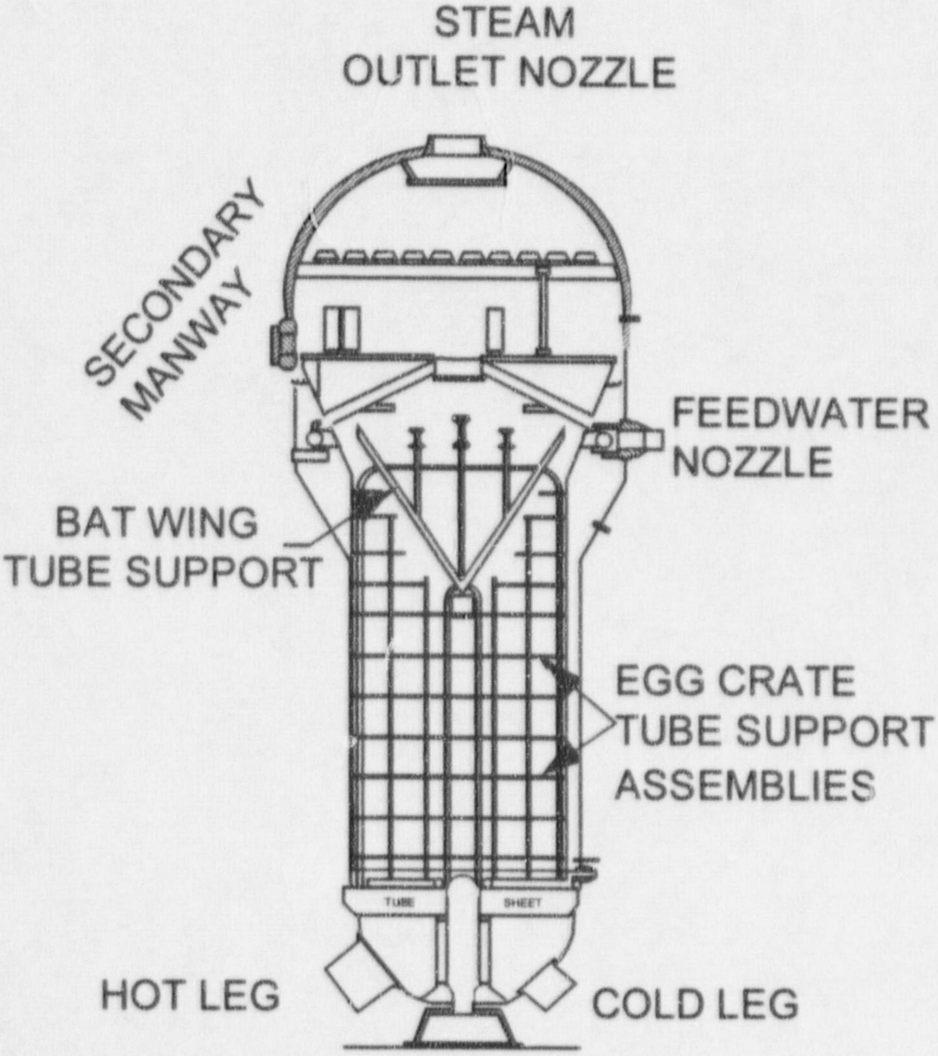
Entergy

Probabilistic Operational Assessment of ANO-2 Steam Generator Tubing for Cycle 14

May 28th, 1999



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Executive Summary

The purpose of this report is to provide results from evaluations performed to assess steam generator (SG) tube integrity for cycle 14. Based on the results of extensive Eddy Current (ECT) examinations and analysis described in this report, detection capabilities and growth rates are quantifiable and therefore, future steam generator tube performance can be evaluated. The intent of this assessment is to evaluate full cycle operation for the top of the tubesheet circumferential cracks and approximately one half-cycle operation for the axial cracks on the hot leg portion of the generator. A mid-cycle outage is planned to inspect for axial cracks at the eggcrate support plates on the hot leg side of the SG. ANO-2 has four damage mechanisms that were evaluated using probabilistic methods. They were:

- Hot Leg Top of Tubesheet (TTS) Circumferential Cracks
- Tube Support Plate (eggcrate) Axial Cracks
- Free Span Axial Cracks
- Sludge Pile Axial Cracks

Additionally, two other damage mechanisms and leakage due to repair hardware (plugs and sleeves) were evaluated using deterministic methods to be included in the total evaluation. The two damage mechanisms are:

- Batwing wear
- Axial cracks in dented eggcrate intersections

This evaluation follows guidance provided by the Nuclear Energy Institute (NEI) 97-06, "Steam Generator Program Guidelines," for performing condition monitoring and operational assessments of steam generator tubing degradation and the draft NRC regulatory guide Steam Generator Tube Integrity Guideline (DG-1074). The runtime analysis was evaluated to account for an increase in the operating temperature of approximately 1.5°F.

A Monte Carlo computer model was used to simulate the process of crack initiation, crack growth and detection via eddy current inspections over multiple cycles of operation. This allowed calculation of the conditional probability of tube burst (POB) at postulated steam line break conditions. The effect of the projected leakage for a postulated steam line break accident also was determined. Predictions of the Monte Carlo simulation model were benchmarked and agree well with past observations of corrosion degradation at ANO-2.

The projected degraded tube conditions after 0.73 effective full power years (EFPY) of operation for the first half of cycle 14 meets the required performance criteria relative to structural and leakage integrity as specified in NEI 97-06 and DG-1074. The POB given a postulated steam line break after 0.73 EFPY of operation is less than 0.0156 for all four corrosion mechanisms combined. The NEI 97-06 figures of merit on tube integrity are 0.05 for all mechanisms. DG-1074 values are 0.025 for total POB, and 0.01 for any single mechanism. The total projected 95% upper bound leak rate at 95% confidence at postulated steam line break conditions is 0.1112 gpm. The acceptance criterion used for this report is less than 1.0 GPM.

The in-situ pressure testing conducted during the 2R13 outage demonstrated that the degradation found in the ANO-2 steam generators met the 3 delta-P structural criterion with no leakage for all indications with the exception of one axial crack identified in the 01H eggcrate.

A run time of 0.73 EFPY was evaluated to bound the actual run time of approximately 0.7 EFFY. The additional 0.03 EFPY accounts for the increase in operating temperature. The temperature of the primary system was raised approximately 1.5 degrees Fahrenheit following 2R13 to maintain steam pressure. The bases for the increase in run time was to account for a three degree increase in operating temperature that is procedurally allowed to be increased during cycle 14. The methodology to adjust the run time to account for an increase in operating temperature is based on the Arrhenius equation. This takes into account the activation energy of the degradation process as well as the temperature increase and projected operating interval. The additional run time to account for the increase in operating temperature is documented in Engineering Request (ER) 980280 I204. The results demonstrate that ANO-2 can safely operate to the 2P99 mid-cycle outage scheduled in November 1999 with adequate margin. The guidance relative to POB and leakage were all well within the limits specified in NEI 97-06.

Continued operation for the first half of cycle 14 is justified for ANO-2 based on the 2R13 inspection results and this evaluation. Full cycle operation is justified for the TTS circumferential cracking and cold leg axial flaws. Steam generator replacement is currently scheduled for the end of the current fuel cycle (fall of 2000). Control room and off site dose consequences are also addressed in the evaluation.

1. INTRODUCTION

A program which provides reasonable assurance that the steam generator tubes are capable of performing their intended safety function has been developed at ANO using guidance from NEI and the Nuclear Regulatory Commission (NRC). This includes establishing performance criteria commensurate with adequate tube integrity, programmatic considerations for providing reasonable assurance that the performance criteria will be met during plant operation, and guidelines for condition monitoring of the SG tubing to confirm that the performance criteria are met.

Both the condition monitoring and operational assessments have been completed utilizing in-service inspection results. The results from the 2R13 refueling outage and the projected time interval until the next planned mid-cycle outage (2P99), scheduled for November 1999, has been compared to the performance criteria identified in NEI 97-06 and are discussed in detail in this report.

2. STEAM GENERATOR DESIGN

The ANO-2 steam generators are of the U-tube design manufactured by Combustion Engineering (Model 2815). Each steam generator contains 8411 tubes constructed of high temperature mill annealed (HTMA) Inconel alloy 600 material with an outside diameter of 3/4 inches and a wall thickness of 0.048 inches. The tubes are explosively expanded the full depth of the tube sheet. There are seven full eggcrate tube support plates (TSPs), two partial eggcrate TSPs, and two partial drilled TSPs. Commercial operation began March 1980, and all volatile treatment (AVT) chemistry has been used since that time. Secondary side boric acid addition was initiated in 1983 to arrest denting at the partial drilled TSPs. The design hot leg operating temperature was 611° F however initially the unit operated at 607° F. The temperature was reduced to ~600° F following the ninth refueling outage in the fall of 1992. The unit continued to operate at ~600° F until the temperature was raised approximately 1.5 degrees to maintain steam pressure following 2R13 or February 1999. The current steam generators are scheduled to be replaced in the next refueling outage in the fall of 2000 (2R14).

3. INSPECTION HISTORY

Table 3.1 lists the inspection scope of 2R13 and Table 3.2 contains the detected indications that were confirmed as degradation. Detailed inspection results were provided in the C-3 report submitted in February 1999[1].

