Progress Energy

Crystal River Nuclear Plant
Docket No. 50-302
Operating License No. DPR-72

Ref: 10 CFR 50.90

January 27, 2005
3F0105-03

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Subject: Crystal River Unit 3 – License Amendment Request #290, Revision 0
Probabilistic Methodology to Determine the Contribution to Main Steam Line Break Leakage Rates for the Once-Through Steam Generator from the Tube End Crack Alternate Repair Criteria

Dear Sir:

Florida Power Corporation, doing business as Progress Energy Florida, Inc. (PEF), hereby submits License Amendment Request (LAR) #290, Revision 0, which requests a change to the Crystal River Unit 3 (CR-3) Facility Operating License in accordance with 10 CFR 50.90.

This LAR is proposing to utilize a probabilistic methodology to determine the contribution to Main Steam Line Break (MSLB) leakage rates for the Once-Through Steam Generator (OTSG) from the Tube End Crack (TEC) Alternate Repair Criteria (ARC) described in CR-3 Improved Technical Specifications (ITS) 5.6.2.10.2.f. The probabilistic methodology is being issued as Addendum B to Topical Report BAW-2346P, Revision 0, and is provided in Attachment C to this submittal. Addendum B supersedes the previously approved Addendum A. This LAR involves no change to the CR-3 ITS.

PEF respectfully requests NRC review of LAR #290, Revision 0, be performed to support an approval date of October 1, 2005.

This letter establishes no new regulatory commitments.

The CR-3 Plant Nuclear Safety Committee has reviewed this request and recommended it for approval.

Progress Energy Florida, Inc.
Crystal River Nuclear Plant
15760 W. Powerline Street
Crystal River, FL 34428

A001

If you have any questions regarding this submittal, please contact Mr. Sid Powell, Supervisor, Licensing and Regulatory Programs at (352) 563-4883.

Sincerely,

Dale E. Young

Dale E. Young
Vice President
Crystal River Nuclear Plant

DEY/lvc

Attachments:

A. Background, Description of Proposed Change, Reason for Request and Evaluation of Request
B. Regulatory Analysis (No Significant Hazards Consideration Determination, Applicable Regulatory Requirements and Environmental Impact Evaluation)
C. Addendum B to Topical Report BAW-2346P, Revision 0 - Probabilistic Leakage Assessment of Crystal River Unit 3 Steam Generator (SG) Tube End Cracks

xc: NRR Project Manager
Regional Administrator, Region II
Senior Resident Inspector

STATE OF FLORIDA

COUNTY OF CITRUS

Dale E. Young states that he is the Vice President, Crystal River Nuclear Plant for Florida Power Corporation, doing business as Progress Energy Florida, Inc.; that he is authorized on the part of said company to sign and file with the Nuclear Regulatory Commission the information attached hereto; and that all such statements made and matters set forth therein are true and correct to the best of his knowledge, information, and belief.

Dale E. Young

Dale E. Young
Vice President
Crystal River Nuclear Plant

The foregoing document was acknowledged before me this 27th day of January, 2005, by Dale E. Young.

Janet Schroeder

Signature of Notary Public
State of Florida

JANET SCHROEDER
MY COMMISSION # DD 128063
EXPIRES: June 20, 2006
Bonded Thru Notary Public Underwriters

(Print, type, or stamp Commissioned Name of Notary Public)

Personally Known ✓ -OR- Produced Identification ______

PROGRESS ENERGY FLORIDA, INC.

CRYSTAL RIVER UNIT 3

DOCKET NUMBER 50-302/LICENSE NUMBER DPR-72

ATTACHMENT A

LICENSE AMENDMENT REQUEST #290, REVISION 0

Background, Description of Proposed Change, Reason for Request and Evaluation of Request

Background

On October 1, 1999, the NRC issued License Amendment No. 188 for Crystal River Unit 3 (CR-3) approving an alternate repair criteria to be applied to steam generator tubes with crack-like indications within the upper and lower tubesheet areas. The technical basis for the alternate repair criteria is contained in a Babcock and Wilcox Owners Group topical report, "Alternate Repair Criteria for Tube End Cracking in the Tube-to-Tubesheet Roll Joint of Once Through Steam Generators," BAW-2346P, Revision 0 (Proprietary).

The leakage integrity of the steam generator tubes was demonstrated in the topical report by leak testing. Before leak testing, a finite element model to analyze structural behavior of the tubes was used to determine test parameters that would give the least tight test roll joints, which in turn would give maximum possible leak rates in the leakage tests.

Topical Report BAW-2346P, Revision 0, specifies a number of requirements and limitations in order to implement the alternate repair criteria on tubes having Tube End Crack indications (TEC). Calculation of the combined total leakage from all primary-to-secondary sources, including TEC indications left in service, is one of the requirements contained in the topical report. The approved Alternate Repair Criteria (ARC) required that the combined total leakage from all primary-to-secondary sources, including TEC indications left in service, shall not exceed the main steam line break (MSLB) accident leakage limit (one gallon per minute for CR-3) minus operational leakage (150 gallons per day per steam generator). For tubes with multiple indications, a separate leak rate for each indication must be used.

The current CR-3 TEC leakage assessment is based on a deterministic relationship of tube location in the bundle (tubesheet radius), and tubesheet hole dilation during a MSLB event.

The condition monitoring evaluation performed as part of the steam generator inspection conducted during Refueling Outage 13 (October 2003), identified the postulated leakage from the as-found indications did exceed the MSLB limit. CR-3 reported that condition in LER 50-302/2004-004-00.

Probabilistic estimates plus actual tube loading are more realistic and provide better predictions for actual leakage. The predicted leakage from indications found in Refueling Outage 13 would not have exceeded predictions had the probabilistic method and actual tube loading been employed.

The actual operating primary-to-secondary leakage values for CR-3 are significantly under the 5 gallon per day threshold limit from the Electrical Power Research Institute (EPRI) Primary-to-Secondary Leak Guidelines.

Description of the Proposed License Amendment Request

License Amendment Request (LAR) #290, Revision 0, is proposing to utilize a probabilistic methodology to determine the contribution to the MSLB leakage rates for the Once-Through Steam Generator (OTSG) from the TEC ARC described in the CR-3 Improved Technical Specifications (ITS) 5.6.2.10.2.f. This LAR involves no change to the CR-3 ITS. The methodology change for TEC leakage calculation proposed in this LAR utilizes the same probabilistic process approved by the NRC for use by plants implementing Generic Letter (GL) 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking."

Reason for Request

The process approved in License Amendment No. 188 for calculating leakage and currently used by CR-3 uses a very conservative, deterministic method. Due to an increased number of TEC indications and tube repairs, CR-3 is seeking approval for a leakage calculation method which removes some of the excessive conservatism inherent in the current approach while providing conservative results at a high level of confidence.

Evaluation of Request

Current Methodology

Tubesheet distortion caused by differential thermal and pressure effects during a MSLB alters the tightness of the roll expanded tube-to-tubesheet joint. As previously mentioned, during the initial development of BAW-2346P, Revision 0, finite element analyses were performed to conservatively determine key parameters including joint tightness and axial tube load under MSLB conditions. It was determined that joint tightness and axial tube load vary with the distance from the center of the tubesheet. Consequently, a number of concentric tubesheet zones were defined for use in determining TEC leakage based upon the tightness of the joint.

A series of bounding leak tests using 100% through-wall (TW) Electrical Discharge Machine (EDM) notches confirmed that there is a correlation between leakage and joint tightness. Based upon the leakage tests and the defined zones, a leakage value was assigned to all tubes within each zone. The assigned value is the maximum leakage for any tube within that zone. Under the current leakage calculation method, each TEC within a particular zone is assigned that zone's leakage value. The total leakage for all zones is the estimated OTSG leakage resulting from TEC under MSLB conditions.

This approach conservatively assumes that every TEC has perforated the tube wall and will leak, when in fact, many TEC have not advanced to that depth. It also conservatively assumes that multiple TEC within a particular tube will each contribute to the overall TEC leakage, when in fact the leakage from a tube is limited not by the number of cracks present but by the tightness of the joint. Finally, it assumes that the axial tube load applied during the tests was representative of the load which would occur during a CR-3 MSLB, while the CR-3 MSLB loads are much lower than the tests. These assumptions yield very conservative leakage estimates.

The initial submittal of LAR #249, Revision 0, indicated that CR-3 would use specific leak rates for CR-3 based on the MSLB tube loads. These were to be included in an addendum to BAW-2346P. Addendum A was submitted on May 28, 1999. The submittal stated that the Addendum included the CR-3 plant specific MSLB tube loads. In actuality, the Addendum leak rates were partially based upon the bounding laboratory test results with an applied axial load of 3,060 pounds. The increased effect of this laboratory applied axial load on tube dilation (i.e., diameter reduction) has been neglected in Topical Report BAW-2346P, Revision 0 and the subsequent Addendum A. Similarly, this effect was neglected in the development of the CR-3 delta dilations in the topical report and addendum. Neglecting this effect produces overly conservative leakage estimates because the axial load applied during the tests (3,060 pounds) was significantly larger than the maximum axial load which would occur during a CR-3 MSLB (663 pounds). This submittal includes an accounting of the affect of the reduced axial load on tube dilation for both the laboratory test results and the CR-3 MSLB conditions, and provides a more realistic result yet remains conservative.

Probabilistic Methodology

The methodology described in Framatome ANP, "Probabilistic Leakage Assessment of Crystal River Unit 3 Steam Generator (SG) Tube End Cracks," (Attachment C), reduces some of the conservatisms in the current approach while generating appropriately conservative, high confidence leakage estimates.

The methodology relies on the same accident analyses described in Topical Report BAW-2346P, Revision 0, and License Amendment Request #249, Revision 0, and utilizes the same leakage test data and leakage limit. The methodology preserves the assumption that multiple cracks within the same tube will multiply the leakage from that tube. Unlike the GL 95-05 approach, which assumes that some cracks are not capable of leaking (probability of leakage), the probabilistic approach described herein, assumes that every crack leaks.

The currently approved method for calculating leakage assumes that all cracks within a given zone will leak at the maximum level for that zone. In the proposed methodology, each crack is evaluated with respect to its radial position in the tubesheet. The difference in axial loads between CR-3 and the leakage test program are accounted for in this approach. One significant difference between the current method of TEC leakage calculation and the new method proposed herein, is that instead of assigning each crack a fixed quantity of leakage based on its position in the tubesheet, the proposed method assigns individual leakage values probabilistically.

Consistent with the NRC-approved GL 95-05 Outside Diameter Stress Corrosion Cracking (ODSCC) ARC, the probabilistic approach for TEC leakage calculation accounts for the uncertainties associated with the leakage correlation, in this case, the correlation of leakage to joint tightness during a MSLB. Total OTSG leakage is determined by summing the individual probabilistic leakage for each crack. Thousands of estimates of OTSG leakage are developed and processed to determine the upper 95th percentile/95% confidence estimate for total OTSG leakage. This proposed statistical method concludes, with a 95% confidence, that there is a 95% probability the actual leakage will be less than the calculated value.

Conclusion

The results in Attachment C show that the proposed methodology estimates a lower total leak rate for CR-3 OTSGs. Although the proposed methodology preserves conservatisms not assumed in the GL 95-05 approach, it employs the same GL 95-05 calculational methodology which provides a realistic bounding approach to leakage calculation and a high level of confidence.

