Commonwealth Edison Company
1400 Opus Place
Downers Grove, IL 60515

June 20, 1995

ComEd

Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Attn: Document Control Desk

Subject: Additional Information Pertaining to the to Application for Amendment to Facility Operating Licenses:

Byron Nuclear Power Station, Units 1 and 2
NPF-37/66; NRC Docket Nos. 50-454/455

Braidwood Nuclear Power Station, Units 1 and 2
NPF-72/77; NRC Docket Nos. 50-456/457

"Steam Generators"

Reference: D. Saccomando letter to Nuclear Regulatory Commission dated February 13, 1995, transmitting Proposed Technical Specification Amendment Regarding Increase in the IPC Criteria

The Reference Letter transmitted Commonwealth Edison Company's (ComEd's) proposal to amend Appendix A, Technical Specifications of Facility Operating Licenses NPF-37, NPF-66, NPF-72 and NPF-77. The proposed amendment request addresses Technical Specification changes necessary to increase the Interim Plugging Criteria (IPC) value for Braidwood and Byron Station Unit 1 Steam Generators from 1.0 volt to 3.0 volts.

Subsequent to that submittal, ComEd and the Nuclear Regulatory Commission (NRC) met on February 23, 1995, to discuss the submittal. During that meeting ComEd presented a model which addressed leakage from indications restricted from burst (IRBs). After discussions, ComEd pursued the development of an alternate leak rate model along with a test program to support the alternate leak rate model.

Recognizing that the Staff has been actively reviewing our amendment request and that outstanding technical issues may still exists, ComEd is providing the Staff with additional technical justification supporting the 3 volt IPC request. Attachment 1 outlines the development and the available results of a ComEd/EPRI sponsored test program which determined the bounding leak rate value of an IRB by the presence of the tube support plate. The test program is in progress and is scheduled to be completed and final results available by July 15, 1995.

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Attachment 1 contains:

Section I: History and Test Program Objective
Section II: Total Test Program Development and Evaluation of Test Variables
Section III: Proposed Testing Plan
Section IV: Test Specimen Results (Summary and Conclusions)

ComEd has reviewed the results of the bounding IRB test program proposed to the NRC on April 3, 1995. This is nearing completion and the final report will be transmitted to the NRC by July 15, 1995. Based upon Commonwealth Edison's review of this new information, the following conclusions have been reached:

- The free span leak rate calculation methodology approved for ODSCC at the tube support plate, provides sufficient conservatism for use with a calculate leak rates with 3.0 volt IPC.

  Attachment 2 contains the detailed comparison of IRB and free span leak rate methodologies. ComEd has calculated anticipated leak rates, end of cycle, using Braidwood 1 data, using both the free span and IRB leak rate methodology and finds that similar results are obtained. These results indicate that the conservatism built into the IPC leak rate calculation methodology are adequate, with 3 volt IPC.

- ComEd has concluded that the application of an improved probability of detection (POD) algorithm is unnecessary to support the Byron 1 and Braidwood 1 Technical Specification Amendment.

  ComEd believes it is necessary to more clearly understand the ability of eddy current to detect and size steam generator tube defects. This understanding will support a new POD as proposed by ComEd. However, in the interest of expediting the review of the ComEd request for Byron 1 and Braidwood 1, a POD of 0.6 will be used with the 3 volt IPC, until changed by industry activities.

- The data provided in Attachment 1 are the latest final results and clearly demonstrate that extraordinary large leakages should not be anticipated even with substantial offset of the crack outside of the tube support plate.

The bounding leak rate determined as a result of this test program is 4.7 gpm, for a 0.74" long crack extending outside the support plate 0.10". As discussed in meetings with the NRC on February 23, April 11, and May 9, ComEd believes that it has succeeded in producing a test specimen with crack length equal to the thickness of the support plate and tested its leak rate. With the other conservatism assumed as part of other elements of the Technical Specification Amendment, ComEd has concluded that the 4.7 gpm indeed represents the bounding leak rate for a 3/4" diameter tube with a long crack. Based upon this, ComEd has determined that review of the leakage model in Sections 9.7 and 9.8 of WCAP-14273 is no longer necessary.

ComEd is currently preparing a supplement to our February 13, 1995, submittal, that will incorporate information contained in the Generic Letter as well as the data contained in Attachments 1 and 2 of this letter. This supplement, which will supersede that transmitted in the Referenced letter, will be submitted to the Staff shortly.

To the best of my knowledge and belief, the statements contained in this document are true and correct. In some respects these statements are not based on my personal knowledge, but on information furnished by other ComEd employees, contractor employees, and/or consultants. Such information has been reviewed in accordance with company practice, and I believe it to be reliable.

ComEd and the NRC have tentatively scheduled a meeting on June 27, 1995, to further discuss these results, in the interim, if you have any questions concerning this correspondence, please contact this office.

Sincerely,

OFFICIAL SEAL
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NOTARY PUBLIC STATE OF ILLINOIS
MY COMMISSION EXPIRES 11/29/97

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Attachment 1

Indications Restricted From Burst Test Program
(Latest Final Results)

This attachment outlines the development and results of a ComEd / EPRI sponsored test program to determine the bounding leak rate value of an indication which has been restricted from burst (IRB) by the presence of the tube support plate (TSP). Specifically this attachment contains:

- Section I History and Test Program Objective
- Section II Total Test Program Development and Evaluation of Test Variables
- Section III Proposed Testing Plan
- Section IV Test Specimen Results (Summary and Conclusions)

Section I

History

On February 23, 1995, ComEd and the NRC met to discuss the potential increase of the interim plugging criteria for 3/4" tubes from 1.0 volt to 3.0 volts until steam generator replacement at Braidwood 1 and Byron 1. During that meeting ComEd presented a model which quantified the low probability which exists for indications that may potentially "leak" within the confines of the TSP at pressures equal to main steam line break (MSLB) pressure.

At the Staff's request, ComEd provided the Staff with data which would quantify the potential benefit from using this analytical leakage model. Additionally, ComEd also pursued the use of an alternate leak rate model which did not rely on a bobbin voltage correlation with crack length. A description of this model and results quantifying the potential benefits were provided to the Staff in Reference 2.

To fully support the alternate leak rate model, it is necessary to define a fixed leak rate for a single indication restricted from burst (IRB) by the presence of the TSP. One approach is to define an IRB bounding leak rate and apply that leak rate to each IRB independent of size. In an effort to obtain a bounding leak rate for IRB, ComEd submitted a proposed laboratory test program to the Staff in Reference 3. This proposed laboratory test program used 7/8" diameter tubing specimens with throughwall outside diameter stress corrosion cracking (ODSCC) crack lengths of 0.34", 0.40" and 0.50". These specimens would be pressurized to approximately 15% above calculated burst pressure while contained within a simulated support plate. Leak rate measurements would then be performed at both room and operating temperature.

The development of this phase of the test program was based upon samples immediately available for testing. Specifically, our decision to use 7/8" diameter specimens with 0.34", 0.40" and 0.50" ODSCC crack lengths, rather than the Byron and Braidwood size 3/4" diameter tubing was because of specimen availability. Laboratory induced ODSCC specimens take several weeks to generate. Furthermore, it is ComEd's position that the leak rate is a geometrical function that is not dependent on the tube diameter. To demonstrate this, testing includes both 3/4" and 7/8" diameter tubing.

In early April the plan and the preliminary results from this test program were reviewed by the EPRI SGDSM Ad-Hoc committee. Modifications to the test plan, as well as the leak rate calculation, were made based upon suggestions from the committee.

On March 22, 1995, the Staff and ComEd participated in a teleconference to discuss this test program (Reference 3). During that teleconference, ComEd recognized that the proposed test program needed to be enhanced to address new concerns.

Based upon these concerns ComEd proceeded with the following actions:

1. Redefine objectives of a new and expanded laboratory leak rate test program.

2. Develop a list of required test variables to meet the leak rate test program objectives.

3. Develop a parametric sensitivity study test matrix based upon the list of variables.

4. Develop a detailed prioritized test program to bound variables of the parametric sensitivity study.

5. Define a final test plan to meet test objectives.

Section II

TOTAL TEST PROGRAM DEVELOPMENT

Test Plan Objective

Develop a bounding MSLB leak rate for large (>0.6") indications which have been restricted from burst (IRB) by the presence of the tube support plate (TSP). This bounding leak rate value will be used in a leak rate calculation which takes into account both freespan and IRB leakage.

ComEd does not have an objective to create or test a low voltage (1 volt or less) 3/4" long crack. However, long cracks (>0.6") will be created and tested.

Variables Considered in total test program

As part of ComEd's development of a total laboratory test program from which a bounding test program was derived, the following variables were taken into consideration.

Leak rate sensitivity to:

- Tube size
- Crack length
- Test temperature
- Crevice condition
- TSP gap
- Crack exposure outside TSP
- Tube pressurization at pressures up to freespan burst
- Freespan to IRB leak rate comparison

Tables II-1 and II-2 define the elements of a total parametric study which would be required if all these variables were tested for each possible combination.

ComEd's Evaluation of Test Variables

ComEd performed an evaluation of all the possible test variables and determined which are important to the bounding test program. The following is a description of how we addressed each variable in the test program.

Sensitivity to tube size:
Byron and Braidwood Unit 1 tubing is 3/4" diameter. Due to the immediate availability of 7/8" tubing corrosion test specimens, the test program was begun using 7/8" tubing. These test results were used to define additional testing requirements and test modifications. Subsequent testing included 3/4" diameter tubing.

A review of the geometry of the hypothetical crack is contained within WCAP-14273. It is important to note that for an IRB, the equations provided to define the crack opening area depend upon the length of the crack, and the gap between the outside diameter of the tube and the inside diameter of the tube support hole. In addition, the WCAP describes the basis upon which the maximum clearances between hole and tube were assembled. This leads to the fact that the calculation of the crack opening area is based on geometric equations. Review of these equations indicates that there is no dependency of the crack opening on tube diameter.

To demonstrate that the leak rate is a geometrical function of crack opening and is not dependent on tubing diameter, ComEd performed testing on both 7/8" and 3/4" diameter tubing. Based upon the similar test results it is not necessary to do duplicate testing with both 7/8" and 3/4" similar tubing.

Sensitivity to crack length:
Specimens were prepared for 3/4" diameter tubing with a goal of achieving throughwall crack lengths in the following ranges; 0.25" - 0.45", 0.45" - 0.60" and 0.60" - 0.75". Use of these ranges will develop a conservative upper bound leak rate based on the following facts:

- No indications below 10 volts have had a throughwall crack >0.37" per the EPRI pulled tube database.
- Braidwood 1 and Byron 1 largest indications of 10.3 and 10.9 volts had throughwall crack lengths of 0.20" and 0.27", respectively, with burst pressures > 4000 psi at operating temperature. This is well within the experience of the EPRI pulled tube database.

- The critical throughwall crack length for a burst at MSLB pressure of 2560 psid for a 3/4" diameter tube at lower tolerance level (95% / 95%) material properties is 0.75". Such an indication would have a bobbin voltage of > 40 volts.

- The EPRI pulled tube data database demonstrates that no indication of < 10 volts has had a throughwall crack > 0.37". Therefore, it is unrealistic to assume that a 0.75" axial throughwall crack would develop in a plant where a 3.0 volt IPC is applied.

The crack length test variable, with > 0.6" long ODSCC specimens, is expected to bound by a factor of 1.5 the largest indications seen in the EPRI pulled tube data base for indications below 10 volts. In order to obtain indications with throughwall crack lengths >0.6", ComEd used fatigue to lengthen certain laboratory induced ODSCC specimens.

Sensitivity to test temperature:

Westinghouse has modified a test facility to accommodate high leak rates at operating temperature test conditions. The test facility has the capability to measure the leak rates up to at least 10 gpm at 615°F. Testing at elevated temperatures is extremely time consuming; therefore, to expedite testing the test plan included development of a temperature correlation factor. A correlation of operating and room temperature conditions was to be developed from test data obtained in this program. The existing leak rate adjustment procedures indicate that operating temperature leak rates are about a factor of 0.5 to 0.6 room temperature leak rates. This correlation was confirmed for indications confined within the TSP.

Sensitivity to crevice condition:

If the test program is expanded beyond the initial bounding test program described in Section III, some tests may be conducted with both "packed" TSP crevice conditions and "clean" TSP crevices. Crevice packing will be performed by packing the crevice with magnetite and a binder followed by baking of the specimen. This is typical of the deposits seen on pulled tubes. This test is representative of actual steam generator crevice conditions believed to be present at Byron and Braidwood. If the leak rates are considerably different, test results will be evaluated to determine appropriate application of the data in leakrate calculations. The initial bounding test program will be performed using unpacked crevices. This will provide a conservative leak rate value.