Table 3.1
2R13 ECT Inspection

SG"A"

ECT Examination Type	Inspections Conducted	% Scope	Expansion Required
Bobbin	7348	100	No
RPC ET HL	6407	100	No
Small Radius U-bends (1-4)	48	20	No
B&W Sleeves	293	100	No
ABB Sleeves	78	20	Yes
Drilled Support Plate Intersections	604	20	No
Dented Eggcrates	3	100	Yes
Special Interest	264		

SG "B"

ECT Examination Type	Inspections Conducted	% Scope	Expansion Required
Bobbin	7462	100	No
RPC ET HL	7012	100	No
Small Radius U-bends	48	20	No
B&W Sleeves	48	100	No
ABB Sleeves	31	20	Yes
Drilled Support Plate Intersections	603	20	No
Dented Eggcrates	6	100	Yes
Special Interest	193		

Table 3.2
2R13 ECT Inspection Results

Location	SG "A"	SG "B"
Hot Leg ET Region (circumferential)	43	33
Sludge Pile (axial and volumetric)	4	5
EC Support Plate	38	68
B&W Sleeves	7	0
ABB Sleeves	8	4
Free-Span	21	1
U-bends	0	0
Dented Eggcrates	2	0

Table 3.3 list the number of the tubes plugged and sleeved from pre-service to the present:

TABLE 3.3

		PLUGS				SLEEVES			
		SGA		SGB		SGA		SGB	
YEAR	OUTAGE	INSTALL	CUM.	INSTALL	CUM.	INSTALL	CUM.	INSTALL	CUM.
1978	PRE-OPS	3	3	15	15	0	0	0	0
1979	PRE-OPS	12	15	14	29	0	0	0	0
1981	2R1	0	15	0	29	0	0	0	0
1982	2R2	0	15	1	30	0	0	0	0
1983	2R3	0	15	0	30	0	0	0	0
1985	2R4	0	15	0	30	0	0	0	0
1986	2R5	0	15	0	30	0	0	0	0
1988	2R6	0	15	6	36	0	0	0	0
1989	2R7	0	15	0	36	0	0	0	0
1991	2R8	0	15	73	109	0	0	0	0
1992	2F92	29	44	11	120	392	392	56	56
1992	2R9	67	111	132	252	0	388	0	56
1993	2P93	47	158	3	255	0	388	0	56
1994	2R10	170	328	77	332	0	387	0	55
1995	2P95	215	543	85	417	0	387	0	55
1995	2R11	200	743	150	567	442	799	180	230
1996	2F96	73	816	144	711	0	793	0	223
1997	2R12	350	1167	366	1077	0	715	0	205
1998	2P98	156	1323	121	1198	0	683	0	201
1998	2R13	104	1427	112	1310	0	666	0	197

The current plugging limit is based on the amount of asymmetry between the two generators. The maximum limit is based on 500 tube asymmetry with a maximum plugging limit of 18.5% or 22.5% with zero asymmetry. The actual equivalent plugging is currently 17.26% in SGA and 15.65% in SGB with an asymmetry of 136.
Table 3.4 lists the historical indications by damage mechanism:

TABLE 3.4

YEAR	OUTAGE	EFPY	SGA BW	SGA TSP	SGA SP	SGA CC	SGA FS	SGA OTH	SGB BW	SGB TSP	SGB SP	SGB CC	SGB FS	SGB OTH
1978	PRE SER		0	0	0	0	0	15	0	0	0	0	0	29
1981	2R1	0.89	0	0	0	0	0	0	0	0	0	0	0	0
1982	2R2	1.69	0	0	0	0	0	0	1	0	0	0	0	0
1983	2R3	2.33	0	0	0	0	0	0	0	0	0	0	0	0
1985	2R4	3.31	0	0	0	0	0	0	0	0	0	0	0	0
1986	2R5	4.16	0	0	0	0	0	0	0	0	0	0	0	0
1988	2R6	5.38	0	0	0	0	0	0	6	0	0	0	0	0
1989	2R7	6.52	0	0	0	0	0	0	0	0	0	0	0	0
1991	2R8	7.67	0	0	0	0	0	0	16	52	5	0	0	0
1992	2F92	8.51	1	1	166	253	0	0	2	3	4	58	0	0
1992	2R9	8.85	9	30	11	17	0	0	25	94	5	8	0	0
1993	2P93	9.36	0	0	2	45	0	0	0	0	0	3	0	0
1994	2R10	10.16	3	7	13	147	0	0	17	32	5	23	0	1
1995	2P95	10.86	0	0	12	203	0	0	0	0	5	80	0	0
1995	2R11	11.46	2	43	38	519	16	21	19	73	19	215	0	4
1996	2F96	12.43	0	29	6	13	4	21	11	100	3	13	0	17
1997	2R12	12.8	4	170	31	66	38	41	24	250	21	53	4	14
1998	2P98	13.5	2	45	9	39	44	17	5	74	7	28	6	1
1999	2R13	14.27	0	38	4	43	21	11	0	68	5	33	1	4

BW = Batwing Support Straps
TSP = Tube Support Plates
CC = Circumferential Cracks
FS = Freespan
OTH = Other repairs

4. OPERATIONAL ASSESSMENT

A detailed probabilistic analysis of the effects of the eggcrate, freespan, and sludge pile axial cracking as well as TTS circumferential cracking in the ANO-2 steam generator tubing was performed to address allowable operating intervals. Each of the cracking mechanisms are addressed in accordance with the NEI 97-06 guidance and are demonstrated to meet the 0.05 cumulative POB for a given operating interval. Additionally, leakage under an accident scenario is also addressed. The information from the leakage model is then used to address off site and control room dose consequences. Probabilistic calculations were performed considering approximately a half cycle operation for the eggcrate, freespan and sludge pile axials on the hot leg side, and full cycle operation for the axials on the cold leg side and TTS circumferential cracks. This section provides a detailed look at how the values are obtained.

A deterministic analysis was performed on the bat wing wear, axial cracking at dents, and leakage due to repair hardware.

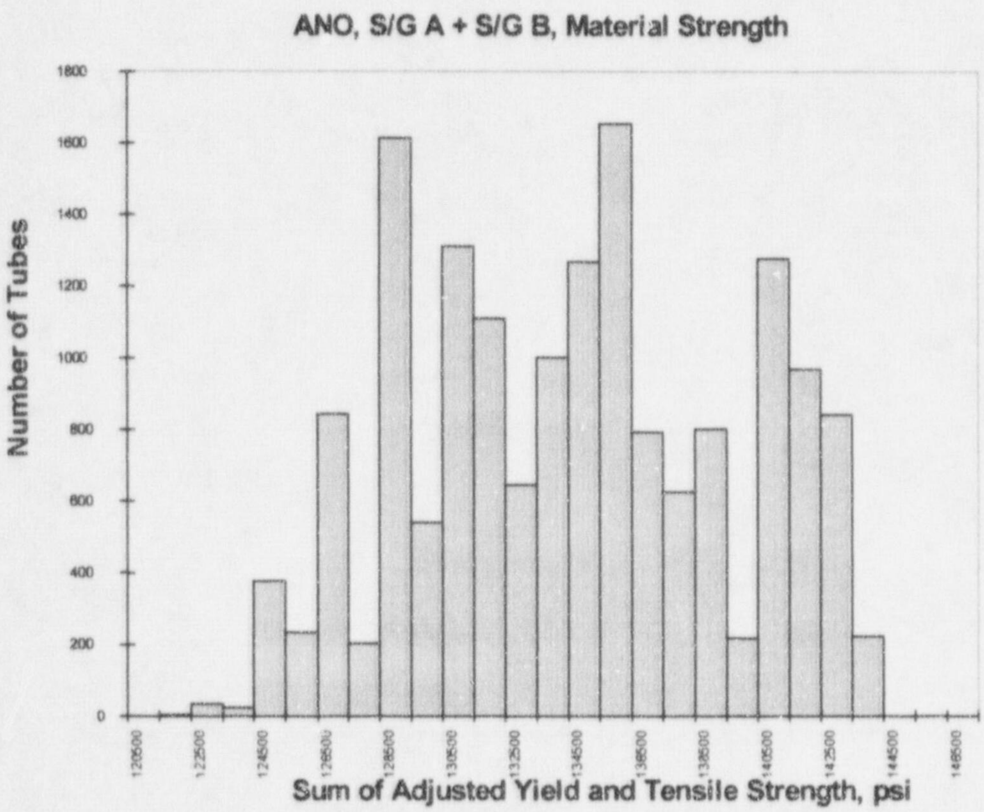
4.1 Probabilistic Analysis

A number of input parameters are needed for the Monte Carlo simulation model. A distribution of material properties is used rather than a lower bound strength value. Hence the distribution of tensile properties of the steam generator tubing is needed. The distribution of structurally significant axial crack lengths is equated to the distribution of measured lengths as found by the RPC eddy current probe. Thus a sampling distribution of axial crack lengths is needed. This simulation model conducts virtual inspections. This requires knowledge of the probability of detection (POD) as a function of degradation severity for the various eddy current techniques used. Since degradation growth is simulated, the distribution of crack growth rates for both axial and circumferential degradation is required. These inputs are included in Reference 2.

4.2 Tubing Mechanical Properties

Figure 4.0 shows a histogram of tube strength for both steam generators at ANO-2.

Figure 4.0
Histogram of Tube Flow Stresses



The sum of yield and ultimate tensile strength is obtained from mill reports. An adjustment has been made to correct for operating temperature. A normal distribution was fitted to the data of Figure 4.0 for application in the simulated model. This distribution was truncated at the measured extremes of the tensile property database. The mean value of the distribution used in the model is 134,000 psi with a standard deviation of 6,000 psi.

