Entergy

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

February 3, 2000

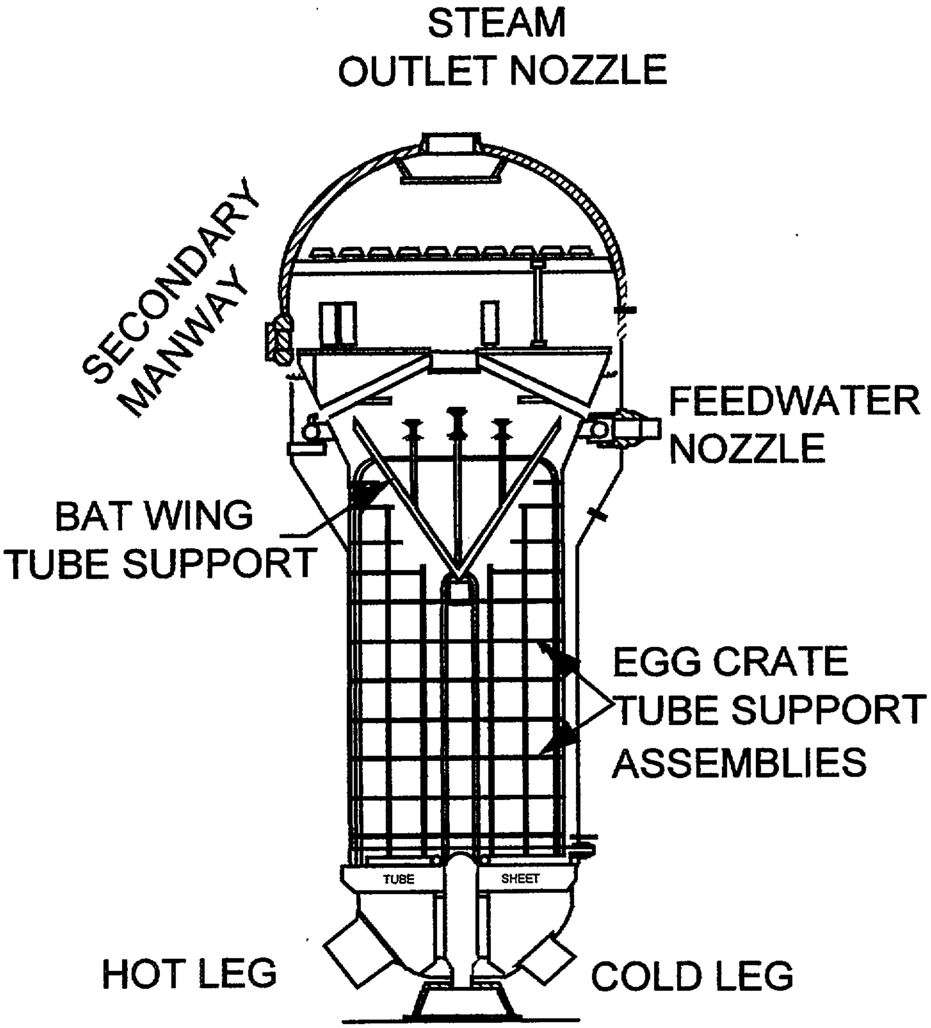


Table of Contents

EXECUTIVE SUMMARY

The purpose of this report is to provide results from evaluations performed to assess Arkansas Nuclear One, Unit 2 (ANO-2) steam generator (SG) tube integrity for the remainder of cycle 14. Based on the results of 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 emphasis of this assessment is to evaluate approximately one half-cycle operation for the axial cracks on the hot leg portion of the generator. The previous operational assessment covering the first half of cycle 14 (2CAN069901) was submitted following 2R13. The current assessment utilizes full cycle data based on a deterministic evaluation for all mechanisms, including eggcrate axial flaws. The results from last inspection, performed during the 2P99 mid-cycle outage, are used to evaluate the eggcrate axial cracking based on a deterministic evaluation.

This evaluation follows guidance provided by the Nuclear Energy Institute (NEI) 97-06, "Steam Generator Program Guidelines,"[1] for performing condition monitoring and operational assessments of steam generator tubing degradation. Additionally, guidance from the Electric Power Research Institute (EPRI) "Steam Generator Integrity Assessment Guidelines"[2] was also used. The runtime analysis evaluates an increase in the operating temperature (T-hot) of approximately 3.0° F over the full cycle.

The in-situ pressure testing conducted during the 2P99 outage demonstrated that the degradation found in the ANO-2 steam generators met the three times normal differential operating pressure (3ΔP) structural criterion. One indication at the 02 hot eggcrate in the "B" SG (SGB), Tube R72L72, was not tested to 3ΔP pressure due to leakage greater than the capacity of the testing equipment. Further testing and evaluation using post ECT and electric discharge machine (EDM) notched samples determined that the tube would have met 3ΔP.

A run time of 0.83 effective full power year (EFPY) was evaluated to bound the actual run time of approximately 0.80 EFPY. The additional 0.03 EFPY is an allowance for the increase in operating temperature. The temperature of the primary system was raised approximately 1.5° F following 2P99 to maintain secondary steam pressure. The bases for the increase in run time was to account for a total of three degree increase in operating temperature that was evaluated for cycle 14. The methodology to adjust the run time to account for an increase in operating temperature is based on the Arrhenius equation. This equation takes into account the activation energy of the degradation process, as well as the temperature increase and projected operating interval. The results demonstrate that ANO-2 can safely operate until the 2R14 refueling (steam generator replacement) outage scheduled in September 2000 with adequate margin. Predicted flaw size at the end of cycle (EOC) remains below the 3ΔP structural criterion.

1.0 INTRODUCTION

A steam generator degradation 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. This program includes 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 have been met.

Both the condition monitoring and operational assessments have been completed utilizing inservice inspection results. The results from the 2P99 mid-cycle outage inspection and the projected time interval until the next refueling outage (2R14), scheduled for September 2000, have been evaluated and are discussed in detail in this report. A deterministic evaluation for the identified degradation mechanisms using values specified in the EPRI "Steam Generator Integrity Assessment Guidelines"[2] results in adequate margin to operate until 2R14, when the SGs will be replaced. This report covers the individual deterministic evaluations for each identified mechanism.

2.0 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 Inconel alloy 600 material with an outside diameter of 3/4 inch and a wall thickness of 0.048 inch. The tubes are explosively expanded for 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. All volatile treatment chemistry has been used since initial operation in 1978. 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, the unit initially 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° F to maintain secondary steam pressure following 2R13 in February 1999. Following 2P99 (November 1999), the temperature was increased to ~ 603° F.

3.0 2P99 INSPECTION RESULTS AND HISTORY

3.1 2P99 Scope and Results

The inspection consisted of a 100% bobbin examination from the tube end hot to the 07 hot support plate. Emphasis was placed on the analysis of the lower eggcrates (01-03) due to previously identified degradation in the area. Additionally, a limited top of tubesheet (TTS) examination was performed in the "A" SG (SGA) only to evaluate the potential for leakage. Burst was not an issue for the circumferential cracking at the hot leg expansion transition region (ETR) based on the previous operational assessment.

Table 3.1 lists the inspection scope of 2P99, while Table 3.2 contains the detected indications that were confirmed as degradation.

Table 3.1
2P99 ECT Inspection

SG	ECT Examination Type	Inspections Conducted	% Scope	Expansion Required
A	Bobbin	6984	100	No
A	MRPC ETR HL	503	~ 8	No
A	Special Interest	354		
B	Bobbin	7101	100	No
B	MRPC ETR HL	0		
B	Special Interest	239		

HL = hot leg

MRPC = motorized rotating pancake coil

Table 3.2
2P99 ECT Inspection Results

Location	SG "A"	SG "B"
Hot Leg ETR (circumferential)	9	0
Sludge Pile (axial and volumetric)	2	0
Eggcrate Support Plate	49	184
Free span	5	0

3.2 In-situ Testing

The performance criterion associated with 3ΔP is evaluated based on in-situ testing of the largest indications detected. During the 2P99 inspection, in-situ testing of axial cracking at the eggcrates was performed on six tubes. The result of the testing was documented in the condition monitoring report (2CAN129911)[3]. The testing concluded that 5 flaws met the criterion. In-situ testing performed on tube R72L72 in SGB was not completed to 3ΔP due to leakage in excess of the testing equipment capability. The following is a summary of the test performed on Tube R72L72:

PSIG	GPM
1568	No leakage
2232	No leakage
2882	No leakage at main steam line break (MSLB) pressure
3737	Leakage detected
3774	Leakage = 0.02 gpm
3971	Step increase in leakage and pressure drop
3573	Leakage = 0.560 gpm
4132	0.920 gpm
4147*	1.16 gpm

* Unable to reach the maximum target pressure due to exceeding pump capacity. Value adjusted for leakage and equipment error.

As noted above, the flaw started leaking well above MSLB pressure. The flaw experienced a change at 4147 psi. Post in-situ eddy current testing indicated that the flaw opened due to ligament tearing, but did not burst based on the amount of circumferential opening. The actual circumferential extent of Tube R72L72 went from 36° to 61°. This extent suggests that the flaw did open but did not burst. Testing was performed with EDM notched specimens to determine the actual burst pressure based on the dimensions of the flaw. This testing indicated that the burst pressure was ~ 500 psi above the maximum pressure achieved during testing. This additional pressure would have resulted in a total pressure of 4647 psi (4147 + 500), which is above the 3ΔP value of 4369 psi. ANO-2 design pressures are 2250 psi on the primary side and 900 psi on the secondary side, resulting in a normal operating differential pressure of 1350 psi. 3ΔP is then equal to 4050/0.927 = 4369 psi, based on ANO-2 specific material properties corrected for temperature. Tube R72L72, the most limiting tube identified during the 2P99 inspection, had a margin of 278 psi above 3ΔP. The deterministic evaluation performed following the previous outage (2R13) determined that the most limiting flaw would have margin over 3ΔP at the end of the half cycle of operation. This result was verified with testing performed by Westinghouse, as described in the attached report.