Sensitivity to TSP gap:

The range of possible maximum TSP clearances for drilled hole TSP steam generators is 0.025". The 0.025" value was obtained by applying a 95% confidence level to the upper diameter limit of a drilled support plate hole and the 95% confidence level of the minimum diameter of the tubing. This test at 0.025" clearance will provide a bounding leak rate value for maximum gap.

Sensitivity to crack exposure outside TSP:

The maximum TSP deflection with tube support plate stabilization is shown in WCAP-14273 to be 0.10" for model D-4 units with 3/4" tubing. This value is extremely conservative with a factor of 2 applied to the Tranflo loads. A review of inspection data for Byron 1 and Braidwood 1 has not found any axial ODSCC indications extending beyond the edges of the TSP. Therefore, based upon a comparison of the real location of indications within the tube support plates and a review of the conservatisms within the calculation of tube support plate maximum deflection, ComEd's assessment is that testing with TSP offset of 0.10" for 3/4" tubing is extremely conservative. For 7/8" diameter tubing, offset values of 0.15" will be used to simulate the expected TSP maximum deflection value for Model 51 units.

Leakrate vs. Tube Pressurization:

Indications contained within the TSP will be pressurized and leak rates measured;

- at MSLB pressure
- between MSLB pressure and calculated burst
- above calculated burst pressure
- 1000 psi increments up to approximately 10,000 psi.

Testing may be repeated with crack offset of 0.1" and 0.15" outside TSP.

The objective of these pressurization steps is to determine the maximum leak rate vs crack opening configuration which is postulated to occur.

Comparison of freespan to IRB leak rate:

Certain specimens will be pressurized to values below MSLB conditions while in freespan so that the freespan leak rate can be measured and extrapolated to MSLB conditions using the EPRI leak rate procedure. This value will then be compared to the IRB leak rate obtained from these specimens while they are confined within the TSP.

These data will be used to show a correlation between the freespan and IRB leak rate. The result may be that the freespan leak rate is higher than the IRB leak rate for certain size indications.

TABLE II-1 INDICATION RESTRICTED FROM BURST (IRB) PARAMETRIC TEST MATRIX

PARAMETRIC STUDY										
		3/4" DIA. TUBES		CRACK LENGTH SENSITIVITY			DELTA P =	DELTA P =	TEMPERATURE	
		PACKED	UNPACKED	.25 - .45"	.45 - .6"	.6 - .75 "	2650psi	10,000psi	ROOM	615 F
0" OFFSET		X	X							
0.1" OFFSET		X	X	X	X	X	X	X	X	X
0.2" OFFSET		X	X	X	X	X	X	X	X	X
DELTA P = 2650psi		X	X	X	X	X			X	X
DELTA P = 10000 psi		X	X	X	X	X			X	X
0 MIL GAP		X	X	X	X	X	X	X	X	X
15 MIL GAP		X	X	X	X	X	X	X	X	X
23 MIL GAP		X	X	X	X	X	X	X	X	X
25 MIL GAP		X	X	X	X	X	X	X	X	X
CRACK LENGTH SENSITIVITY										
.25 - .45"		X	X				X	X	X	X
.45 - .6"		X	X				X	X	X	X
.6 - .75 "		X	X				X	X	X	X
VOLTAGE SENSITIVITY		X	X	X	X	X	X	X	X	X
ROOM TEMPERATURE		X	X	X	X	X	X	X		
615 F		X	X	X	X	X	X	X		

TABLE II-2 INDICATION RESTRICTED FROM BURST (IRB) PARAMETRIC TEST MATRIX

PARAMETRIC STUDY										
		7/8" DIA. TUBES		CRACK LENGTH SENSITIVITY			DELTA P =	DELTA P =	TEMPERATURE	
		PACKED	UNPACKED	.25 - .45"	.45 - .6"	.6 - .75 "	2650psi	10,000psi	ROOM	615 F
0" OFFSET		X	X							
0.1" OFFSET		X	X	X	X	X	X	X	X	X
0.2" OFFSET		X	X	X	X	X	X	X	X	X
DELTA P = 2650psi		X	X	X	X	X			X	X
DELTA P = 10000 psi		X	X	X	X	X			X	X
0 MIL GAP		X	X	X	X	X	X	X	X	X
15 MIL GAP		X	X	X	X	X	X	X	X	X
23 MIL GAP		X	X	X	X	X	X	X	X	X
25 MIL GAP		X	X	X	X	X	X	X	X	X
CRACK LENGTH SENSITIVITY										
.25 - .45"		X	X				X	X	X	X
.45 - .6"		X	X				X	X	X	X
.6 - .75 "		X	X				X	X	X	X
VOLTAGE SENSITIVITY		X	X	X	X	X	X	X	X	X
ROOM TEMPERATURE		X	X	X	X	X	X	X		
615 F		X	X	X	X	X	X	X		

Section III

TEST PROGRAM

Test Plan Objective

Develop a bounding MSLB leak rate for large (>0.6") indications which have been restricted from burst (IRB) by the presence of the tube support plate (TSP). This bounding leak rate value will be used in a leak rate calculation which takes into account both freespan and IRB leakage.

ComEd does not have an objective to create or test a low voltage (1 volt or less) 3/4" long crack. However, long cracks (>0.6") will be created and tested.

Total Test Program

Based on ComEd's evaluation of the critical variables required to meet the programs objective, a total test program was developed and is provided in Table III-1. The notes for Table III-1 outline the general testing sequence and prioritization criteria which determine the order in which specimens are tested. The specific testing parameters and specimen characteristics for completed tests are given in Section IV.

This test total program was developed to address sensitivity to:

- Differences in leak rates between 3/4" and 7/8" diameter tubing
- Sensitivity of crack length inside the support
- Differences in leak rate data between room temperature and operating condition tests (validate room temperature to operating condition correlation)
- Differences between leak rates in packed versus clean crevices
- Differences in TSP crevice clearances
- Length of crack extending outside the TSP
- Differences in pressurization levels
- Differences between freespan and IRB leak rates

Bounding Test Plan

Using Table III-1, the bounding test program is defined as tests 1-1, 1-2, 1-6, 1-7, 2-1, 2-4, 2-7, 2-10 and 4-1. This testing will provide a conservative bounding leak rate value for IRBs at MSLB. Testing of these nine specimens is scheduled for completion by July 15, 1995.

It is ComEd's position that the only testing required to bound the MSLB leak rate are tests 2-1, 2-4, 2-7 and 1-7. Other tests are only planned to improve the industries understanding of leakage from IRB's.

TABLE III-1
Test Matrix for Indications Restricted from Burst (IRBs)

Test No.	Test Seq.	Pri-ority	Tube Dia.	Temp	Crevice		Crack Length			Gap		Free Span Leak Test	Crack to TSP Offset			Bladder Pres. $\Delta P^{(1)}$ Offset (inch)	Test Time Days
					Open	Pack	.25-.45	.45-.6	.6-.75	.02	.025		0.0"	0.1"	.15"		
1-1	1a	1	7/8	615°	x				x		x	x	x		x	0.0	12
1-2	1a	1	7/8	615°	x				x		x	x	x		x	0.15	12
1-3	1a	2	7/8	615°	x				x		x	x	x		x	0.15	12
1-4	1b	4	7/8	615°	x				x	x			x		x		7
1-5	1b	5	7/8	615°	x				x		x		x		x		12
1-6	1a	1	3/4	615°	x				x		x	x	x	x		0.0	12
1-7	1a	1	3/4	615°	x				x		x	x	x	x		0.1	12
1-8	1a	2	3/4	615°	x				x		x	x	x	x		0.1	12
1-9	1b	4	3/4	615°	x				x	x			x	x			7
1-10	1b	5	3/4	615°	x				x		x		x	x			12
1-11	1a	3	7/8	615°		x			x		x	x	x		x	0.15	12
1-12	1a	3	3/4	615°		x			x		x	x	x	x		0.1	12
2-1	2	1	7/8	615°	x			x			x	x	x		x	0.15	12
2-2	2	2	7/8	615°	x			x			x	x	x		x	0.15	12
2-3	2	3	7/8	615°		x		x			x	x	x		x	0.15	12
2-4	2	1	7/8	615°	x		x				x	x	x		x	0.15	12
2-5	2	2	7/8	615°	x		x				x	x	x		x	0.15	12

TABLE III-1

Test No.	Test Seq.	Priority	Tube Dia.	Temp	Crevice		Crack Length			Gap		Free Span Leak Test	Crack to TSP Offset			Bladder Pres. $\Delta P^{(1)}$ Offset (inch)	Test Time Days
					Open	Pack	.25-.45	.45-.6	.6-.75	.02	.025		0.0"	0.1"	.15"		
2-6	2	3	7/8	615°		x	x				x	x	x		x	0.15	12
2-7	2	1	3/4	RT, T	x			x			x	x	x	x		0.1	12
2-8	2	2	3/4	615°	x			x			x	x	x	x		0.1	12
2-9	2	3	3/4	615°		x		x			x	x	x	x		0.1	12
2-10	2	1	3/4	RT, T	x		x				x	x	x	x		0.1	12
2-11	2	2	3/4	615°	x		x				x	x	x	x		0.1	12
2-12	2	3	3/4	615°		x	x				x	x	x	x		0.1	12
3-1	3	3	7/8	T,RT	x			x			x		x		x	0.15	10
3-2	3	3	7/8	T,RT		x		x			x		x		x	0.15	10
3-3	3	4	7/8	T,RT	x			x		x			x		x	0.15	10
4-1	4	1	7/8	RT	x			x			x		x		x	0.15	10
4-2	4	2	3/4	RT	x			x			x		x	x		0.1	10

Notes:

1. Test sequence includes pressurizing with a bladder typically to above the free span burst pressure. Some specimens include incremental increases in bladder pressure beyond that equivalent to a free span burst. For test sequences 1 and 2, the bladder pressurization and subsequent leak tests follow leak tests that apply primary side pressure and flow to obtain the ΔPs. Thus, for these tests, the bladder pressurization is performed to open the crack beyond that obtained within the pressure capability of the facility.

NOTES FOR TABLE III-1

Test Plan for IRBs
Test Sequences

Test Sequence 1: 615°F, Crack Lengths > 0.6"

Sequence 1a

A. Free span leak test at 1500, 1700 and 2000 psi ΔP
B. Leak test with crack centered (0.0 offset) in TSP at 2000, 2335 and 2560 psi ΔP
C. Measure crack opening diameter and area
D. Leak test with crack 0.1" offset outside TSP at 2560, 2700, 2900 psi ΔP (up to facility limit)
E. Measure crack opening diameter, area and evaluate crack extension
F. With crack centered or 0.1" (test matrix specification) offset outside TSP, pressurize to above calculated burst pressure with bladder
   - Note: Test sequence 1 is applied to the longest cracks which are expected to open up and contact the ID of the TSP hole within the pressure/flow limits of the facility. The bladder pressurization step is applied to assure crack flank to TSP contact for comparisons with the leak rates from step D.
G. Leak test with crack centered or 0.1" offset outside TSP at 2335 and 2560 psi ΔP
H. Measure crack opening diameter, area and evaluate crack extension
I. With the same crack position as step F, pressurize with a bladder (with foil if necessary) to about 1000 psi above the prior pressurization step
J. Repeat leak test of step G
K. Repeat steps I and J with increases in bladder pressure in 1000 psi increments until bladder/foil pressurization increase cannot be achieved (approximately burst pressure inside TSP on order of 8000 psi)
   - Note: If it is demonstrated on one sample in this test sequence, that the leak rates do not significantly increase by the pressurizations of steps I to K, steps I to K may not be repeated on additional specimens and this test sequence will be terminated at step H for the later specimens
L. Measure crack opening diameter, area and evaluate crack extension

Sequence 1b

Perform test with Sequence 1a steps A to E (i.e., no bladder pressurization steps)

NOTES FOR TABLE III-1

Test Sequence 2: 615°F and Room Temperature, Crack Lengths < 0.6"

A. Free span leak test at 1500, 1700 and 2000 psi ΔP
B. Leak test with crack tip centered at 2000, 2335, 2560 psi ΔP up to facility limit
C. Leak test with crack tip 0.1" offset from the edge of the TSP at 2560, 2700 psi ΔP up to facility limit
D. Measure crack opening diameter, area and evaluate crack extension
E. With crack tip 0.1" offset, pressurize to above calculated burst with bladder

- Note: Test sequence 2 is applied for shorter cracks which may not open to significantly contact the ID of the TSP hole within the pressure/flow limits of the facility. Thus, steps A and B may result in comparable leak rates. The bladder pressurization step is applied to assure that crack flank to TSP contact is achieved to assess the influence on leak rates.