4.2.1 Axial Flaws

Probability of Detection Evaluation

In order to enhance the accuracy of the probabilistic output values the input values must be as consistent and accurate as possible. The process begins with the eddy current POD. The model was altered to reflect three different POD conditions reflective of the different inspection techniques utilized in the recent past. The bobbin coil inspections conducted prior to 2R12 were performed with a 0.580" or less bobbin coil that resulted in a lower delectability. This technique was not as effective as that depected by the industry accepted St. Lucie qualification. The POD for this technique was derived based upon benchmarking previous ANO2 results. The next two outage (2R12 and 2P98), utilized a practice of detection with a 0.600 bobbin and confirmation with a 0.115 pancake coil. Resolution was allowed to disposition the indications and throw out those that did not meet a certain criteria. For these two outages, curves developed from a site-specific qualification were utilized that mimicked the process of resolution to disposition the bobbin indications. The 2R12/2P98 curve is based on actual data that was validated by a site specific performance demonstration with independent vendors. Independent teams of analyst for both primary and secondary production, and resolution analyzed the data. The data consisted of pulled tube data from ANO-2, St. Lucie and Palo Verde. Additionally, tubes that have been in-situ tested from ANO-2 and actual flawed tubes from the most recent outage (2R13) were used. In an attempt to use pulled tube data with low amplitude flaws, data from Westinghouse plants was also evaluated. The project was developed and documented by Aptech Engineering and Entergy[3]. The validated POD curve provides the most accurate input possible into the model. The model randomly selected from the five curves in an attempt to replicate actual testing from the production data. A second model was then developed using a single curve that represented a composite of the five production curves. The output results of this model were consistent with that of the previous model. For 2R13, the same data and process as that used to develop the 2R12/2P98 POD was employed except the effect of the resolution analysis was taken out. Additionally, a second POD function based on MRPC was applied to determine if the indication was identified by the confirming MRPC inspection. A sensitivity check was conducted utilizing the new POD curves and bench marked against the actual results. All three of the composite curves are depicted in Figure 4.1 below.

Figure 4.1
Site Specific Performance Demonstration Curves

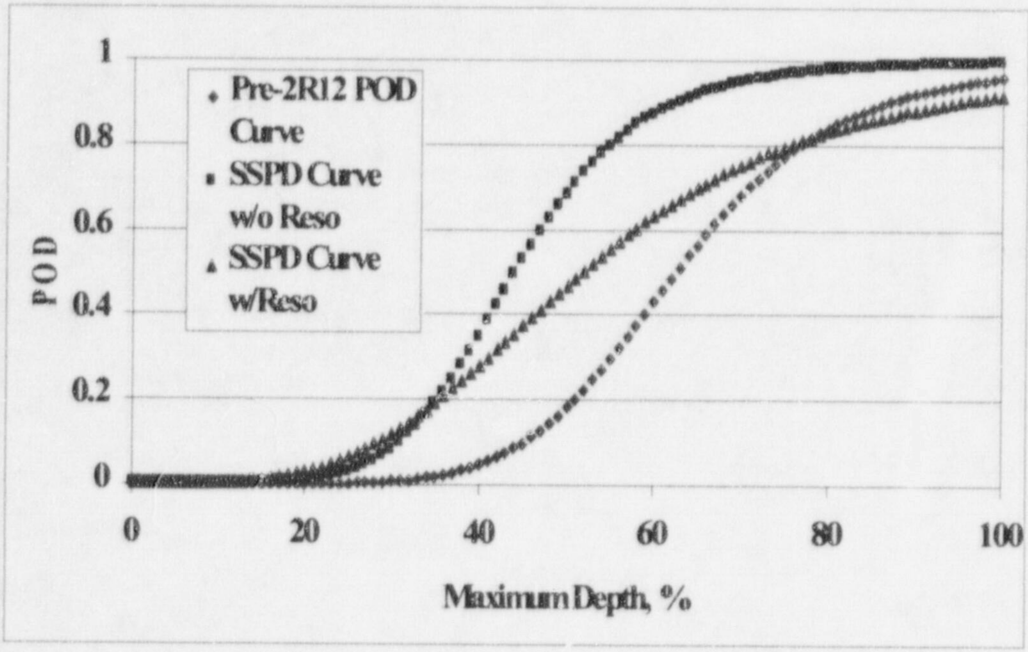
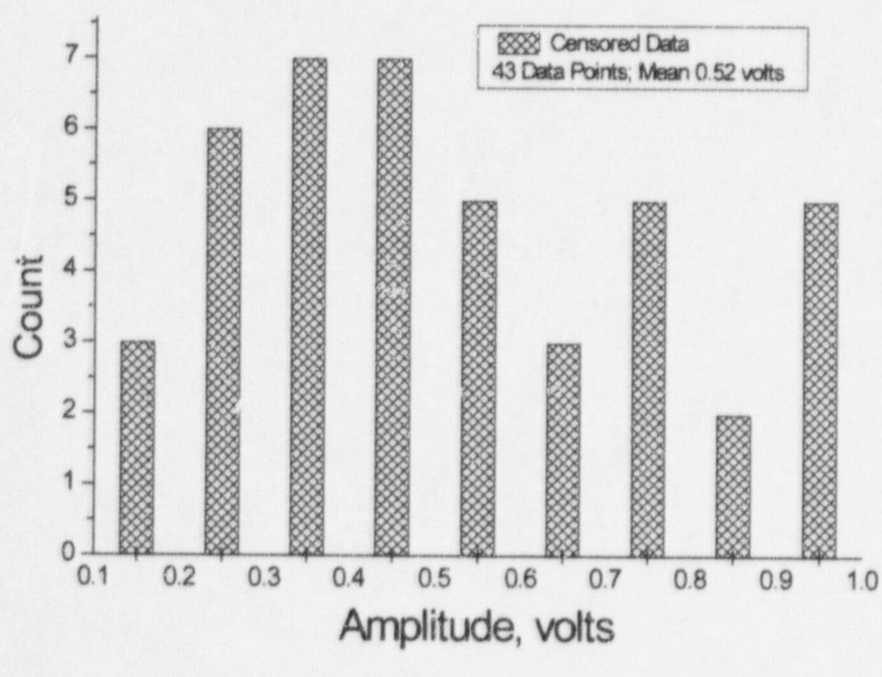


Figure 4.2
SSPD Eddy Current Grading Units
Voltage Histogram for Intermediate Depths



During the outage (2R13) condition monitoring based on in-situ testing determined that an axial crack at an eggcrate failed to meet the 3ΔP pressure. A corrective action plan was developed to mitigate this issue during the outage. In the previous outage, this tube was called by a production analyst, but was dispositioned as acceptable for continued service by a resolution analyst based on its low amplitude and signal response. During 2R13, it was decided that all bobbin indications at the lower eggcrates (01H-03H) would be tested with MRPC regardless of the resolution determination. The lower eggcrates were chosen because of the size of flaws historically seen at those intersections. Approximately 192 indications were tested with MRPC resulting in 44 indication that were determined to be crack-like which were removed from service. If this process had been implemented in the previous outage, the tube that failed to meet 3ΔP would have been removed from service.

Initiation

Due to the threshold of detection for stress corrosion cracks with eddy current techniques, detected flaws were likely initiated during a previous cycle. The initiation function is the most complex input to the model. A projection is made based on Weibull distribution established from inspection data with several thousand POD and growth samples being applied. The end result is an initiation function that is used in the model. The initiation function used in the model is included in reference 2. Note the methodology in which the initiation function is determined is the same as used in previous analysis.

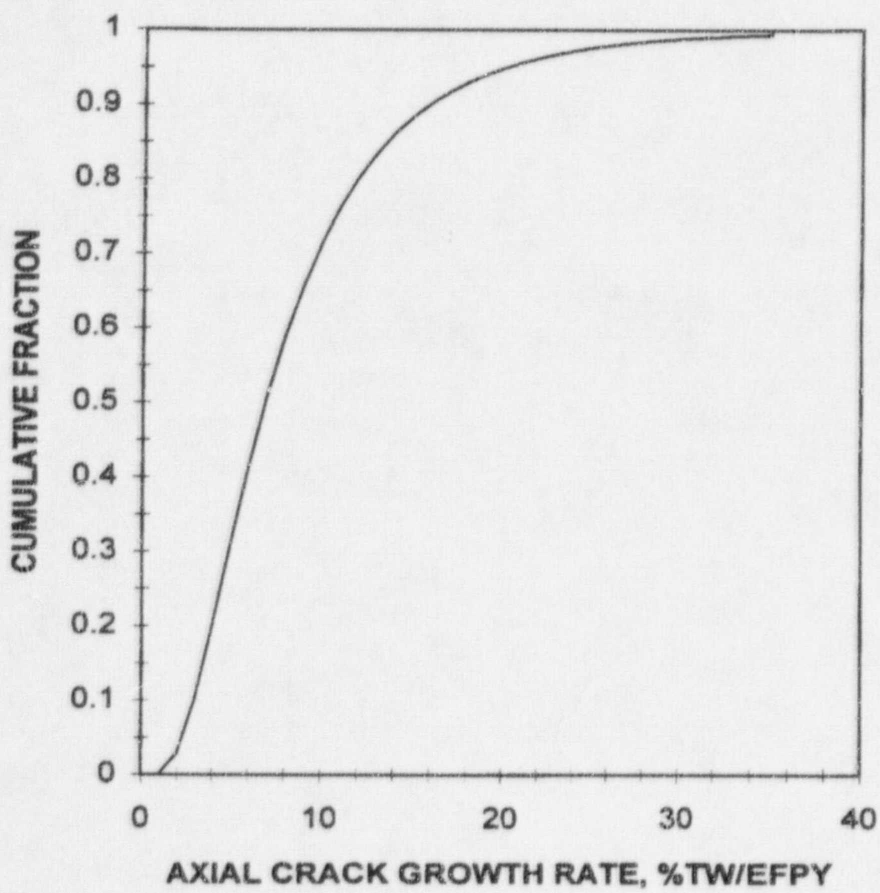
Sizing and Growth Rate Evaluation

The probabilistic models for leakage and burst require several inputs. In addition to the POD, other inputs required are size (length) distribution, and growth rate estimates. Previous evaluations have been performed using conservative estimates for ANO-2. A study was conducted during 2R12 using ANO-2 data[4] that allowed a conservative yet current growth rate value to be obtained. The growth rates identified during 2R13 were comparable to the study performed during 2R12. Detected results from the 2R13 inspection were compared to the projected operational assessment results and were conservative relative to the total number and size of flaws. The growth rates that were documented following 2R12 are still reasonable and bound the current conditions.