3.3 Indication and Repair History

During 2P99, 60 tubes in SGA and 150 tubes in SGB were repaired by mechanical plugging. The current plugging limit is 30% with a maximum asymmetry of 1000 tubes. The actual equivalent plugging is currently 17.97% in SGA and 17.43% in SGB with an asymmetry of 45 tubes.

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

Table 3.3
Repair History

		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
1999	2P99	60	1487	150	1460	0	661	0	194

Table 3.4 lists the historical indications by damage mechanism:

Table 3.4
Indication History

				SGA							SGB					
YEAR	**OUTAGE**	**EFPY**		**BW**	**TSP**	**SP**	**CC**	**FS**	**OTH**		**BW**	**TSP**	**SP**	**CC**	**FS**	**OTH**
1978	PRE			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
1999	2P99	14.98		0	49	2	9	5	0		0	184	0	0	0	0

BW = Batwing Support Straps
TSP = Tube Support Plates
CC = Circumferential Cracks

FS = Free span
OTH = Other Repairs
SP = Sludge Pile

Graphic displays of the above data are presented below:

Figure 3.1

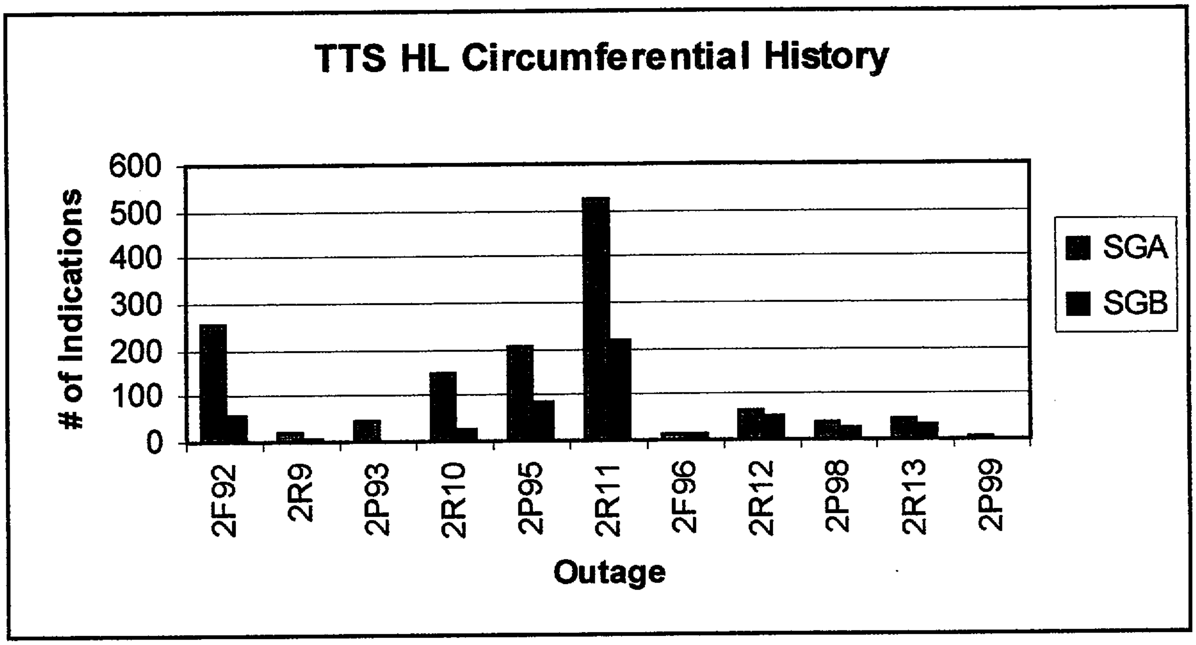


Figure 3.2

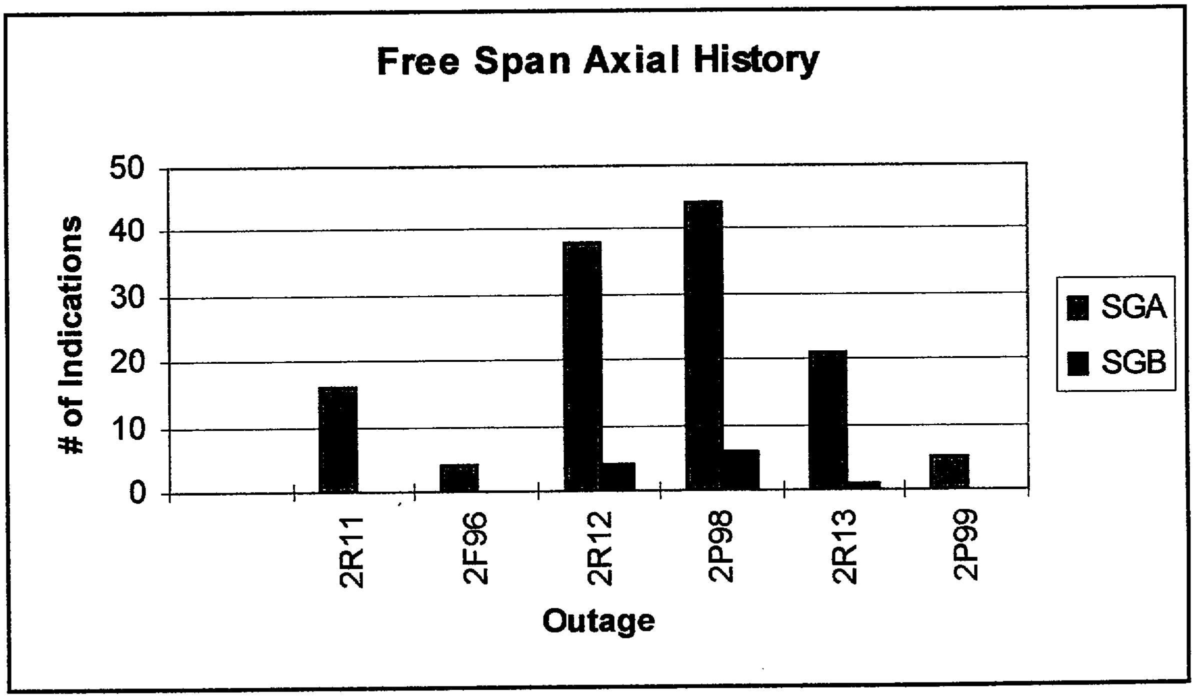


Figure 3.3

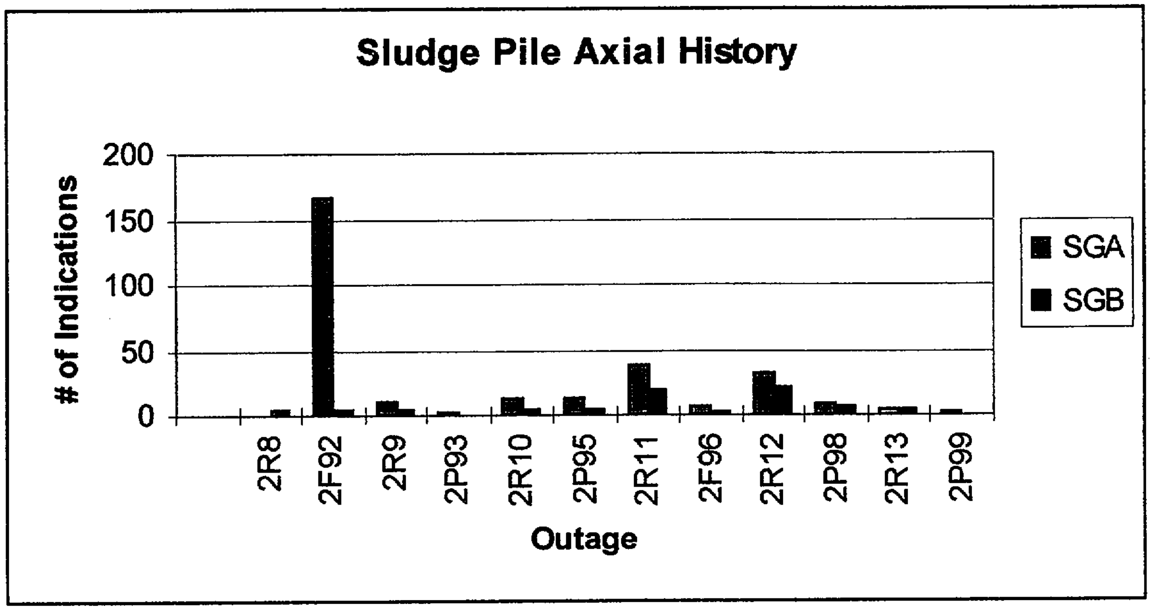
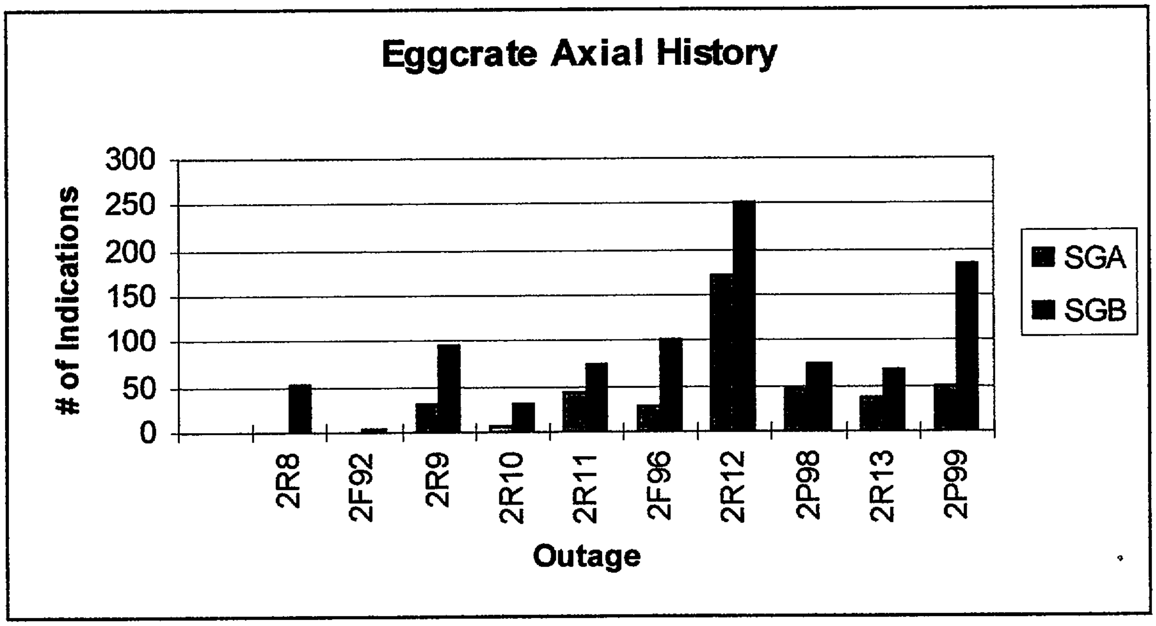