F. Leak test at 2335, 2560 psi ΔP at both room and operating temperature for at least one specimen.
G. Measure crack opening diameter, area and evaluate crack extension
H. With the 0.1" crack position, pressurize with a bladder (and foil if necessary) to about 1000 psi above the prior pressurization step
I. Repeat leak test of step F
J. Repeat steps H and I with increases in bladder pressure of 1000 psi increments until bladder/foil pressurization increase cannot be achieved (approximately burst pressure inside TSP on order of 8000 psi)

- Note: If it is demonstrated on one sample in this test sequence or by the equivalent pressurizations of Sequence 1a tests, that the leak rates do not significantly increase by the pressurizations of steps H to J, steps H to J may not be repeated on additional specimens and this test sequence will be terminated at step G for the later specimens

K. Measure crack opening diameter, area and evaluate crack extension

Test Sequence 3: 615°F and Room Temperature Leak Rate Comparisons

A. Pressurize to above calculated burst pressure with bladder
B. Room temperature test at 2000, 2335, 2560 psi ΔP
C. Operating temperature test at same pressure differentials
D. Measure crack opening diameter, area and evaluate crack extension
E. Move crack to 0.1" outside TSP, pressurize to same pressure with bladder
F. Room temperature test at same pressure differentials
G. Operating temperature test at same pressure differentials
H. Measure crack opening diameter, area and evaluate crack extension

NOTES FOR TABLE III-1

Test Sequence 4: Room Temperature, Bladder Pressurization to Establish IRB Leak Rate Magnitude and Effects of High "Burst" Pressures on Leak Rates

A. Pressurize to above calculated burst pressure with bladder
B. Room temperature test at 2335, 2560 psi ΔP
C. Measure crack opening diameter, area and evaluate crack extension
D. Move crack to 0.1" outside TSP and pressurize to the same pressure
E. Room temperature repeat of step B leak rate tests
F. Measure crack opening diameter and area
G. With the 0.1" crack position, pressurize with a bladder (and foil if necessary) to about 1000 psi above the prior pressurization step
H. Repeat leak test of step B
I. Repeat steps F and G with increases in bladder pressure of 1000 psi increments until bladder/foil pressurization increase cannot be achieved (approximately burst pressure inside TSP on order of 8000 psi)
   - Note: If it is demonstrated on one sample in this test sequence or by the equivalent pressurizations of Sequences 1a or 2 tests, that the leak rates do not significantly increase by the pressurizations of steps G to I, steps G to I may not be repeated.
J. Measure crack opening diameter, area and evaluate crack extension

Packed Crevice Simulation

- Pack crevice with magnetite and a binder followed by baking of the specimen to obtain a fairly hard deposit typical of that found on pulled tubes at TSP crevices

NOTES FOR TABLE III-1

Test Plan for IRBs Test Priorities

Priority 1 (Bounding Test Program)

- Recommended test matrix to establish bounding leak rate for large cracks (test sequence 1) and the leak rate dependence for more realistic crack lengths (test sequence 2)
- An initial test (sequence 4) of an indication pressurized by a bladder to obtain an early estimate of the magnitude of leak rates to be expected

Priority 2

- Repeat of priority 1 tests. Tests performed upon completion of priority 1 tests only if bad test data are obtained or the initial test results in unacceptable uncertainties on the leak rates relative to adequately defining a leak rate model for IRBs

Priority 3

- Tests performed to compare room temperature leak rates with operating temperature leak rates. These tests would be performed only if the leak rates of priority 1 tests exceed the facility capability at operating temperatures and some of the priority 1 tests must be run at room temperature.
- Tests with packed crevices. Tests to be performed if in situ leak rates are to be used for reference SLB leak rates rather than free span plus IRB leak rates. These tests would provide physical insight into expectations to be obtained with in situ leak rate measurements.

Priority 4

- Tests of additional variables not considered to be necessary to adequately define IRB leak rates.

Priority 5

- Test variables that are judged not worthy of considertion for testing

Section IV

Bounding Test Program Results

Table IV-1 lists the nine specimens defined as the bounding test program. The last column of the table gives the test status to date.

The following Section gives the available test results. A test status is given, followed by summary of results, overall conclusions, general test information, test sequence and testing results. Testing is underway on test numbers 1-1, 1-2 and 2-1, the test sequence and available specimen information for these tests is given for clarification.

The significant tests to determine a bounding leak rate value for 3/4" tubing with a 0.10" TSP offset have been completed and are discussed in the attached pages. The remaining portions of the "bounding" test program are scheduled to be complete and results available by July 15, 1995.

Bounding Test Program Differences Since 4/3/95 Submittal

In order to facilitate testing and apply lessons learned during the early phases of the test program, minor changes were made to the test program as submitted to the NRC on April 3, 1995 reference 6. These changes do not significantly effect the test results or conclusions.

The following is a detailed listing of differences between the test program submitted in reference 6 on April 3, 1995 and the actual testing that either has been or will be conducted. The corresponding notes to describe numbered changes follow the specimen listed below.

Test 1-1

• ODSCC throughwall crack length of 0.62" was obtained by lengthening an existing ODSCC specimen with fatigue.

NOTES: 1, 2, 3, 4, 5

Test 1-2

• ODSCC throughwall crack length of 0.62" was obtained by lengthening an existing ODSCC specimen with fatigue.

NOTES: 1, 2, 3, 4, 5

Test 1-6

• Test plan calls for a 0.025" TSP gap, test was inadvertantly run with a 0.028" gap. This adds an unecessary conservatism to the test results.

NOTES: 2, 3, 4, 5

Test 1-7

• ODSCC throughwall crack length of 0.60" was obtained by lengthening an existing ODSCC specimen with fatigue.

• Freespan leak rate testing was not performed on this specimen. Testing was not performed due to an oversite at the test facility. Upon discovery testing had already been completed beyond bladder pressurization, making freespan testing at that point of no value.

The freespan tests were originally planned to aid identification of crack interaction with the TSP based on differences between freespan and with TSP leak rates. However, freespan testing might plastically open the crack face more than the tube to TSP gap and then require deformation of the crack face to perform offset leak tests. It was then decided to perform a freespan leak test after the offset only as a demonstration of the magnatude change in leak rates and without the the presence of the TSP.

Test 1-7 freespan data is not a significant loss of data since TSP interaction above about 2200 psi is apparent in the slope of the leak rate verses ΔP curve. The free span data point for Test 1-6 adaquately demonstrates the large difference in leak rate between freespan and within the TSP for large cracks.

NOTES: 2, 3, 5

Test 2-1

• ODSCC throughwall crack length of 0.515" was obtained by lengthening an existing ODSCC specimen with fatigue.

NOTES: 1, 2, 3, 5, 6

Test 2-4

• Testing originally called for crack to be centered in TSP. After initial flow testing was completed, and prior to bladder pressurization, program was revised to call for the crack tip to be placed at the edge of the TSP prior to leak rate testing. This provides a more conservative leak rate value. The results for this test show leakage is essentially freespan with or without the TSP and thus the change in crack alignment had no influence on the Test 2-4 results.

This change is consistent with the May 25, 1995 clarification letter reference 7, and the leak rate test program.

NOTES: 1, 3, 5, 6, 7

Test 2-7

• ODSCC throughwall crack length of 0.577" was obtained by lengthening an existing ODSCC specimen with fatigue.

• Testing originally called for freespan and 0.0" offset to be conducted at operating temperature conditions. "Low pressure" testing was performed for these test steps at room temperature up to 2355 ΔP. This was to expedite testing program by 4 to 6 days. This does not limit the applicabilty of the test results since the most limiting 0.10" offset condition was tested hot, and the cold to hot adjustment procedure is well supported by the test results.

This change is as describes in the May 25, 1995 test program reference 7.

NOTES: 2, 3, 5, 6

Test 2-10

NOTES: 2, 3, 5, 6, **7**

Test 4-1

• Added operating temperature test condition leak rate test after bladder pressurization up to 8900 psi. This provides additional data to strengthen temperature correlation.

NOTES FOR DESCRIPTION OF CHANGES

1. Testing for 7/8" diameter tubing was conducted with a 0.15" TSP offset rather than the originally specified value of 0.10". This is the maximum calculated TSP displacement value with the anticipated tube expansion, for a Model 51 steam generator which has 7/8" diameter tubing.

2. Testing originally called for crack to be centered in TSP. Program was revised to call for the crack tip to be placed at the edge of the TSP prior to leak rate testing. This provides a more conservative leak rate value.

3. Testing originally called for TSP to be offset 0.10", it was not specifically stated that the crack should extend 0.10" (or 0.15" for 7/8" tubing) outside TSP. Program was revised to state that the crack tip should extend 0.10" (0.15") outside TSP.

4. Original test sequence called for free span leak rate up to 2000 psid to be conducted prior to 0.0" offset testing. Test sequence was changed to require freespan leak rates after 0.0" and 0.10" (0.15" for 7/8" tubing) offset at the highest pressure achieved. This allows freespan leak rates to be conducted at pressures higher than the original 2000 psid without concern of opening the crack face beyond the TSP gap for later testing within the TSP.

5. Original test program called for 0.0" offset at pressures up to 2560 psid followed by 0.10" offset starting at 2560 psid. Program was changed to perform 0.0" offset testing up to 2335 psid followed by 0.10" (0.15" for 7/8" tubing) offset starting at 2335 psid. This change was made to obtain more leak rate data for the limiting 0.10" offset conditions.

6. Original test sequence called for freespan leak rate up to 2000 psid to be conducted prior to 0.0" offset testing. Test sequence was changed to require freespan testing after the 0.0" offset and before the 0.10" offset. This change for moderate length cracks was made to permit easier comparison of freespan and offset 0.10" leak rates (more limiting than 0.0"offset) to aid assessment of potential interaction with the TSP. In addition, the start of 0.10" offset testing was lowered from 2560 psid to 2335 psid to obtain more leak rate data for the limiting 0.10" offset condition.

7. Original test program called for initial bladder pressurization above calculated burst, step was added to pressurize approximately 1000 psi below calculated burst. This provides another data point to determine where max leak rate occurs.

TEST PROGRAM (LATEST FINAL) CONCLUSIONS

Test 1-6

Test 1-6 provides a conservative upper bound of 4.7 gpm for IRB at the maximum potential TSP offset for 3/4" tubing of 0.10". The test specimens throughwall crack length of 0.74" is essentially equal to the thickness of the TSP. ODSCC at Byron and Braidwood has been shown to stay contained within the TSP by both eddy current analysis and tube pull results. Throughwall crack lengths of 0.74" are expected to have eddy current indications in the >40 volts range. The Byron and Braidwood Unit 1 largest indications seen to date had voltages of 10.3 and 10.9 volts, with throughwall crack lengths of 0.20" and 0.27" respectively. Therefore, it is not likely that a cracklength of 0.74" could ever develop in a plant where 3 volt IPC is applied. In addition, for this specimen it was shown that TSP constraint reduced the maximum SLB leak rate by more than a factor of three compared to freespan, and that TSP interaction occurred at 1950 psid.

Throughwall Crack Lengths > About 0.5" - Tests 1-6, 1-7, 2-7 (3/4")

- Indications with throughwall crack lengths greater than approximately 0.5" result in crack faces opening to interact with TSP prior to reaching SLB conditions of 2335 to 2560 psi ΔP and result in leak rates less than free span indications.

- SLB leak rates resulting from flow pressurization to ΔP_{SLB} are approximately 3.0, 3.2 and 4.7 gpm for initial start of test throughwall crack lengths of 0.577", 0.60" and 0.74", respectively.

Throughwall Crack Lengths <About 0.5" - Tests 2-4 (7/8"), 2-10 (3/4")

- Indications with throughwall crack lengths less than approximately 0.5" have leak rates typical of free span indications and show no significant interaction with the TSP

- SLB leak rates resulting from flow pressurization to ΔP_{SLB} are approximately 0.47 and 1.2 gpm for initial throughwall crack lengths of 0.29" and 0.425", respectively.

Effects of Bladder Pressurization on Leak Rates

- SLB leak rates following bladder pressurization at the TSP offset condition are not significantly different from leak rates obtained by flow pressurization to 2560 psi for throughwall crack lengths > approximately 0.5 inch which result in interaction with TSP prior to reaching SLB conditions.