The overriding consideration in the bobbin depth growth study is the measurement error involved in phase angle depth calls. The distribution of bobbin depth calls over the last three inspections together with paired growth observations leads to a measurement error estimate. Assuming a normal distribution of measurement error which is not dependent on actual crack depth and a zero mean error leads to the conclusion that one standard deviation of bobbin depth measurement error is greater than 20% TW. The global average axial crack growth rate from all observations was 6.89%TW per EFPY. When only larger amplitude signals are considered, the average growth rate drops to about half this value. The phase angle depth measurement error associated with larger signals should be less than that of smaller amplitude signals. The phase angle from a signal with small vertical amplitude will be affected by background signals that are intentionally adjusted to the horizontal channel.

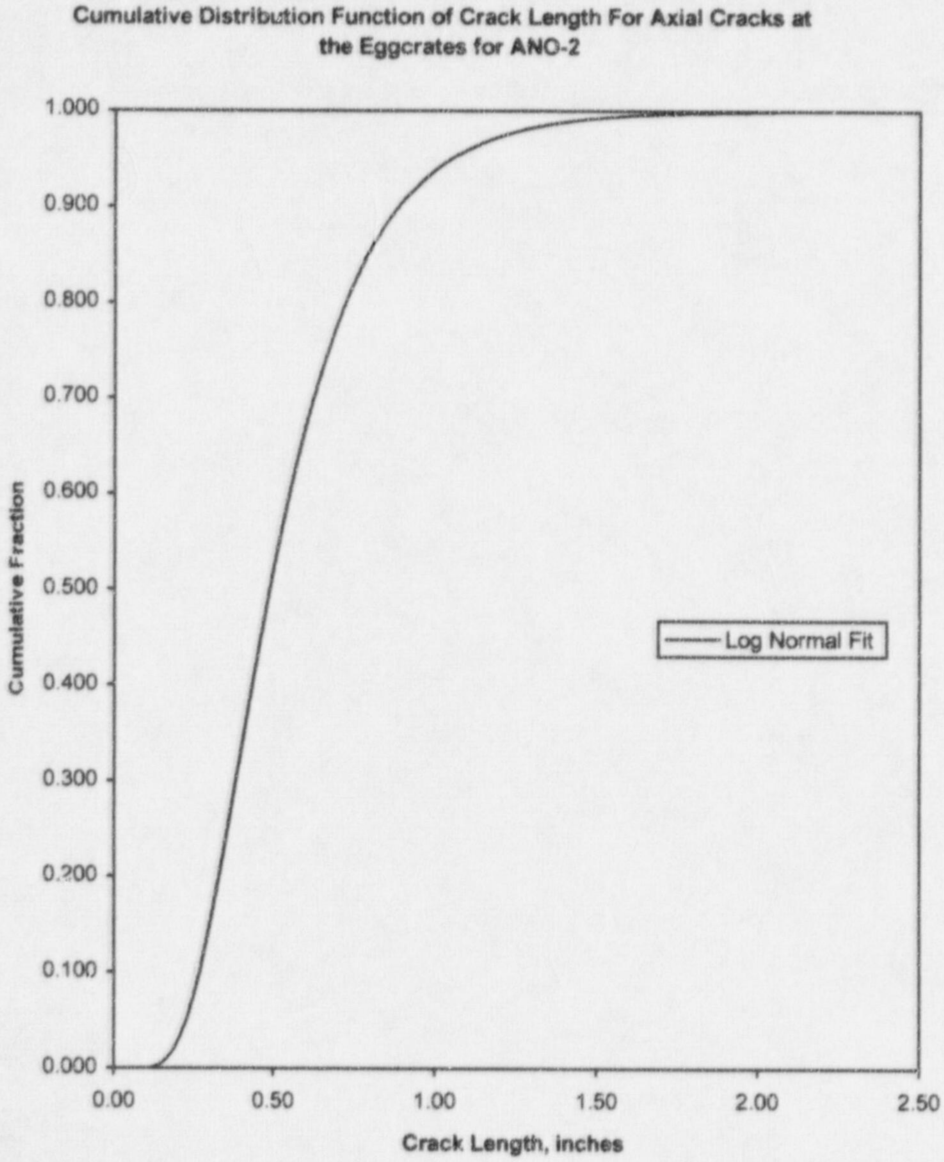
The end result of the growth study is that a reasonable upper bound growth rate distribution is given by a log normal distribution with a standard deviation of 0.70 and a mean growth rate of 6.89%TW/EFPY. This growth rate distribution bounds the results of several growth rate studies for plants of similar design. Based on the ANO growth rate data and data from other plants, the maximum growth rate was limited to 40%TW/EFPY. A realistic growth distribution would have an average crack growth rate of about 4%TW/EFPY. Note that the growth rates are based on average depth as compared to maximum depth. The average depth growth rate is used in the model. For any particular crack, maximum depths are calculated based on known distributions of ratios of maximum depths to structural (average) depth. Listed below in Figure 4.3 is the distribution curve for the growth rates used in the model.

Figure 4.3
Distribution of Axial Crack Growth Rates



As with POD, the length of the flaws is a critical input. The use of MRPC to determine the axial extent and then establishing a distribution to sample allows this input to be obtained. By MRPC sizing the axial flaws during the 2R13 outage, it is believed that an accurate distribution is obtained. Once the distributions are obtained they are sampled during the model simulation. Figure 4.4 shows the function obtained from the MRPC measured eggcrate axial length distributions.

Figure 4.4
Distribution of Eggcrate Axial Crack Lengths used in Probabilistic Model

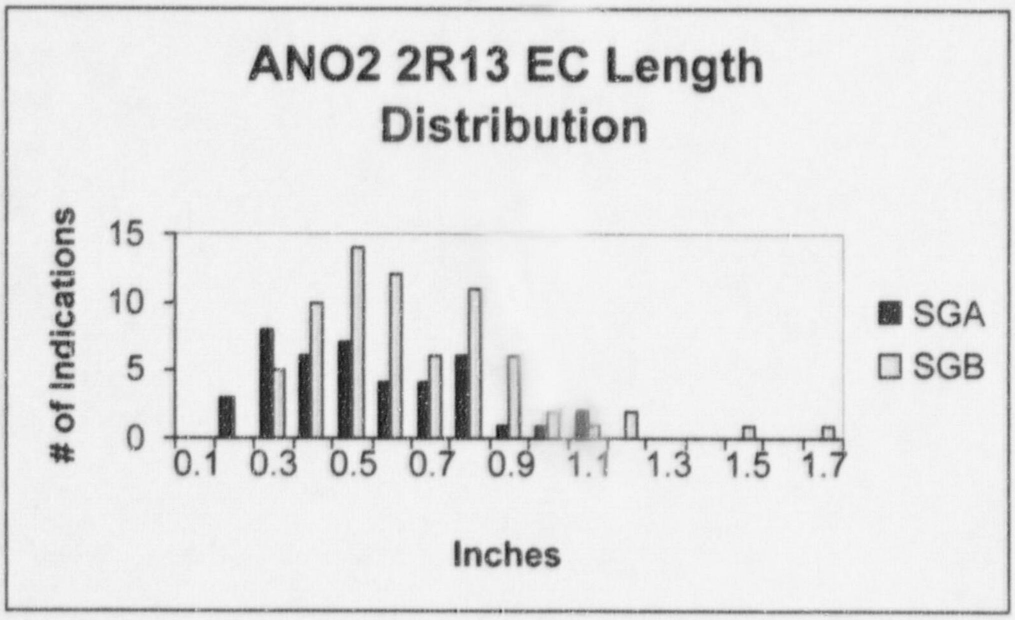


The length values were obtained directly from the raw MRPC data. This is a conservative method of determining extent due to the eddy current field look ahead and fall behind, which is defined as the influence of the flaw seen prior to the coil reaching the metal loss and after the coil passes the flaw. Therefore, the MRPC values used are, on average, longer than what actually exists as confirmed by previous ANO-2 tube pull data. Of the five axial flaws pulled from ANO-2, the MRPC axial extent oversized the flaws by an average of 15% indicating that a conservative distribution is being used for axial lengths. A comparison between the field MRPC length and the length determined by the destructive analysis (DA) is given in Table 4.1. Length distributions for axial eggcrate flaws in both the "A" and "B" SGs are provided in Figure 4.5.