Figure 3.4



As noted in the condition monitoring report[3], a higher than expected number of eggcrate axial indications were identified in SGB

3.4 Eddy Current Program Improvements

Several changes were performed prior to and during the 2P99 outage to improve the probability of detection. For purposes of this evaluation, no credit was taken for those changes because of difficulty in quantification. The following changes were incorporated into the program:

3.4.1 Training of Analysts

Based on the 2R13 inspection results, special emphasis was placed on the fact that ANO-2 flaws exhibit low amplitude indications at the lower hot leg eggcrates that could potentially challenge the structural integrity limits. ANO-2 specific data was used in the training and testing of the analysts prior to the 2P99 inspection. The analysts were trained to conservatively call all possible indications identified at the lower hot leg eggcrates for dispositioning by MRPC.

3.4.2 Localized Testing

The 2P99 inspection was limited to the area of interest, namely the lower hot leg eggcrates. In a general inspection, analysts would be responsible for analyzing the full tube bobbin data, in addition to all the other testing that would be performed, e.g., TTS MRPC, sleeve and U-bend analysis. During 2P99, the analysts were concentrating specifically on the hot leg eggcrate intersections.

3.4.3 Effect of the New Calibration Standards

During the 2P99 inspection, different calibration standards were used for the bobbin analysis because of a change in the tooling used for the examination. A review was performed to evaluate the possible effect that the new standards had on the process. Indications were analyzed using the old standards as well as the new standards. A direct comparison of flaws, with both the old and new standards, identified a 15% increase in voltage. Larger amplitude signals are easier to detect and could result in the identification of more indications.

4.0 OPERATIONAL ASSESSMENT

This operational assessment will consist of a deterministic evaluation performed for each identified degradation mechanism. Credit was taken for the 2P99 inspection results for the hot leg eggcrate, free span, and sludge pile axial flaws. This was due to a 100% bobbin examination performed from the tube end hot to the 07 hot support plate.

4.1 Deterministic Evaluations

The methodology employed used a flaw sized at a POD of 0.95 and the 0.95 value for growth rate from the growth rate distribution in accordance with the EPRI Steam Generator Integrity Assessment Guidelines[2]. Growth rate studies are discussed in Section 5. The operating intervals of interest are:

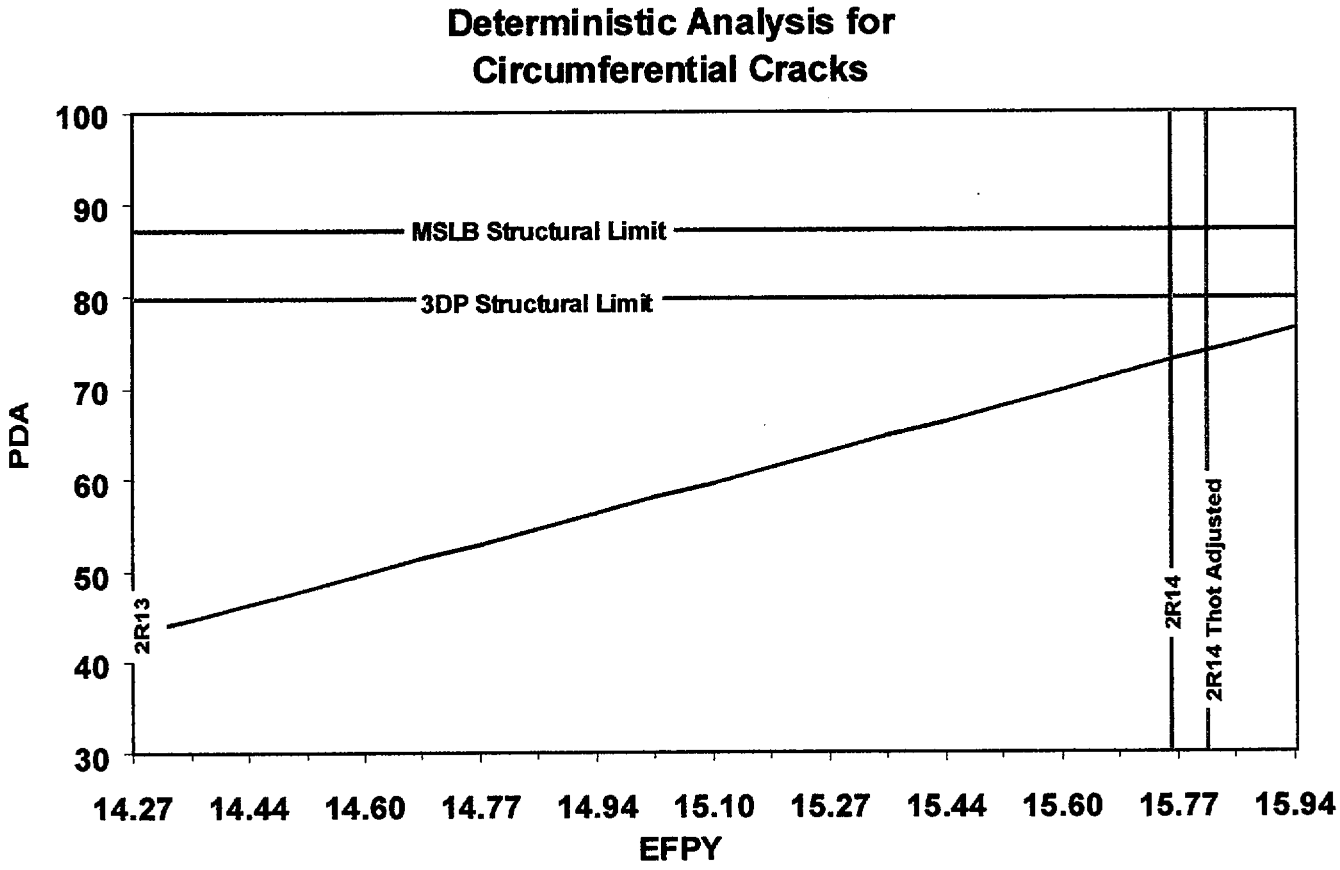
Outage	Total EFPY	EFPY to Next Outage
2P98	13.50	0.77
2R13	14.27	0.69
2P99	14.96	0.80
2R14	15.76	N/A

The assessments for each damage mechanism follow:

4.1.1 Circumferential Cracking at the TTS

During 2P99, a limited inspection (503 tubes), was performed to mitigate potential leakage. The size and number of indications were well within the number projected in the previous operational assessment. No credit for this inspection was taken in the deterministic evaluation. Nine indications were identified and repaired. The beginning of cycle flaw size at a POD of 0.95 was used. This was equivalent to 43 percent degraded area (PDA)[4]. The growth rate used was the 0.95 value from the growth rate distribution based on a site specific sizing evaluation from 2R13. This value was equal to 20 PDA/EFPY[5]. Based on these inputs, operation for the full cycle is justified with added margin. This analysis was offset 3.7%[6] for increasing T-hot and is depicted in Figure 4.1 below:

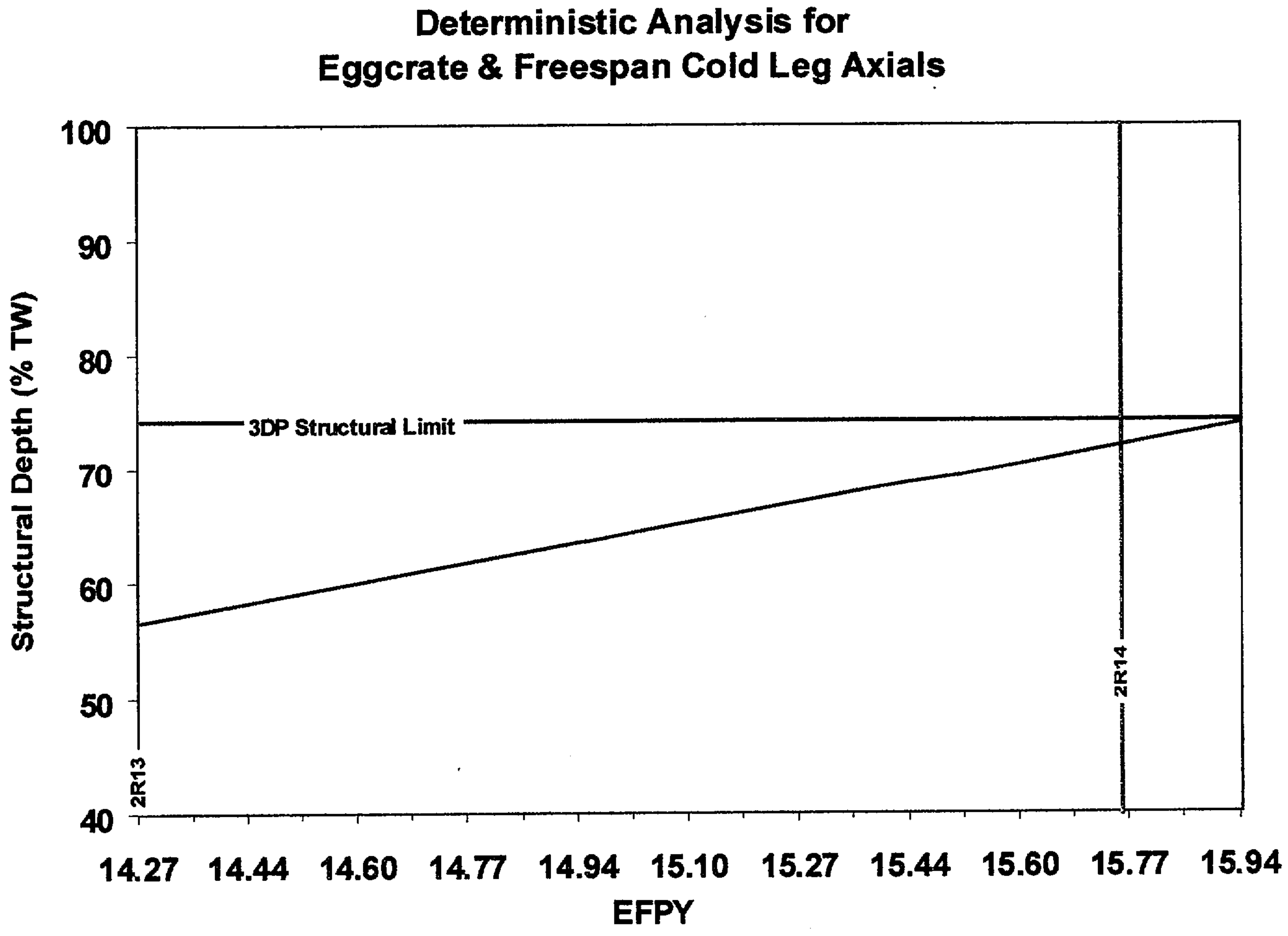
Figure 4.1



4.1.2 Free Span and Eggcrate Axial Cracking on the Cold Leg

During 2P99, this area of the generator was not inspected. The operational assessment performed following 2R13 concluded operation for the full cycle was justified due to the limited number of indications and the size of the flaws, as well as the lower temperature this tubing experiences during full power operation. Based on these facts, it was not feasible to perform a growth rate study for this type of flaw. For the deterministic evaluation, the 0.95 growth rate of the hot leg eggcrates was used offset by a reduction in temperature of 15° F, which accounts for the location of the flaws high in the tube bundle. An approximate 50° F drop occurs across the bundle. The growth rate value is 10.35% per EFPY. The 0.95 POD value for this type of flaw is 56.6% structural depth with a length of 0.58 inch. These values result in a deterministic evaluation that meets the 3ΔP criterion at the next scheduled outage. This is depicted below in Figure 4.2.

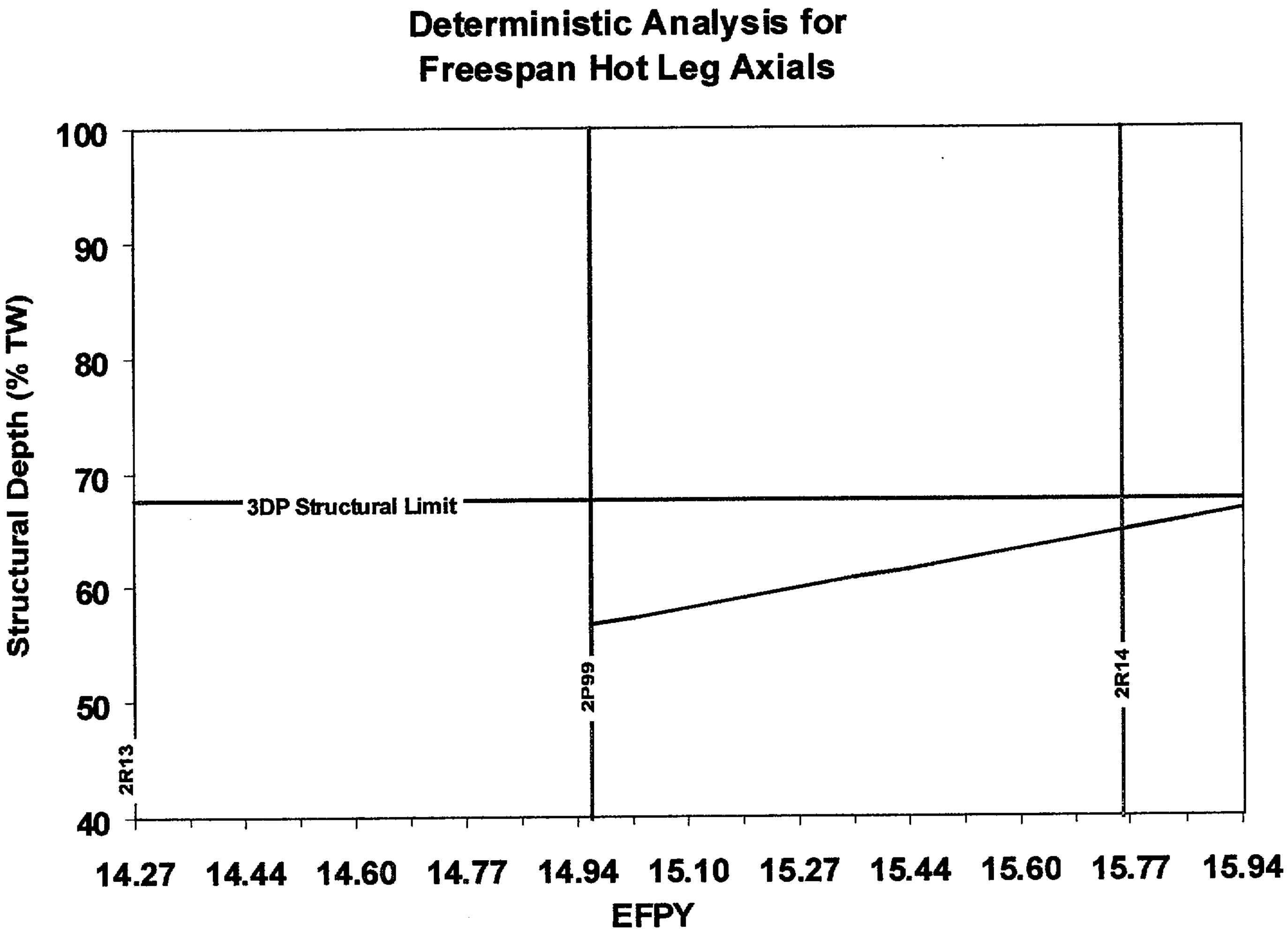
Figure 4.2



4.1.3 Free Span Axial Cracking on the Hot Leg

The hot leg free span area of the generator was included in the bobbin examination conducted during the 2P99 inspection. Five indications were identified and repaired. The sizes of the flaws were bound by the previous operational assessment. Once again, the 0.95 POD value was taken from the site specific performance demonstration (SSPD) performed following 2R13. This value was equal to 56.6% structural depth with a length of 1.48 inches. The 0.95 value on growth was offset by 15° F since the majority of the free span indications are found in the upper portion of the tube bundle. This value is equivalent to 10.35% per EFPY. This data is depicted in Figure 4.3 below:

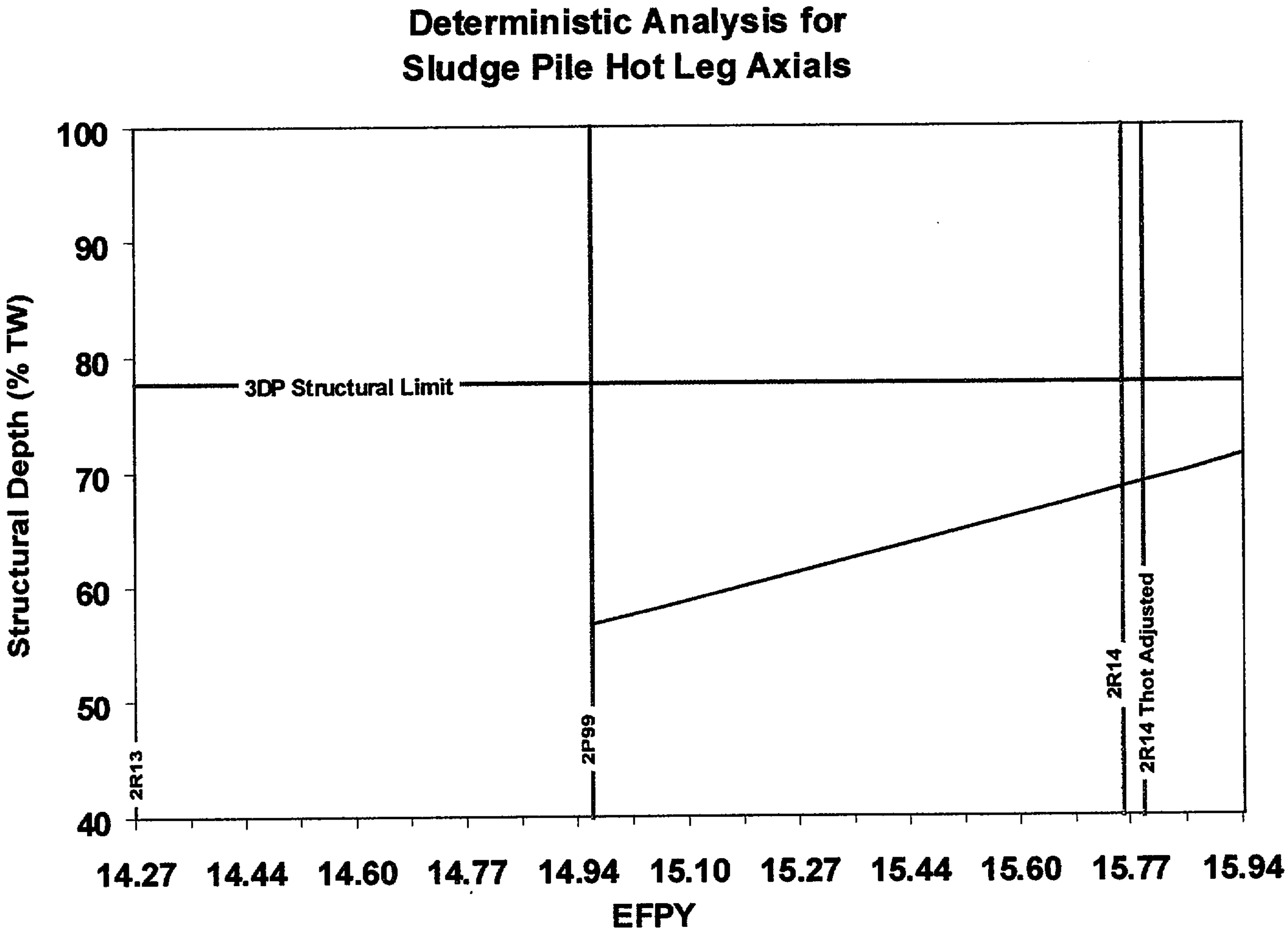
Figure 4.3



4.1.4 Sludge Pile Axial Cracking

In previous outages, it was proven that consistent detection of axial cracking in the sludge pile was achieved with MRPC. Since the 2P99 inspection was performed in 100% of the tubes in the sludge pile area, credit was taken for the inspection. The 0.95 POD value for the sludge pile axials was a 56.6% structural depth with a 0.44 inch length. The 0.95 growth rate value was used due to the proximity of the flaws to the hot leg tube sheet. This growth rate was equivalent to 15.0% per EFPY. Additionally, a correction for increasing T-hot was used (3.7 %). This analysis is depicted below in Figure 4.4:

Figure 4.4

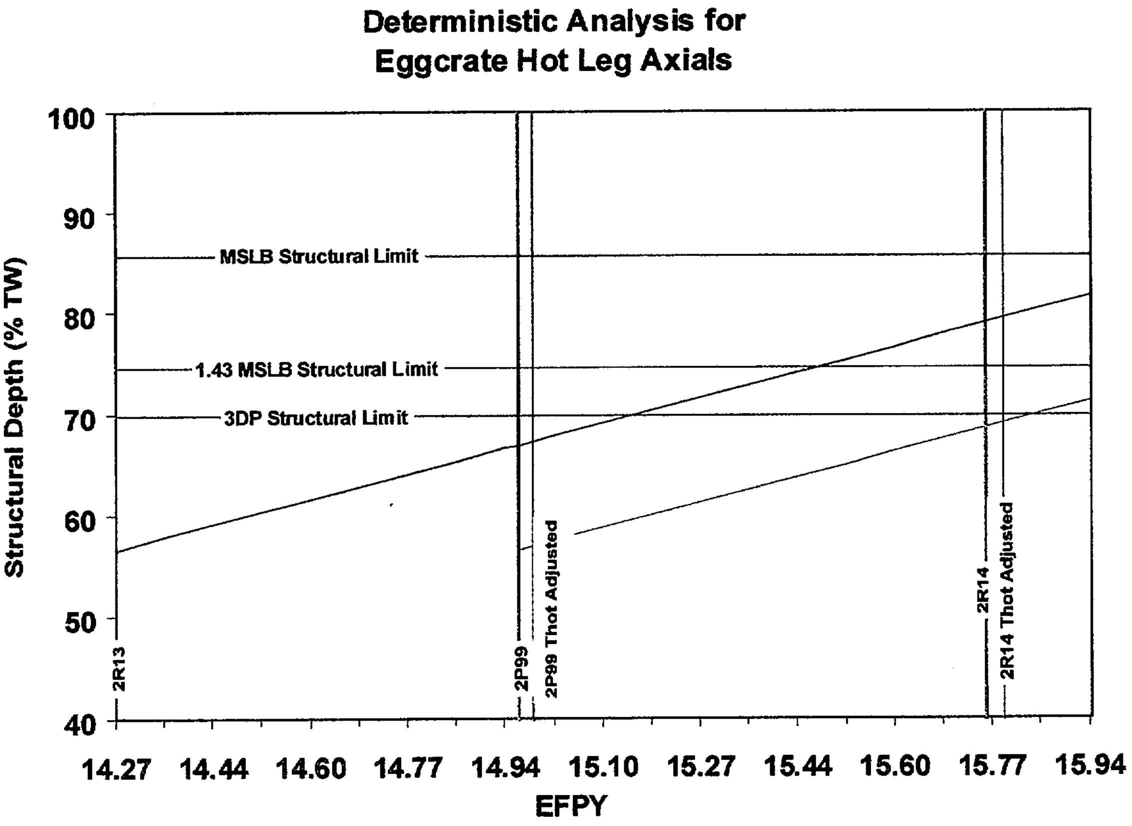


4.1.5 Eggcrate Axial Cracking on the Hot Leg

The initial deterministic evaluation for the eggcrate axial indications on the hot leg was performed during 2P99 to justify startup as part of the condition monitoring program. This initial evaluation justified approximately 7 months of operation and was submitted to the Staff December 21, 1999 (2CAN129911)[1], based on using the peak in-situ pressure achieved on the worse case flaw identified (R72L72). After analysis to determine the maximum achieved pressure and completion of the growth rate study, this evaluation was repeated using the data in accordance with the EPRI Steam Generator Integrity Assessment Guidelines[2]. A 0.95 growth rate value of 15.0% per EFPY was used. The growth rate data was developed using information from the last three outages. To calculate the beginning of cycle flaw, the 0.95 value from the POD curve was used. The POD curve was developed from the SSPD performed following 2R13. The SSPD was previously described in the operational assessment submitted following 2R13 (2CAN069911). The 0.95 value for beginning of cycle structural depth was determined to be 56.6% with a length of 0.98 inch.

Based on the attached evaluation, tube R72L72 had a 278 psi of margin above the 3ΔP criterion. The inputs to the model were benchmarked against the previous outage (2R13) to evaluate if the values were appropriate. This data is depicted in Figure 4.5 below. The point at which 3ΔP would have been exceeded for the first half of the cycle was approximately 0.12 EFPY beyond 2P99. Using the same input values for the remainder of the cycle, the 3ΔP criterion would not be reached until after the designated EOC. This evaluation also accounts for the increase in operating temperature.

Figure 4.5



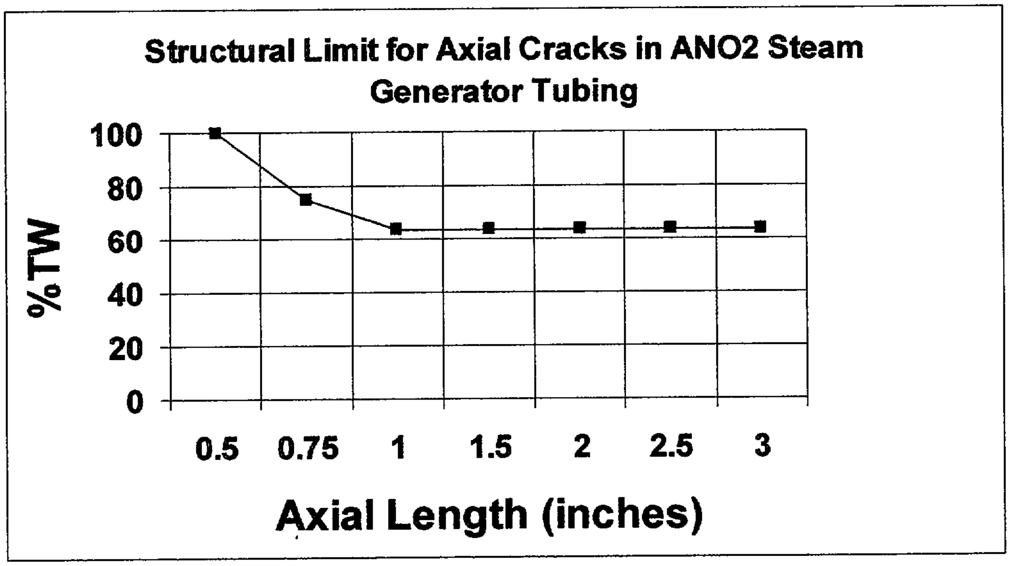
4.1.6 Axial Cracking in Dented Eggcrate Intersections

During the 2R13 outage, an inspection was performed in response to industry experience with 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 to detect small amplitude indications within the dents. Two indications were identified during the examination. Both indications were 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 (in.)	Max. Depth (% TW)
44	112	0.28	60
50	114	0.33	75

It is not possible to review data from previous inspections to quantify the growth rate, since 2R13 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 4.6 that was derived from a study sponsored by the Combustion Engineering Owners Group[7] to determine the structural length vs. depth. The structural limit curve was based on a conservative burst correlation and used for screening data.