- For crack lengths < 0.5", which do not interact with the TSP prior to reaching SLB conditions, bladder pressurization to the free span burst pressure increase the leak rates above that obtained by flow pressurization but the leak rates remain less than those obtained with > 0.5" crack lengths.

- Bladder pressurization above the free span burst pressure result in predictable increases indicative of controlled crack openings.

IRB Leak Rate Impact with 3.0 Volt IPC

The maximum leak rate value for an IRB in a 3/4" tube is conservatively bounded by 4.7 gpm (obtained by flow pressurization at 2560 psi and 0.10" TSP offset). The conservatisms in this value are:

- The largest leak rate of 4.7 gpm obtained in the tests completed (including all 3/4" diameter tubing tests) was found for an upper bound 0.74" throughwall crack (larger than would be expected to develop with a 3 volt IPC) under flow pressurization to ΔP_{SLB} = 2560 psi.

- No credit was taken for the TSP crevice being packed and reducing the leak rate. The crevices at both Byron and Braidwood are believed to be packed.

- The maximum throughwall crack length tested (0.74"), is the maximum crack length that could develop in a 0.75" thick TSP.

- The largest indications seen at Byron and Braidwood had voltages of 10.3 and 10.9 volts, with throughwall crack lengths of 0.20" and 0.27," respectively. Crack lengths of 0.74" are expected to produce indications > 40 volts, which are not likely to develop in a plant where 3 volt IPC is applied.

- Testing was performed using a minimum TSP gap of 0.025". This bounds the 95% confidence level for gap sizes.

- TSP deflection values of 0.10" for 3/4" diameter tubing and 0.15" for 7/8" diameter tubing are double that expected to be seen due to a conservative factor of two being applied to TRANFLO loads.

- Indications > approximately 0.5" throughwall interact with the TSP prior to reaching ΔP_{SLB} and show no significant increases in leakage above the TSP offset leak rate at ΔP_{SLB} even after bladder pressurization to the free burst pressure at the offset condition.

- For throughwall indications < approximately 0.5", which can be expected to bound indications at Braidwood-1 and Byron-1 following implementation of a 3.0 volt repair limit, the crack openings do not interact with the TSP and the resulting leak rates are typical of free span leak rates.

- The locking of TSPs through tube expansion actually reduces the amount of leakage possible through large (>0.5") indications as compared to freespan leak rates. This coupled with the effect of eliminating the possibility of tube burst, actually makes the application of a 3 volt IPC with tube expansion more conservative than a 1 volt IPC without tube expansion.

TEST 1-1

TEST RESULTS ARE NOT YET AVAILABLE

Table IV-1

Test Matrix for Indications Restricted from Burst (IRBs): Status - June 20, 1995

Test No.	Tube Dia.	Specimen Type, No.	Temp. °F	Throughwall Crack Length			Free Span Leak Test	Crack to TSP Offset			Bladder Press. ΔP[1] Offset (inch)	Test Status
				.25-.45	.45-.60	.60-.75		0.0"	0.10"	0.15"		
1-1	7/8	Corr./Fat. 8161G	615°			0.62"	x	x		x	0.15	Offset tests after bladder pressurization required
1-2	7/8	Corr./Fat. 8161E	615°			0.62"	x	x		x	0.15	
1-6	3/4	Corrosion 2008E	615°			0.76"	x	x	x		0.10	Needs final R.T. offset test
1-7	3/4	Corr./Fat. 2051A	615°			0.60"	x	x	x		0.10	Needs final R.T. offset test
2-1	7/8	Corr./Fat. 8161A	615°		0.515"		x	x		x	0.15	Initial freespan and centered tests complete
2-4	7/8	Corrosion 4C218	615°, R.T. after Press.	0.29"			x	x		x	0.15	Complete
2-7	3/4	Corr./Fat. 2051E	R.T., 615° after Press.		0.577"		x	x	x		0.10	Needs final R.T. offset test
2-10	3/4	Corrosion 2051B	615°	0.425"			x	x	x		0.10	Needs final R.T. offset test
4-1	7/8	Corrosion 4B214	R.T.	0.24"	0.50" (UT)			x		x	0.15	Complete - up to 8900 psi bladder press.

Note 1. Test sequences include pressurizing with a bladder typically to the free span burst pressure. Test 4-1 includes incremental increases in bladder pressure beyond that equivalent to a free span burst. Tests 2-4 and 2-10 include bladder pressurizations below and at the free span burst pressure. Bladder press. is performed to open the crack beyond that obtained within the pressure capability of the facility.

Test Plan for (IRBs)
Test 1-1

General Test Information

- Utilize large leak test facility testing
- Test 7/8" diameter, corrosion plus fatigue specimen 8161G:
  Silastic mold dye penetrant - 0.62" OD with 0.62" ID
- Leak test at 615°F except as noted. Testing at > 615°F is acceptable.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Hot (615°F) leak test with crack inside the TSP and crack tip at edge of TSP at 1900 and 2050 and 2335 psi ΔP
B. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
C. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335, 2560, 2700, 2800 psi ΔP up to facility limit
D. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
E. Perform hot (615°F) free span leak test at the highest ΔP reached in the Step C test. Care must be excercised in performing this test such that higher ΔPs are not applied to the specimen due to the potential for significant tearing of the crack. Although the test results would not be valid, start testing at a ΔP about 100 psi lower than the highest ΔP from Step C and terminate testing if the measured leak rate is about a factor of 3 (factor of 5 for a cold test) or more higher than the largest leak rate obtained from Step C.
F. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
G. With the crack tip 0.15" offset outside the TSP, pressurize to 4150 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.15" outside the TSP, adjust the specimen to obtain 0.15" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.15" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
H. Hot (615°F) leak test with crack inside the TSP and crack tip at the edge of the TSP at 2335 and 2560 psi ΔP
I. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
J. R.T. leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
K. Measure corrosion throughwall length and length versus depth profile.

TEST 1-2

TEST RESULTS ARE NOT YET AVAILABLE

Test Plan for (IRBs)
Test 1-2

General Test Information

- Utilize large leak test facility testing
- Test 7/8" diameter, specimen 8161-E: Silastic mold dye penetrant - 0.64" OD with 0.62" ID
- Leak test at 615°F except as noted. Testing at > 615°F is acceptable.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Hot (615°F) leak test with crack inside the TSP and crack tip at edge of TSP at 1900 and 2050 and 2335 psi ΔP
B. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
C. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335, 2560, 2700, 2800 psi ΔP up to facility limit
D. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
E. Perform hot (615°F) free span leak test at the highest ΔP reached in the Step C test. Care must be excercised in performing this test such that higher ΔPs are not applied to the specimen due to the potential for significant tearing of the crack. Although the test results would not be valid, start testing at a ΔP about 100 psi lower than the highest ΔP from Step C and terminate testing if the measured leak rate is about a factor of 3 (factor of 5 for a cold test) or more higher than the largest leak rate obtained from Step C.
F. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
G. With the crack tip 0.15" offset outside the TSP, pressurize to 4,080 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.15" outside the TSP, adjust the specimen to obtain 0.15" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.15" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
H. Hot (615°F) leak test with crack inside the TSP and crack tip at the edge of the TSP at 2335 and 2560 psi ΔP
I. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
J. R.T. leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
K. Measure corrosion throughwall length and length versus depth profile.

TEST 1-6

Test 1-6: Summary of Test Results
Status - June 15, 1995

Test Status

- Specimen with 0.74" TW crack by dye penetrant at start of test
- Test was performed with a 0.028" gap as the TSP simulant had been sized to a larger tube diameter than the 0.745" diameter of this specimen
- Hot leak testing complete
- Room temperature leak tests following bladder pressurization not complete

Summary of Test Results

- Shallow slope of leak rate versus ΔP curve above about 1900 psi indicates interaction with TSP and reduced leak rates
  - All slopes of leak rate curve are less than typical of free span slope
  - Larger slope and leak rate for CRACKFLO free span predictions supports TSP interaction
  - Pressurization to 2276 psi with the crack within the TSP opened the plastic crack width to a maximum of 0.024"
- Leak rates at SLB pressure differential with 0.10" offset are bounded by about 4.7 gpm prior to and after bladder pressurization
  - This test, performed with a 0.028" gap, resulted in the widest crack openings of all tests performed (except subsequent bladder pressurization for this specimen) with maximum crack opening widths of 0.044" inside the TSP and 0.026" outside the TSP
  - The crack opening visible by light through the crack was 0.724" of the total 0.750" crack length and was more than 0.019" wide for > 0.6" length
  - Plastic deformation increased the crack opening diameter to the ID of the tube over about 0.2" at the center of the crack
- Leak rates for crack within the TSP following bladder pressurization at 0.10" offset to the free span burst pressure of about 3220 psi are approximately equal to that obtained for 0.10" offset prior to bladder pressurization.
  - The bladder pressurization had no significant influence on the leak rate even though the maximum plastic width increased from 0.044" to 0.050". However, the increased bladder pressurization did not significantly open the crack width at the ends of the crack
- It is not clear whether the increase in leak rate at about 2270 psi for the crack within the TSP is an error in the measurement or due to additional crack opening within the TSP. The measurable crack opening did not extend outside the TSP during this test
- The measured freespan leak rate of 13.1 gpm (facility limit) at a ΔP of 1495 psi following prior testing at 2530 psi is substantially higher than the 4.7 gpm obtained for the crack constrained by the TSP even though the pressure differential is much lower
  - The measured leak rate at 1495 psi is high due to hysterisis effects. CRACKFLO would predict a free span leak rate of about 17 gpm at SLB conditions for a 0.70" throughwall crack.

Test 1-6: Summary of Test Results
Status - June 15, 1995

Overall Conclusions

- This test of a 0.74" throughwall crack represents an upper bound leak test since throughwall lengths of this magnitude would not be expected.
  - Cracks are not expected to grow larger than the thickness of the TSP (0.75")
  - Cracks of this length would be in the >40 volt range, therefore they are not likely to develop in a plant applying 3.0 volt IPC
  - A 0.74" TW length is larger than would ever be expected in field service even for a repair limit of about 15 volts as shown by European experience
- The SLB leak rate prior to and after bladder pressurization is bounded by about 4.7 gpm including the maximum potential 0.10" TSP offset condition
- TSP constraint reduces the maximum SLB leak rate by more than a factor of three compared to free span conditions
- For this 0.74" TW indication prior to leak testing, the leakage results indicate the TSP interaction occured at 1950 psi ΔP or lower