References

1. CR-3 to NRC letter, 3F0599-02, dated May 5, 1999, "License Amendment Request #249, Revision 0, Once Through Steam Generator Tube Surveillance Program, Alternate Repair Criteria for Axial Tube End Crack Indications" (includes BAW-2346P, Revision 0)

2. CR-3 to NRC letter, 3F0599-21, dated May 28, 1999, "License Amendment Request #249, Revision 0, Once Through Steam Generator Tube Surveillance Program (TAC No. MA5395), Addendum to Babcock & Wilcox Owners Group Topical Report BAW 2346P" (includes BAW-2346P, Revision 0, Addendum A)

3. NRC to CR-3 letter, 3N1099-01, dated October 1, 1999, "Crystal River Unit 3 – Issuance of Amendment Regarding Alternate Repair Criteria for Steam Generator Tubing" (TAC No. MA5395)

4. Generic letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995

5 Licensee Event Report 50-302/2004-004-00 dated November 22, 2004

PROGRESS ENERGY FLORIDA, INC.

CRYSTAL RIVER UNIT 3

DOCKET NUMBER 50-302/LICENSE NUMBER DPR-72

ATTACHMENT B

LICENSE AMENDMENT REQUEST #290, Revision 0

Regulatory Analysis

No Significant Hazards Consideration Determination
Applicable Regulatory Requirements
Environmental Impact Evaluation

No Significant Hazards Consideration Determination

License Amendment Request (LAR) #290, Revision 0, proposed change consists of a change in methodology for Tube End Crack (TEC) leakage calculation.

This LAR proposes to utilize a probabilistic methodology to determine the contribution to the Main Steam Line Break (MSLB) leakage rates from the Once-Through Steam Generator (OTSG) TEC Alternate Repair Criteria (ARC) approved in License Amendment No. 188. This change involves no change to the ARC described in the CR-3 Improved Technical Specifications (ITS).

1. *Does not involve a significant increase in the probability or consequences of an accident previously evaluated.*

This LAR proposes to change the method to determine the projected MSLB leakage rates for TEC. Potential leakage from OTSG tubes, including leakage contribution from TEC, is bounded by the MSLB evaluation presented in the Final Safety Analysis Report (FSAR). The inspection required by the ARC will continue being performed as required by CR-3 ITS 5.6.2.10. This inspection provides continuous monitoring of tubes with TEC indications remaining in service, and ensures that degradation of new tubes containing TEC indications is detected. The proposed change in method to determine MSLB leakage rates for TEC does not change any accident initiators.

Therefore, granting this LAR does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. *Does not create the possibility of a new or different type of accident from any accident previously evaluated.*

This LAR proposes to change the method to determine the projected MSLB leakage rates for TEC. The change introduces no new failure modes or accident scenarios. The proposed change does not change the assumptions made in Topical Report BAW-2346P, Revision 0, which demonstrated structural and leakage integrity for all normal operating and accident conditions for CR-3. The design and operational characteristics of the OTSGs are not impacted by the use of a probabilistic methodology to determine MSLB leakage rates.

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

3. *Does not involve a significant reduction in the margin of safety.*

This LAR proposes to change the method to determine the projected MSLB leakage rates for TEC. The resulting leakage estimates will be lower than the estimates from the old method. However, the estimates from the proposed method will be more realistic and do not impact the acceptance criteria. The methodology relies on the same accident analyses described in Topical Report BAW-2346P, Revision 0, and License Amendment Request #249, Revision 0, and utilizes the same leakage test data and leakage limit. The FSAR analyzed accident scenarios are not affected by the change and remain bounding. The limits established in CR-3 ITS 3.4.12, and 5.6.2.10.2.f have not been changed. Therefore, the proposed change does not reduce the margin of safety.

Based on the above, Progress Energy Florida, Inc. (PEF) concludes that the proposed LAR presents a no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and accordingly, a finding of "no significant hazards consideration" is justified.

Applicable Regulatory Requirements

PEF has evaluated the Regulatory Requirements applicable to the proposed changes. PEF has determined that the proposed change does not require any exemptions or relief from regulatory requirements other than the change in methodology for TEC leakage calculation. The proposed probabilistic methodology involves no change to the CR-3 ITS. The probabilistic methodology is being provided as Addendum B to Topical Report BAW-2346P, Revision 0. Addendum B supersedes the previously approved Addendum A.

Environmental Impact Evaluation

10 CFR 51.22(c)(9) provides criteria for identification of licensing and regulatory actions eligible for categorical exclusion from performing an environmental assessment. A proposed amendment to an operating license for a facility requires no environmental assessment if operation of the facility in accordance with the proposed amendment would not:

(i) involve a significant hazards consideration,

(ii) result in a significant change in the types or significant increase in the amounts of any effluents that may be released offsite, and

(iii) result in a significant increase in individual or cumulative occupational radiation exposure.

PEF has reviewed proposed License Amendment Request #290, Revision 0, and concludes it meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(c), no environmental impact statement or environmental assessment needs to be prepared in connection with this request.

PROGRESS ENERGY FLORIDA, INC.

CRYSTAL RIVER UNIT 3

DOCKET NUMBER 50-302/LICENSE NUMBER DPR-72

ATTACHMENT C

LICENSE AMENDMENT REQUEST #290, REVISION 0

Addendum to Topical Report 2346P, Revision 0 –
Probabilistic Leakage Assessment of Crystal River Unit 3
Steam Generator (SG) Tube End Cracks

AREVA

ENGINEERING INFORMATION RECORD

Document Identifier 51 - 5053331 - 00

Title Probabilistic Leakage Assessment of Crystal River Unit 3 SG Tube End Cracks

PREPARED BY: **REVIEWED BY:**

Name K.A.Colgan Name J.A.Begley

Signature [signature] Date 12/14/04 Signature [signature] Date 12/14/2004

Technical Manager Statement: Initials AMS for JMF

Reviewer is Independent.

Remarks:

This report documents a probabilistic methodology, developed for Crystal River Unit 3, to determine MSLB leakage rates for the OTSG tube end crack alternate repair criteria. This approach employs the same calculational methodology as that of the tube support plate alternate repair criteria (GL 95-05) incorporated in some PWR licenses. It involves no change to the alternate repair criteria as described in the Crystal River Technical Specifications; however, regulator approval is expected to be required prior to implementation. The methodology is implemented in a MathCad spreadsheet entitled "LeakTEC" which is described and benchmarked herein.

This document contains 37 pages including 13 in Appendix A (i.e., A1 through A13).

Record of Revisions

Section	Revision	Description of Change	Date
All	00	Original Release	12/2004

<u>**Table of Contents**</u>

1.0 Introduction

The NRC-approved bobbin voltage alternate repair criteria (ARC) described in Generic Letter 95-05 utilizes a probabilistic methodology to calculate total steam generator accident leakage at an upper 95% probability and 95% confidence level for axial ODSCC at tube support plates. This report documents an application of the same calculational approach to determine 95%/95% accident leakage rates for Crystal River Unit 3 tube end cracks (TEC). The probabilistic approach calculates bounding SG leakage at a high level of confidence, while reducing some of the conservatisms inherent in the current approach. The methodology is implemented in a MathCad spreadsheet entitled "LeakTEC" which is described and benchmarked within this report.

2.0 Background

Tube cracks have been identified within the roll expanded region near the primary tubesheet face in the Crystal River Unit 3 (CR-3) once through steam generators (OTSGs). An ARC which allows certain tubes containing TECs to remain inservice has been implemented at CR-3 for several years (Ref. 1). The determination of primary to secondary leakage under main steam line break (MSLB) conditions is an important aspect of the ARC, and is the subject of this evaluation.

MSLB leakage must be evaluated following each tube inspection and the calculated leakage must remain below the limit specified in the ARC. The leakage rates currently used to implement the ARC are based on the results of a laboratory test program (Ref. 1). The program applied simulated MSLB loads to a tube/tubesheet mockup and measured the resultant leakage though EDM notches within the tube under test. The testing demonstrated that expansion joint tightness is the key parameter which correlates with leakage rate. Joint tightness is quantified with a parameter called "delta dilation," a plant specific parameter which depends primarily upon axial tube load, tubesheet deformation, and primary pressure.

In the development of the ARC, the leakage test results were used with plant specific delta dilations to develop bounding leak rate estimates for various regions of the tubesheet. As currently implemented, these limiting leak rates are assigned to each identified TEC; a significant source of conservatism. Another significant source of conservatism lies in the use of delta dilation values which do not reflect the substantial difference between CR-3 axial tube loads and those employed in the leakage testing program. This is discussed in more detail in Section 3.0.

In recent years, the number of identified TECs has continued to increase and continued initiation is expected in both the hot and cold tube end regions. This, coupled with the conservatisms discussed above, may lead to significant increases in the number of tube repairs required. As a result, CR-3 initiated an effort to refine the method used to determine SG leakage associated with TECs. This report documents the results of that effort.

3.0 Crystal River Unit 3 MSLB Conditions

Specific CR-3 MSLB conditions which relate to this evaluation are discussed in this section. A more detailed discussion of MSLB conditions and assumptions is provided in Ref. 2.

During a CR-3 MSLB, the SG which is unaffected by the line break is rapidly isolated from the break, effectively preventing any leakage from that SG from significantly impacting offsite radiation dose rates. Therefore, the SG loads most appropriate for evaluating leakage to the environment are those associated with the SG whose steam line breaks (i.e., the "affected" SG).

The parameters most relevant to this evaluation are axial tube load and delta dilation. Table 3-1 summarizes CR-3 axial tube load and delta dilation values as a function of radial position within the tubesheet for the affected SG (Ref. 2). These values are based on the limiting assumption that 25% of the tubes are plugged when the MSLB occurs.

The unadjusted delta dilation values in Table 3-1 reflect tubesheet distortion, tube/tubesheet thermal deformation, and free (non-end capped) pressure tube dilation effects. However, they do not reflect the affect of axial load on tube dilation (Ref. 3). For the ARC as it is currently implemented, this approach is appropriate because leakage test results are applied in a similar manner. Specifically, even though a bounding axial load was imposed during the leak testing, the calculated delta dilations for the leak tests did not reflect that effect; therefore, the tested joint was actually looser (i.e., greater tube-to-tubesheet delta dilation) than indicated by the calculated delta dilation values. Because the CR-3 MSLB tube loads (663 lbf. max) are substantially lower than the tube load employed during the leak tests (3,060 lbf.), exclusion of this effect imposes an excessive level of conservatism on the estimated CR-3 MSLB leakage rate.

For this evaluation, CR-3 MSLB delta dilation values are adjusted to reflect the affect of axial tube load on joint tightness. This adjustment is discussed below. The leakage data, also adjusted for this effect, is discussed in Section 4.0.

