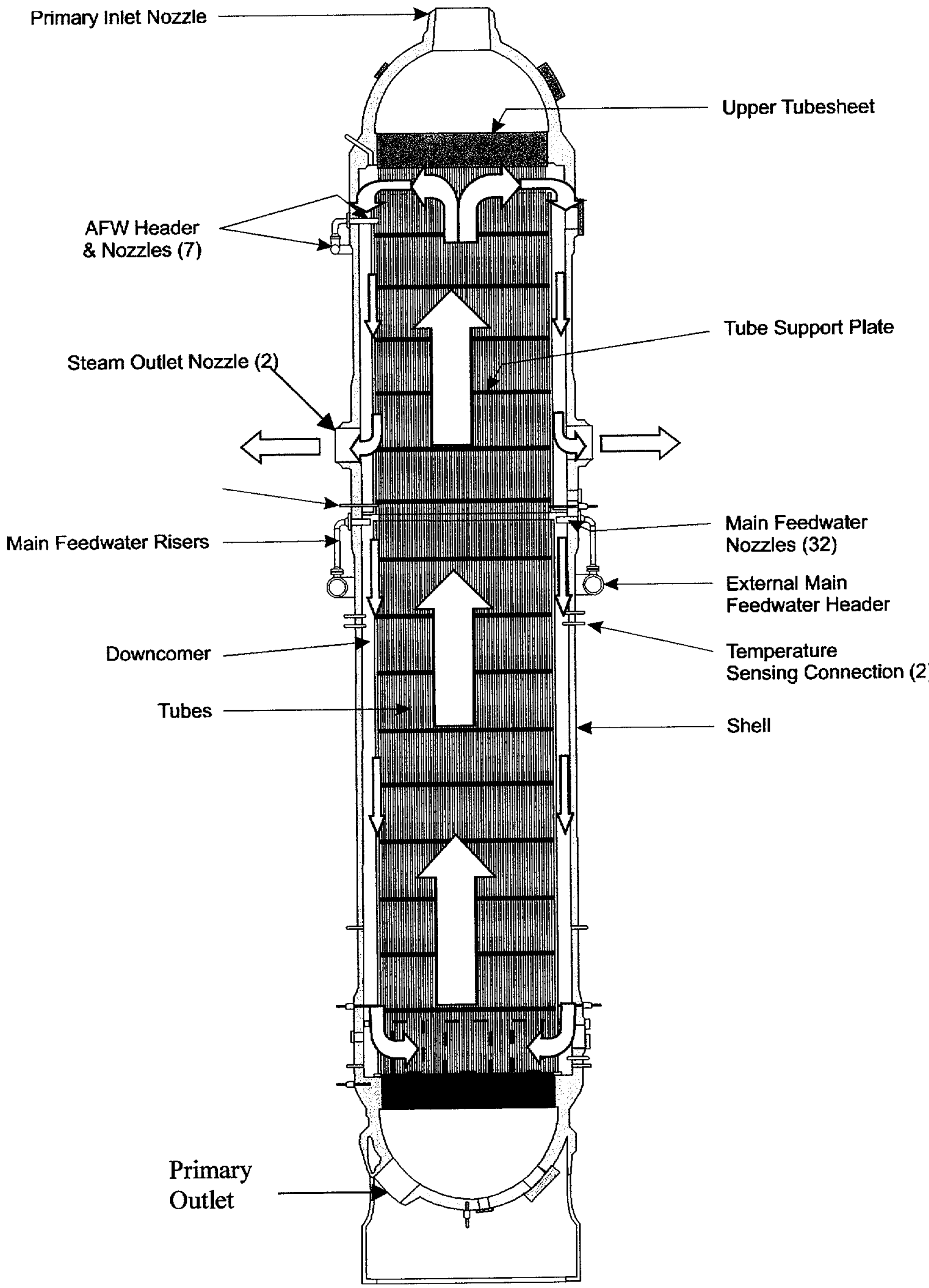
The MSLB transient initiates with the severance of the steam line. This causes a large pressure differential between the OTSG secondary side and the downstream steam line break. The resulting accelerated flow of water and steam impose cross flow loads on tubes in the top and bottom spans (see Figure 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.

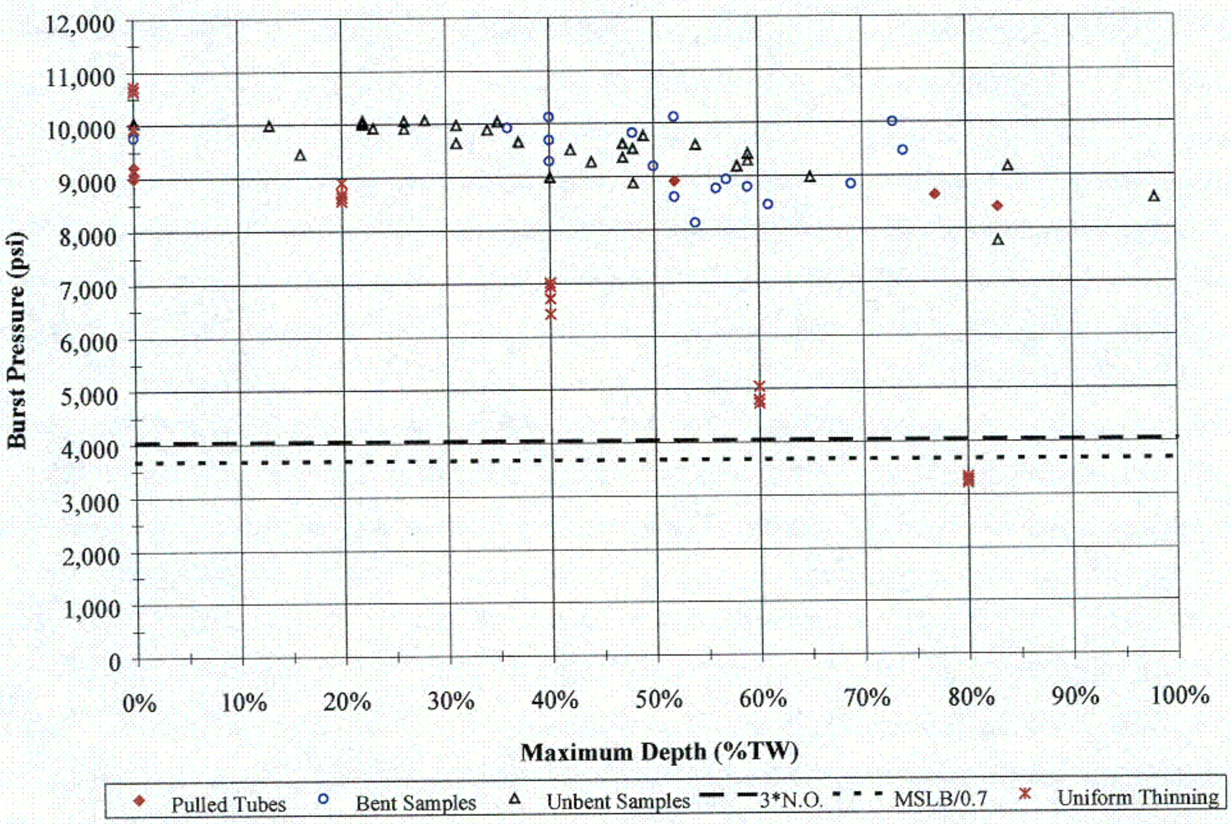
Results of the burst testing showed no decrease in burst strength relative to the unflawed tube, as all tube ruptures occurred in the freespan portion of the tubing, typically 1.5 inches or more away from the tubesheet. These test results demonstrate that volumetric ODIGA, which is located within the 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



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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