Figure 4.6



As shown in the figure, the structural limit in the range of lengths observed during 2R13 is 100% through-wall (TW). The largest of the two flaws (R50L114) was 0.33 inch in length and had a maximum depth of 75% TW. Since 2R13 was the first time that this mechanism was examined, it is possible that a flaw could have been left in service if it was 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.

4.1.7 Wear

ANO-2 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. 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. The ANO-2 Technical Specifications require that all indications 40% TW and greater be removed from service. A conservative 35% TW administrative limit is used at ANO. 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 from the Appendix H qualification[8] was 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[7], this condition is acceptable for the full cycle of operation with no additional leakage.

4.2 Repair Hardware

Following 2P99, the total number of plugs and sleeves per generator were evaluated for leakage potential at MSLB conditions. The ANO-2 SGs have 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 a failure of the ribbed plug occurred. Two types of sleeves installed in the ANO-2 SGs, a double kinetic sleeve design and a tungsten inert gas (TIG) welded sleeve. Both sleeve types are installed at the TTS interface to repair the circumferential cracking on the hot leg. The following is a summary of the total number of plugs and sleeves currently installed:

	SGA	**SGB**
Plugs	1487	1460
Sleeves		
Kinetic	285	48
TIG	376	146
Total	661	194
Equivalent Plugged	1511.38	1465.99
Equivalent % Plugged	17.97 %	17.43 %
Average % Plugged	**17.70 %**	

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 at MSLB conditions. This value was conservatively rounded up to the nearest hundredth.

4.3 Summary of Deterministic Evaluations

Listed below in Table 4.1 is a summary of the inputs of the deterministic evaluation:

Table 4.1

Flaw Type	POD Value	Growth Rate Value	Growth Rate	BOC Length	BOC Depth	T-Hot Correction
Circumferential HL TTS	95%	95%	20 PDA/EFPY	N/A	43 PDA	3.7%
Freespan/EC Axial CL	95%	95%	10.35%/EFPY	0.58"	56.6% Struc. Depth	N/A
Freespan HL	95%	95%	10.35%/EFPY	1.48"	56.6% Struc. Depth	N/A
Sludge Pile Axial HL	95%	95%	15.0%/EFPY	0.44"	56.6% Struc. Depth	3.7%
Eggcrate Axial HL	95%	95%	15.0%/EFPY	0.98"	56.6% Struc. Depth	3.7%

5.0 GROWTH RATE EVALUATION

In previous operational assessments, growth rates calculated from Palo Verde (PV) SG inspections were used to bound those found at ANO-2. Palo Verde operates at approximately 611° F reduced from 621° F. ANO-2 currently operates at 603° F. Since temperature directly affects the growth rate, use of PV data would seem to be conservative. To validate this, a growth rate evaluation was performed following 2R12 (1997)[9]. The study utilized three outages and was based on bobbin sizing methodologies. 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 was that a reasonable upper bound growth rate distribution is given by a log normal distribution with a standard deviation of 0.70% TW and a mean growth rate of 6.89% TW per EFPY. This growth rate distribution bounds the results of several growth rate studies for plants of similar design.

To reconfirm that the previous growth rate assumptions were valid for the current cycle of operation, a second growth rate evaluation was performed using the most recent three outages (2P98, 2R13 and 2P99)[10]. The results of the study were once again consistent with those performed through out the industry and the previous ANO-2 studies. The 95/95 values were 22.1% TW per EFPY. The 95/50 value based on the same distribution is equal to 15.0% TW per EFPY.

A depiction of the ANO growth data from 2P99 is presented as Figure 5.1 where negative growth values are explicitly indicated. Data from both SGA and SGB are included in Figure 5.1.

Figure 5.1 is normalized to the 1.48 EFPY of operation from 2P98 to the most recent inspection at 2P99. The data suggests the presence of a significant non-destructive examination (NDE) uncertainty component. That is, the overall shape of the distribution, its symmetry about a small growth value near zero and the preponderance of negative values, are consistent with a measurement process where NDE uncertainty is the dominant statistical component for the bulk of the distribution. The empirical data therefore suggest that apparent growth is the superposition of an NDE uncertainty distribution and a "true" depth growth distribution.

From these observations, an axial flaw growth model for the remainder of cycle 14 was developed by explicitly accounting for contributions from NDE uncertainty and actual growth. The general form of the model for an observation, d, is a linear combination of normal and lognormal components for the NDE and actual growth:

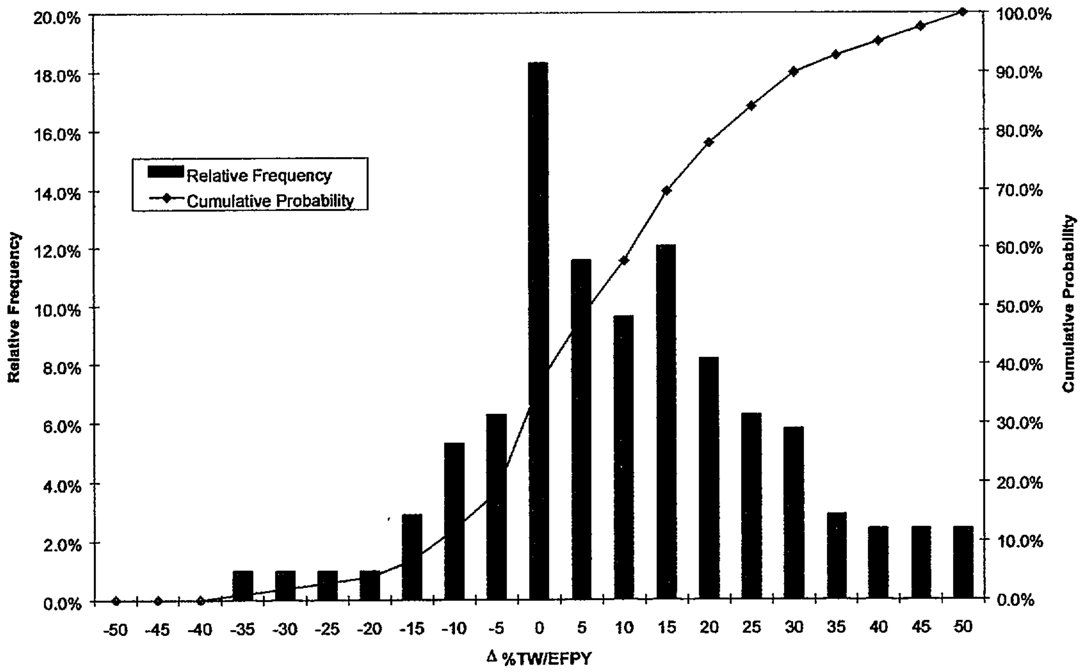
$$d_i = \delta_i + \varepsilon_i$$
$$\varepsilon_i \leftarrow N[0,\sigma_{NDE}]$$
$$\delta_i \leftarrow LN[\mu_G,\sigma_G]$$

where:

d = observed growth rate
δ = true growth rate
ε = measurement error
N = normal distribution
LN = lognormal distribution
μ = mean
σ = standard deviation

A numerical optimization algorithm was used to determine valid parameters for ANO-2 for the remainder of cycle 14. The algorithm yields a super-set of families of likely parameter pairs for the actual growth component. The algorithm is constrained so as to incorporate an NDE uncertainty component that is consistent with known inspection technique uncertainties.

Figure 5.1
ANO Axial Flaw Growth/EFPY (2P99 – 2R13)



To eliminate the uncertainty of sizing, a series of 1000 models were performed using the ANO-2 data from SGB during 2P99. From this data set, an optimization process was performed to minimize the effects of the negative growth rates or uncertainty in sizing. The resulting actual growth parameter super-set is indicated in Figure 5.2. If the center value was taken from the scatter plot, the value taken would be consistent with values seen at other Combustion Engineering plants.

The superset of ANO-2 axial flaw growth model parameters are an important input to the probability of burst calculation. This family of lognormal models accounts for uncertainties in the relative contribution to the observed (apparent) growth data from NDE uncertainty and actual growth. The equivalent distribution of actual growth rates that corresponds to this model is provided in Figure 5.3.