Figure 3-1 illustrates that the axial tube load varies with tubesheet radius. Tubes located near the center of the tubesheet will experience compressive axial loads during an MSLB therefore no dilation adjustment is applied for these tubes. The tube diameter reduction resulting from an axial tensile load is calculated with the following equation:

$$\Delta Diameter = -\frac{PR_o v}{\pi R_{mid} Et}$$

where:

P = axial load from Table 3-1 (lbf)
R_o= outer radius within roll expansion (inch)
? = Poisson's ratio

R_{mid}= mid wall radius within roll expansion (inch)
E = modulus of elasticity at MSLB tube temperature (psi)
t = tube wall thickness within roll expansion (inch)

This calculation is documented in Ref. 4 and the resulting adjusted delta dilations are provided in Table 3-1. Figures 3-2 and 3-3 illustrate that because of the relatively low loads, the adjustment causes very little change in the delta dilation values.

Figure 3-1, CR-3 MSLB Axial Tube Load

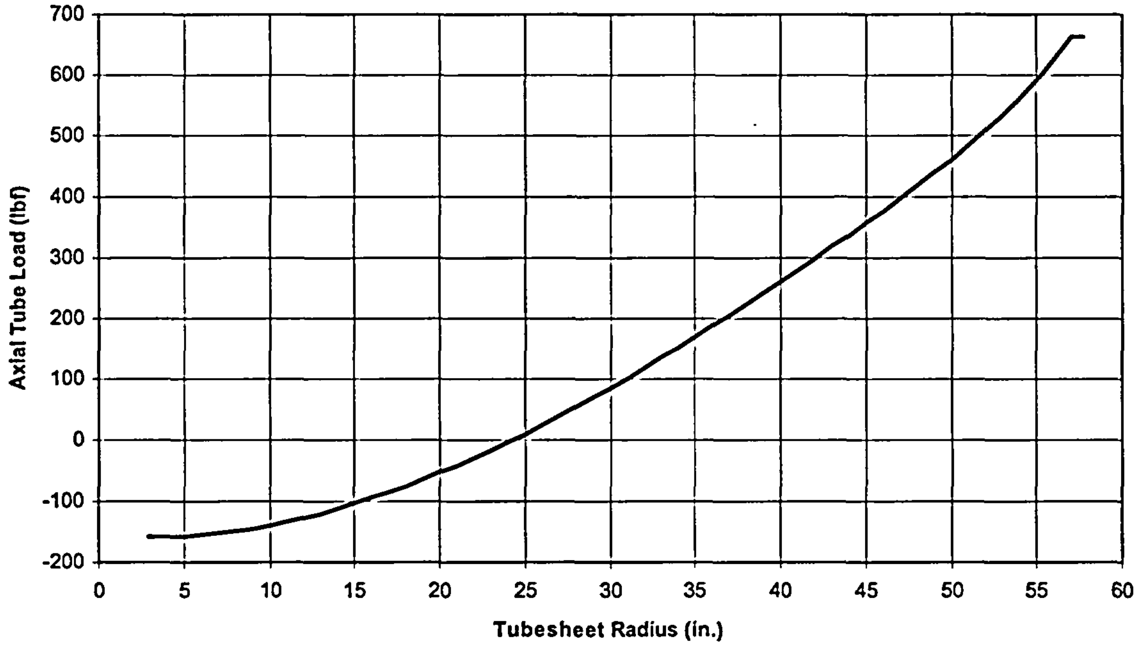

Figure 3-2, CR-3 Upper Tube End Delta Dilation

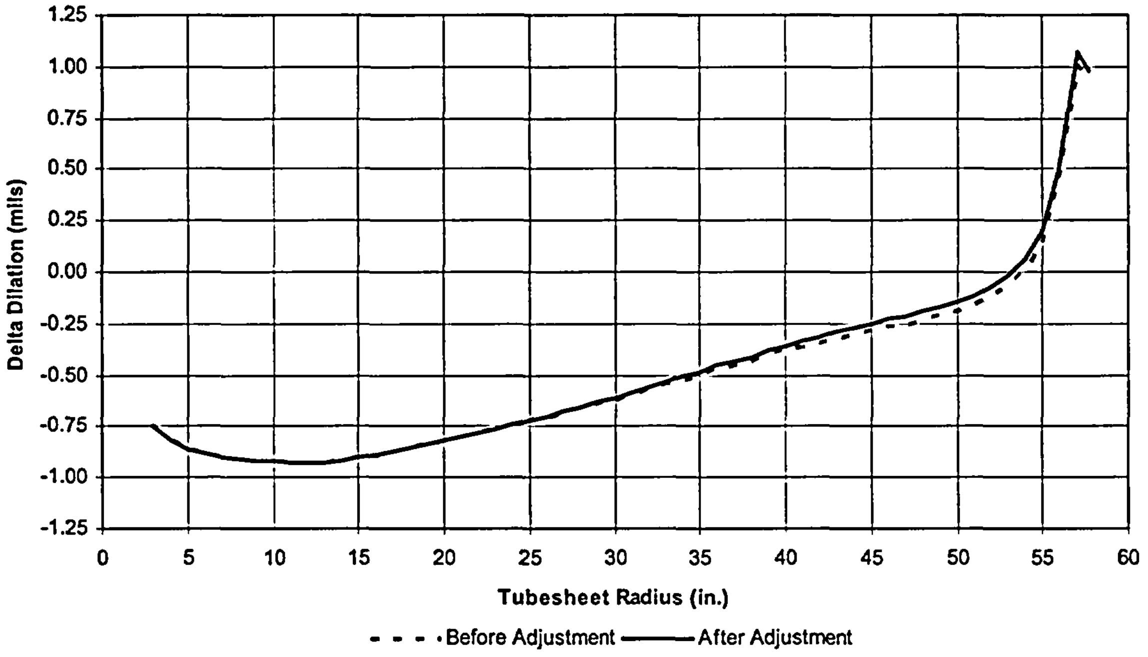

Figure 3-3, CR-3 Lower Tube End Delta Dilation

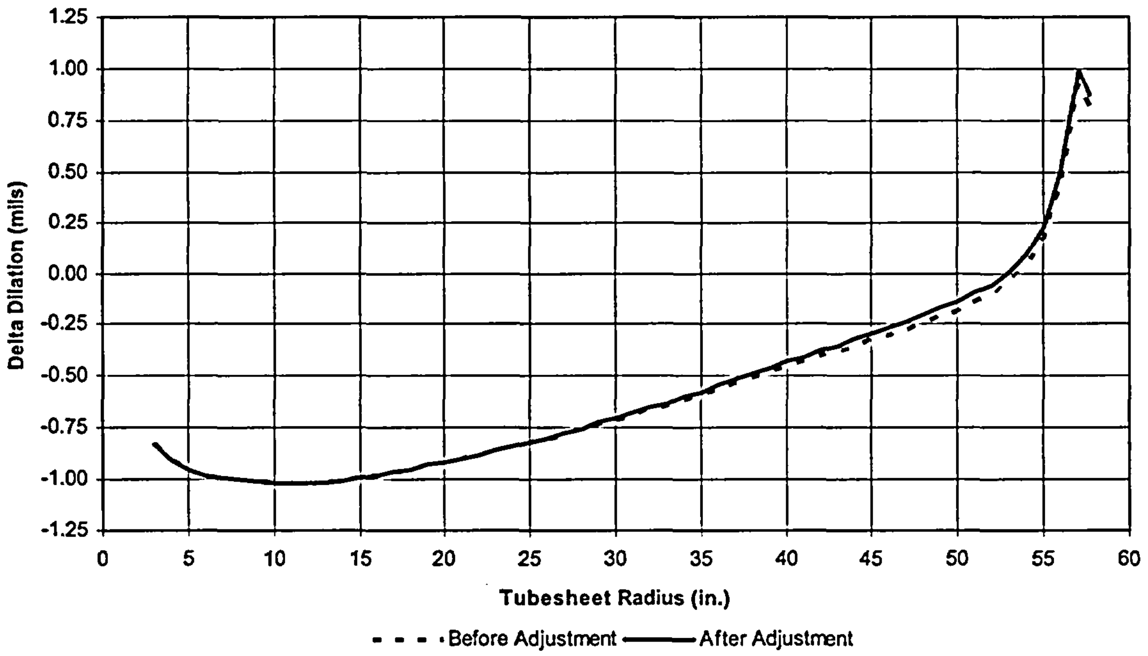

Table 3-1, CR-3 MSLB Delta Dilations and Tube Loads
(Affected SG, 25% tube plugging)

Tubesheet Radius (in.)	Axial Load (lbf)	Delta Dilation (mils)			
		Before Adjusting for Axial Load		After Adjusting for Axial Load	
		Upper Tube End	Lower Tube End	Upper Tube End	Lower Tube End
3	-159	-0.75	-0.83	-0.75	-0.83
4	-159	-0.82	-0.91	-0.82	-0.91
5	-157	-0.86	-0.95	-0.86	-0.95
6	-155	-0.88	-0.98	-0.88	-0.98
7	-152	-0.90	-0.99	-0.90	-0.99
8	-149	-0.91	-1.00	-0.91	-1.00
9	-144	-0.92	-1.01	-0.92	-1.01
10	-139	-0.92	-1.02	-0.92	-1.02
11	-134	-0.93	-1.02	-0.93	-1.02
12	-127	-0.93	-1.02	-0.93	-1.02
13	-120	-0.93	-1.02	-0.93	-1.02
14	-112	-0.92	-1.01	-0.92	-1.01
15	-104	-0.90	-0.99	-0.90	-0.99
16	-95	-0.89	-0.98	-0.89	-0.98
17	-85	-0.87	-0.96	-0.87	-0.96
18	-75	-0.85	-0.95	-0.85	-0.95
19	-65	-0.84	-0.93	-0.84	-0.93
20	-53	-0.82	-0.92	-0.82	-0.92
21	-42	-0.80	-0.90	-0.80	-0.90
22	-29	-0.78	-0.88	-0.78	-0.88
23	-17	-0.76	-0.86	-0.76	-0.86
24	-3	-0.74	-0.84	-0.74	-0.84
25	10	-0.72	-0.82	-0.72	-0.82
26	25	-0.70	-0.80	-0.70	-0.80
27	39	-0.68	-0.78	-0.68	-0.78
28	54	-0.66	-0.76	-0.66	-0.76
29	70	-0.64	-0.73	-0.63	-0.72
30	85	-0.62	-0.71	-0.61	-0.70
31	101	-0.59	-0.69	-0.58	-0.68
32	118	-0.57	-0.66	-0.56	-0.65
33	135	-0.54	-0.64	-0.53	-0.63
34	152	-0.52	-0.61	-0.51	-0.60
35	169	-0.50	-0.59	-0.48	-0.57
36	187	-0.47	-0.56	-0.45	-0.54
37	205	-0.45	-0.53	-0.43	-0.51
38	223	-0.43	-0.51	-0.41	-0.49
39	242	-0.40	-0.48	-0.38	-0.46
40	260	-0.38	-0.45	-0.36	-0.43
41	279	-0.36	-0.43	-0.33	-0.40
42	298	-0.34	-0.40	-0.31	-0.37
43	318	-0.32	-0.38	-0.29	-0.35
44	337	-0.30	-0.35	-0.27	-0.32
45	357	-0.28	-0.32	-0.25	-0.29
46	377	-0.26	-0.30	-0.23	-0.27
47	398	-0.25	-0.27	-0.21	-0.23
48	419	-0.23	-0.24	-0.19	-0.20
49	440	-0.21	-0.21	-0.17	-0.17
50	462	-0.19	-0.18	-0.15	-0.14
51	485	-0.16	-0.14	-0.12	-0.10
52	509	-0.12	-0.10	-0.07	-0.05
53	534	-0.07	-0.04	-0.02	0.01
54	561	0.01	0.04	0.06	0.09
55	591	0.14	0.17	0.19	0.22
56	624	0.44	0.44	0.50	0.50
57	663	1.01	0.93	1.07	0.99
57.72	663	0.92	0.81	0.98	0.87

4.0 Leakage Test Data

In a manner similar to that described above for the CR-3 delta dilations, the leakage test results documented in Ref. 1 were adjusted to account for tube dilation under the applied test conditions.