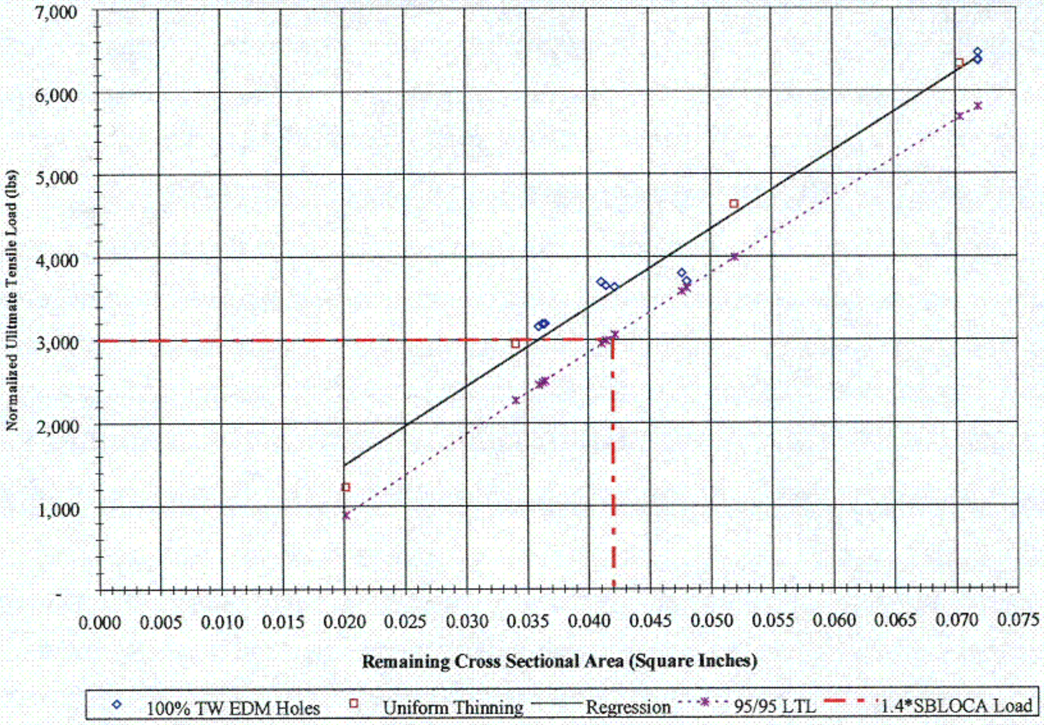
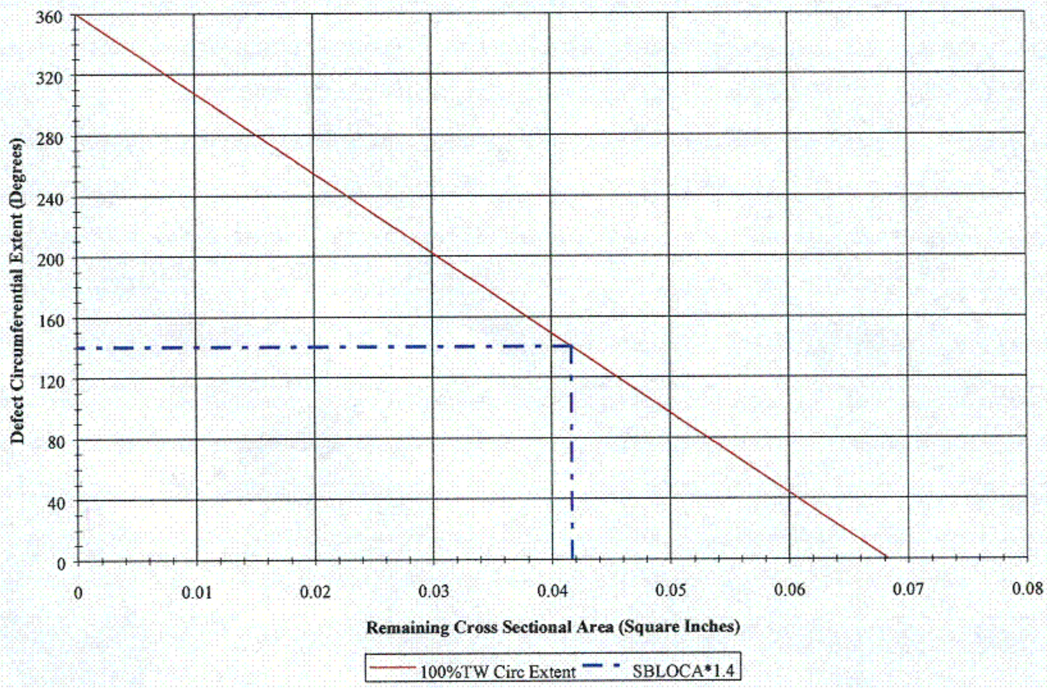


Figure 10 Maximum Allowable Circumferential Extent vs Remaining CSA



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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 ≤ 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, 39 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 35 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 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