Table 4.1
Axial Crack Lengths from ANO-2 Pulled Tubes

Year	S/G	Tube	Field MRPC Length (inches)	DA Length (inches)
1992	"B"	19-55	0.72	0.66
1992	"B"	19-55	0.57	0.31
1992	"B"	96-116	0.51	0.65
1996	"B"	16-56	1.20	1.03
1996	"B"	70-98	1.40	0.96

Figure 4.5



Axial Flaw Probability of Burst

After the flaws are initiated and allowed to propagate through a simulated cycle, the size of the flaw must then be assessed. The goal is to determine if the flaw will withstand accident pressures. The physical parameters of the flaws are obtained from the model and compared to the burst correlation to see if it can withstand accident pressure. The formula used in the burst pressure determination is[5]:

$$P = \frac{0.58St}{R_i}\left[1 - \frac{Ld/t}{L + 2t}\right]$$

where:

P = estimated burst pressure
S = flow stress
t = tube thickness
R_i = inner radius of tube
L = characteristic degradation length
d = characteristic degradation depth

This formula has consistently demonstrated a conservative estimate of measured burst pressure. Figure 4.6 shows a comparison between calculated values and measured data. The data in Figure 4.6 was obtained from numerous tests with a wide range of steam generator tubing.[6]

Figure 4.6
Calculated vs. Measured Burst Pressure Using the Framatome Equation

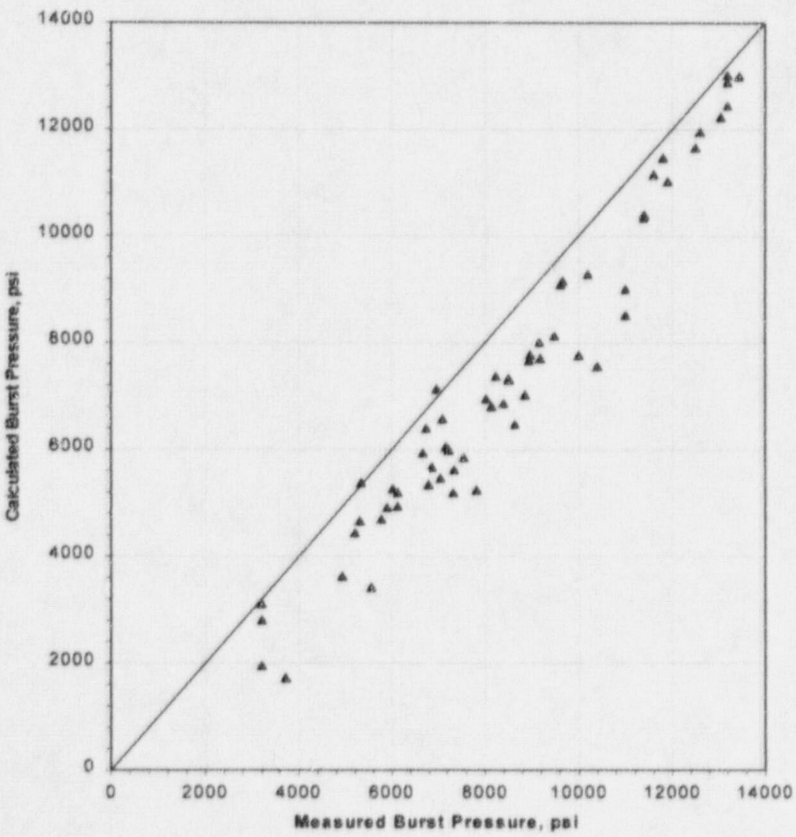


Table 4.2 shows the POB value at the postulated main steam line break (MSLB) accident for each axial damage mechanism at a run time of 0.73 EFPY. This data shows that the 0.05 figure of merit for a all degradation mechanisms is not challenged at the scheduled mid cycle outage date. The largest contributor of the three axial degradation areas is the hot leg eggcrates with a 0.0050 conditional probability, which is well below 0.05. A cycle length of 0.73 EFPY was chosen to demonstrate that operation prior to a bobbin exam at the mid-cycle could be achieved. Using the inputs described above, the 2R13 data was benchmarked to verify model accuracy. A POB at 3ΔP was calculated to be 45% for the eggcrate axial indications for the previous outage. That value indicates the model reasonably predicted the results of the last inspection. For the projected runtime until 2P99, this value drops to 9.2 % at 3ΔP when the effect of resolution analysis dispositioning flaws is taken into account. This value is considered to be reasonably low for a pressure of this magnitude.

Table 4.2
Structural Margin and Projected MSLB
Leak Rates for 0.73/14.7 EFPY

Degradation Mechanism	Conditional Probability of Burst at Postulated MSLB (95% Confidence Level)	95/95 Leak Rate at Postulated MSLB (GPM)
Axial ODSCC at Eggcrate hot leg (half cycle)	0.0050	0.0000
Axial ODSCC at Eggcrate cold leg (full cycle)	0.0005	0.0030
Freespan Axial ODSCC hot leg (half cycle)	0.0005	0.0000
Freespan Axial ODSCC cold leg (full cycle)	0.0005	0.0030
Sludge Pile Axial (full cycle)	0.0003	0.0570

Axial Flaw 95/95 Leakage

A leakage assessment was performed using the Monte Carlo sampling model. During the leakage evaluation the physical properties are assigned the same way as in the burst model. The main difference is how the accident at MSLB leakage profiles are assigned. The flaws are viewed as a single idealized planar crack. This is a conservative approach in that the strengthening and leak limiting effects of the ligaments are neglected. Additionally, the physical depth profile, which typically varies in a non-uniform fashion over the length of the crack, is modeled as a simplified ideal profile for leak calculations. The profile is allowed to grow until it is detected by eddy current. When the flaw is detected, the upper bound leak rate is based on a 95% probability with a 95% confidence level (95/95). For example, for 10,000 steam generator simulations, the 9537th highest computed leak rate represents the 95th percentile leak rate with 95% confidence. As expected the majority of the 95/95 leak rates are negligible, except for the most adverse combinations of growth rate and initiation. Each simulated through wall (TW) defect has an associated leakage value. This value is calculated using Version 3.0 of the PICEP two-phase flow algorithm[5]. The flow rate is calculated as a function of pressure differential (p), temperature (T), crack opening area (A), and total TW crack length (L). Friction effects and crack surface roughness were included in the model. Main steam line break, room temperature, and normal operating condition leak rates calculated by PICEP were fitted to regression equations. The PICEP based leak rate regression equation for steam line break conditions is given as:

$$Q = \left\{a + b\exp\left[c\left(A / L\right)^{0.151} + d\left(A / L\right)\right]\right\}Ap^{1.333}$$

where:

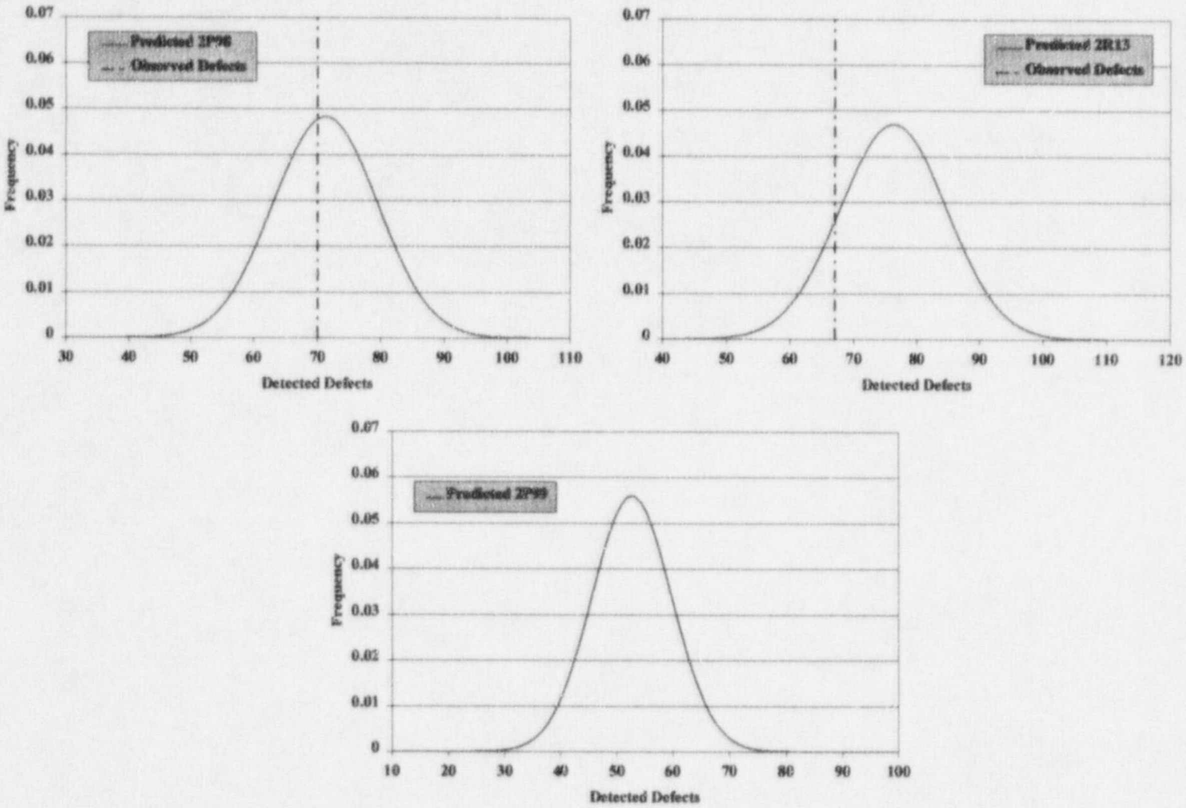
a - d = regression coefficients
Q = gallons per minute
p = pressure
A = inches^2
L = characteristic degradation length

The tabulated data for the axial indications is summarized in Table 4.2 above.