During the tests the tubesheet mockup was loaded bilaterally to vary the extent of bore hole dilation while the tube was internally pressurized and axially loaded in tension. Positive bore hole dilation and the axial tensile load work to reduce joint tightness (i.e., a more positive delta dilation) while the internal tube pressure works to increase joint tightness.

As discussed in Section 3.0, the ARC as it is currently applied is based upon leak test results which do not account for the affect of axial load on delta dilation. However, for this evaluation, axial loading is taken into account. Under the limiting MSLB conditions tested (axial load 3060 lbf; pressure 2640 psi), the net tube dilation was determined to be +0.13 mils (Ref. 4)[1]. This value was subtracted from the tubesheet mockup bore dilations to arrive at the appropriate delta dilation values. The mockup bore dilations and resulting delta dilations, along with measured leakage rates, are provided in Table 4-2.

One test point (X bore dilation: 0.2 mils; Y bore dilation 1.5 mils; log(leakage): -6.69) had an indicated leakage that was several orders of magnitude lower than all other tests with the same delta dilation value and was therefore omitted from the evaluation.

Figure 4-1 illustrates the linear relationship between delta dilation and the logarithm of leakage. Table 4-1 provides the sample estimates of regression parameters for this relationship:

Table 4-1, Leakage Regression Sample Parameters

Regression Line	
Number of Data Points (N)	119
Intercept (B)	-4.7493
Slope (M)	1.0063
Standard Error of Regression (S)	0.79382

Variance-Covariance Matrix	
Intercept	Slope
0.011564 (V_{11})	-0.0090940 (V_{12})
-0.0090940 (V_{21})	0.013193 (V_{22})

In order to employ the probabilistic techniques as described in this report, it is necessary to confirm that the variation of log(leakage) about the regression line is normally distributed, and that no systematic variation of residuals exists with respect to delta dilation. Figure 4-2 illustrates that the regression residuals closely follow a normal distribution. An examination of Figure 4-3 confirms that there is no significant systematic relationship between the magnitude of regression residual and delta dilation. This validates the underlying assumptions required to implement the probabilistic evaluation described in the next section.

1. The tube dilation associated with test pressure alone is +0.41mils, the value used to determine delta dilation in Reference 1.

Figure 4-1, OTSG Tube End Leakage vs Delta Dilation

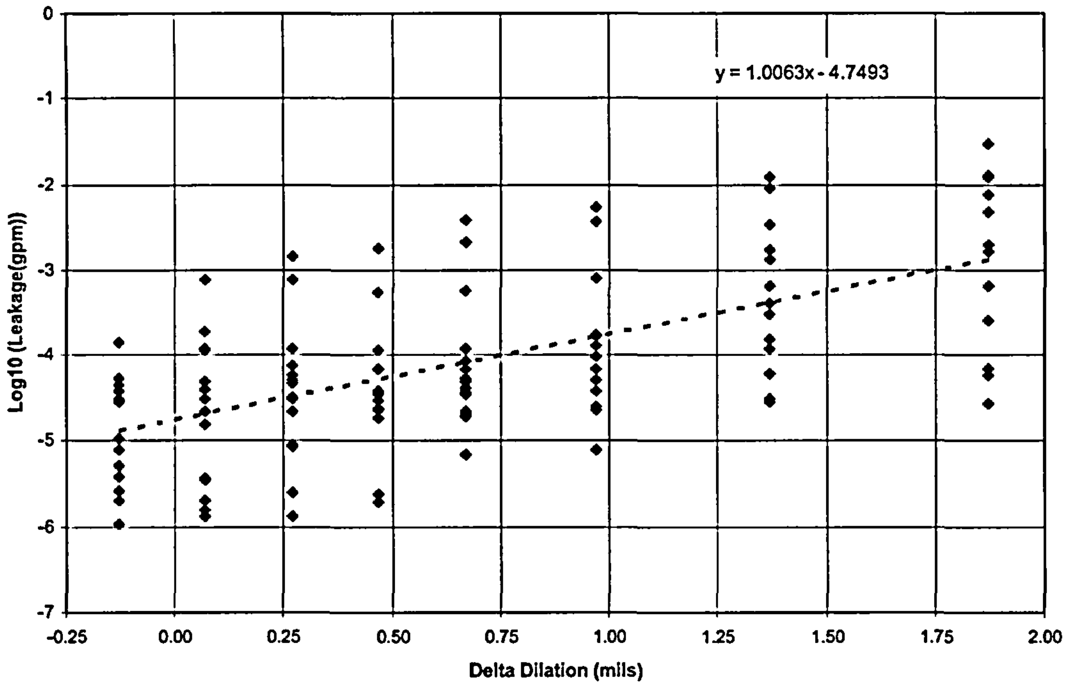

Figure 4-2, Residual Distribution

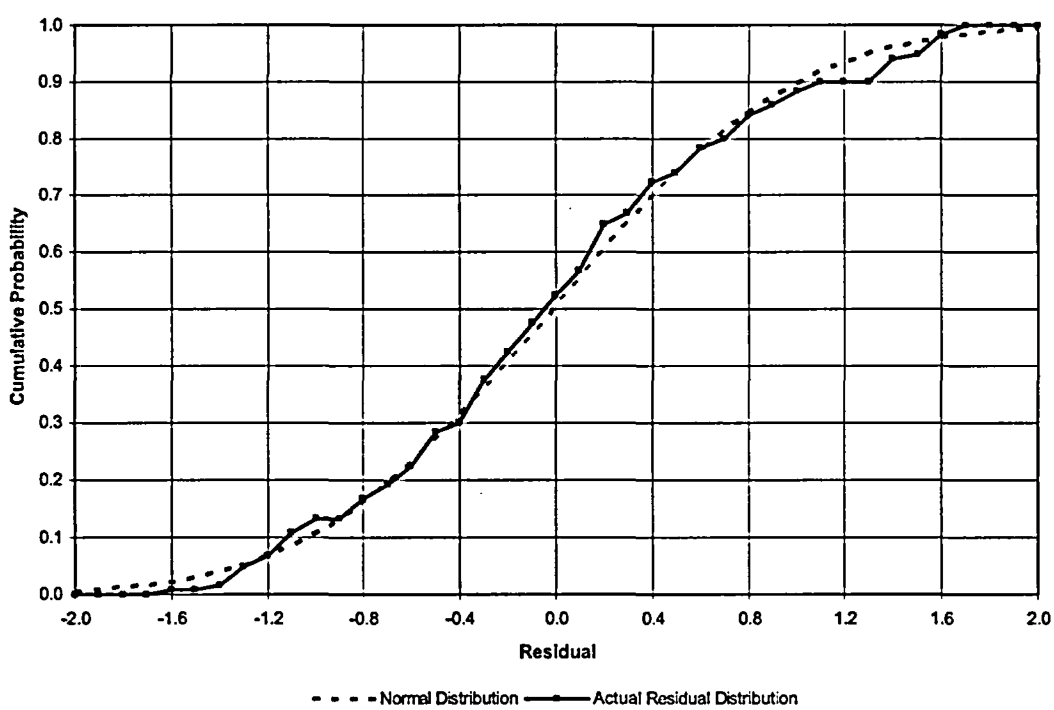

Figure 4-3, Regression Residuals

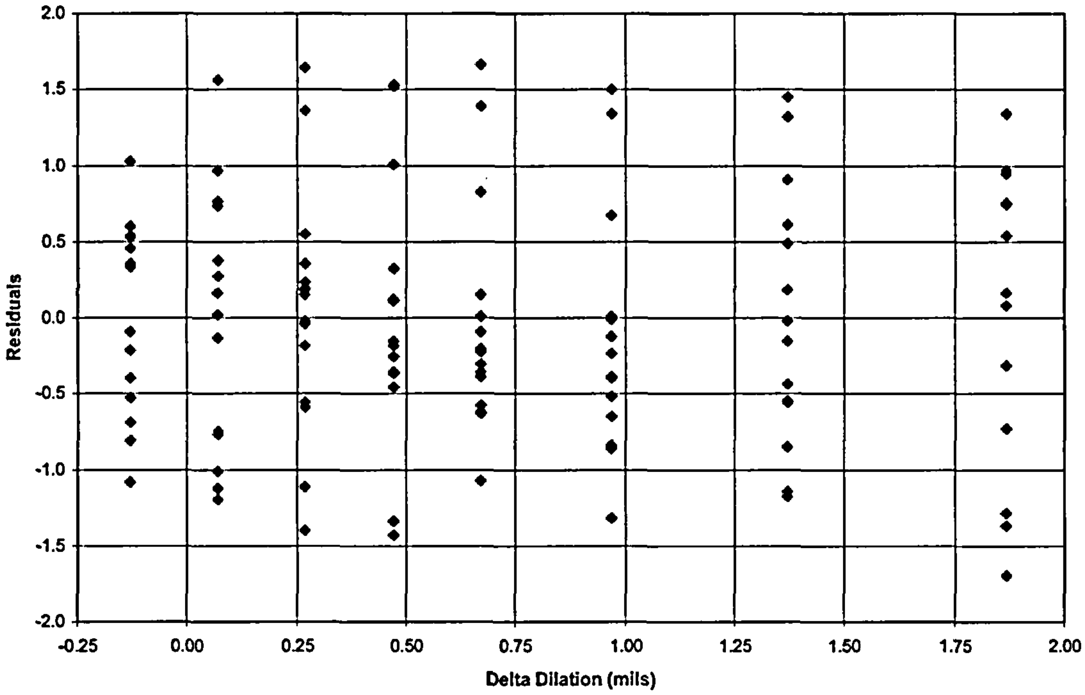

Table 4-2, Leakage Test Results
(Total axial load: 3,060 lbf; Pressure: 2,640 psi)