Figure 5.2

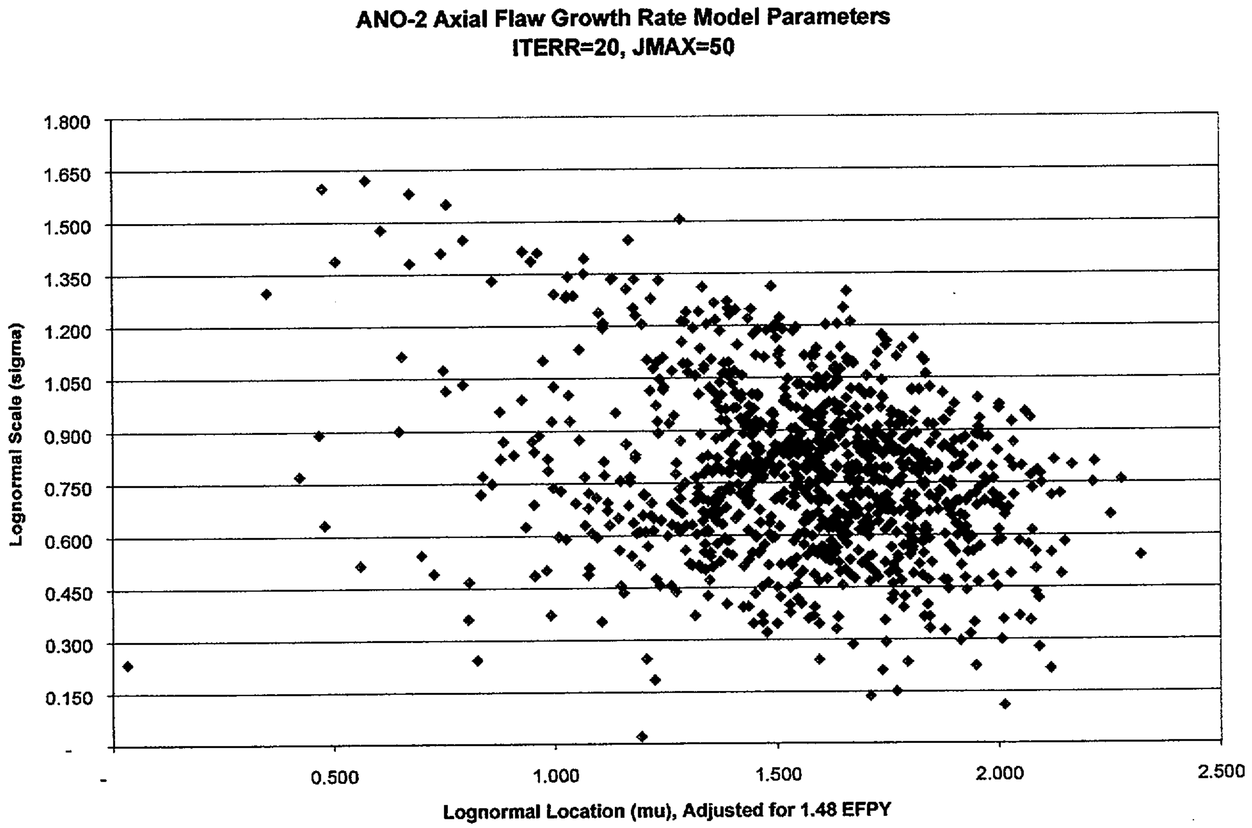
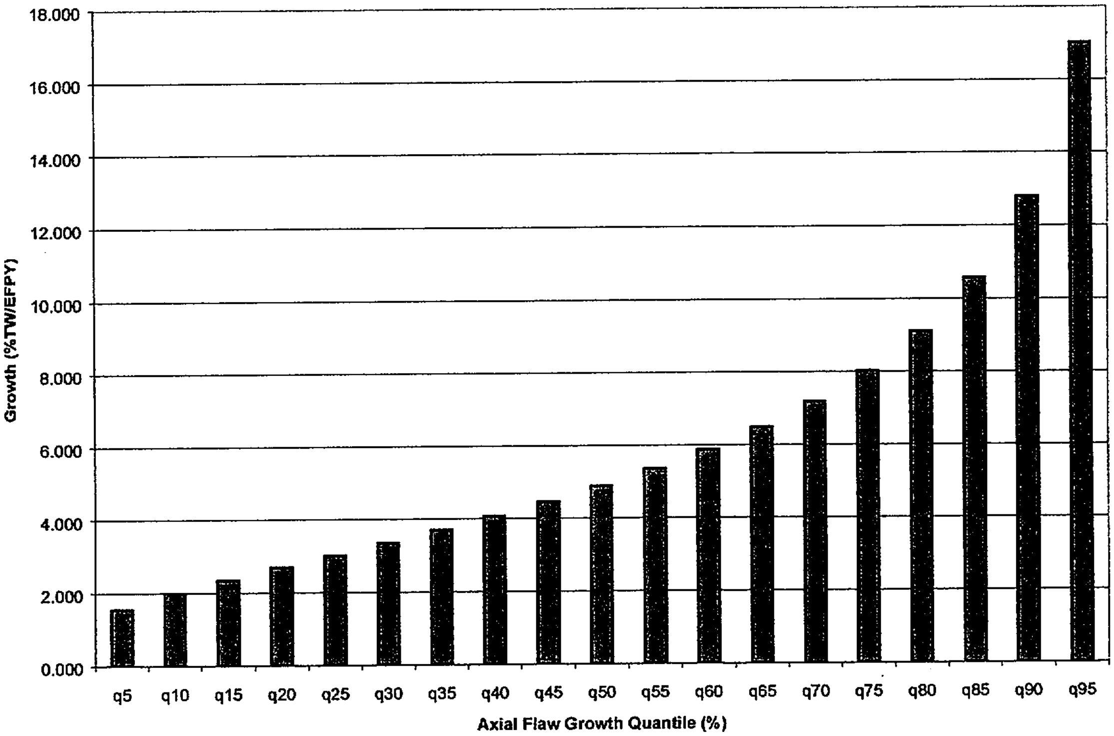


Figure 5.3
ANO Axial Flaw Actual Growth Model



Additionally, parameters such as length and depth are also checked to validate the growth rate data. Distribution charts of the two are listed below in Figures 5.4 and 5.5:

Figure 5.4

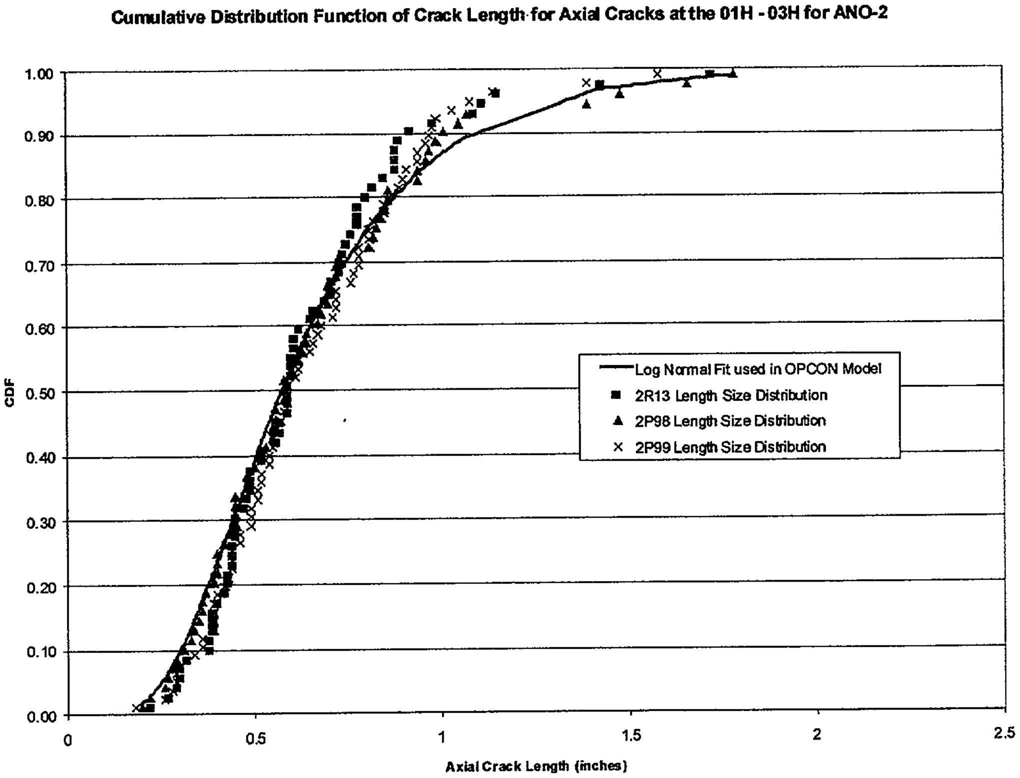


Figure 5.4 confirms that the distribution on crack lengths has not changed significantly in the last three outages.

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 5.1. Depth distributions for axial eggcrate flaws are provided in Figure 5.5.