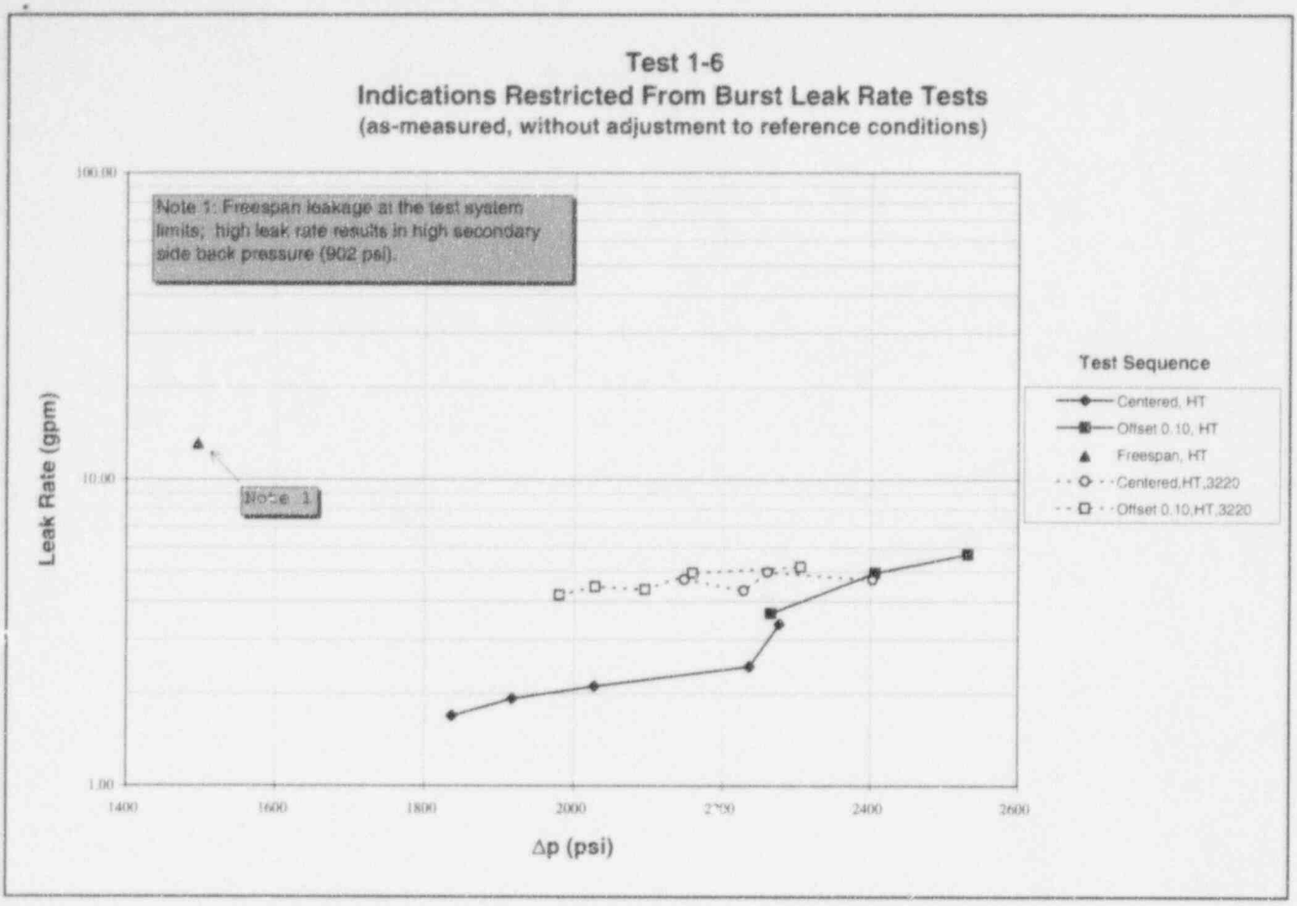
Test Plan for (IRBs)
Test 1-6

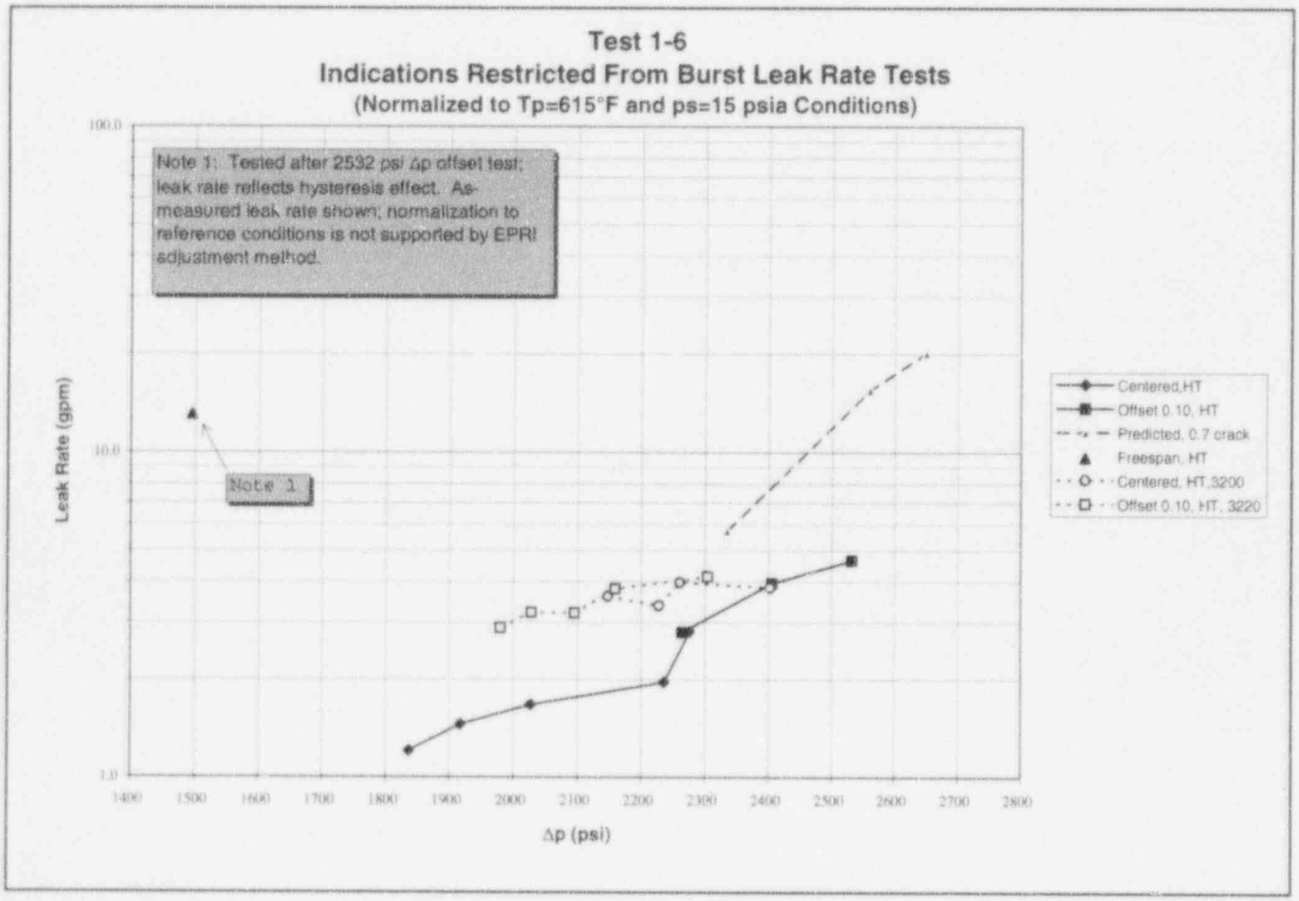
General Test Information

- Utilize large leak test facility testing
- Test 3/4" diameter, specimen 2008E
  - Corrosion (no fatigue) crack length: Silastic mold dye penetrant - 0.735" OD with 0.76" ID
- Leak test at 615˚F except as noted. Testing at > 615˚F is acceptable.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180˚ from the crack being leak tested.

Test Sequence

A. Hot (615˚F) leak test with crack inside the TSP and crack tip at edge of TSP at 1900 and 2050 and 2335 psi ΔP
B. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
C. Hot (615˚F) leak test with crack tip 0.10" offset outside TSP at 2335, 2560, 2700, 2800 psi ΔP up to facility limit
D. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
E. Perform hot (615˚F) free span leak test. Care must be excercised in performing this test such that higher ΔPs are not applied to the specimen due to the potential for significant tearing of the crack. Although the test results would not be valid, start testing at a ΔP lower than the highest ΔP from Step C and terminate testing if the measured leak rate is about a factor of 3 or more higher than the largest leak rate obtained from Step C.
F. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
G. With the crack tip 0.10" offset outside the TSP, pressurize to 3200 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.10" outside the TSP, adjust the specimen to obtain 0.10" of the corrosion crack outside the TSP prior to the leak testing of Step H. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.10" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
H. Hot (615˚F) leak test with crack inside the TSP and crack tip at the edge of the TSP at 2335 and 2560 psi ΔP
I. Hot (615˚F) leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
J. R.T. leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
K. Measure corrosion throughwall length and length versus depth profile.


Test 1-6
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)
Note 1: Freespan leakage at the test system limits; high leak rate results in high secondary side back pressure (902 psi).
Note 1
Leak Rate (gpm)
100.00
10.00
1.00
1400
1600
1800
2000
2400
2600
Δp (psi)
Test Sequence
Centered, HT
Offset 0.10, HT
Freespan, HT
Centered,HT,3220
Offset 0.10,HT,3220


Test 1-6
Indications Restricted From Burst Leak Rate Tests
(Normalized to Tp=615°F and ps=15 psia Conditions)
Note 1: Tested after 2532 psi Δp offset test; leak rate reflects hysteresis effect. As-measured leak rate shown; normalization to reference conditions is not supported by EPRI adjustment method.
Note 1
Leak Rate (gpm)
100.0
10.0
1.0
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
Δp (psi)
Centered,HT
Offset 0.10, HT
Predicted, 0.7 crack
Freespan, HT
Centered, HT,3200
Offset 0.10, HT, 3220

Test 1-6. Summary of Test Results
Specimen 2008E, Tube Dia. = 0.745", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
None	0.0 Steps A & B	0°	0.735 OD[3]	0.760[3]	N.A.[2]	0.0	N.A.[2]	0.745	N.A.[2]	1837[5]	1.69	630°F
		180°	0.0	0.0[3]	-	-	-			1918	1.92	639°F
		0°	0.738[4]							2028	2.11	642°F
		0°	0.749[4]	0.619[4] (0.024W)	0.0118	0	N.A.	0.760	0.747 0.743	2236[5]	2.44	655°F
										2276	3.37	627°F
None	0.10 Steps C&D	0°	0.760[4]	0.724[4] (0.044W)	0.0249	0.094 (0.026W)	0.0024	0.772	0.746 0.752	2265	3.65	657°F
										2406	4.95	639°F
										2532	5.69	633°F
None	Free Span Steps E & F		Same as above for unpressurized tube with crack offset from the TSP							1495[5]	13.1	646°F
3220	0.0 Steps G & H	0°	0.760[4]	0.726[4]	0.0257	0.094	0.0024	0.773	0.752 0.755	2148[5]	5.12	621°F
				(0.050W)		(0.026W)				2228	4.70	642°F
										2262	5.40	615°F
										2403[5]	5.10	634°F

Test 1-6. Summary of Test Results
Specimen 2008E, Tube Dia. = 0.745", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
3220	0.10 Step I		Same as above for bladder pressurization to 3220 psi steps G&H							1980[5]	4.55	639°F
										2028[5]	4.84	626°F
										2095[5]	4.74	636°F
										2159[5]	5.37	618°F
										2305	5.62	622°F

Notes:
1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.745" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Cracks are tight for specimens not pressurized with a bladder and TW area is not applicable.
3. Crack lengths from dye penetrant tests.
4. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening ~0.001"
5. Single leak rate measurement. Other test results are an average of two measurements at comparable ΔPs.

TEST 1-7

Test 1-7: Summary of Test Results
Status - June 15, 1995

Test Status

- Specimen with 0.60" TW crack by dye penetrant at start of test
- Completed hot leak tests with crack at TSP edge and 0.10" offset and bladder pressurization to free span burst pressure
- Room temperature leak tests following bladder pressurization not complete

Summary of Test Results

- Shallow slope of leak rate versus ΔP curve above 2200 psi shows interaction with TSP reduces leak rates
  - Initial slope of leak rate curve up to 2030 psi test point is more typical of free span slope
  - Larger slope and leak rate for CRACKFLO free span predictions supports TSP interaction > 2200 psi
- Initial increase in leak rate at 2445 psi after 0.10" offset may indicate reduced TSP restriction on flow after offset
- Above 2445 psi, the leak rate tends to decrease due to further interaction with the TSP
- Maximum leak rate at any test condition is 3.1 gpm at 2445 psi prior to bladder pressurization
- Following bladder pressurization to 2970 psi (slightly under the free span burst pressure of about 3035 psi), the leak rate for the crack within the TSP is approximately the same as obtained with 0.10" offset prior to bladder pressurization and less than the maximum 3.1 gpm leak rate

Overall Conclusions

- The SLB leak rate for 0.6" TW crack at start of test is limited to about 3.1 gpm prior to and after bladder pressurization
  - This indication can be expected to be an upper bound TW length for Byron-1 and Braidwood-1 implementing a 3.0 volt APC for which < 0.5 TW lengths would be the largest expected
- Large (> about 0.5") throughwall cracks interact with the TSP to limit leak rates including conditions with a 0.10" TW crack outside the TSP
  - For this 0.6" TW crack, interaction with the TSP is indicated at about 2200 psi and higher
- SLB leak rates following bladder pressurization are essentially the same as obtained for the 0.10" offset condition with prior flow pressurization