Diametral Dilation (mils)					Leakage (gpm) (Ref. 1, Table B-1)	
Tubesheet Mockup Bore Dilation		Bore / Tube Delta Dilation		Limiting Delta Dilation		
X	Y	X	Y		Measured	Log 10
0	0	-0.13	-0.13	-0.13	1.41E-04	-3.851
0	0	-0.13	-0.13	-0.13	5.24E-05	-4.281
0	0	-0.13	-0.13	-0.13	1.09E-06	-5.963
0	0	-0.13	-0.13	-0.13	3.87E-06	-5.412
0	0	-0.13	-0.13	-0.13	2.66E-06	-5.575
0	0.2	-0.13	0.07	0.07	1.91E-04	-3.719
0	0.2	-0.13	0.07	0.07	4.92E-05	-4.308
0	0.2	-0.13	0.07	0.07	1.33E-06	-5.876
0	0.2	-0.13	0.07	0.07	3.75E-06	-5.426
0	0.2	-0.13	0.07	0.07	3.51E-06	-5.455
0	0.4	-0.13	0.27	0.27	1.47E-03	-2.833
0	0.4	-0.13	0.27	0.27	4.78E-05	-4.321
0	0.4	-0.13	0.27	0.27	2.54E-06	-5.595
0	0.4	-0.13	0.27	0.27	8.60E-06	-5.066
0	0.4	-0.13	0.27	0.27	5.69E-05	-4.245
0	0.6	-0.13	0.47	0.47	1.82E-03	-2.740
0	0.6	-0.13	0.47	0.47	1.84E-05	-4.735
0	0.6	-0.13	0.47	0.47	2.42E-06	-5.616
0	0.6	-0.13	0.47	0.47	2.30E-05	-4.638
0	0.6	-0.13	0.47	0.47	3.74E-05	-4.427
0	0.8	-0.13	0.67	0.67	2.09E-03	-2.680
0	0.8	-0.13	0.67	0.67	1.96E-05	-4.708
0	0.8	-0.13	0.67	0.67	2.03E-05	-4.693
0	0.8	-0.13	0.67	0.67	6.76E-05	-4.170
0	0.8	-0.13	0.67	0.67	2.23E-05	-4.652
0	1.1	-0.13	0.97	0.97	3.70E-03	-2.432
0	1.1	-0.13	0.97	0.97	1.65E-04	-3.783
0	1.1	-0.13	0.97	0.97	7.99E-06	-5.097
0	1.1	-0.13	0.97	0.97	3.75E-05	-4.426
0	1.1	-0.13	0.97	0.97	6.73E-05	-4.172
0.2	1.5	0.07	1.37	1.37	1.20E-02	-1.921
0.2	1.5	0.07	1.37	1.37	1.20E-04	-3.921
0.2	1.5	0.07	1.37	1.37	2.80E-05	-4.553
0.2	1.5	0.07	1.37	1.37	1.57E-04	-3.804
0.2	1.5	0.07	1.37	1.37	3.03E-04	-3.519
0.3	2	0.17	1.87	1.87	1.19E-02	-1.924
0.3	2	0.17	1.87	1.87	6.50E-04	-3.187
0.3	2	0.17	1.87	1.87	2.71E-05	-4.567
0.3	2	0.17	1.87	1.87	1.95E-03	-2.710
0.3	2	0.17	1.87	1.87	7.48E-03	-2.126
0	0	-0.13	-0.13	-0.13	8.04E-06	-5.095
0	0	-0.13	-0.13	-0.13	4.50E-05	-4.347
0	0	-0.13	-0.13	-0.13	5.25E-06	-5.280
0	0	-0.13	-0.13	-0.13	1.08E-05	-4.967
0	0	-0.13	-0.13	-0.13	2.93E-05	-4.533

Table 4-2, Continued

Diametral Dilation (mils)					Leakage (gpm) (Ref. 1, Table B-1)	
Tubesheet Mockup Bore Dilation		Bore / Tube Delta Dilation		Limiting Delta Dilation		
X	Y	X	Y		Measured	Log 10
0	0.2	-0.13	0.07	0.07	4.98E-05	-4.303
0	0.2	-0.13	0.07	0.07	1.13E-04	-3.947
0	0.2	-0.13	0.07	0.07	1.56E-05	-4.807
0	0.2	-0.13	0.07	0.07	3.93E-05	-4.406
0	0.2	-0.13	0.07	0.07	1.20E-04	-3.921
0	0.4	-0.13	0.27	0.27	3.15E-05	-4.502
0	0.4	-0.13	0.27	0.27	1.17E-04	-3.932
0	0.4	-0.13	0.27	0.27	2.17E-05	-4.664
0	0.4	-0.13	0.27	0.27	5.14E-05	-4.289
0	0.4	-0.13	0.27	0.27	7.54E-05	-4.123
0	0.6	-0.13	0.47	0.47	2.98E-05	-4.526
0	0.6	-0.13	0.47	0.47	1.13E-04	-3.947
0	0.6	-0.13	0.47	0.47	2.96E-05	-4.529
0	0.6	-0.13	0.47	0.47	3.48E-05	-4.458
0	0.6	-0.13	0.47	0.47	5.41E-04	-3.267
0	0.8	-0.13	0.67	0.67	4.13E-05	-4.384
0	0.8	-0.13	0.67	0.67	1.20E-04	-3.921
0	0.8	-0.13	0.67	0.67	3.46E-05	-4.461
0	0.8	-0.13	0.67	0.67	3.71E-05	-4.431
0	0.8	-0.13	0.67	0.67	5.61E-04	-3.251
0	1.1	-0.13	0.97	0.97	6.88E-05	-4.162
0	1.1	-0.13	0.97	0.97	1.28E-04	-3.893
0	1.1	-0.13	0.97	0.97	2.44E-05	-4.613
0	1.1	-0.13	0.97	0.97	5.11E-05	-4.292
0	1.1	-0.13	0.97	0.97	7.96E-04	-3.099
0.2	1.5	0.07	1.37	1.37	1.19E-04	-3.924
0.2	1.5	0.07	1.37	1.37	4.03E-04	-3.395
0.2	1.5	0.07	1.37	1.37	1.72E-03	-2.764
0.2	1.5	0.07	1.37	1.37	3.38E-03	-2.471
0.3	2	0.17	1.87	1.87	1.95E-03	-2.710
0.3	2	0.17	1.87	1.87	1.64E-03	-2.785
0.3	2	0.17	1.87	1.87	6.95E-05	-4.158
0.3	2	0.17	1.87	1.87	4.69E-03	-2.329
0.3	2	0.17	1.87	1.87	7.53E-03	-2.123
0	0	-0.13	-0.13	-0.13	3.73E-05	-4.428
0	0	-0.13	-0.13	-0.13	2.84E-05	-4.547
0	0	-0.13	-0.13	-0.13	3.02E-05	-4.520
0	0	-0.13	-0.13	-0.13	2.04E-06	-5.690
0	0	-0.13	-0.13	-0.13	4.44E-05	-4.353
0	0.2	-0.13	0.07	0.07	3.07E-05	-4.513
0	0.2	-0.13	0.07	0.07	7.61E-04	-3.119
0	0.2	-0.13	0.07	0.07	2.17E-05	-4.664
0	0.2	-0.13	0.07	0.07	2.04E-06	-5.690
0	0.2	-0.13	0.07	0.07	1.57E-06	-5.804
0	0.4	-0.13	0.27	0.27	5.13E-05	-4.290

Table 4-2, Continued

Diametral Dilation (mils)					Leakage (gpm) (Ref. 1, Table B-1)	
Tubesheet Mockup Bore Dilation		Bore / Tube Delta Dilation		Limiting Delta Dilation		
X	Y	X	Y		Measured	Log 10
0	0.4	-0.13	0.27	0.27	7.66E-04	-3.116
0	0.4	-0.13	0.27	0.27	3.04E-05	-4.517
0	0.4	-0.13	0.27	0.27	9.13E-06	-5.040
0	0.4	-0.13	0.27	0.27	1.33E-06	-5.876
0	0.6	-0.13	0.47	0.47	6.99E-05	-4.156
0	0.6	-0.13	0.47	0.47	1.77E-03	-2.752
0	0.6	-0.13	0.47	0.47	6.88E-05	-4.162
0	0.6	-0.13	0.47	0.47	2.35E-05	-4.629
0	0.6	-0.13	0.47	0.47	1.94E-06	-5.712
0	0.8	-0.13	0.67	0.67	4.99E-05	-4.302
0	0.8	-0.13	0.67	0.67	3.91E-03	-2.408
0	0.8	-0.13	0.67	0.67	8.56E-05	-4.068
0	0.8	-0.13	0.67	0.67	5.30E-05	-4.276
0	0.8	-0.13	0.67	0.67	7.02E-06	-5.154
0	1.1	-0.13	0.97	0.97	9.74E-05	-4.011
0	1.1	-0.13	0.97	0.97	5.35E-03	-2.272
0	1.1	-0.13	0.97	0.97	1.71E-04	-3.767
0	1.1	-0.13	0.97	0.97	1.71E-04	-3.767
0	1.1	-0.13	0.97	0.97	2.30E-05	-4.638
0.2	1.5	0.07	1.37	1.37	1.32E-03	-2.879
0.2	1.5	0.07	1.37	1.37	8.98E-03	-2.047
0.2	1.5	0.07	1.37	1.37	6.47E-04	-3.189
0.2	1.5	0.07	1.37	1.37	3.01E-05	-4.521
0.2	1.5	0.07	1.37	1.37	5.96E-05	-4.225
0.3	2	0.17	1.87	1.87	2.99E-02	-1.524
0.3	2	0.17	1.87	1.87	1.24E-02	-1.907
0.3	2	0.17	1.87	1.87	7.57E-03	-2.121
0.3	2	0.17	1.87	1.87	2.55E-04	-3.593
0.3	2	0.17	1.87	1.87	5.72E-05	-4.243

5.0 Probabilistic Leakage Evaluation

The probabilistic calculation of CR-3 TEC leakage is implemented in MathCad spreadsheet "LeakTEC" (Appendix A). LeakTEC uses the delta dilation values from Section 3.0, the regression parameters developed in Section 4.0, and specific ECT inspection results to determine total SG leakage at various probability and confidence levels. This section describes the methodology employed within LeakTEC to accomplish this task. A complete validation of LeakTEC is documented in Ref. 4.

5.1 Overview

For each TEC identified during an inspection, a leakage value corresponding to the crack's delta dilation is obtained by sampling from the leakage regression. These probabilistic leakage values reflect the uncertainty that is inherent in the regression. The sum of the leakage samples from all identified cracks represents one probabilistic estimate – or one Monte Carlo trial – of total SG leakage. Repeated many times, this process generates a collection of probabilistic estimates of total SG leakage. This collection is the simulated distribution of total SG leakage from which values at a desired probability and confidence level can be directly obtained.

Leakage may be evaluated for either condition monitoring (CM) or operational assessment (OA) purposes. This is the only option required to be specified by the LeakTEC user. The CM evaluation estimates MSLB leakage for all cracks as found, while the OA evaluation accounts for the inspection technique's probability of detection (POD) and any tube repairs performed to address TECs. The leakage associated with new cracks which develop during the next operating interval must also be accounted for in the OA. Section 7.0 identifies a means of accomplishing this using LeakTEC.

LeakTEC accepts as an input, a list of tubes which contain TECs, identified by row and column. For each tube the following additional information must also be provided: the affected tube end, the number of cracks, maximum crack voltage, and an indicator as to whether the tube will be repaired. The spreadsheet determines each tube's radial position within the tubesheet matrix based on the row and column values. In turn, the CR-3 MSLB delta dilation is determined for each tube based on its radial position within the tubesheet.

5.2 Condition Monitoring Leakage Determination

At the heart of LeakTEC lies the Monte Carlo simulation which generates probabilistic leakage estimates for each crack and determines total leakage at desired probability and confidence levels. The approach employed is closely modeled on the process used in the TSP ODSCC ARC (Ref. 5). Probabilistic slope, intercept, and regression error values are generated for each Monte Carlo trial. For each crack, these values are used along with a random normal deviate applied to the regression error, to generate a probabilistic leak rate estimate. These estimates are summed to generate a probabilistic estimate of total SG leakage; a process that is repeated thousands of times. This process as applied to condition monitoring is described in more detail below.