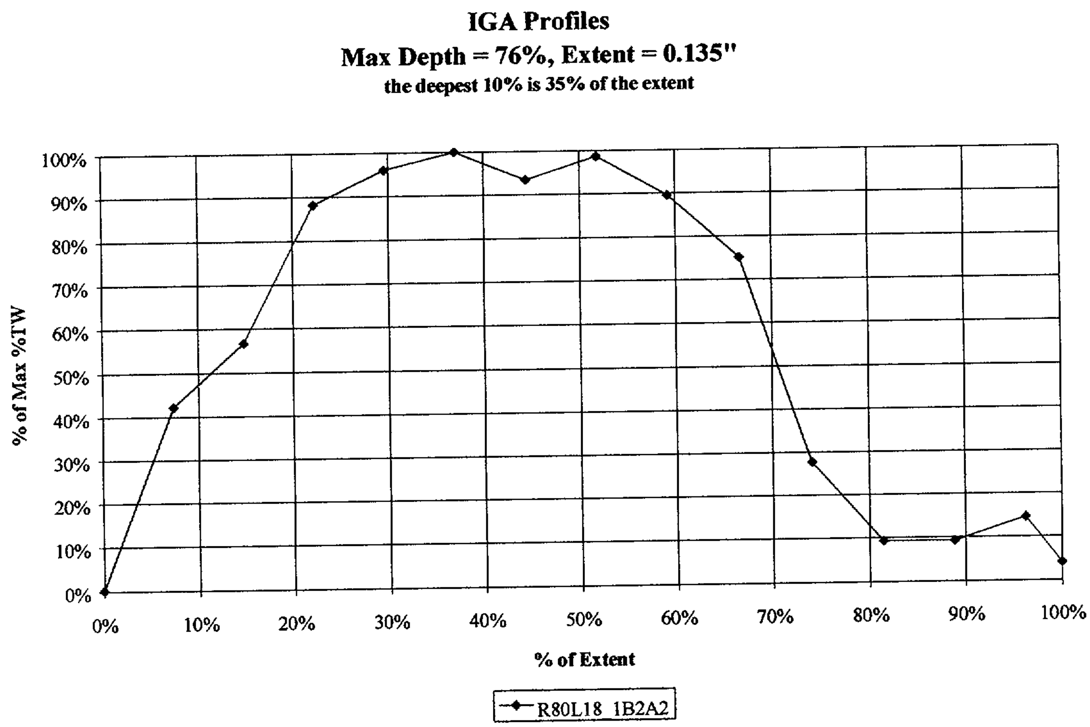


Figure 12 ODIGA Profile of Tube 79-63, Section 1B2A

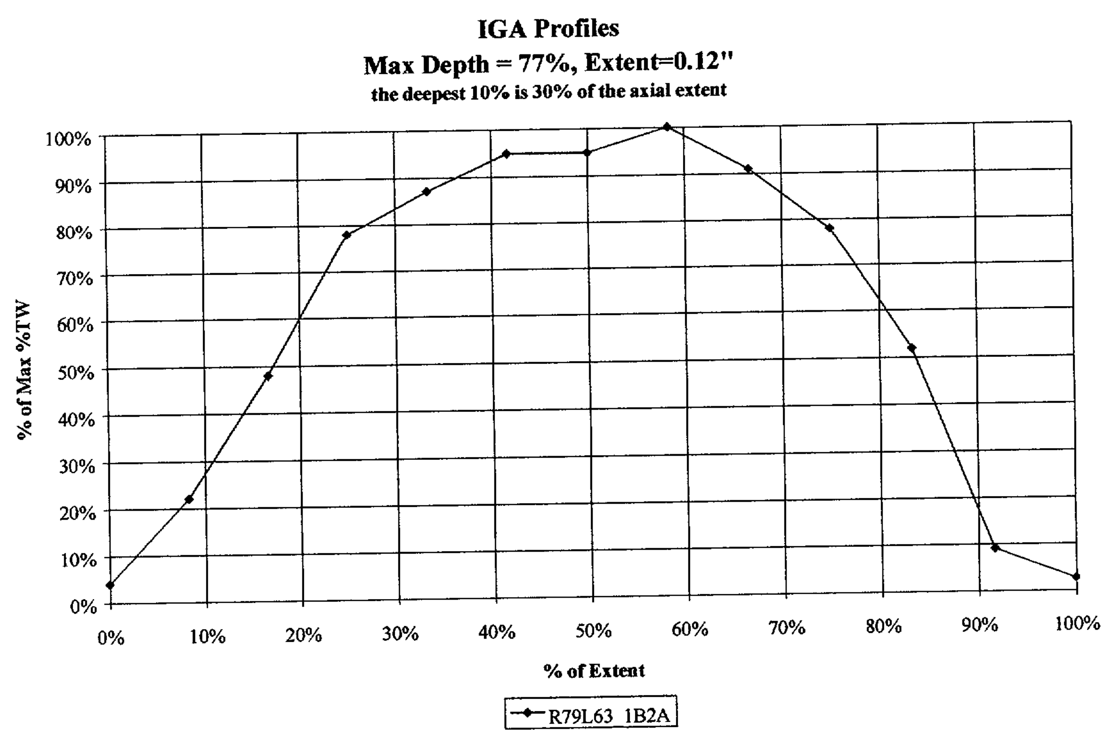


Figure 13 ODIGA Profile of Tube 83-47, Section 1B2B1

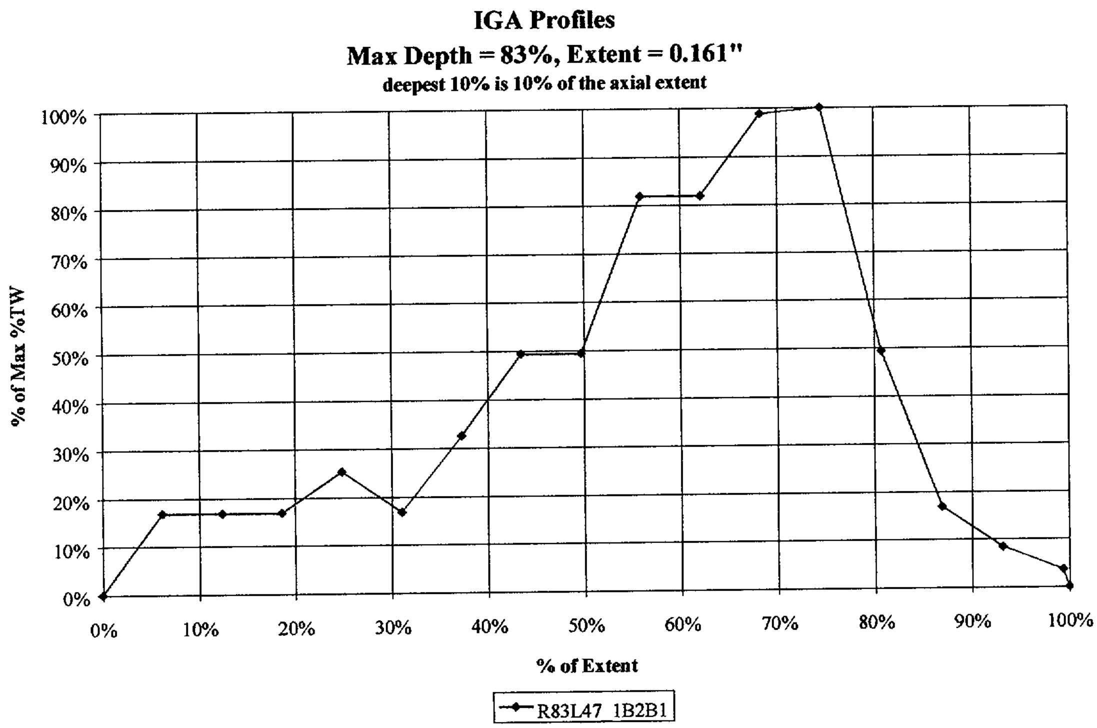
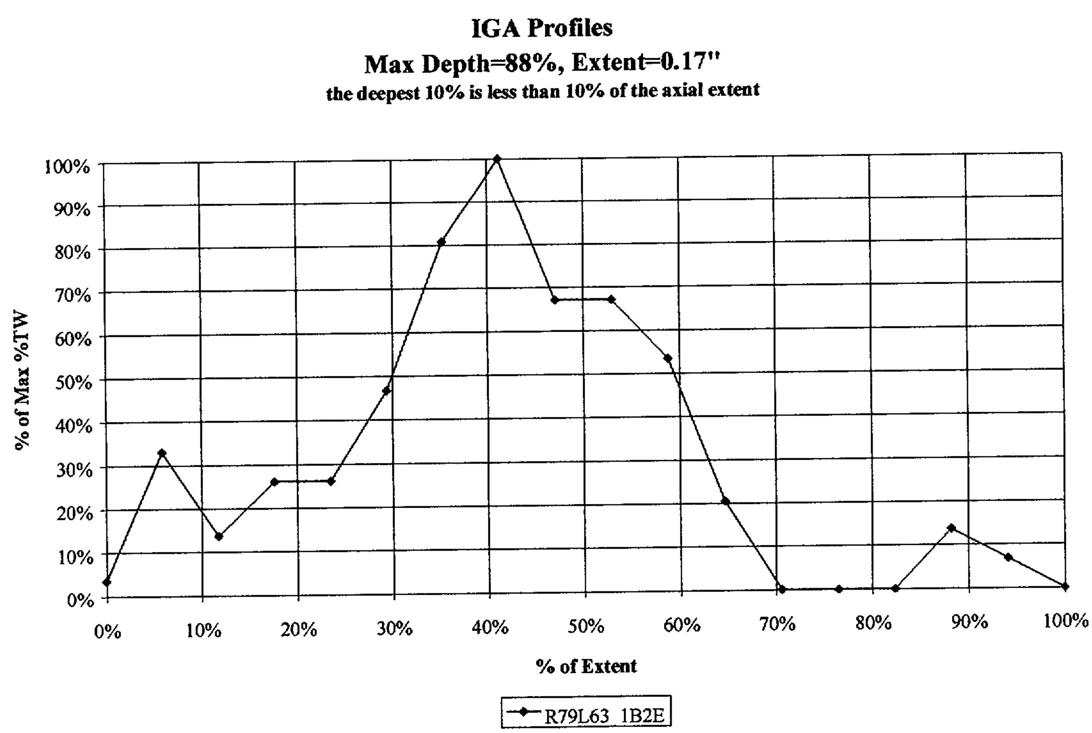


Figure 14 ODIGA Profile of Tube 79-63, Section 1B2E



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.

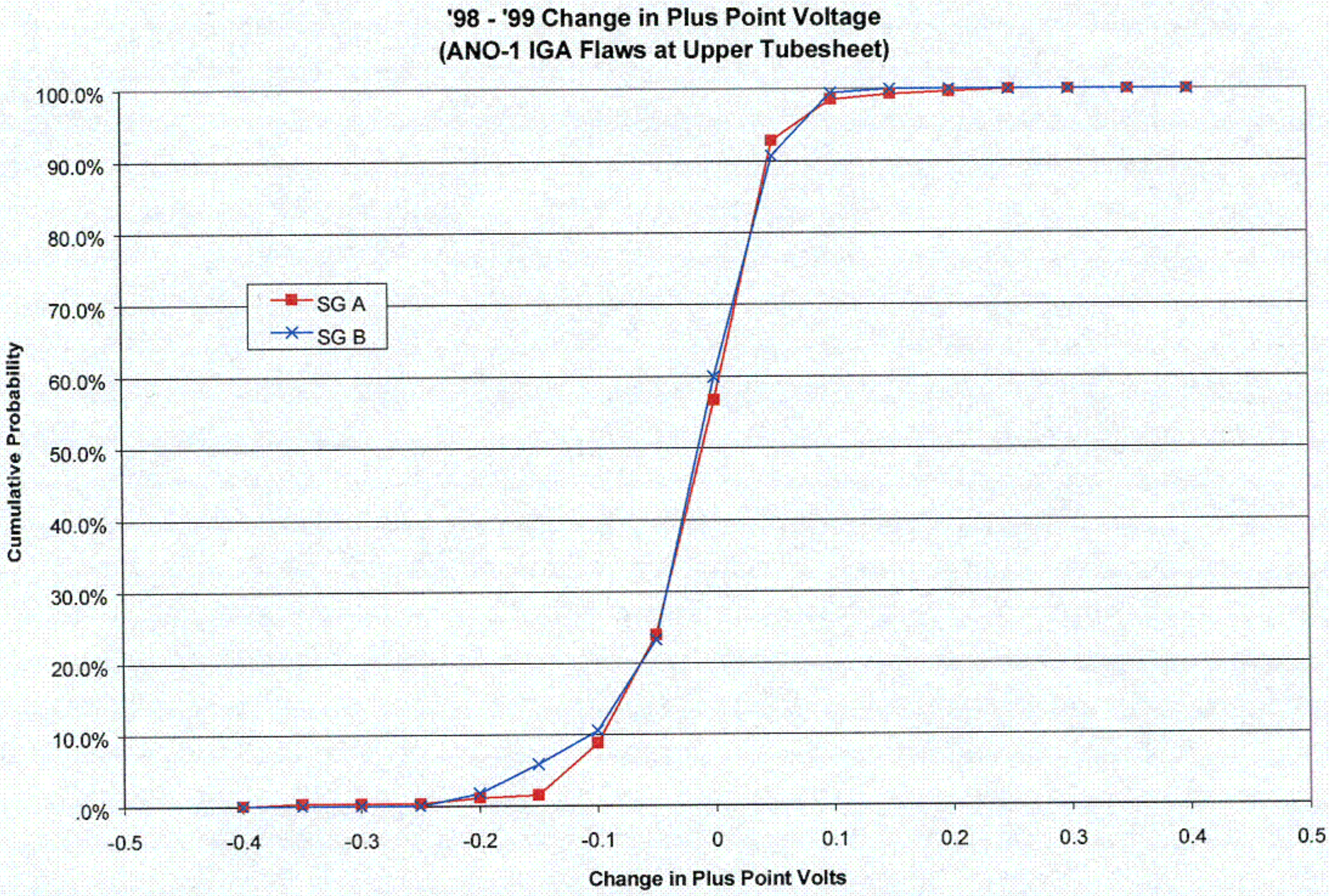


Figure 15. Apparent Change in ANO-1 UTS OD-IGA Plus Point Volts ('98 – '99)