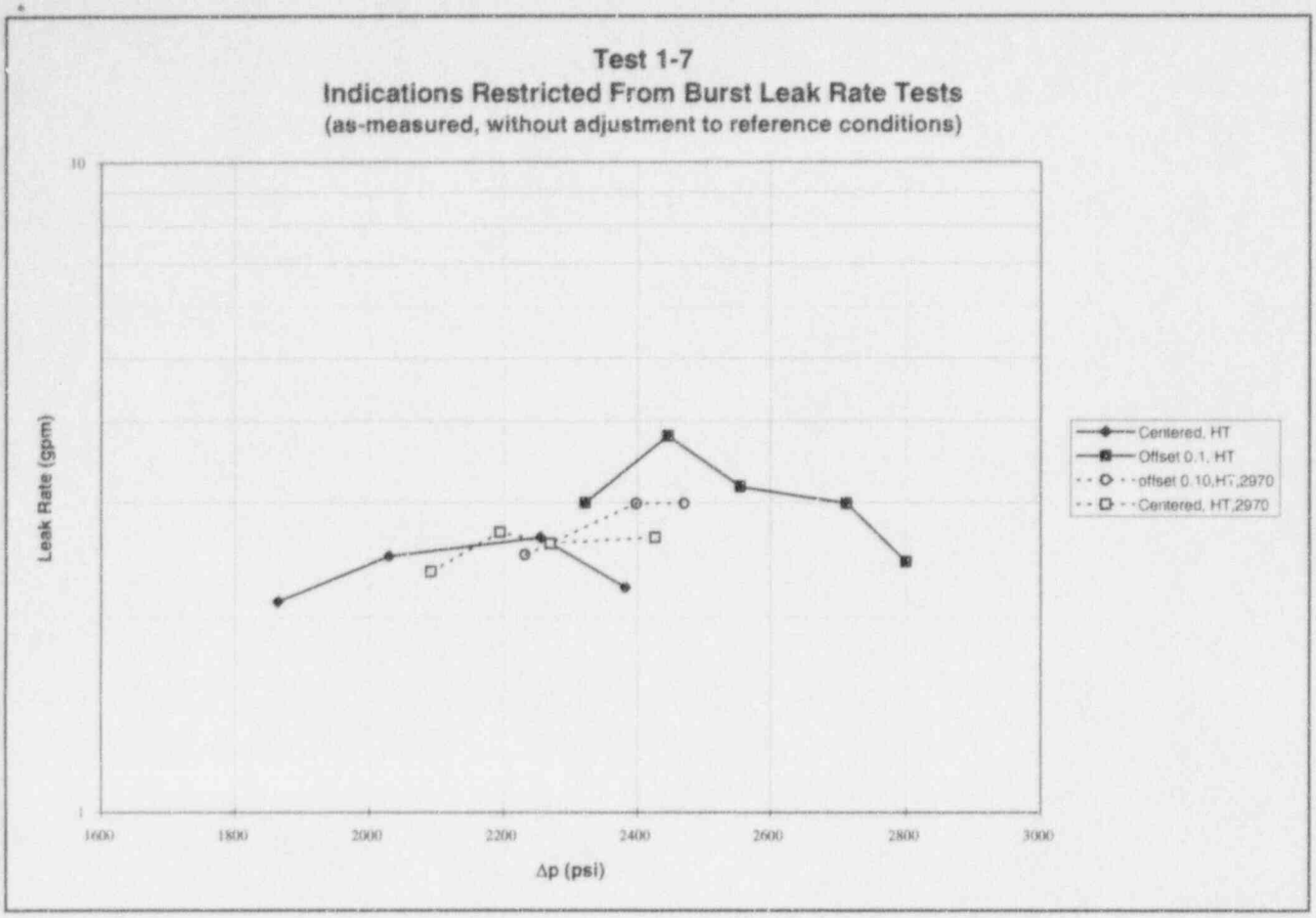
Test Plan for (IRBs)
Test 1-7

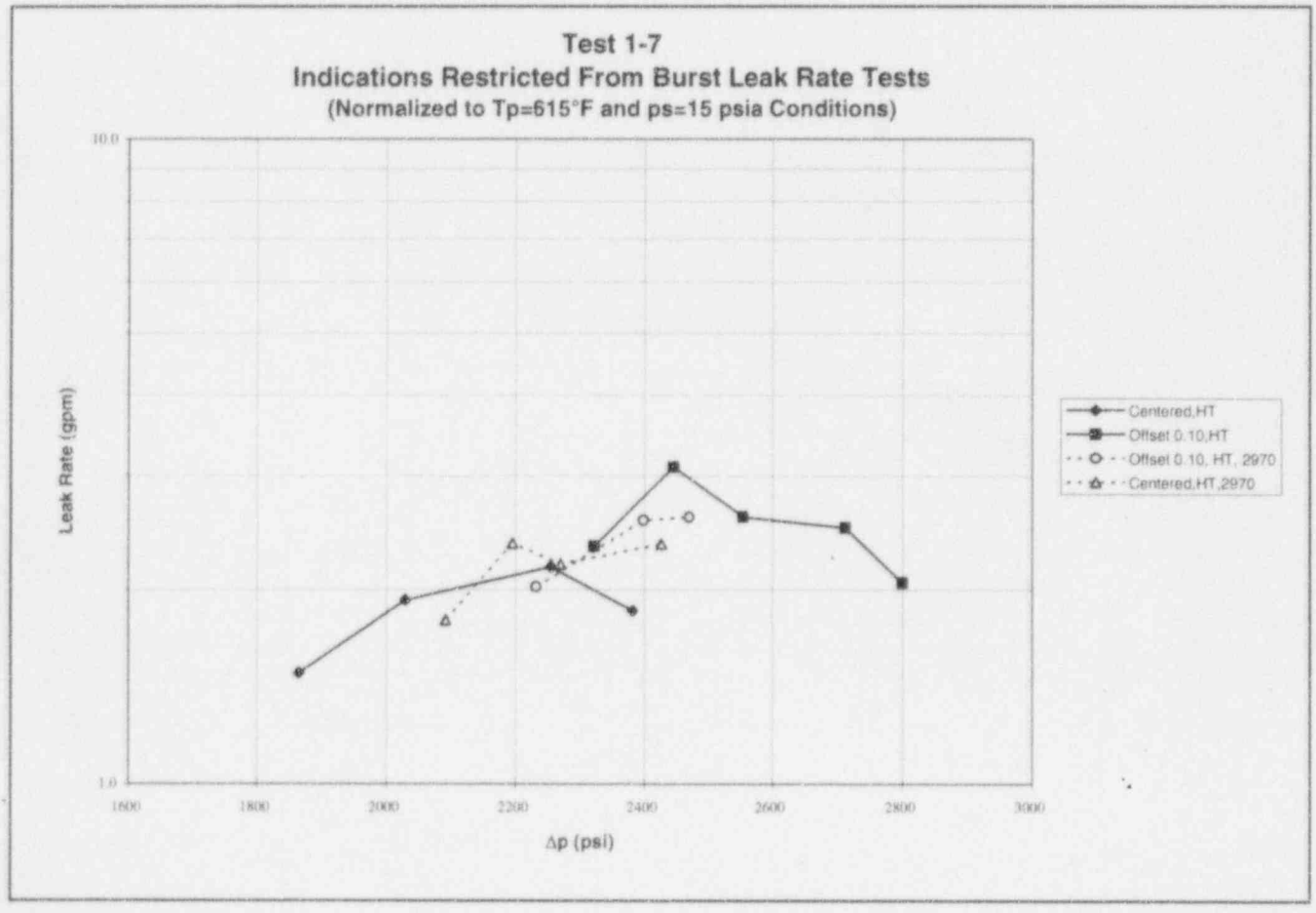
General Test Information

- Utilize large leak test facility testing
- Test 3/4" diameter, specimen 2051A
  - Corrosion plus fatigue crack length: Silastic mold dye penetrant - 0.58" OD with 0.60" TW
- Leak test at 615°F except as noted. Testing at > 615°F is acceptable.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Hot (615°F) leak test with crack inside the TSP and crack tip at edge of TSP at 1900 and 2050 and 2335 psi ΔP
B. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
C. Hot (615°F) leak test with crack tip 0.10" offset outside TSP at 2335, 2560, 2700, 2800 psi ΔP up to facility limit
D. Measure crack opening length, diameter, area (total lengths and thruwall lengths/width) and evaluate crack tearing extension (beyond corrosion crack length).
E. With the crack tip 0.10" offset outside the TSP, pressurize to about 3035 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.10" outside the TSP, adjust the specimen to obtain 0.10" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.10" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
F. Hot (615°F) leak test with crack inside the TSP and crack tip at the edge of the TSP at 2335 and 2560 psi ΔP
G. Hot (615°F) leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
H. R.T. leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
I. Measure corrosion throughwall length and length versus depth profile.


Test 1-7
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)
Leak Rate (gpm)
10
1
1600
1800
2000
2200
2400
2600
2800
3000
Δp (psi)
Centered, HT
Offset 0.1, HT
offset 0.10,HT,2970
Centered, HT,2970


Test 1-7
Indications Restricted From Burst Leak Rate Tests
(Normalized to Tp=615°F and ps=15 psia Conditions)
Leak Rate (gpm)
10.0
1.0
1600
1800
2000
2200
2400
2600
2800
3000
Δp (psi)
Centered,HT
Offset 0.10,HT
Offset 0.10, HT, 2970
Centered,HT,2970

Test 1-7. Summary of Test Results
Specimen 2051A, Tube Dia. = 0.747", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
None	0.0 Steps A & B	0°	0.60[3] .58-OD	0.60[3]	N.A.[2]	0.0	N.A.[2]	0.748	0.747 0.748	1865	2.11	636°F
		180°	0.0	0.0[3]	-	-	-			2030	2.48	647°F
		0°	0.609[4]	0.530[4] (0.011W)	0.0043	0.017 Tight	ΔP Opening	0.759	0.748 0.746	2255[5]	2.65	650°F
										2382[5]	2.22	664°F
None	0.10 Steps C & D	0°	0.621	0.602 (0.014W)	0.0071	0.084 (~.014W)	0.00059	0.767	0.747 0.746	2323	2.95	668°F
		180°	0.0	0.0	-	-	-			2445[5]	3.79	648°F
										2557	3.17	664°F
										2712[5]	2.99	677°F
										2800[5]	2.43	690°F
2970	0.10 Steps E & G	0°	0.621	0.604 (0.018W)	0.0087	0.085 (~.016W)	0.00068	0.769	0.748 0.748	2233	2.49	647°F
		180°	0.0	0.0[3]	-	-	-			2399	2.99	634°F
										2469[5]	2.99	638°F

Test 1-7. Summary of Test Results
Specimen 2051A, Tube Dia. = 0.747", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
2970	0.00 Step F	Same as above for 2970 psi bladder pressurization with 0.10" offset								2092[5]	2.35	639°F
										2195[5]	2.7	623°F
										2270	2.6	636°F
						-	-			2426[5]	2.65	640°F

Notes:
1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.875" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Cracks are tight for specimens not pressurized with a bladder and TW area is not applicable.
3. Crack lengths from dye penetrant tests.
4. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening ~0.001"
5. Single leak rate measurement. Other test results are an average of two measurements at comparable ΔPs.

TEST 2-1

TEST RESULTS ARE NOT YET AVAILABLE

Test Plan for (IRBs)
Test 2-1

General Test Information

- Utilize large leak test facility testing
- Test 7/8" diameter, specimen 8161-A
  - Corrosion plus fatigue crack length: silastic mold dye pentrant -0.62" OD with 0.515" ID
- Leak test at 615°F except as noted. Testing at > 615°F is acceptable.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Hot (615°F) leak test with simulated crack inside TSP and crack tip at edge of TSP at 1800, 1900 and 2000 psi ΔP
B. Hot (615°F) free span leak test at 2000, 2150 and 2335 psi ΔP
C. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335, psi ΔP (adjust, if necessary, to the same ΔP as last test of Step C), 2560, 2700 psi ΔP and another higher ΔP at facility limit
D. Leak Test at R.T. with 0.15" offset starting from the highest ΔP obtained in Step C and increase to facility limit
E. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length).
F. With the crack tip 0.15" offset outside the TSP, pressurize to **4,450** psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.15" outside the TSP, adjust the specimen to obtain 0.15" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.15" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
G. Hot (615°F) leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
H. Hot (615°F) leak test with crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
I. R.T. leak test with crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
J. Measure corrosion throughwall length and length versus depth profile.