Step 1: The ?[2] distribution is used to model the uncertainty which is inherent in the sample estimate of standard error of regression provided in Section 4.0. In the equations below a random ?[2] deviate for N-2, or 117 degrees of freedom is used to generate a probabilistic value of the standard error of regression:

$$f_v = \frac{(N-2)}{\chi^2_{(N-2),RANDOM}}$$

$$RnS = S\sqrt{f_v}$$

where:

N = number of data pairs used to calculate the regression coefficients
N = 119
S = sample estimate of the standard error of regression
S = 0.79382
RnS = probabilistic standard error of regression

Step 2: The same approach is used to generate probabilistic estimates of the variance-covariance values for slope and intercept:

$$RnV_{11} = f_v V_{11}$$
$$RnV_{12} = f_v V_{12}$$
$$RnV_{22} = f_v V_{22}$$

where:

V_{11} = sample estimate of the variance of the intercept
V_{12} = sample estimate of the covariance of intercept and slope
V_{22} = sample estimate of the variance of the slope
RnV_{xx} = probabilistic value

Step 3: A probabilistic intercept value is then generated as follows:

$$Rn\beta 3 = B + Z_1\sqrt{RnV_{11}}$$

where:

B = sample estimate of the intercept
B = -4.7493
Z_1 = a random normal deviate
$Rn\beta 3$ = probabilistic intercept

Step 4: A probabilistic value for slope must also be generated. While the slope and intercept are individually normally distributed, they are not independent of each other. Taken together they are bivariate normally distributed. The probabilistic value of slope is constrained by the probabilistic value of intercept developed in Step 3. This co-dependence is quantified by parameter V_{12}, the covariance of intercept and slope. The probabilistic slope value is calculated as follows:

$$Rn\beta 4 = M + Z_1 \frac{RnV_{12}}{\sqrt{RnV_{11}}} + Z_2 \sqrt{RnV_{22} - \frac{(RnV_{12})^2}{RnV_{11}}}$$

where:

M = sample estimate of the slope
M = 1.0063
Z_2 = a random normal deviate
$Rn\beta 4$ = probabilistic slope

Step 5: Using the probabilistic values of slope, intercept, and regression error a probabilistic estimate of leakage is obtained for each crack. The sum of the leakage for all cracks represents one probabilistic estimate of total SG leakage:

$$Leakage_i = InvLog_{10}(Rn\beta 3 + DD_i Rn\beta 4 + Z_3 RnS)$$

$$SGLeak_k = \sum_{i=1}^{NumCracks} Leakage_i$$

where:

DD_i = delta dilation for crack i
Z_3 = a random normal deviate
$Leakage_i$ = leakage rate for crack i
$SGLeak_k$ = total SG leakage rate for trial k

Step 6: Steps 1 through 6 are repeated, generating thousands of $SGLeak_k$ values. Together these values represent the simulated distribution of expected total SG leakage. Once ordered from smallest to largest, leakage values at desired probability and confidence levels can be taken directly from the distribution using an appropriate index value. For example, the one-sided upper 95% probability / 95% confidence value of leakage in an ordered distribution of 10,000 values would be the 9,537th value. This index is the smallest value of n for which the following relationship is true (Ref. 5):

$$\frac{1}{1 + \frac{N-n+1}{n} F_{1-\alpha,2(N-n+1),2n}} \geq P$$

where:

P = probability (fractional)
$1\text{-}a$ = confidence (fractional)
N = number of trials
F = critical value from the F-distribution
n = the index corresponding to the specified probability and confidence

5.3 Operational Assessment Leakage Determination

The OA calculation is identical to the process described above except for one additional step. That step adjusts the number of cracks in each tube to reflect the inspection POD and to reflect any tube repairs to be performed prior to returning the SG to service (new cracks must also be considered in the OA -- see Section 7.0). Within LeakTEC this step is performed for all imported tubes prior to each Monte Carlo trial. It is applied probabilistically such that "fractional cracks" are appropriately represented in the results.

As illustrated by the following equation, a POD value of less than one increases the number of inservice cracks expected during the next operating cycle, while tube repairs reduce the number of inservice cracks:

$$NumCracks_{(n+1)} = \frac{NumCracks_n}{POD} - NumRepaired_n$$

where:

$NumCracks_n$ = the number of TECs identified in a particular tube during the current outage
$NumRepaired_n$ = of the TECs above, the number removed from service during the current outage
$NumCracks_{(n+1)}$ = the number of TECs expected at the next outage in a tube having the same delta dilation value

For example if POD is 0.84, a tube with two cracks identified and repaired during the current outage would yield 0.381 cracks for OA evaluation purposes. To account for the fractional crack, prior to each Monte Carlo trial the fraction is compared with a random number between zero and one. If the random number is greater than the fraction, the number of cracks is rounded down to the nearest integer. Otherwise it is rounded up to the nearest integer. For this example, in a large number of trials the number of cracks evaluated for this tube will equal one in 38.1% of the trials (i.e., 0.381 x 100%) and will equal zero in 61.9% of the trials.

6.0 Benchmarking

It is desirable to benchmark the probabilistic approach described in this report against the deterministic approach described in Ref. 1. To accomplish this, October 2003 (EOC13) CR-3 inspection results were evaluated using LeakTEC and the results were compared with those documented in the post-inspection CMOA (Ref. 6). Tables 6-1 and 6-2 summarize the leakage values determined using the two approaches. Detailed LeakTEC results are provided in Table 6-3.

As expected, the probabilistic approach yields lower leakage estimates than the deterministic approach. Tables 6-1 and 6-2 illustrate that LeakTEC reduces the estimated MSLB leakage by a factor of up to 3.3.

Table 6-1, SG A EOC13 MSLB Leakage Comparison

	Lower TECs		*Upper TECs*		*Combined*	
	CMOA Ref. 6	*LeakTEC (95/95)*	*CMOA Ref. 6*	*LeakTEC (95/95)*	*CMOA Ref. 6*	*LeakTEC (95/95)*
As-Found (CM)	0.013	0.00712	0.932	0.296	0.945	0.298
Returned to Service	0.013	0.00726	0.266	0.127	0.279	0.132
Projected EOC 14 (OA)	--	0.00848	--	0.186	0.459	0.188

Table 6-2, SG B EOC13 MSLB Leakage Comparison

	Lower TECs		*Upper TECs*		*Combined*	
	CMOA Ref. 6	*LeakTEC (95/95)*	*CMOA Ref. 6*	*LeakTEC (95/95)*	*CMOA Ref. 6*	*LeakTEC (95/95)*
As-Found (CM)	0.124	0.0418	1.102	0.344	1.226	0.376
Returned to Service	0.107	0.0388	0.278	0.123	0.385	0.156
Projected EOC 14 (OA)	--	0.0455	--	0.191	0.619	0.228

Table 6-3, LeakTEC Results based on EOC13 Inspection Data

	Type	POD	Leakage (gpm) @ 50/50	Leakage (gpm) @ 95/50	Leakage (gpm) @ 95/95	Computation Time (min.)*
SG A Upper						
1467 UTECs, 246 Repaired, 1221 RTS	CM	--	0.151	0.293	0.296	7.0
	OA	0.84	0.0909	0.184	0.186	9.5
	OA	1.00	0.0625	0.126	0.127	8.0
SG A Lower						
7 LTECs, 0 Repaired, 7 RTS	CM	--	0.000863	0.00686	0.00709	0.05
	OA	0.84	0.00110	0.00815	0.00848	0.07
	OA	1.00	0.000832	0.00702	0.00726	0.07
SG A Combined						
1467 UTECs, 7 LTECs, 246 Repaired, 1228 RTS	CM	--	0.153	0.294	0.298	7.0
	OA	0.84	0.0932	0.185	0.188	10.0
	OA	1.00	0.0641	0.130	0.132	8.5
SG B Upper						
1173 UTECs, 214 Repaired, 959 RTS	CM	--	0.175	0.340	0.344	5.75
	OA	0.84	0.0949	0.189	0.191	8.5
	OA	1.00	0.0609	0.122	0.123	6.5
SG B Lower						
115 LTECs, 3 Repaired, 112 RTS	CM	--	0.0156	0.0410	0.0418	0.5
	OA	0.84	0.0175	0.0446	0.0455	1.0
	OA	1.00	0.0142	0.0381	0.0388	0.75
SG B Combined						
1173 UTECs, 115 LTECs, 217 Repaired, 1071 RTS	CM	--	0.193	0.372	0.376	6.25
	OA	0.84	0.114	0.225	0.228	8.75
	OA	1.00	0.0772	0.154	0.156	7.5

RTS = Returned to service
UTEC = Upper Tube End Cracks
LTEC = Lower Tube End Cracks
Number of Trials = 20,000 in all cases
*With a 2.16 GHz Pentium 4 CPU

7.0 Field Implementation

7.1 User Instructions

A typical implementation of LeakTEC involves the following steps:

1) Confirm that the spreadsheet to be used is the validated version by running it with input data from a documented case such as those discussed in Section 6.0. Confirm that the same results are generated. Note that due to the probabilistic nature of this calculation, the repeatability of results is dependent upon the number of trials used. If the number of trials specified is too low, the results will vary significantly from one run to another.

2) Within the "Options and Inputs" section of LeakTEC, perform the following:

   a) Choose the type of leakage assessment to be performed (CM or OA).

   b) If "Operational Assessment" was selected, specify the POD value.

   c) Specify an appropriate voltage screening threshold. If no screening is to be applied, VThresh should equal zero.

CAUTION
A non-zero value for voltage threshold may only be used if approved by the utility and/or NRC.

   d) Specify the Excel file which contains crack data to be imported. Do this by modifying the filename and data range within the properties of the "InCrkDat" source file. The following example illustrates the required Excel file format:

Row	Column	Tube End	Number of Cracks	Repair Flag	Maximum Voltage
113	115	UTE	2	N	0.2

   N = not to be repaired
   R = to be repaired

3) Occasionally it may be desirable to modify the number of Monte Carlo trials to be used. This parameter "NumTrials," is defined within the "Constants" section of LeakTEC. This parameter must be a positive integer and is constrained to be =100 within the spreadsheet. However, in practice the value should be set to at least 10,000.

4) Press CTRL+F9 to recalculate the entire spreadsheet.

5) Once the evaluation is complete, calculated leakage rates are available in the "Results" section.

7.2 Consideration of New Cracks in the Operational Assessment

TECs which may initiate during the next operating cycle (i.e., new TECs) should be considered in the OA estimation of accident leakage. Three options for addressing new TECs are discussed briefly below. In each case, the OA leakage estimate from the previous outage should equal or exceed the CM estimate for the current outage, validating the OA methodology as an effective predictor of leakage at the next EOC.

1) TECs identified during the current outage which were not present during the previous outage can be used to estimate the quantity and distribution of future new TECs. The leakage contribution from these TECs can be determined by inputting these cracks into LeakTEC and executing with the CM option.