Benchmarking

The predictions of the degradation numbers generated by the Monte Carlo simulation agrees well with past observations of corrosion degradation at ANO-2. Benchmarking of several parameters were conducted to verify this. The actual observations match well with the numbers predicted by the model as illustrated in Figure 4.7 for the axial eggcrate hot leg defects.

Figure 4.7
Predicted Axial Cracks vs. Observed Axial Cracks
Hot Leg Eggcrates

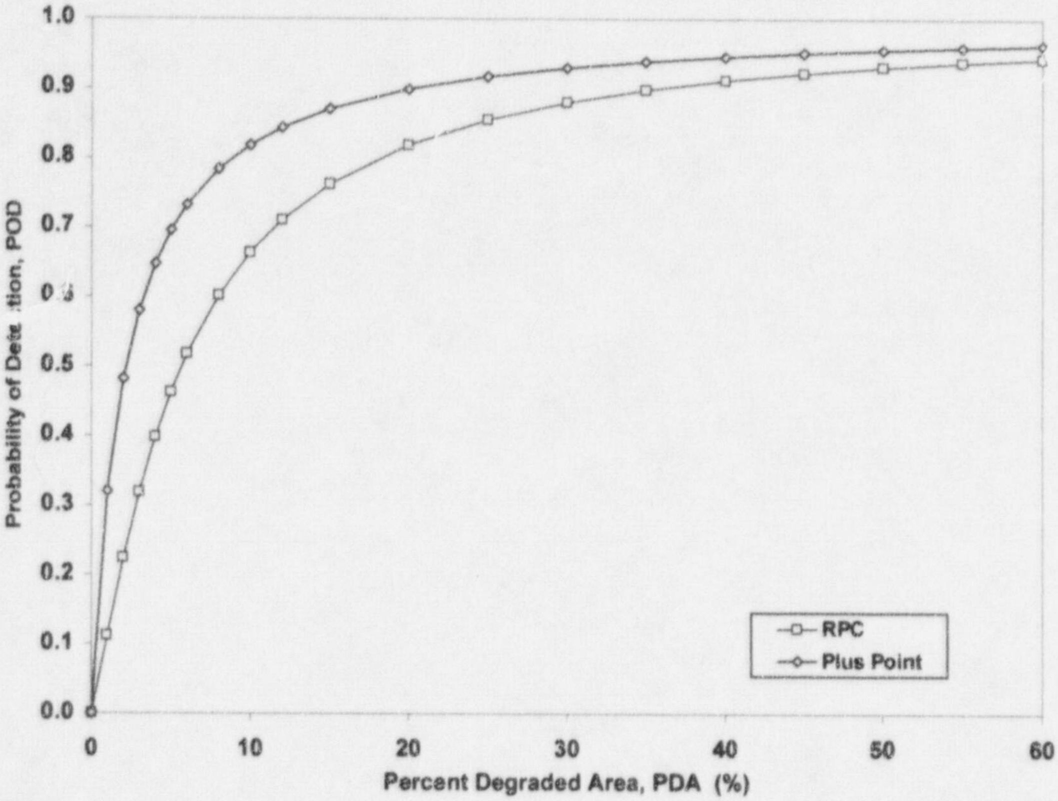


4.2.2 Circumferential Flaws

Probability of Detection Evaluation

The Monte Carlo methodology used for the circumferential cracking probabilistic model is identical to that for axial flaws. Distributions used for input were based on ANO-2 MRPC exams over the previous inspection. Two different POD curves are illustrated for plus point and MRPC as shown in Figure 4.8. These curves were established by a simulation process that yields a detected defect population that was observed at the last inspection (Outage 2R13). The simulation process included a POD function based on maximum depth and a distribution of depths verses percent degraded area (PDA) that reflects the nondestructive examination defect profiles from Outage 2R13. A uniform distribution for depth was assigned for PDAs up to 20% consistent with the nondestructive examination. For PDAs greater than 20%, a near through-wall depth was assigned in the simulation.

Figure 4.8
TTS Circumferential Cracking POD Curves



Initiation

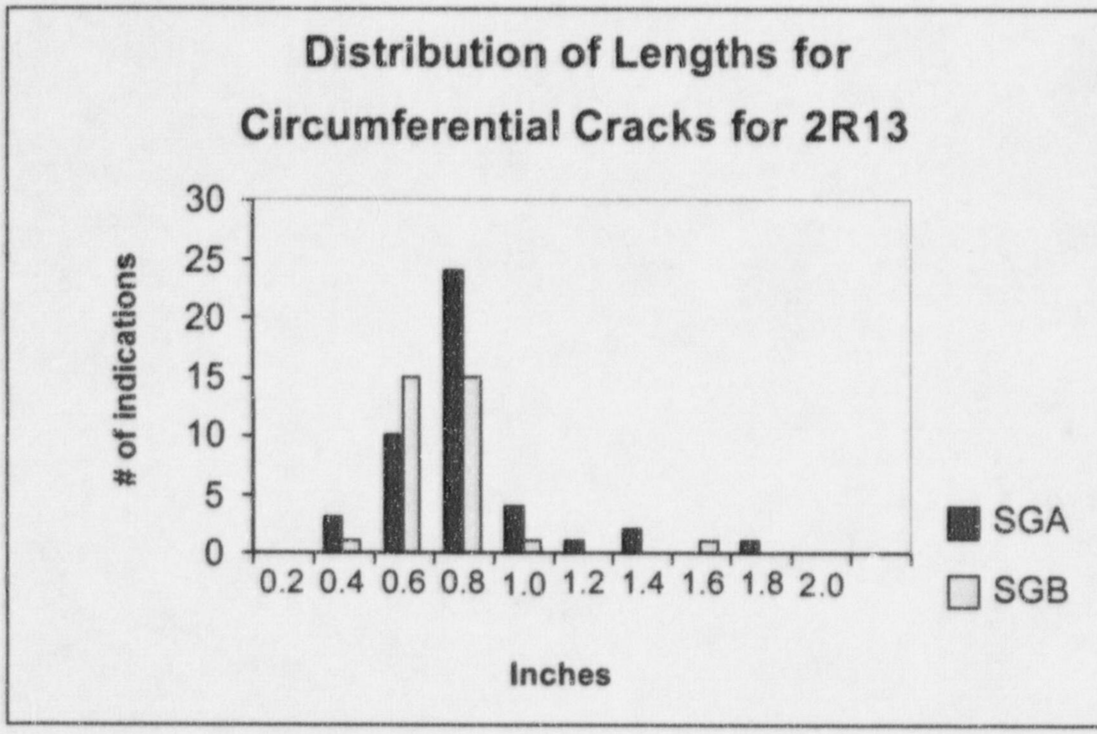
Due to the threshold of detection for stress corrosion cracks with eddy current techniques, detected flaws were likely initiated during a previous cycle. The initiation function is the most complex input to the model. A projection is made based on Weibull distribution established from inspection data with several thousand POD and growth samples being applied. The end result is an initiation function that is used in the model. The initiation function used in the model is included in reference 2.

Sizing and Growth Rate Evaluation

As with the axial cracking model, the circumferential cracking model requires similar inputs. Eddy current examinations provide the data to determine the growth rates based on PDA or an average value.

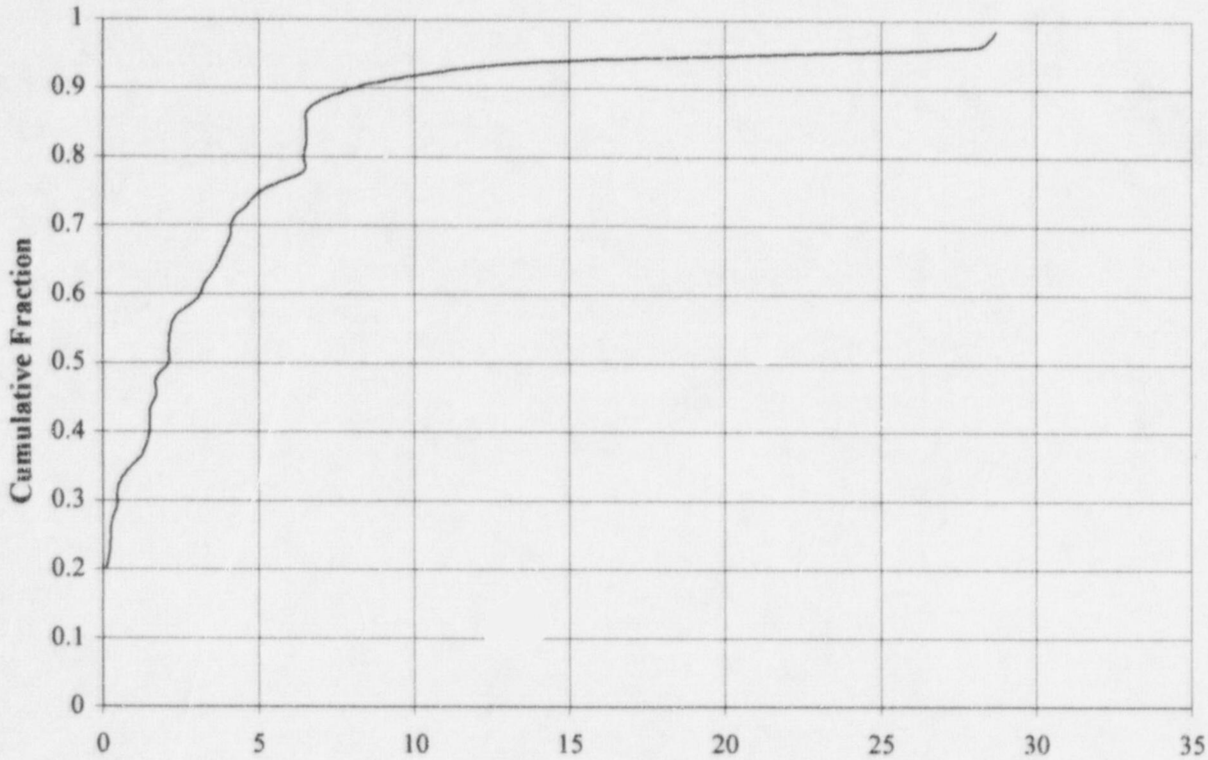
Due to the inability of the bobbin coil to adequately detect a circumferential flaw in an expansion transition, a 100% MRPC examination is typically performed at the hot leg TTS. Flaws detected during 2R13 were sized to determine in-situ candidates and to validate the PDA distribution utilized in the Monte Carlo simulation. The arc length distribution for 2R13 is provided in Figure 4.9. The figure shows that the majority of the flaws are small and thus are of no structural concern. The growth rate data used in the Monte Carlo simulation was obtained from the most recent ANO Circumferential Crack Growth Rate Evaluation[7].