TEST 2-4

Test 2-4: Summary of Test Results
Test Complete, Evaluation Status June 12, 1995

Test Status

- 7/8" diameter specimen 4C218 with, 0.60" OD, 0.29" TW crack by dye penetrant at start of test
  - Two TW lengths of 0.33" and 0.12" after flow tests with 0.15" offset
  - Two TW lengths of 0.38" and 0.28" after 5550 bladder pressurization
  - Bobbin voltage of 11.4 volts for specimen prepared in doped steam is expected to be low based on prior experience
- All tests complete - with and without bladder pressurization

Summary of Test Results

- Leak rates for the crack at edge of TSP, free span and offset 0.15" result in leak rates typical of free span behavior
  - The flow pressure increases extended the length of the inital TW crack to 0.33" and opened a second TW crack of 0.12". High slopes of leak rate versus ΔP indicate ligament tearing up to about 2200 psid
  - Maximum tube diameter of 0.878" after test also indicates a low likelihood of tube to TSP contact at test conditions
  - Small slope of room temperature tests up to 2716 psid may be due to hysterisis effect on 2534 psid measurement since this test ΔP is 37 psi lower than the prior pressurization
- Bladder pressurization to a ΔP of 4125 psi did not result in crack faces contacting the TSP ID and leak rates are significantly lower (about factor of 2) than obtained with bladder pressurization at the estimated free span burst pressure of 5550 psi
  - Test 4-1 results show that further increases in bladder pressurization above the free span burst pressure do not result in increased leakage
- For this indication, the leak rates following bladder pressurization to 4125 psi with the crack inside the TSP are approximately the same as obtained prior to bladder pressurization
- For 0.15" offset and bladder pressurization to the free span burst pressure of 5550 psi, the leak rates at SLB conditions are about 1.5 gpm and about 50% higher than with the crack inside the TSP and the crack tip at the edge of the TSP
  - Pressurization opened the longest throughwall crack to 0.382" (> 1 0 mil wide) with an average TW width of 0.010" and the second TW to 0.284" with an average TW width of 0.004". A TW length > 1.0 mil wide of 0.076" with an average width of 0.010" was exposed outside the TSP.

Test 2-4: Summary of Test Results
Test Complete, Evaluation Status June 12, 1995

Assessment of EPRI Cold Test to Reference Hot Conditions Leak Rate Adjustment Procedure

- Pressurization by primary flow pressure
  - Calculated cold test adjustment factor of 0.58 brings cold tests results into very good agreement with hot test results
- Bladder pressurization
  - EPRI adjustment procedure for temperature factor, β, modified to exclude ratio of flow stresses and Young's modulus as these factors are intended to reflect the effect of temperature on crack opening area, which is not applicable to bladder pressurized specimens
  - Calculated cold test adjustment factor of 0.45 shows good agreement with hot test results although unexpected high hot data point at 2400 psi leads to a residual uncertainty in the comparison

Overall Conclusions

- Initial TW crack lengths of about 0.29", OD = 0.60" (Average length = 0.445") do not result in interaction with the TSP ID at SLB conditions and the leak rates for the indication inside the TSP behave as free span indications with an SLB leak rate < 0.4 gpm
- Although this indication would not burst at SLB conditions, bladder pressurization tests were performed to bound the leak rate at pressures of 4125 psi and 5550 psi (estimated free span burst pressure for this indication)
- Bladder pressurization to 4125 psi resulted in a leak rate approximately the same as the free span leak rate for the indication inside the TSP and about 0.65 gpm with the crack 0.15" offset outside the TSP
- Bladder pressurization to the free span burst pressure of 5550 psi resulted in SLB leak rates of < 1.1 gpm with the crack inside the TSP and < 1.7 gpm with the crack offset 0.15" outside the TSP
- Comparisons of cold and hot test results strongly support the EPRI cold to hot leak rate adjustment procedure and, thereby, the adequacy of performing leak rate tests at cold conditions

Test Plan for (IRBs)
Test 2-4

General Test Information

- Utilize small leak test facility followed by testing in large leak test facility
- Test 7/8" diameter specimen 4C 218
  - Crack length: Dye Penetrant - 0.60" with 0.29" TW; UT - 0.62" with 0.40" TW
- Leak test at ≥ 615°F except as noted
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Leak test with crack centered at 1500, 1700 and 2000 psi ΔP
B. Free span leak test at 2000, 2335 and 2560 psi ΔP
C. Leak test with crack 0.15" offset outside TSP at 2560 and 2720 psi ΔP (facility limit)
- Move tube by 0.15" relative to the TSP

D. Leak test at R.T. with 0.15" offset starting from the highest ΔP obtained in Step C and increase to the facility limit
E. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length).

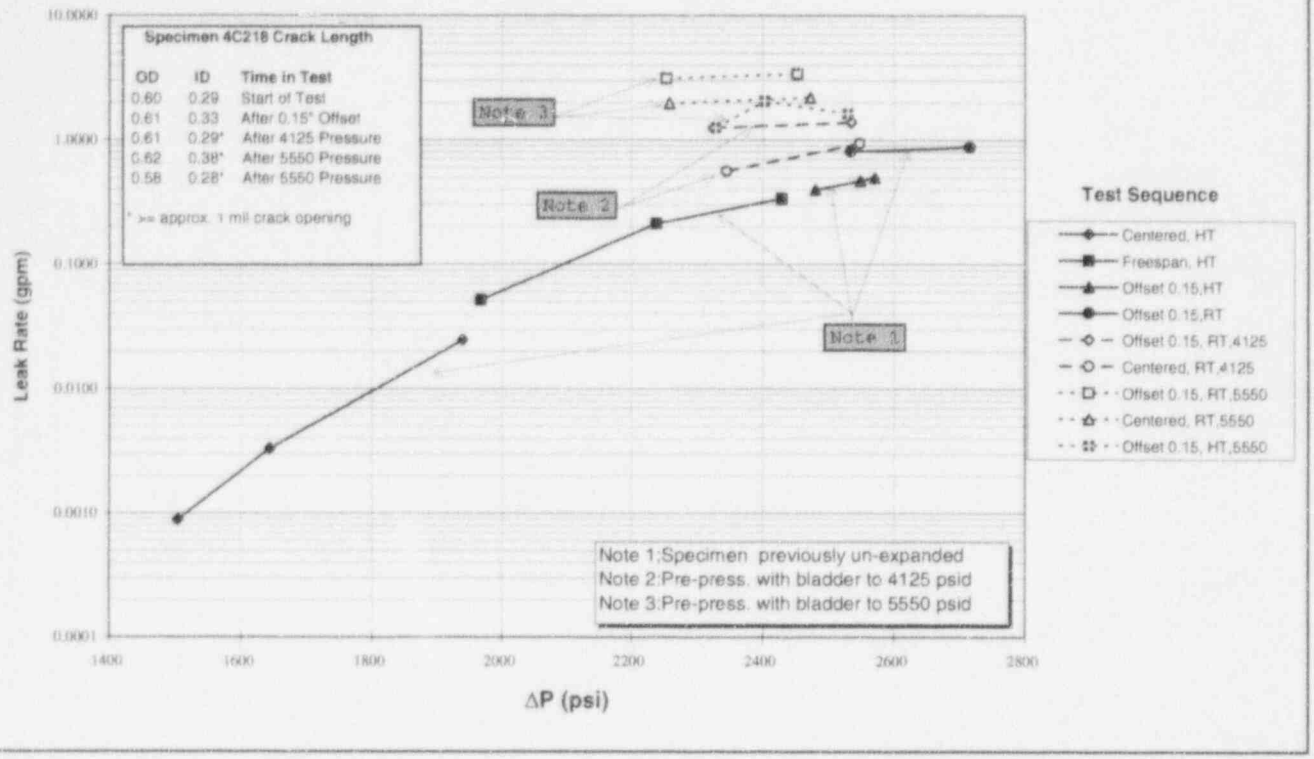
Decontaminate the specimen

The following tests are to be performed in the large leak test facility with a collar that provides a 25 mil diametral gap relative to the tube diameter prior to any of the above leak testing:

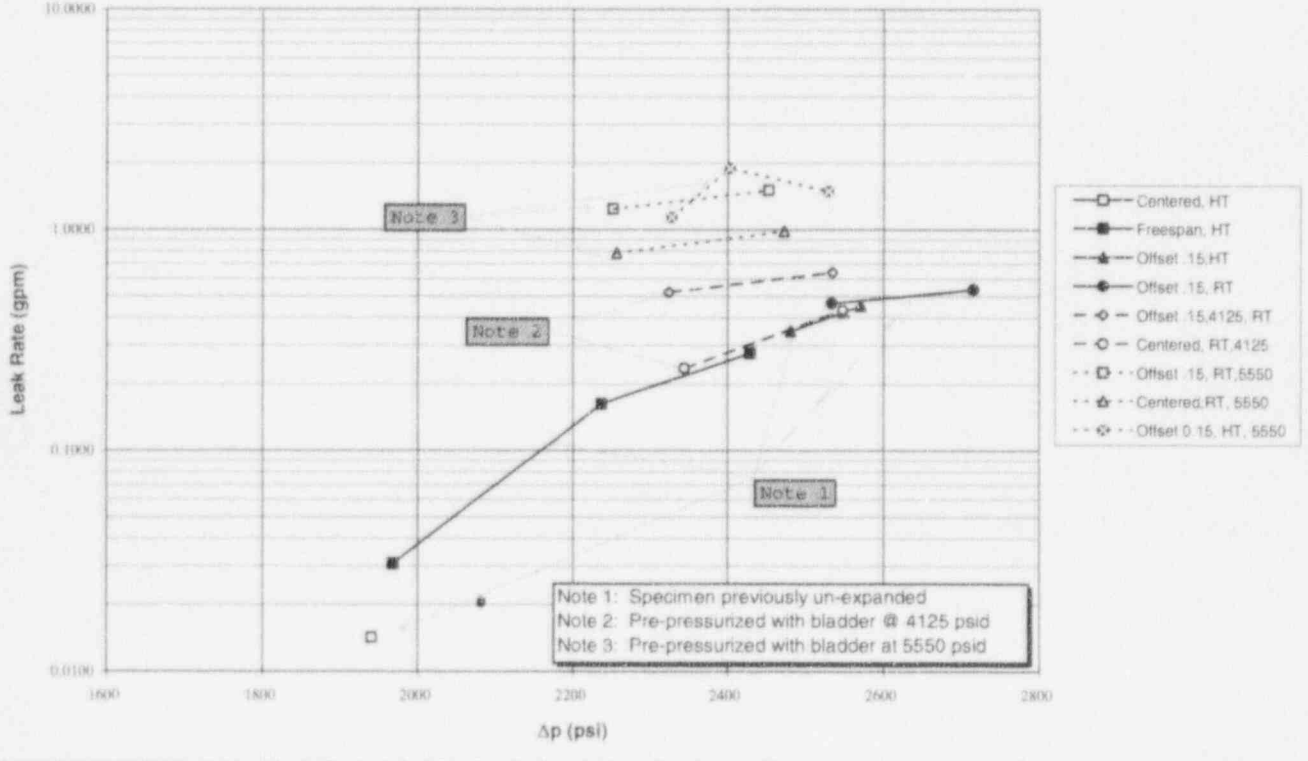
F. With the crack tip 0.15" offset outside the TSP, pressurize to about 4000 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.15" outside the TSP, adjust the specimen to obtain 0.15" of the corrosion crack outside the TSP prior to the leak testing of Step G. For each crack (2 expected), measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.15" offset and at the edge of the TSP.
- Report whether the tube is tight or loose in TSP following pressurization.