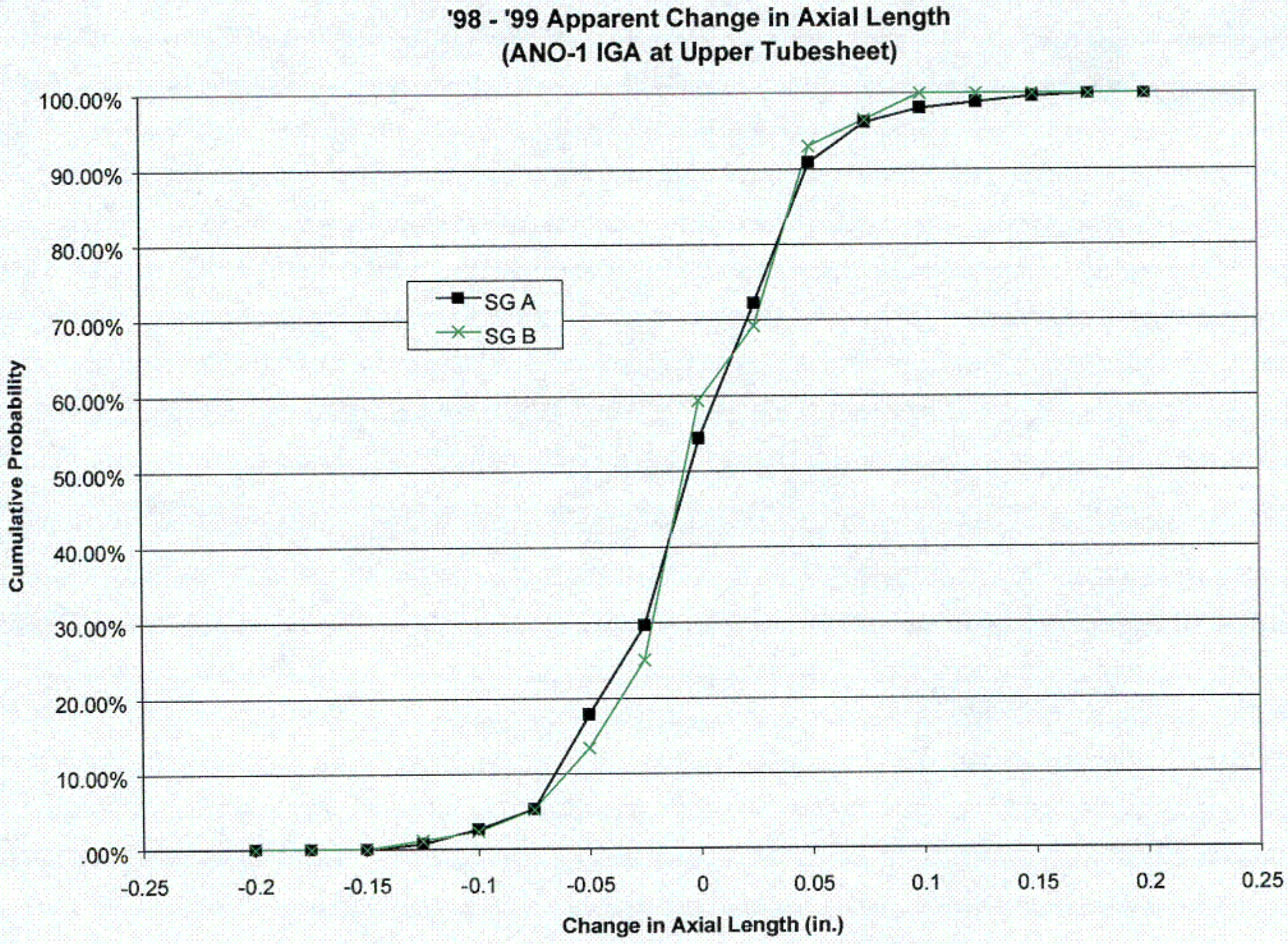


Figure 16. Apparent Change in ANO-1 UTS OD-IGA Axial Length ('98 – '99)

C04

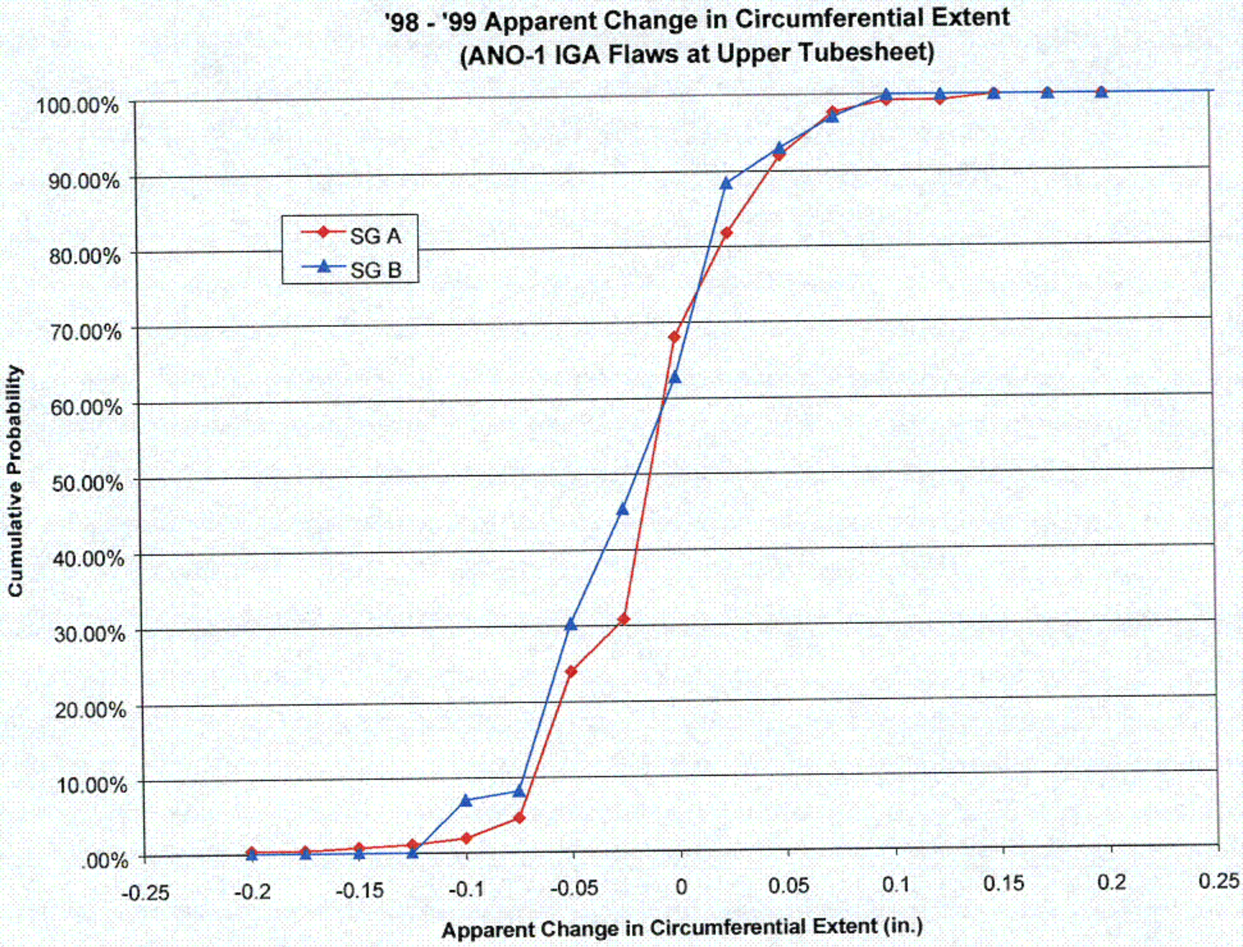


Figure 17. Apparent Change in ANO-1 UTS OD-IGA Circumferential Extent ('98 – '99)