Figure 4.9



The size distributions are obtained from the MRPC measured values and from the ANO2 Circumferential Crack Growth Rate Study[7]. In this case growth rates are expressed as changes in PDA verses maximum depth. A detailed crack growth rate study was conducted with the most recent outage data. Negative growth rates were set to zero and the resulting cumulative distribution of circumferential crack growth rates is shown in Figure 4.10. This growth rate distribution is conservative in the sense that no attempt was made to account for PDA measurement errors. Measurement errors increase the dispersion of observed growth rates compared to actual growth rates. Historically, flaws that had significant length circumferentially were detected which resulted in larger PDA values. Currently, the flaws being identified are shorter in length but have a larger maximum depth. For this reason the model was altered to reflect a distribution more typical of what was observed.

Figure 4.10
Distribution of Circumferential Crack Growth Rates



Data obtained form the EPRI/ANO Circ Crack Program[8] shows that burst pressure of tubing with circumferential degradation is bounded by the single planar crack. The bounding equation for pressure differential is:

$$P = \left(\left(R_o^{\,2} - R_I^{\,2}\right) / R_I^{\,2}\right)\left(1 - PDA\right)\left(S/2\right)$$

where:

PDA = percent degraded area
S = flow stress
P = pressure
R_O = outer radius
R_I = inner radius

As with the axial flaws, the assigned physical characteristics are carried through the Monte Carlo simulation and the above equation is applied to determine if the flaw will fail. The conditional probability of burst for circumferential cracking after 1.65 EFPY is 0.0088, which is well below the 0.05 figure of merit established in NEI 97-06.

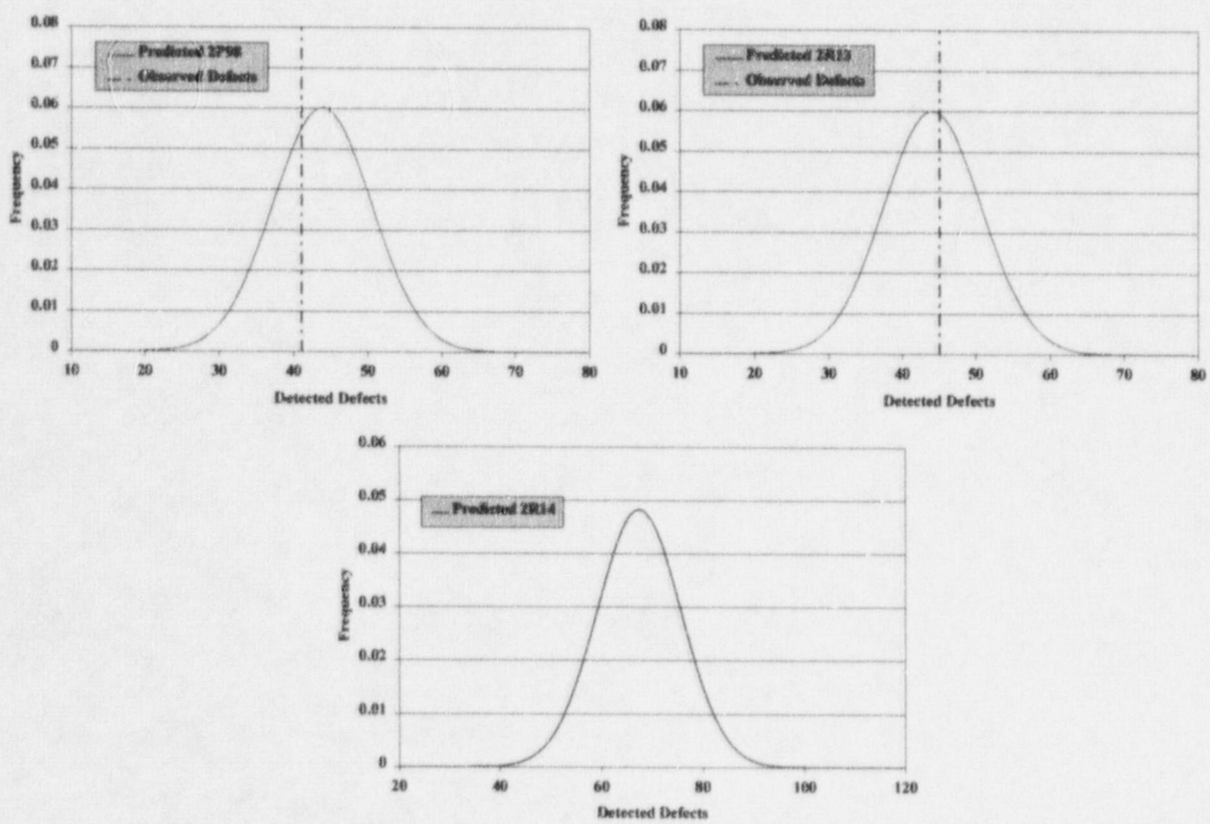
Circumferential Crack 95/95 Leakage

The Monte Carlo leakage models revealed the largest leak rate of all the degradation mechanisms was attributed to circumferential cracks; however, the leakage values are still low. The total value of 0.0460 gpm is calculated to be the 95/95-leakage value after 1.65 EFPY. This estimate is bounded by the 1.0 gpm accident value included in the ANO-2 Safety Analysis Report (SAR).

Benchmarking

The predictions of the degradation numbers generated by the Monte Carlo simulation agrees well with past observations of corrosion degradation at ANO-2. Benchmarking of several parameters were conducted to verify this. The numbers from actual observations match well with the numbers predicted by the model as illustrated in Figure 4.11

Figure 4.11
Predicted Circumferential Cracks vs. Observed Circumferential Cracks
Expansion Transition



4.3 Deterministic Run Time Assessment

A deterministic operational assessment was performed for the wear indications at the bat wing supports and the axial indications identified in dented intersections at the eggcrate supports.

4.3.1 Wear

ANO2 has experienced wear at the batwings since the early years of operation. There are approximately 277 total wear indications. The majority of the indications are in SGB. A growth rate study was performed using the 2R12 and 2P98 data [10]. Batwing wear has changed very little over the last several inspections. A bounding approach was taken due to the low growth rate and limited number of indications. ANO technical specifications require that all indications 40% TW and greater be removed from service. A conservative 35% TW limit is used to account for maximum growth relative to a repair limit. The largest indication remaining in service is 33 %TW. Based on the growth rate study the maximum growth rate would be 12% TW for a half cycle or 24%TW for a full cycle of operation.

The root mean square error (RMSE) from the Appendix H qualification based on the EPRI document was equivalent to 4.9% TW. The following is the calculation for a bounding approach:
(Maximum depth flaw left in service) + (4.9%TW) + (Maximum growth rate for 1 cycle)

33%TW + 4.9%TW + 24%TW = 61.9% TW

Based on the structural limit of 64%TW for 3/4 x 0.048 tubing [11], this condition acceptable for the full cycle of operation with no additional leakage.