   LeakTEC can then be executed for all as-found cracks using the OA option. This determines the leakage for TECs which were not detected, or were detected and left in service. The total leakage at the next EOC is simply the sum of these two leakage values.

2) In a similar manner, all of the as-found TECs plus a duplicate entry for all newly initiated TECs can be used as the input to LeakTEC. Executing with the OA option will then directly generate a leakage estimate which accounts for those TECs: a) not detected, b) detected and left inservice, and c) expected to initiate during the next operating cycle. With this approach the POD is applied not only to as-found TECs but also to newly initiated TECs making the leakage estimate somewhat unnecessarily conservative.

3) As an alternative to using new TECs identified during the current outage as a predictor of new TECs at the next EOC, historical TEC initiation can be modeled using Weibull techniques. The resulting Weibull failure distribution can then be used to produce an estimate of the number of new TECs expected to initiate during the next operating cycle. These TECs, distributed across the tubesheet in a manner consistent with the historical distribution, will then be included as an input to LeakTEC as described in item (1) or item (2) above.

7.3 LeakTEC Usage Notes

1) MathCad's automatic calculation feature should be disabled (Tools|Calculate). This will prevent the spreadsheet from recalculating before all desired input changes have been made.

2) Two files which contain information imported within the "Constants" section must reside within the same file directory as the spreadsheet. The files are: "DeltaDilation

w Axial Load.xls" and "TRvTID.xls." If it should become necessary to re-link these files within LeakTEC, the appropriate data ranges are as follows:

Filename	Data Range
DeltaDilation w Axial Load.xls	CR3-Specific!k3:m58
TRvTID.xls	Sheet1!a2:c15532

3) A read-only master copy and backup of the spreadsheet and above files should be maintained.

4) For CM simulations, the following equation provides an order of magnitude estimate of computation time:

$$t = \frac{(NumTrials)(NumCracks)}{(1.92E06)(P)}$$

where:

t = computation time (minutes)
$NumTrials$ = number of Monte Carlo trials
$NumCracks$ = number of cracks evaluated
P = CPU clock speed (GHz)

5) The OA computation takes longer than the CM computation. The time depends upon the POD value and the number of cracks to be repaired, in addition to the number of cracks imported.

8.0 Summary and Conclusions

A refinement of the MSLB leakage calculation methodology which is applicable to the CR-3 ARC for SG tube end cracking has been described in this report. This methodology employs Monte Carlo techniques and is implemented in MathCad spreadsheet "LeakTEC." Several benchmarking cases have demonstrated that, as expected, this approach yields lower leakage estimates than the deterministic approach currently in use. Instructions for field implementation of the spreadsheet have also been provided.

9.0 References

1) FANP, "ARC for Tube End Cracking in the Tube-to-Tubesheet Roll Joint of OTSGs," BAW-2346P, April 1999

2) FANP Calculation 32-5003879-03, "OTSG Tube End Crack Leak Rate vs. Tubesheet Radius," November 11, 1999

3) FANP Calculation 32-5002623-02, "OTSG Transient Analysis," May 1999

4) FANP Calculation 32-5053981-00, "Probabilistic Implementation of CR-3 TEC ARC - Supporting Calculations"

5) WCAP-14277, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections," Revision 1, December 1996

6) FANP Calculation 32-5035732-00, "CR3 RFO-13 TEC ARC Leakage Calculation," January 16, 2004

Appendix A – LeakTEC Listing

INTRODUCTION

This spreadsheet calculates the total primary to secondary steam generator leak rate from tube end cracks (TEC) for Crystal River Unit 3 under limiting MSLB conditions. The spreadsheet employs Monte Carlo simulation techniques to generate leak rates at 50%/50%, 95%/50%, and 95%/95% probability/confidence levels, and may be used for both Condition Monitoring and Operational Assessment purposes. The probabilistic aspects of this evaluation are similar to that of the tube support plate ODSCC alternate repair criteria currently employed by several PWRs.

Required inputs are identified in the "OPTIONS AND INPUT DATA" section below. Calculated leak rates are obtained from the "RESULTS" section further on in the spreadsheet.

The master version of this spreadsheet is entitled "LeakTEC.mcd."

INTRODUCTION

OPTIONS AND INPUT DATA

Choose Leakage Assessment Type:

(•) Condition Monitoring

( ) Operational Assessment

Specify Probability of Detection (for OA):

POD ≡ 1.0 *This value has no affect on CM results*

Specify Crack Voltage Threshold:

VThresh ≡ 0 *Cracks with voltage below this value will be excluded from the evaluation.* **CAUTION: A non-zero value for voltage threshold may only be used if approved by the utility and/or NRC.**

Specify Filename to Import Crack Locations, Quantities, and Repair Plans:

InCrkDat :=

NC := CntCrks(InCrkDat) *Simulation will not run if the number of cracks to evaluate is zero.*

NC =

	0	1
0	"Number of lines in the data file:"	1115
1	"Number of UTE cracks imported:"	1467
2	"Number of LTE cracks imported:"	0
3	"Number of cracks flagged for repair:"	246
4	"Number of cracks not flagged for repair:"	1221
5	"Total cracks imported:"	1467
6	"Number of cracks to evaluate:"	1467

	0	1	2	3	4	5
0	1	7	"UTE"	2	"R"	100
1	1	8	"UTE"	3	"R"	100
2	1	9	"UTE"	1	"R"	100
3	2	10	"UTE"	1	"R"	100
4	2	11	"UTE"	1	"R"	100
5	3	14	"UTE"	1	"R"	100
6	3	21	"UTE"	1	"R"	100
7	3	31	"UTE"	1	"R"	100
8	4	17	"UTE"	2	"R"	100
9	4	26	"UTE"	2	"R"	100
10	4	37	"UTE"	1	"R"	100
11	5	1	"UTE"	2	"R"	100
12	5	3	"UTE"	1	"R"	100
13	5	20	"UTE"	2	"R"	100
14	5	21	"UTE"	1	"N"	100
15	5	23	"UTE"	1	"N"	100

InCrkDat =

Row, column, tube end, number of cracks, repair flag, max crack voltage (truncated listing if more than 16 lines)

OPTIONS AND INPUT DATA

CONSTANTS

Number of Monte Carlo Trials:

NumTrials ≡ 2000C

The number of Monte Carlo trials should should be as large as necessary to achieve repeatable run-to-run results.

Mode := if(NumTrials < 100, −2, Mode)

Mode = 1

Log(Leak) v Delta Dilation Regression Parameters:

N ≡ 119 *Number of points*

S ≡ 0.79382 *Standard error of regression*

$RgV \equiv S^2$ *Regression error variance* RgV = 0.63

M ≡ 1.0063 *Slope*

B ≡ −4.7493 *Intercept*

$V_{11} \equiv 0.011564$ $V_{12} \equiv -0.009094C$ *Variance matrix*

$V_{21} \equiv -0.009094C$ $V_{22} \equiv 0.013193$ *Variance matrix*

Delta Dilation v Tubesheet Radius:

DDilation := *Import accident delta dilation values*

rows(DDilation) = 56 *Number of data lines imported*

DDilation =

	0	1	2
0	3	-0.75	-0.83
1	4	-0.82	-0.91
2	5	-0.86	-0.95
3	6	-0.88	-0.98
4	7	-0.9	-0.99
5	8	-0.91	-1
6	9	-0.92	-1.01
7	10	-0.92	-1.02
8	11	-0.93	-1.02
9	12	-0.93	-1.02
10	13	-0.93	-1.02
11	14	-0.92	-1.01
12	15	-0.9	-0.99
13	16	-0.89	-0.98
14	17	-0.87	-0.96
15	18	-0.85	-0.95

Tubesheet radius (in.), upper TS delta dilation (mils), lower TS delta dilation (mils) (truncated listing)

Tubesheet Radius v Tube Number:

TRvTID := *Import tubesheet radius vs tube number*

rows(TRvTID) = 15531 *Number of data lines imported*

$TRvTID =$

	0	1	2
0	1	1	57.21
1	1	2	57.12
2	1	3	57.04
3	1	4	56.97
4	1	5	56.92
5	1	6	56.88
6	1	7	56.85
7	1	8	56.84
8	1	9	56.84
9	1	10	56.85
10	1	11	56.88
11	1	12	56.92
12	1	13	56.97
13	1	14	57.04
14	1	15	57.12
15	1	16	57.21

Tubesheet radius vs tube number (truncated listing)

$ORIGIN \equiv 0$

CONSTANTS

PREPROCESSING

<u>Check the Crack Input File for Problems</u>:

$Mode := if[(NC_{1,1} + NC_{2,1} \neq NC_{5,1}), -1, Mode]$

$Mode := if[(NC_{3,1} + NC_{4,1} \neq NC_{5,1}), -1, Mode]$

$Mode = 1$ *If mode is not 1 or 2, simulation will not run.*

$TCrks := NC_{5,1}$

<u>Eliminate Cracks Not > or = to the Voltage Threshold</u>:

$CrkDat := ElimLoVolts(InCrkDat)$

<u>Add the Radius Value to the Crack Data Matrix</u>:

$i := 0 .. rows(CrkDat) - 1$

$CrkDat_{(i,5)} := RadLookup[CrkDat_{(i,0)}, CrkDat_{(i,1)}, TRvTID]$

Add the Delta Dilation Value to the Crack Data Matrix:

$CrkDat_{(i,6)} := DDLookup\left[CrkDat_{(i,5)}, CrkDat_{(i,2)}, DDilation\right]$

This array contains: Row, Col, Leg, #Cracks, TS Radius, Delta Dilation. If simulation does not run, check this array for "Error" entry caused by invalid tube row or column.

CrkDat =

	0	1	2	3	4	5	6
0	1	7	"UTE"	2	"R"	56.85	0.9841
1	1	8	"UTE"	3	"R"	56.84	0.9783
2	1	9	"UTE"	1	"R"	56.84	0.9783
3	2	10	"UTE"	1	"R"	56.19	0.6055
4	2	11	"UTE"	1	"R"	56.14	0.5769
5	3	14	"UTE"	1	"R"	55.4	0.3148
6	3	21	"UTE"	1	"R"	55.4	0.3148
7	3	31	"UTE"	1	"R"	56.57	0.8235
8	4	17	"UTE"	2	"R"	54.67	0.1498
9	4	26	"UTE"	2	"R"	54.74	0.1591
10	4	37	"UTE"	1	"R"	56.33	0.6858
11	5	1	"UTE"	2	"R"	57.29	1.0339
12	5	3	"UTE"	1	"R"	56.72	0.9095
13	5	20	"UTE"	2	"R"	53.89	0.0518
14	5	21	"UTE"	1	"N"	53.85	0.0485
15	5	23	"UTE"	1	"N"	53.81	0.0452

Calculate Index Values for 50/50, 95/50, and 95/95 Leakage:

$Indx5050 \equiv round[(NumTrials \cdot 0.5) - 1]$ $\quad$ $Indx5050 = 9999$

$Indx9550 \equiv round[(NumTrials \cdot 0.95) - 1]$ $\quad$ $Indx9550 = 18999$

$$Indx9595 \equiv \left| \begin{array}{l} P \leftarrow 0.95 \\ n_0 \leftarrow trunc(0.95 \cdot NumTrials) \\ \text{for } n \in n_0 .. NumTrials \\ \quad \left| \begin{array}{l} Crit \leftarrow \dfrac{1}{1 + \dfrac{NumTrials - n + 1}{n} \cdot qF[0.95, [2 \cdot (NumTrials - n + 1)], 2 \cdot n]} \\ \text{return } n - 1 \text{ if } Crit \ge P \end{array} \right. \\ n \leftarrow \text{"error"} \end{array} \right.$$

$Indx9595 = 19050$

PREPROCESSING

RESULTS

Press CTRL + F9 to calculate.