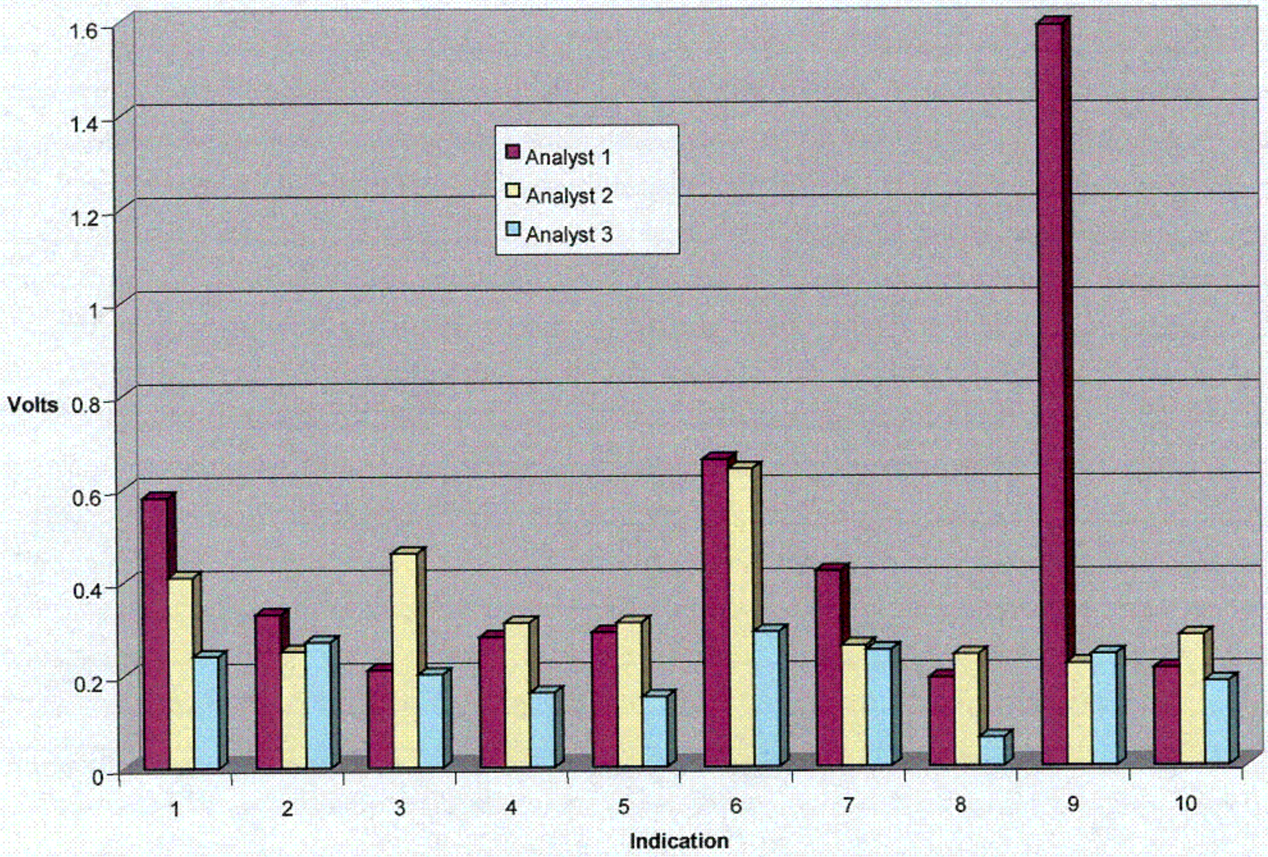


Figure 18. Volts for ANO-1 Pulled Tube IGA Flaws by Analyst

C26

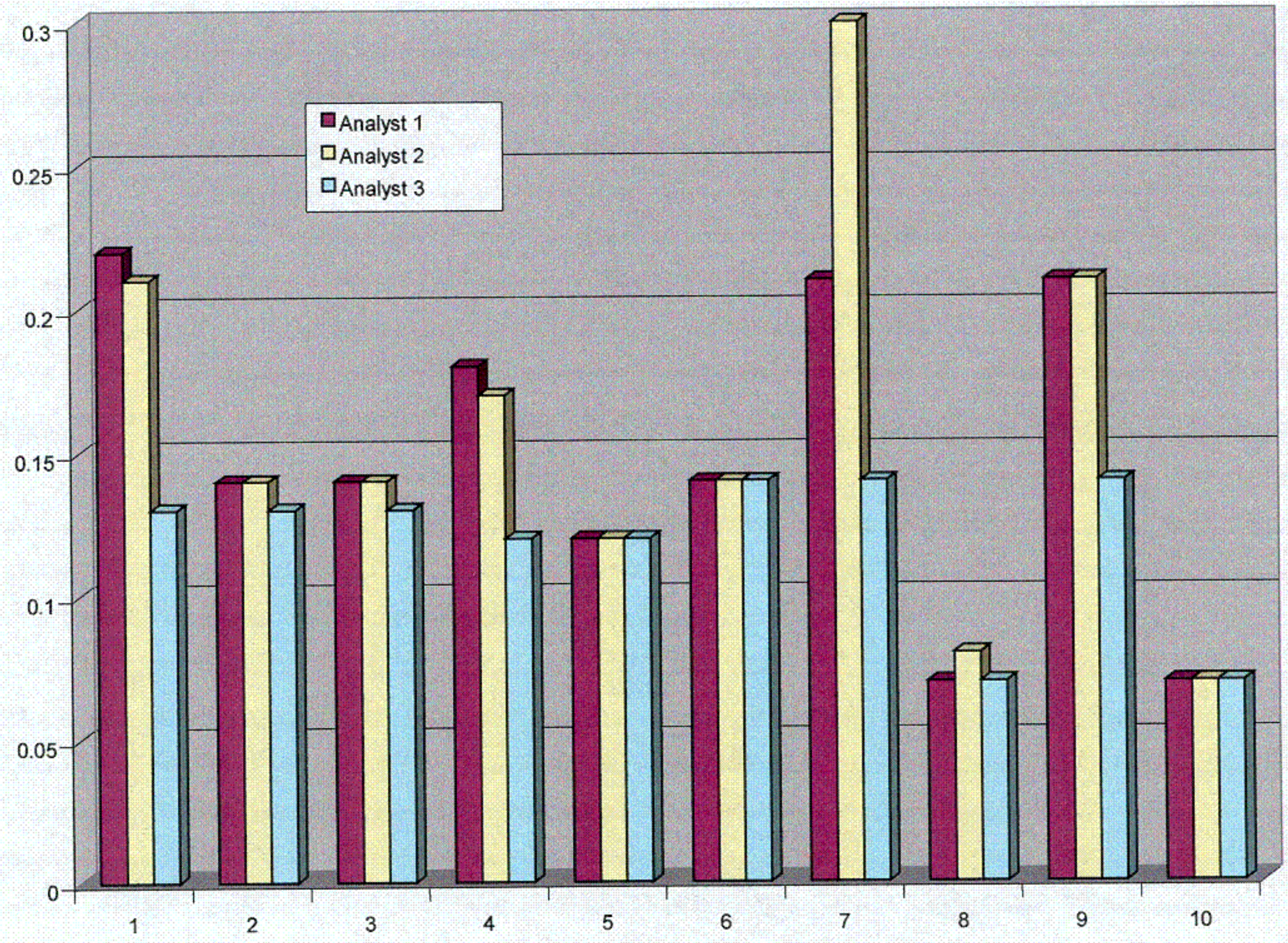


Figure 19. Axial Extents for ANO-1 Pulled Tube IGA Flaws by Analyst

C07

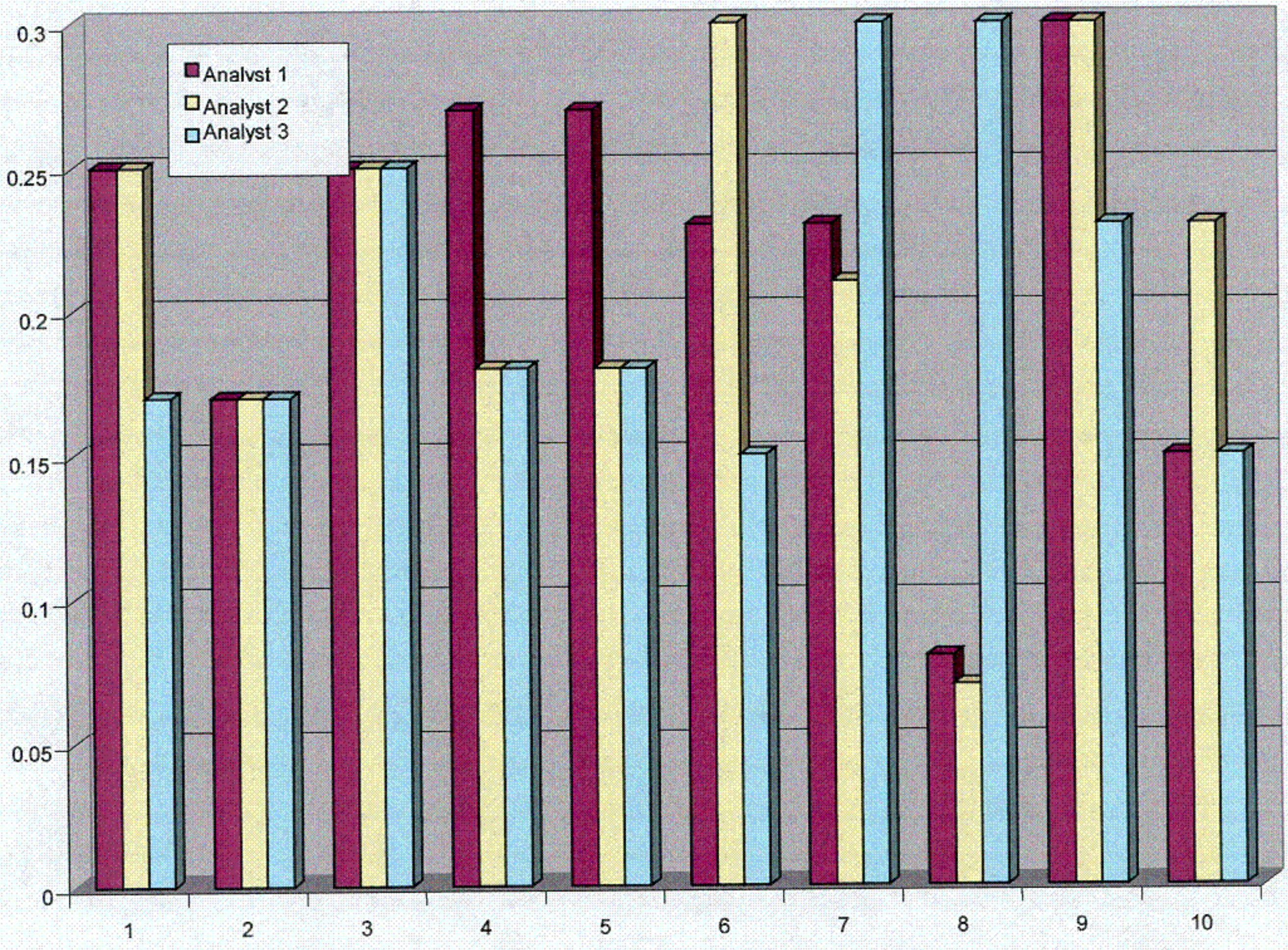


Figure 20. Circumferential Extents for ANO-1 Pulled Tube IGA Flaws by Analyst

C08

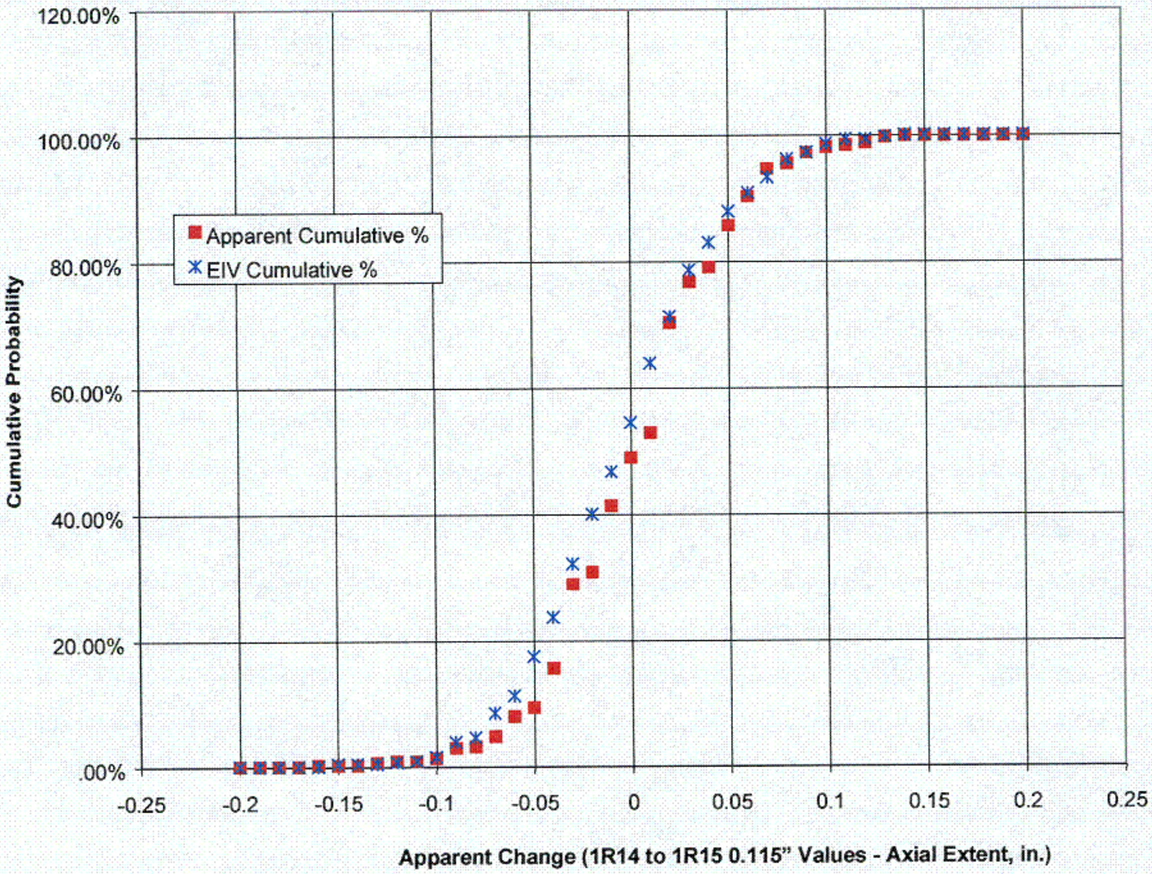


Figure 21. Apparent Change in Axial Length (Field Measurements vs. EIV Prediction)

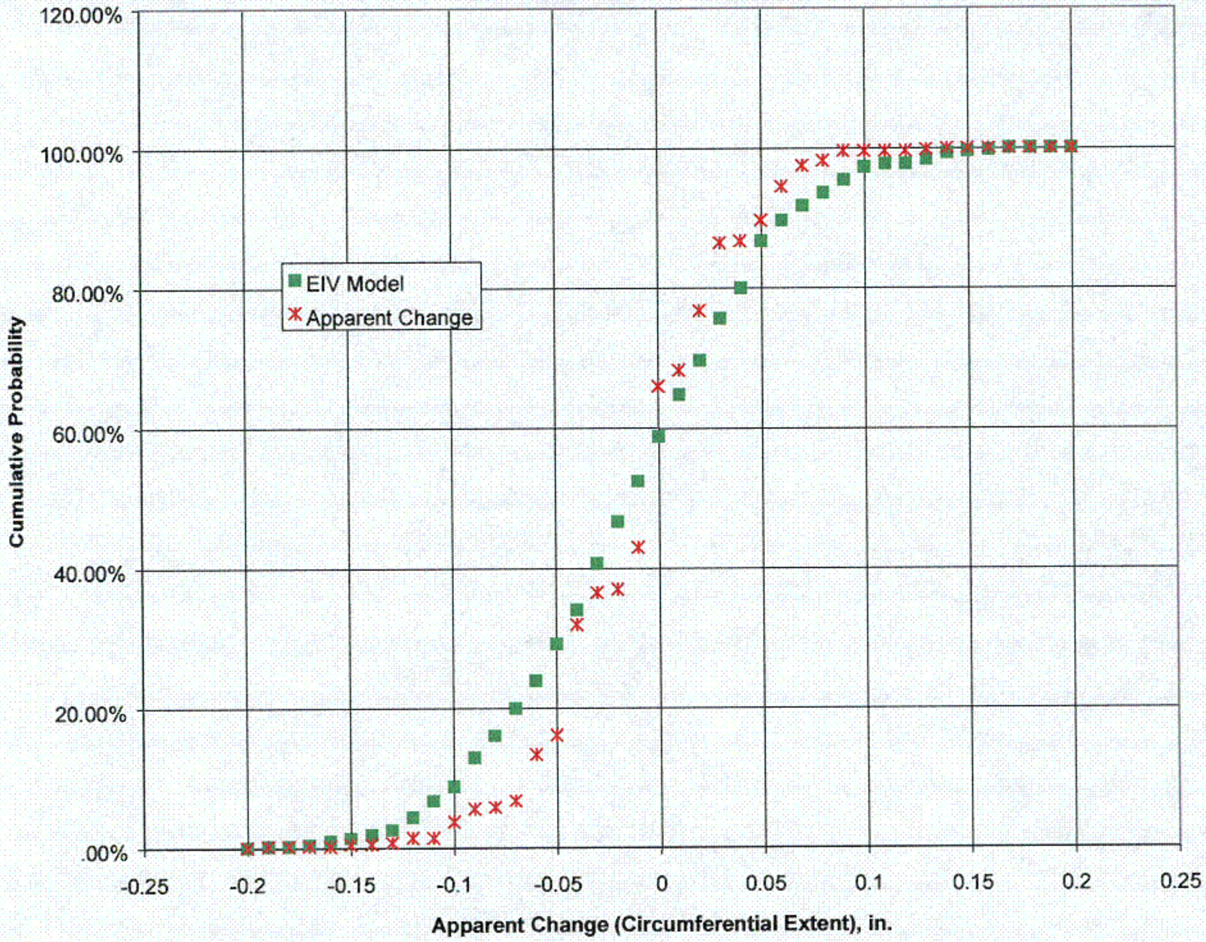


Figure 22. Apparent Change in Circumferential Extent (Field Measurements vs. EIV Model)

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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 procedure that consists of three tests that will be applied to both the Plus Point volts and axial length measurements for the ODIGA inspection data. This will involve the application of a sign test, a paired t-test and an extreme value test. These three tests will be applied to each variable. If all tests are passed (that is, if all test statistics calculated from the ODIGA growth data are statistically insignificant), it will be concluded that the ODIGA population is not growing.

If these tests are unsuccessful to ensure that growth is not occurring, 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.