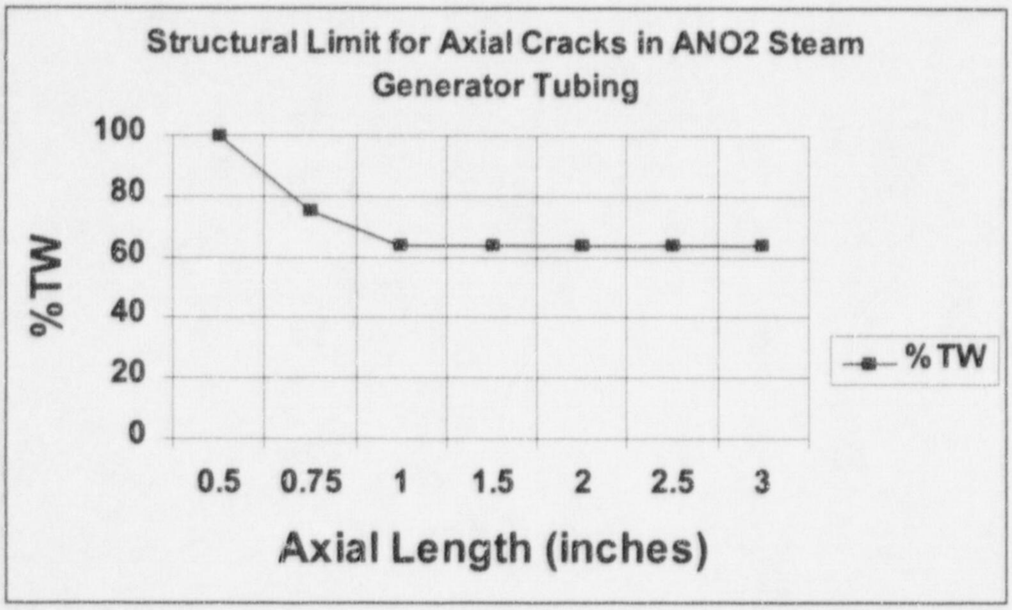
4.3.2 Axial Cracking in Dented Eggcrate Intersections

During the most recent outage (2R13), an inspection was performed in response to industry experience relative to axial cracking at dented eggcrate intersections. The bobbin coil is not qualified to detect a flaw that is within a dented section of tube. For this reason, the plus point coil was used for the first time to detect small amplitude indication within the dent. Two indications were identified during the examination. Both were contained in SGA at the 01 hot eggcrates. A total of 52 dents were examined down to three volts. The following details the information on the flaws:

Row	Line	Length	Max. Depth
44	112	0.28	60
50	114	0.33	75

It is impossible to go back to previous outages in an attempt to quantify growth rate since this was the first time these intersections were tested with a rotating coil. However, due to the limited length of the indications, a deterministic approach was utilized. A structural limit curve is shown in Figure 4.12 that was derived from a study sponsored by the Combustion Engineering Owners Group (CEOG)[11] to determine the structural length vs. depth:

Figure 4.12



As noted in the graph, the structural limit in the range of length specified is 100% TW. The largest of the two flaws (R50L114) was 0.33 inches in length and had a maximum depth of 75% TW. Since this was the first time that this mechanism was examined one can assume that it is possible that a flaw could have been left in service if it is at the detection level of the test. Using the plus point coil, the minimum detectable depth would be approximately 20% based on the EPRI qualification. To be conservative, a 40% TW value was used. Applying a maximum growth rate based on the eggcrate axial data, 40% TW would be added for a total of 80% TW. Based on the length and calculated depth, the largest postulated flaw would pose no threat from a structural or leakage standpoint. Based on the above results, it is acceptable to operate full cycle due to potential axial cracks in a dented eggcrate.

4.3.3 Repair Hardware

Following 2R13, the total number of plugs and sleeves per generator was evaluated for leakage potential at MSLB conditions. ANO2 has mechanically rolled plugs, welded plugs and 6 ribbed plugs that have been repaired with a plug a plug (PAP). The PAP was installed to prevent a plug top release if there was a failure of the ribbed plug. There are two type of sleeves installed in the ANO2 steam generators. They include a double kinetic sleeve design and a tungsten inert gas (TIG) welded sleeve. Both are installed at the TTS interface to mitigate the circumferential cracking on the hot leg. The following is a summary of the total number of plugs and sleeves currently installed:

	SGA	SGB
Repaired to date plugs	1427	1310
Repaired to date sleeves		
Kinetic	286	48
TIG	380	149
Total	666	197
Equivalent Plugged	1451.53	1316.05
Equivalent % Plugged	17.26%	15.65%
Average % Plugged	16.46%	

Leakage values were taken from the qualification/topical reports for each repair method. The total accident leakage estimate was determined to be 0.02 gpm. This value was conservatively rounded up to the nearest hundredth.

5. Operational Leakage

An operational leak rate limit is established to provide reasonable assurance that flaws either missed during inspection or growing more rapidly than expected will not render the tube vulnerable to tube rupture in the event of a MSLB. The ANO-2 T.S. limit of 150 GPD per SG exists to provide adequate margin against burst. In addition, rate of change limits exist to ensure rapidly propagating cracks or damage will be addressed at the earliest possible stages.

Upon any control room alarm indicating primary to secondary leakage, abnormal operating procedures are entered. If the leak rate is ≥0.1 GPM, a plant shutdown is procedurally required. In addition, a plant shutdown is procedurally required if the leak rate is projected to be ≥0.1 GPM in one hour. Stable leak rates of >0.01 GPM procedurally require management awareness for continued plant operations.

Steam line radiation levels, condenser off-gas activity, and activity measurements from the steam generator sample systems are trended in determining the indication of a steam generator tube leak. Steam lines are monitored via radiation monitors and nitrogen sixteen (N-16) gamma detectors, which provide the capability of quantifying leakage. Procedures are utilized when the monitors or trend recorders for the aforementioned systems exhibit increasing trends. These procedures are entered to place the plant in a stable condition and to mitigate the consequences of a steam generator tube leak.

Extensive training for operators is provided and emphasis is placed on changes in SG primary to secondary leakage parameters. Developing an aggressive strategy to identify early signs of a potential steam generator tube rupture are an essential part of ANO-2 steam generator management program.

Both the primary and secondary water systems, as well as condenser off-gas are sampled routinely. Sample results are trended to monitor and identify possible primary-to-secondary leakage occurrences.

6. Summary

Entergy Operations has performed an extensive investigation into the axial and circumferential cracking occurring at ANO-2. The investigation includes comprehensive inspections, application of appropriate safety factors, use of statistically valid (95/95) material properties, accurate NDE data, enhanced growth rate and tube burst test data.

Monte Carlo simulation models were used to project the results of different forms of degradation in the ANO-2 steam generator tubing. When modeling the degradation mechanisms, all forms of degradation are conservatively represented as a planar cracks. The processes of crack initiation, crack growth, and detection of cracking by eddy current inspections were simulated for multiple cycles of operation. Allowing the severity of degradation to be projected, the simulation model is benchmarked by comparing simulation results with actual eddy current inspection results, notable in-situ test results and operational occurrences. Excellent benchmarking results were obtained.

At 2P99, the conditional POB given a postulated steam line break event, is less than 0.0156 for all four-corrosion mechanisms combined. The largest contribution from the axial flaw types is the ODSCC/IGA at eggcrate intersections, with a value of 0.0050. The circumferential crack probability of burst is 0.0088 at the end of the cycle, which supports continued operation until 2R14. Table 6.1 summarizes all model outputs relative to probability of burst at accident conditions and the 95/95 leakage.

The value obtained from the probabilistic evaluation demonstrates significant margin above the performance criteria of NEI 97-06 Steam Generator Tube Integrity guidelines[12] and the current draft regulatory guide DG-1074 [13]. The calculated accident leakage values are considered low (0.1112 gpm), and are well below the dose limits of 10CFR100 and GDC 19.

Table 6.1
Summary of Results

Degradation Mechanism	Conditional Probability of Burst at Postulated SLB (95% Confidence Level)	95/95 Leak Rate at Postulated MSLB (GPM)
Axial ODSCC at Eggcrate hot leg (half cycle)	0.0050	0.0000
Axial ODSCC at Eggcrate cold leg (full cycle)	0.0005	0.0030
Freespan Axial ODSCC hot leg (half cycle)	0.0005	0.0000
Freespan Axial ODSCC cold leg (full cycle)	0.0005	0.0030
Axial at Dented Eggcrates (full cycle)	0.0000	0.0000
Wear at Batwings (full cycle)	0.0000	0.0000
Sludge Pile Axial (full cycle)	0.0003	0.0570
Circumferential ODSCC at Expansion Transitions*	0.0088	0.0460
Leakage due to Hardware (plugs and sleeves)	N/A	0.0022
Total of all Degradation Mechanism	**0.0156**	**0.1112**
NEI 97-06 Limit for 1 Burst	0.05	
SAR Limit for Leakage		1.0000
DG-1074 Guidance	0.01 for 1 or more 0.025 for total degradation	1.0000

ANO has an excellent primary-to-secondary leakage detection program that is supplemented by extensive operator training in steam generator tube leakage/rupture scenarios and effective departmental interaction and support in the steam generator area. Together these ensure early detection and prompt corrective action should leakage occur.

Based on the inspections performed in 2R13 and the subsequent analysis, ANO-2 is safe to operate until the planned mid-cycle outage 2P99 in November 1999.

7. REFERENCES

1. 2CAN029902, "Special Report: Steam Generator Tube Inspection Results," February 11, 1999.

2. ER 9821220 E202, "Probabilistic Operational Assessment of ANO-2 Steam Generator Tubing for Cycle 14"

3. AES 99033642-1-1, "Detection Probability for Axial ODSCC at Supports Structures Determined using a Supplemental Performance Demonstration"

4. ANO-2 Eggcrate Growth Rate Study.

5. AES 95102556-1-6, "Probabilistic Operational Assessment of Steam Generator Tube Degradation at ANO-2".

6. AES 96112906-1Q-2, "Aptech Axial Crack Burst Pressure Methodology"

7. ER 991701E201, "ANO-2 Circ Crack Growth Rate Study".

8. EPRI TR-107197-P1, "Depth Based Structural Analysis Methods for Steam Generator Circumferential Indications," November 1997

9. 2CAN079604, Evaluation of Steam Generator Integrity for Cycle 12 Operation, July 30, 1996.

10. ER 974855 E203, "ANO2 Steam Generator Growth Rate Study"

11. CE NPSD-1125-P, "Methodology For Evaluation of Axial Degradation in Steam Generator Tubing – Laboratory Test Program"

12. NEI 97-06, "Steam Generator Program Guidelines", December 1997.

13. DG 1074," Steam Generator Tube Integrity".