Leak(CrkDat, Mode) =

	0	1
0	"50/50 CM Accident Leakage"	0.1512575
1	"95/50 CM Accident Leakage"	0.2931619
2	"95/95 CM Accident Leakage"	0.2958761

GPM

RESULTS

FUNCTIONS

Given a Matrix of Crack Data, Keep only Those Exceeding the Voltage Threshold:

```
ElimLoVolts(InCrkDat) ≡ | j ← -1
                        | for i ∈ 0.. rows(InCrkDat) - 1
                        |   if InCrkDat(i,5) ≥ VThresh
                        |      | j ← j + 1
                        |      | CrkDat(j,0) ← InCrkDat(i,0)
                        |      | CrkDat(j,1) ← InCrkDat(i,1)
                        |      | CrkDat(j,2) ← InCrkDat(i,2)
                        |      | CrkDat(j,3) ← InCrkDat(i,3)
                        |      | CrkDat(j,4) ← InCrkDat(i,4)
                        | CrkDat
```

Given a Row and Col, Return the TS Radius:

```
RadLookup(Ro, Co, Tr) ≡ | Radius ← "Error"
                        | rows ← rows(Tr) - 1
                        | for r ∈ 0.. rows
                        |   if [Tr(r,0) = Ro] ∧ [Tr(r,1) = Co]
                        |      | Radius ← Tr(r,2)
                        |      | break
                        | return Radius
```

Given a Radius, Return the Appropriate Delta Dilation Value:

This function interpolates to obtain the delta dilation value.

$$
\mathrm{DDLookup}(\mathrm{Rad}, \mathrm{Leg}, \mathrm{DDilation}) \equiv \left|
\begin{array}{l}
\mathrm{return}\ \ \text{"Error"}\ \ \mathrm{if}\ \ \mathrm{Rad} = \text{"Error"} \\
j \leftarrow 1 \\
j \leftarrow 2\ \ \mathrm{if}\ \ \mathrm{Leg} = \text{"LTE"} \\
\mathrm{Rad} \leftarrow 3\ \ \mathrm{if}\ \ \mathrm{Rad} < 3 \\
\mathrm{RadFloor} \leftarrow \mathrm{floor}(\mathrm{Rad}) \\
\mathrm{RadCeil} \leftarrow \mathrm{ceil}(\mathrm{Rad}) \\
\mathrm{RadCeil} \leftarrow 57.72\ \ \mathrm{if}\ \ \mathrm{RadCeil} > 57.72 \\
\mathrm{RadDel} \leftarrow \mathrm{RadCeil} - \mathrm{RadFloor} \\
\mathrm{RadInc} \leftarrow \mathrm{Rad} - \mathrm{RadFloor} \\
\mathrm{DDFloor} \leftarrow \mathrm{DDFloor} \leftarrow \mathrm{DDilation}_{(\mathrm{RadFloor}-3,\, j)} \\
\mathrm{DDCeil} \leftarrow \mathrm{DDCeil} \leftarrow \mathrm{DDilation}_{(\mathrm{RadFloor}-2,\, j)} \\
\mathrm{DDDel} \leftarrow \mathrm{DDCeil} - \mathrm{DDFloor} \\
\mathrm{DeltaD} \leftarrow \mathrm{DDFloor} + \dfrac{\mathrm{RadInc} \cdot \mathrm{DDDel}}{\mathrm{RadDel}} \\
\mathrm{DeltaD}
\end{array}
\right.
$$

Count Various Crack Classifiers:

```
CntCrks(CrkDat) ≡ | UCrks ← 0
                  | LCrks ← 0
                  | RCrks ← 0
                  | NCrks ← 0
                  | TCrks ← 0
                  | ECrks ← 0
                  | Lines ← rows(CrkDat)
                  | for  i ∈ 0.. Lines − 1
                  |   | UCrks ← UCrks + CrkDat(i,3)  if  CrkDat(i,2) = "UTE"
                  |   | LCrks ← LCrks + CrkDat(i,3)  if  CrkDat(i,2) = "LTE"
                  |   | RCrks ← RCrks + CrkDat(i,3)  if  CrkDat(i,4) = "R"
                  |   | NCrks ← NCrks + CrkDat(i,3)  if  CrkDat(i,4) = "N"
                  |   | TCrks ← TCrks + CrkDat(i,3)
                  |   | ECrks ← ECrks + CrkDat(i,3)  if  CrkDat(i,5) ≥ VThresh
                  |        ( "Number of lines in the data file:"           Lines )
                  |        ( "Number of UTE cracks imported:"              UCrks )
                  |        ( "Number of LTE cracks imported:"              LCrks )
                  | Out ←  ( "Number of cracks flagged for repair:"        RCrks )
                  |        ( "Number of cracks not flagged for repair:"    NCrks )
                  |        ( "Total cracks imported:"                      TCrks )
                  |        ( "Number of cracks to evaluate:"               ECrks )
```

CM Leakage Calculation: Total SG Leakage at 50/50, 95/50, and 95/95 Prob./Conf. Levels:

'CMLeaks' calculates accident leakage values for condition monitoring purposes (i.e., calculates total SG leakage for cracks as-found). Within the function, a vector containing "NumTrials" leakage values is generated. Each value is a probabilistic estimate of total SG leakage. The 50/50, 95/50, and 95/95 leakage values are taken directly from this (sorted) vector.

```
CMLeaks(CrkDat) ≡ | NDatLim ← rows(CrkDat) − 1
                  | for t ∈ 0.. NumTrials − 1
                  |   | CumuL ← 0
                  |   | fv ← (N − 2) / rchisq(1, N − 2)_0
                  |   | RnS ← √(fv·RgV)
                  |   | RnV11 ← fv·V_11
                  |   | RnV22 ← fv·V_22
                  |   | RnV12 ← fv·V_12
                  |   | Z1 ← rnorm(1,0,1)_0  on error  Z1 ← rnorm(1,0,1)_0
                  |   | Z2 ← rnorm(1,0,1)_0  on error  Z2 ← rnorm(1,0,1)_0
                  |   | Rnβ3 ← B + Z1·√RnV11
                  |   | Rnβ4 ← M + Z1·RnV12/√RnV11 + Z2·√(RnV22 − (RnV12)^2/RnV11)
                  |   | for r ∈ 0.. NDatLim
                  |   |   | continue  if  CrkDat(r,3) = 0
                  |   |   | for c ∈ 1.. CrkDat(r,3)
                  |   |   |   | DD ← CrkDat(r,6)
                  |   |   |   | Z3 ← rnorm(1,0,1)_0  on error  Z3 ← rnorm(1,0,1)_0
                  |   |   |   | LogL ← Rnβ3 + DD·Rnβ4 + Z3·RnS
                  |   |   |   | CumuL ← (CumuL + 10^LogL)
                  |   | TotLeakTrials_t ← CumuL
                  | Leak_Sorted ← sort(TotLeakTrials)
                  | L_5050 ← Leak_Sorted_Indx5050
                  | L_9550 ← Leak_Sorted_Indx9550
                  | L_9595 ← Leak_Sorted_Indx9595
                  |         ( "50/50 CM Accident Leakage"  L_5050 )
                  | Out ←   ( "95/50 CM Accident Leakage"  L_9550 )
                  |         ( "95/95 CM Accident Leakage"  L_9595 )
```

Alter the Number of Cracks to Account for Repairs and POD:

```
ApplyPODtoCrackData(CDat) ≡ | NDatLim ← rows(CDat) − 1
                            | for r ∈ 0.. NDatLim
                            |   | NCrks ← CDat(r,3)
                            |   | PODCrks ← NCrks / POD
                            |   | PODCrks ← PODCrks − NCrks  if  CDat(r,4) = "R"
                            |   | Lo ← floor(PODCrks)
                            |   | Hi ← ceil(PODCrks)
                            |   | Frac ← PODCrks − Lo
                            |   | PODCrks ← Lo
                            |   | Rndm ← rnd(1)
                            |   | PODCrks ← Hi  if  Rndm < Frac
                            |   | CDat(r,3) ← PODCrks
                            | return  CDat
```

OA Leakage Calculation: Total SG Leakage at 50/50, 95/50, and 95/95 Prob./Conf. Levels:

'OALeaks' calculates accident leakage values for operational assessment purposes (i.e., calculates total SG leakage for cracks projected at the next EOC). The function is very similar to 'CMLeaks'; however, prior to each Monte Carlo trial, the number of cracks at each location is adjusted to account for those repaired, and to reflect the affect of POD.

OALeaks(CrkDat) ≡

```
NDatLim ← rows(CrkDat) − 1
for  t ∈ 0.. NumTrials − 1
    AdCrkDat ← ApplyPODtoCrackData(CrkDat)
    CumuL ← 0
    fv ← (N − 2) / rchisq(1, N − 2)_0
    RnS ← √(fv·RgV)
    RnV11 ← fv·V_11
    RnV22 ← fv·V_22
    RnV12 ← fv·V_12
    Z1 ← rnorm(1, 0, 1)_0   on error  Z1 ← rnorm(1, 0, 1)_0
    Z2 ← rnorm(1, 0, 1)_0   on error  Z2 ← rnorm(1, 0, 1)_0
    Rnβ3 ← B + Z1·√RnV11
    Rnβ4 ← M + Z1·RnV12/√RnV11 + Z2·√(RnV22 − (RnV12)^2/RnV11)
    for  r ∈ 0.. NDatLim
        continue   if  AdCrkDat(r,3) = 0
        for  c ∈ 1.. AdCrkDat(r,3)
            DD ← AdCrkDat(r,6)
            Z3 ← rnorm(1, 0, 1)_0   on error  Z3 ← rnorm(1, 0, 1)_0
            LogL ← Rnβ3 + DD·Rnβ4 + Z3·RnS
            CumuL ← (CumuL + 10^LogL)
    TotLeakTrials_t ← CumuL
Leak_Sorted ← sort(TotLeakTrials)
L_5050 ← Leak_Sorted_Indx5050
L_9550 ← Leak_Sorted_Indx9550
L_9595 ← Leak_Sorted_Indx9595
Out ← ( "50/50 OA Accident Leakage"   L_5050
        "95/50 OA Accident Leakage"   L_9550
        "95/95 OA Accident Leakage"   L_9595 )
```

Process Errors and Execute Correct Function based on User Selection:

```
Leak(CrkDat, Mode) ≡ | return "'NumTrials' is too small"  if  Mode = −2
                     | return "Crack file contains improper characters"  if  Mode = −1
                     | return "Must specify CM or OA"  if  Mode = 0
                     | return CMLeaks(CrkDat)  if  Mode = 1
                     | return OALeaks(CrkDat)  if  Mode = 2
                     | "Error"
```

FUNCTIONS