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 two-step procedure is proposed as a replacement for the existing procedure for assessing IGA growth. Step I of the procedure consists of three tests that will be applied to both the Plus Point volts and axial length measurements for the ODIGA inspection data:

(1) Sign test
(2) paired t-Test
(3) extreme value test

These three tests will be applied to each variable. If all tests are passed (that is, if all test statistics calculated from the ODIGA growth data are statistically insignificant), it will be concluded that the ODIGA population is not growing. In this case, 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.

If the Step I test results are unsuccessful, then significant evidence exists in the apparent growth data that the population of ODIGA has changed. At this point, Step II calls for the development of a cycle-specific growth model that will separate NDE uncertainty from true growth to quantify the amount of true growth that should be applied in the operational assessment. In this case, credit cannot be taken for (only) previous in-situ pressure testing and additional in situ testing may be required.

An outline of the procedure follows:

Step I. Perform Statistical Tests for Change in ODIGA Flaw Population

a. Sign Test

b. Paired t-Test

c. Extreme Value Test

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

A cycle-specific growth model will characterize changes in the mean, variability and extremes of apparent growth and will be required 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.

8.3.1 Step Ia. Perform Sign Test for Change in ODIGA Population

A generalization of the classic nonparametric sign test will be used to identify the presence of statistically significant (positive) change in the ODIGA flaws based on measurements of Plus Point voltage and axial length. This approach will not require that the data be normally distributed.

The (univariate) sign test is a binomial type test which is useful in the context of ODIGA growth assessment to identify whether one random variable in a pair of measurements (call them X,Y) is larger than the other. In the case at hand, if we assume that the measurement X corresponds to an earlier inspection and that Y corresponds to the current inspection then the condition of interest is where Y > X which indicates that the flaws are growing.

Designating Plus 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 standard test statistic for detecting a change in one variable, call it T_1, is calculated as described in Reference 2.18 by counting all the positive changes in the n measurements for variable 1 (for example, +Point volts):

$$D_{1j} = \{y_{1j} - x_{1j}\} \qquad j = 1,\ldots,n$$
$$T_1 = \#\, where\ D_{1j} > 0$$

The standard sign test for a single variable compares the observed value of T_1 with the one-sided critical value:

$$t_1 = \frac{1}{2}\left[n + z_\alpha \sqrt{n}\right]$$

If the calculated value from the measurement data exceeds the critical value $n - t_1$, we reject the hypothesis of zero change in the median of the variable. That is, we reject the hypothesis that there exists zero growth in ODIGA flaws at the 100α% significance level based on the measurements for the single variable. This is test is easy to perform. The procedure can be applied to a second variables (axial length) by calculating the statistics T_2 where

$$D_{2j} = \{y_{2j} - x_{2j}\} \qquad j = 1,\ldots,n$$
$$T_2 = \#\, where\ D_{2j} > 0$$

The critical region for both Plus Point volts and axial length change in the ODIGA flaws is then defined by the condition where any of the following are true:

$\{T_1 > t_1, T_2 > t_2, T_1 > t_1 \text{ and } T_2 > t_2\}$

In this case the values of t_1, t_2 are calculated at the α = 2.5% value, yielding an effective critical region of approximately 5%. This approximation can be compared with an exact tabulation of the two-dimensional distribution under the null hypothesis of zero growth in both variables. Such tabulation can be obtained by computer simulation.

8.3.2 Step Ib. Perform Paired t-Test for Change in ODIGA Population

The standard paired t-test will be used to further evaluate whether growth is indicated by this classic parametric test. For this application, the null hypothesis is that the mean change (growth) in the ODIGA flaws is zero.

The paired t-Test statistic is calculated with the observed difference for measurement j on variable i (for example, i=1 for Plus Point volts, i=2 for axial length):

$$T_i = \frac{\overline{D_i}}{S_d / \sqrt{n}}$$

$$\overline{D_i} = \frac{1}{n}\sum_{i=1}^{n} D_{ij}$$

$$S_d = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}\left(D_{ij} - \overline{D_i}\right)^2}$$

The critical value for the (one-sided) alternative hypothesis that mean ODIGA growth > 0 is (for each variable):

$$T_i > t_{\alpha,n-1}$$

Again, the critical region is apportioned to allocate half of the region to Plus Point volt growth and half of the region to axial length growth so α = 2.5% for each test. If both the sign test and the paired t-tests indicate no growth, the data for each variable (Plus Point volts and axial length) will be reviewed per Section 8.3.3 to determine whether any extreme value is statistically significant.

8.3.3 Steps 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. 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 II. Develop Cycle Specific Growth Model

In the event that future ANO-1 ODIGA field data indicate a statistically significant change from the historical population of apparent growth as evidenced by the inability to demonstrate via the procedure in Step I for 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. Any growth analysis performed using the Cycle Specific Growth Model described here will require a revision to this report to include information substantiating the growth conclusions reached and the basis for the conclusions. The revised report will be submitted in a license amendment to the NRC well ahead of the subsequent refueling outage with any actions to address potential growth.