Table 5.1
Axial Crack Lengths from ANO-2 Pulled Tubes

Year	SG	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 5.5

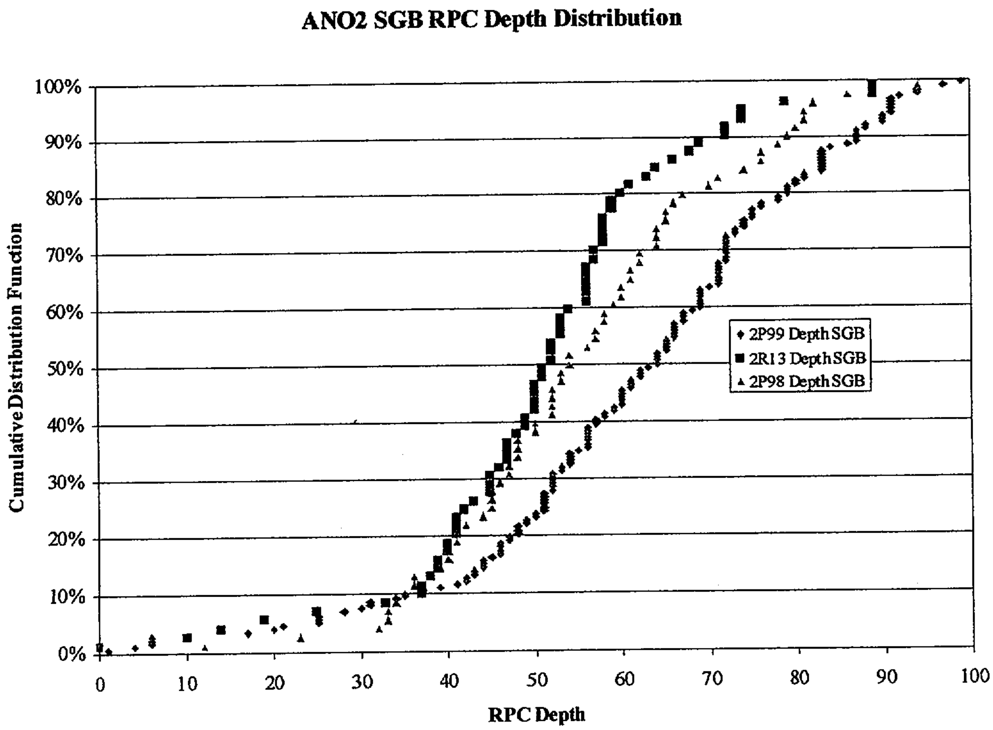
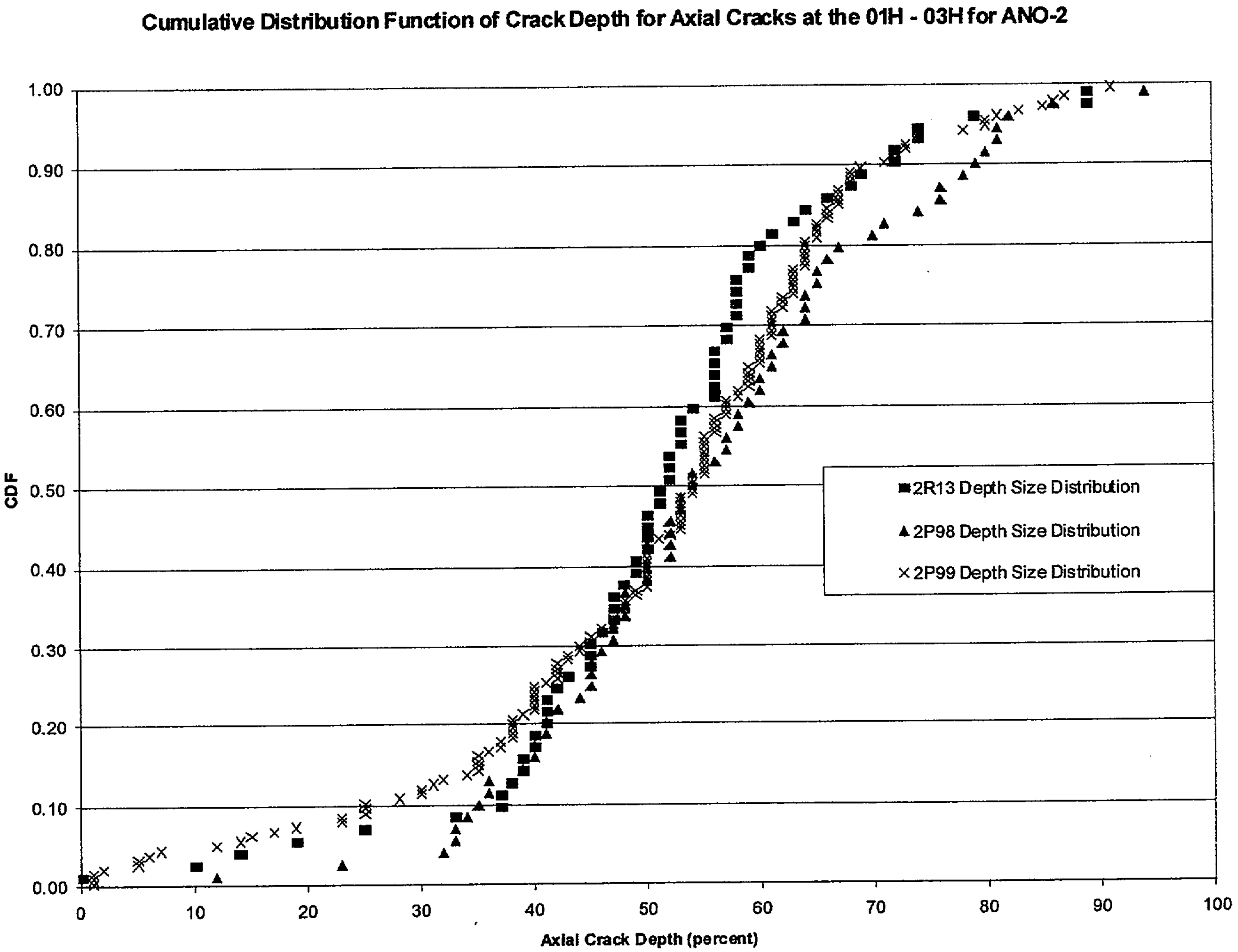


Figure 5.5 represents the distributions of maximum depths as measured by MRPC for the last three outages which was previously submitted in the condition monitoring report (2CAN129911)[3]. It is apparent in this figure that in the most recent outage (2P99), the depths were approximately 10-15% deeper than those sized in previous outages. Further investigation into the rationale for this result determined that several of the analysts were using channel 1 (300 KHz) instead of the mix channel P1 (300/100 KHz) to perform sizing of the flaws. This data was re-analyzed using the P1 mix. Both the 2P98 and 2R13 outages were performed using the P1 channel for sizing. This resulted in a reduction in depth consistent with the two previous outages. This is depicted in Figure 5.6:

Figure 5.6



6.0 LEAKAGE

6.1 Accident Leakage

Accident induced leakage for all mechanisms would be zero based on previous in-situ testing. The worst case flaws in-situ tested during 2R13 and 2P99 did not leak at MSLB conditions. In the previous operational assessment (2CAN069911), a 95/95 probabilistic evaluation was performed to evaluate leakage. This value was equal to 0.0156 GPM for all mechanisms combined. Using these very conservative inputs, this value would still be well below the 1.0 GPM criterion specified in NEI 97-06[1].

6.2 Operational Leakage

An operational leak rate limit is established to provide reasonable assurance that in-service flaws will not render the tube vulnerable to tube rupture in the event of a MSLB. The ANO-2 TS leakage limit of 150 GPD per SG provides adequate margin against burst. In addition, administrative 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 a potential steam generator tube rupture is an essential part of the 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.

7.0 SUMMARY

Entergy Operations has performed an extensive investigation into the condition of the steam generators at ANO-2. The investigation includes comprehensive inspections, application of appropriate safety factors, use of material properties, NDE data, growth rate and tube burst test data in accordance with the EPRI Steam Generator Integrity Assessment Guidelines[2].

Condition monitoring was performed following the 2P99 outage to assess the performance of the steam generator tubing for the previous operating period. In-situ testing was conducted during the outage for the largest flaws identified during the inspection. Test results were supplemented with laboratory testing and additional analyses where necessary. The testing and evaluation shows that the performance criteria specified in NEI 97-06 were met. Structural integrity was verified because all tubes maintained a margin to burst of three times the normal operating differential pressure. The postulated primary-to-secondary leak rate during a MSLB event would have remained below the allowed value of 1 GPM. Operational primary-to-secondary leakage during the operating period was well below 150 GPD.

Subsequently, an operational assessment has been conducted in accordance with industry guidance from NEI 97-06[1] to ensure the performance criteria will continue to be met for the operating period until the 2R14 outage. This assessment used the latest industry guidance for the evaluation methods, margins, and uncertainty considerations in determining tube integrity. The results indicate the performance criteria for structural integrity and accident induced leakage will be met for the planned operating interval. These results also provide reasonable assurance the ANO-2 license basis will be maintained throughout the remainder of cycle 14.

Primary-to-secondary leakage indications are closely monitored by Entergy Operations. Leakage monitoring is performed by both on-line and analytical methods. Extensive operator training on steam generator tube leak/rupture scenarios and effective management interaction ensure early detection and prompt corrective actions should leakage occur.

Based on the results of condition monitoring and operational assessment following 2P99, steam generator tubing integrity criteria will be met until the next refueling outage scheduled for September 2000.

8.0 REFERENCES

1. NEI 97-06, "Steam Generator Program Guidelines", December 1997
2. EPRI TR-107621-R0, "Steam Generator Integrity Assessment Guidelines, December 1999
3. 2CAN129911, "2P99 Steam Generator Tubing Inspection Results," December 21, 1999
4. EPRI TR-107197-P1, "Depth Based Structural Analysis Methods for Steam Generator Circumferential Indications," November 1997
5. ER 991701 E201, "Growth Rates for ANO-2 Circumferential Cracking"
6. ER 980280 I204, "Monitor ANO-2 SG Tube Plugging Impacts Against Eval Limits"
7. CE NPSD-1125-P, "Methodology For Evaluation of Axial Degradation in Steam Generator Tubing – Laboratory Test Program"
8. EPRI Performance Demonstration database ETSS# 96004
9. ER 974855 E203, "ANO-2 Steam Generator Growth Rate Study"
10. AES 99113855-1-1, Structural Integrity Evaluation of Axial ODSCC at Supports for ANO-2 During Cycle 14 Post Mid-cycle Operation"