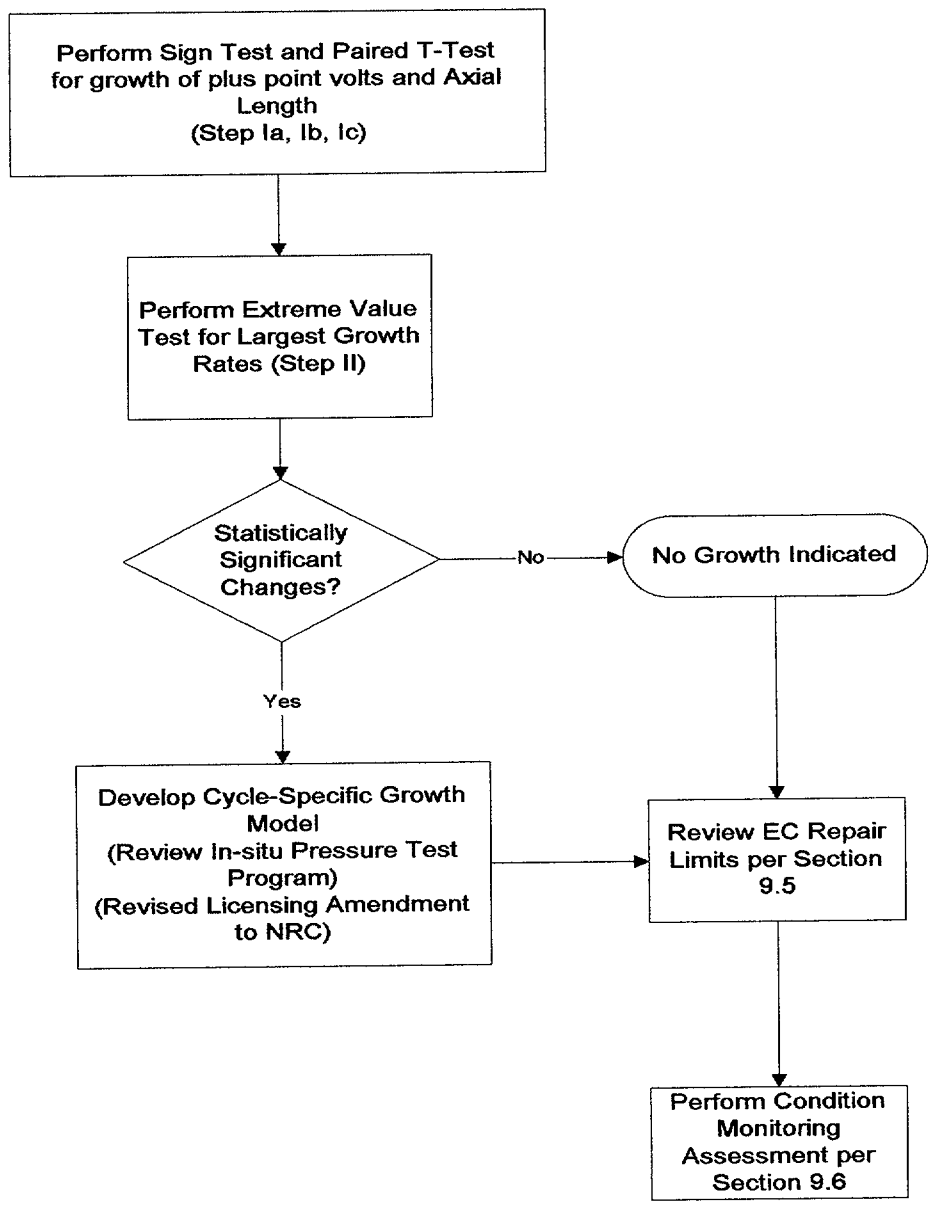


Figure 24. Revised Procedure for IGA Growth Condition Monitoring

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

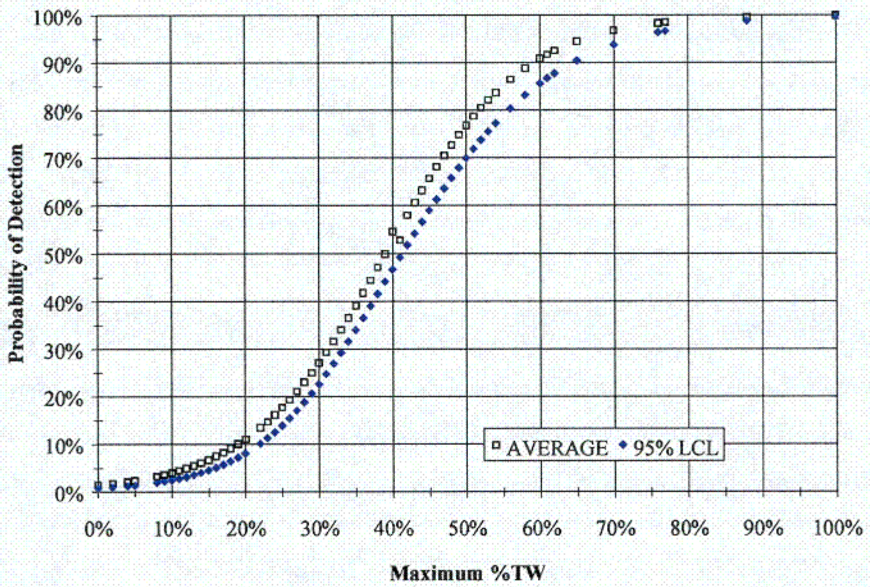
The purpose of POD is to quantify how reliably the ODIGA is detected. This probability is presented as a function of the maximum depth of the ODIGA. Quantifying the probability of detection is important when it is necessary to estimate the size of the ODIGA population based on the number of indications 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. The POD is based solely on ODIGA defects removed from various OTSG plants. 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

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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 extent 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 or considered a new indication and are not included in the growth evaluation.

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 34 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.

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.

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

$$1-P(0\_leaks)=1-\frac{{}_{a}C_{0}\times{}_{b}C_{n}}{{}_{(a+b)}C_{n}}=0.95$$

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

$$P(d\_leaks)=1-\sum_{X_f=0}^{d}\frac{{}_{a}C_{X_f}\times{}_{b}C_{n-X_f}}{{}_{(a+b)}C_{n}}=0.95$$

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 cause MSLB primary-to-secondary leakage rates in excess of the plant technical specification allowable. The testing will be conducted on the SG which requires the greatest number of samples in order to meet the leakage performance criteria at the end of the next cycle of operation. 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. Therefore, leak tests will be conducted at the MSLB pressure differential of 2575 psig without a specific axial load in order to maximize the hoop stress in the tube. If the indication leaks, then the test will be repeated with the limiting MSLB axial load and the associated pressure differential.

Upon completion of the leak testing, the hypergeometric distribution assumptions (section 8.4.4.2) will be verified. If any of the assumptions except the number of predicted leakers in the tested sample have changed such that a 95% confidence level is not achieved, then more samples shall be tested in order to reach the 95% confidence. If the assumption about the number of sample leakers proves to be non-conservative, then the procedure of sections 8.4.2 through 8.4.5 must be repeated with the reduced population. In this case, however, previous testing will not be credited.

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.

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 Axial Extents for Leakage Estimate

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 of operation. The projected EOC axial extent measurements are estimated using the upper 95% confidence limit for population growth (Equation 5). The EOC circumferential extents and voltages are not included because they do not effect the predicted leak rates.

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 EC measurements in excess of the repair limits of section 9.5 must be repaired. This evaluation is performed as described in Section 10.0.

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.

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	Plus-Point Voltage	RC Axial Extent (inches)	RC Circ. Extent (inches)	Test Condition Codes
1	A	47	4	UTE - 11.96	(Note 4)	0.17	0.18	1
2	A	47	4	UTE - 13.33	(Note 4)	0.17	0.18	1
3	A	51	116	UTE - 15.09	0.23	0.17	0.18	1
4	A	51	116	UTE - 18.54	0.45	0.17	0.18	1
5	A	53	109	UTE - 14.27	0.38	0.13	0.18	1
6	A	53	109	UTE - 14.48	0.24	0.17	0.18	1
7	A	53	109	UTE - 19.14	0.25	0.17	0.12	1
8	A	69	40	UTE - 3.67	0.36	0.21	0.22	1
9	A	69	40	UTE - 14.23	0.48	0.31	0.33	1
10	A	69	54	UTE - 5.8	0.21	0.25	0.28	1
11	A	69	54	UTE - 10.27	0.73	0.31	0.28	1
12	A	70	21	UTE - 3.62	1.26	0.24	0.28	1
13	A	70	21	UTE - 15.26	0.34	0.19	0.22	1
14	A	71	19	UTE - 13.9	0.22	0.19	0.22	1
15	A	71	19	UTE - 17.17	0.57	0.24	0.28	1
16	A	78	46	UTE - 22.8	0.25	0.18	0.24	1
17	A	78	46	UTE - 23.12	0.21	0.18	0.24	1
18	A	80	14	UTE - 13.74	0.12	0.18	0.18	1
19	A	80	14	UTE - 19.44	0.23	0.18	0.18	1
20	A	81	55	UTE - 7.99	0.20	0.18	0.24	1
21	A	81	55	UTE - 10.93	0.19	0.18	0.18	1
22	A	81	55	UTE - 11.93	0.17	0.18	0.18	1
23	A	81	55	UTE - 12.17	0.13	0.12	0.18	1
24	A	91	56	UTE - 7.6	0.39	0.13	0.17	1
25	A	91	56	UTE - 8.96	0.26	0.13	0.22	1
26	A	92	4	UTE - 6.11	0.45	0.18	0.23	1
27	A	92	4	UTE - 6.6	0.18	0.12	0.18	1
29	A	92	4	UTE - 16.61	0.22	0.18	0.23	1
30	A	94	2	UTE - 17.59	(Note 4)	0.20	0.17	1
31	A	94	2	UTE - 22.91	(Note 4)	0.20	0.17	1
32	A	104	15	UTE - 11.46	1.00	0.24	0.24	1,3
33	A	104	15	UTE - 14.98	0.76	0.24	0.30	1,3
34	A	107	14	UTE - 10.67	0.38	0.18	0.18	1
35	A	107	14	UTE - 17.52	0.21	0.18	0.18	1
36	B	37	114	UTE - 2.66	0.77	0.28	0.37	3

Identification					EC Measurements			In-situ
Index No.	OTSG	Row	Tube	Position	Plus-Point Voltage	RC Axial Extent (inches)	RC Circ. Extent (inches)	Test Condition Codes
37	B	58	87	UTE - 16.93	0.53	0.33	0.31	1
38	B	64	51	UTE - 18.90	0.38	0.10	0.18	2
39	B	95	68	UTE - 3.4	0.87	0.25	0.25	3
40	B	103	17	UTE - 17.58	0.43	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 $\bar{X} + kS$ 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 mth 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.

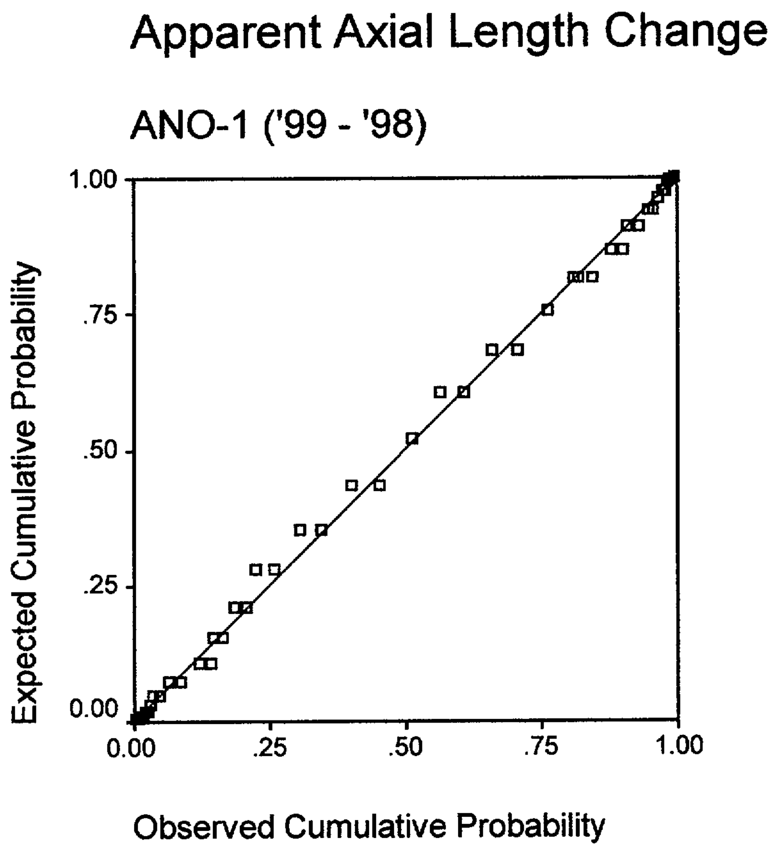

Figure 26. Normal Probability Plot

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