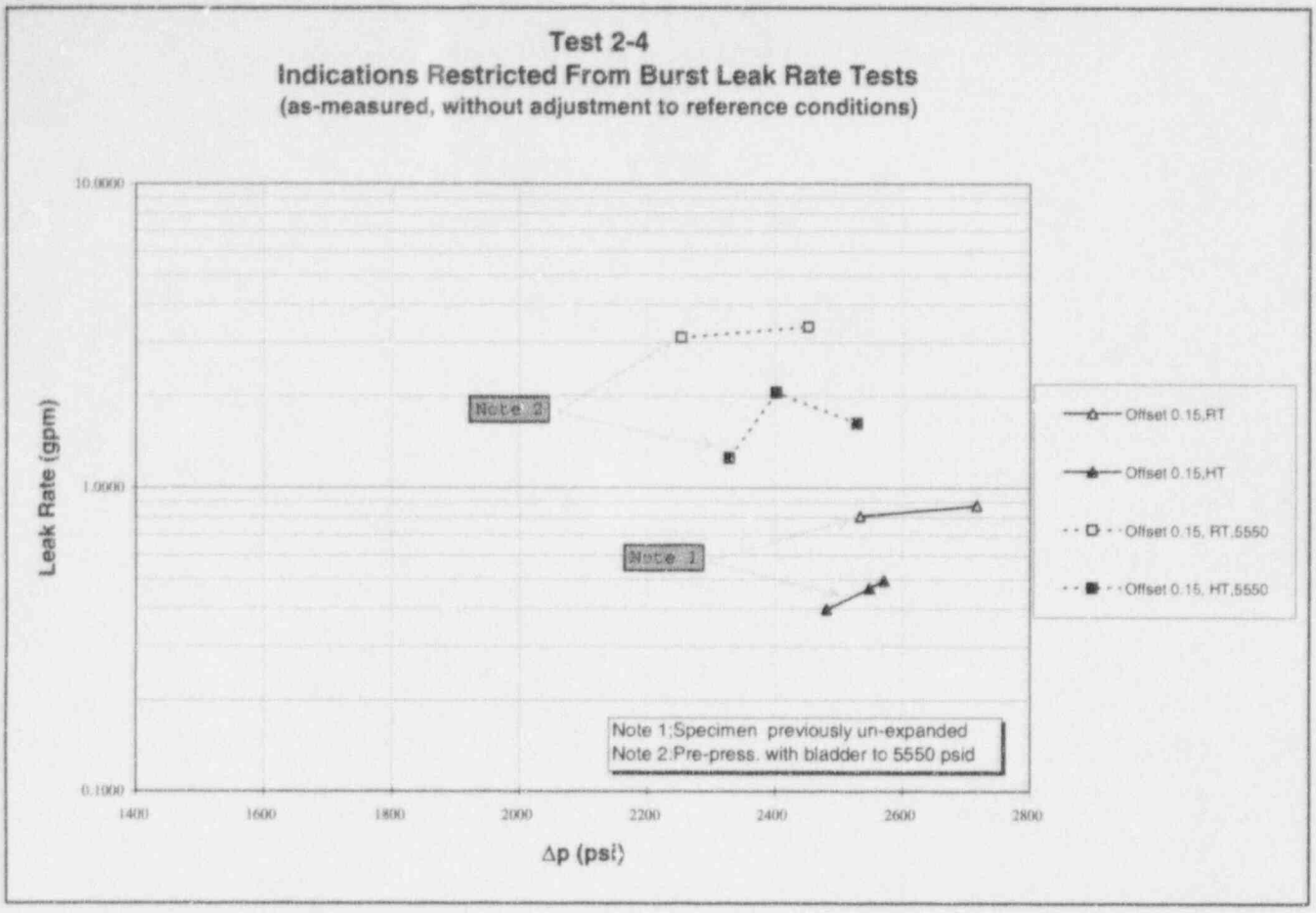
G. R.T. leak test with corrosion crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
H. R.T. leak test with crack inside the TSP and the crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
I. Repeat Step F with a bladder pressurization of 5500 psid
J. R.T. leak test with corrosion crack tip 0 15" offset outside TSP at 2335 and 2560 psi ΔP
K. R.T. leak test with crack inside the TSP and the crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
L. Hot (615°F) leak test with corrosion crack tip 0.15" offset outside TSP at 2335 and 2560 psi ΔP
M. Measure corrosion throughwall length and length versus depth profile.

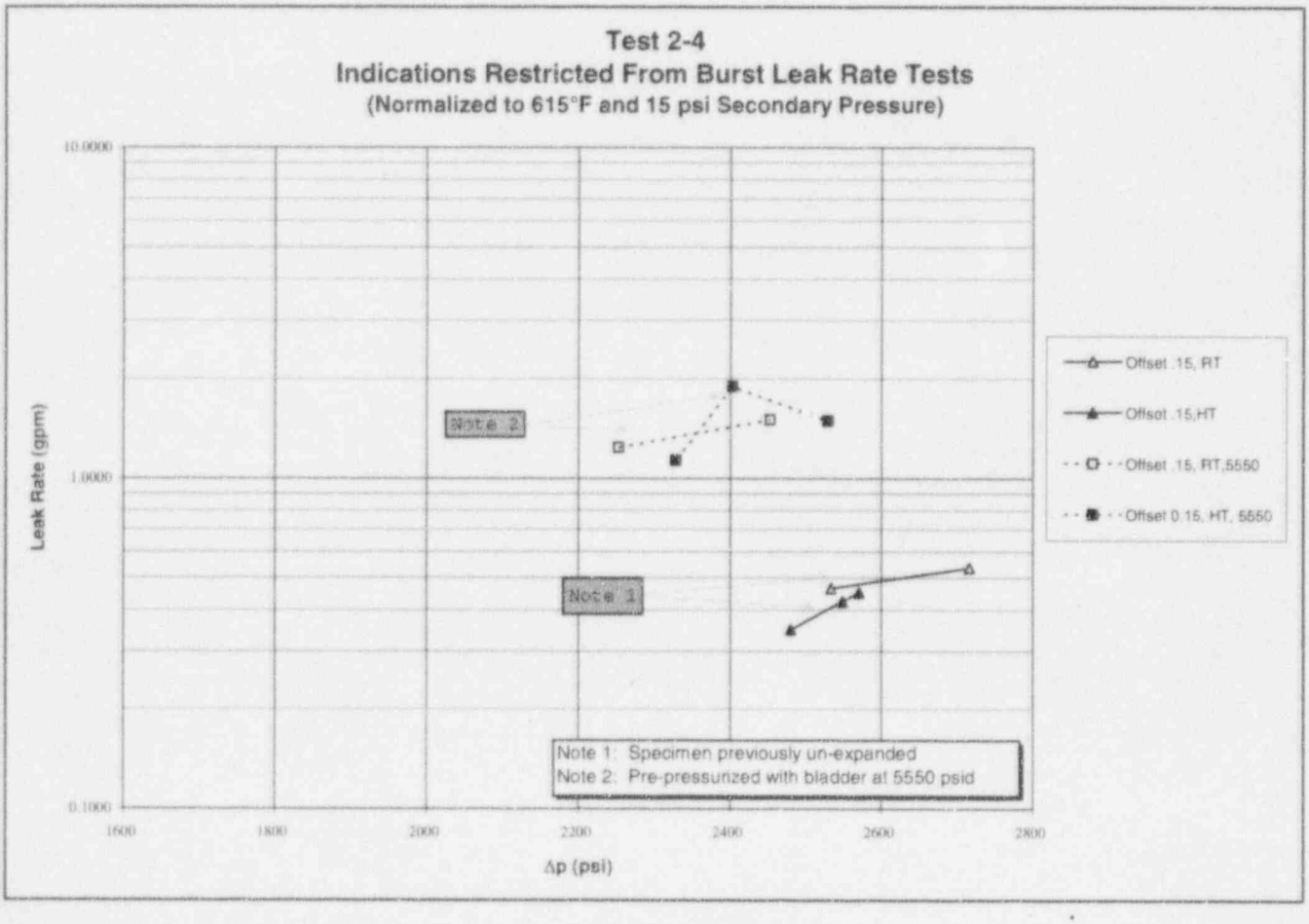
Test 2-4
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)



Test 2-4
Indications Restricted From Burst Leak Rate Tests
(Normalized to 615°F and 15 psi Secondary Pressure)




Test 2-4
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)
Leak Rate (gpm)
10.0000
1.0000
0.1000
1400
1600
1800
2000
2200
2400
2600
2800
Δp (psi)
Note 2
Note 1
Offset 0.15,RT
Offset 0.15,HT
Offset 0.15, RT,5550
Offset 0.15, HT,5550
Note 1;Specimen previously un-expanded
Note 2:Pre-press. with bladder to 5550 psid


Test 2-4
Indications Restricted From Burst Leak Rate Tests
(Normalized to 615°F and 15 psi Secondary Pressure)
Leak Rate (gpm)
10.0000
1.0000
0.1000
1600
1800
2000
2200
2400
2600
2800
Δp (psi)
Note 2
Note 1
Offset .15, RT
Offset .15,HT
Offset .15, RT,5550
Offset 0.15, HT, 5550
Note 1: Specimen previously un-expanded
Note 2: Pre-pressurized with bladder at 5550 psid

Test 2-4 Summary of Test Results Specimen 4C-218, Tube Dia. = 0.875", Gap = 0.025"												
Bladder Pressure (psi)	**Tube Offset (in.)**	**Angle**	**Total Crack Length (in.)**	**Total TW Length (Max. Width) (in.)**	**Total TW Area (in^2)**	**Exposed TW Length (Max. Width) (in.)**	**Exposed TW Area (in^2)**	**Max. Dia. (in.)**	**Min. Dia. (in.) Note 1**	**Leak Rate Test Results**		
										ΔP (psi)	**Rate (gpm)**	**Temp. (°F)**
None	0.0 Step A	270°	0.60[3]	0.29[3]	N.A.[2]	0.0	N.A.[2]	0.875	N.A.[2]	1504	0.0009	613
		90°	0.60[3]	0.0[3]	-	-	-			1645	0.0033	511
										1941	0.025	570
None	Free span Step B	-	-	-	-	-	-	-	-	1968	0.052	590
										2238	0.21	559
										2430	0.34	568
None	0.15 Step C	-	-	-	-	-	-	-	-	2481	0.40	551
										2549	0.47	561
										2571	0.49	564
None	0.15 Steps D & E	270°	0.611[3]	0.33[3]	Tight	0.0	0.0	0.878	0.877 0.875	2534	0.81	R.T.
		90°	0.570[3]	0.12[3]	Tight	0.0	0.0			2716	0.87	R.T.

Test 2-4 Summary of Test Results Specimen 4C-218, Tube Dia. = 0.875", Gap = 0.025"												
Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
4125	0.15 Steps F & G	270°	0.609[4]	0.286[4] (0.003W)	0.00086	0.032 (0.003W)	0.00009	0.881	0.877 0.874	2325	1.25	R.T.
		90°	0.570[4]	Tight	Tight	0.0	-			2535	1.38	R.T.
		0°-180°						0.875	0.875 0.875			
		45°-225°						0.876	0.876 0.875			
		135°-315°						0.877	0.876 0.875			
		-										
4125	0.00 Step H	270°	Same as above for 4125 psi bladder pressure with 0.15" offset					0.881	0.875 0.875	2345	0.56	R.T.
		90°								2548	0.93	R.T.
		0°-180°						0.875	0.875 0.875			
		45°-225°						0.876	0.876 0.875			
		135°-315°						0.877	0.875 0.876			

Test 2-4 Summary of Test Results
Specimen 4C-218, Tube Dia. = 0.875", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
5550	0.15 Steps I, J & L	270°	0.617	0.382 (0.010W)	0.00382	0.076 (0.010W)	0.00076	0.897	0.885 0.874	2253	3.11	R.T.
		90°	0.580	0.284 (0.004W)	0.00114	0.0	0.0			2453	3.37	R.T.
		0°-180°	None					0.874	0.874 0.876	2329	1.25	644°F
		45°-225°	None					0.881	0.879 0.876	2403[5]	2.05	632°F
		135°-315°	None					0.882	0.879 0.877	2530	1.63	645°F
5550	0.0 Step K	270°	Same as above for 5500 psi bladder pressure with 0.15" offset					0.897	0.876 0.875	2258	1.96	R.T.
		90°								2473	2.18	R.T.
		0°-180°						0.874	0.874 0.875			
		45°-225°						0.881	0.877 0.877			
		135°-315°						0.882	0.877 0.877			

Test 2-4 Summary of Test Results
Specimen 4C-218, Tube Dia. = 0.875", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)

Notes:
1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.875" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Cracks are tight for specimens not pressurized with a bladder and TW area is not applicable.
3. Crack lengths from dye penetrant tests
4. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening ~0.001"
5. Single leak rate measurement. Other test results are an average of two measurements at comparable ΔPs.

TEST 2-7

Test 2-7: Summary of Test Results
Status - June 17, 1995

Test Status

- 3/4" diameter specimen with 0.577" TW crack, 0.66" OD by dye penetrant at start of test
- Completed cold leak tests with crack at TSP edge and freespan and hot leak tests with 0.10" offset and following bladder pressurization
- Test complete except for post pressurized cold test

Summary of Test Results

- The flattening of the leak rate slope above about 2300 psi ΔP indicates interaction of the crack face with the TSP ID and the SLB leak rate is bounded by about 3 gpm
- Leak rates below 2300 psi are typical of free span leak rates and are in good agreement with analytical (CRACKFLO) analyses for the leak rate
- Bladder pressurization to the free span burst pressure of about 3700 psi did not significantly affect the leak rate from that obtained by prior flow pressurization
- Following bladder pressurization to the free span burst pressure, the leak rate with the crack inside the TSP of about 2.3 gpm is less than the 3 gpm obtained with flow pressurization in the offset condition

Overall Conclusions

- Flow pressurization to a 2300 psi ΔP resulted in interaction of the crack face with the TSP ID and resulted in an upper bound leak rate of about 3 gpm
- After crack face interaction with the TSP at 2300 psi, the leak rate did not further increase including subsequent leak rate tests after bladder pressurization to the free span burst pressure of about 3700 psi

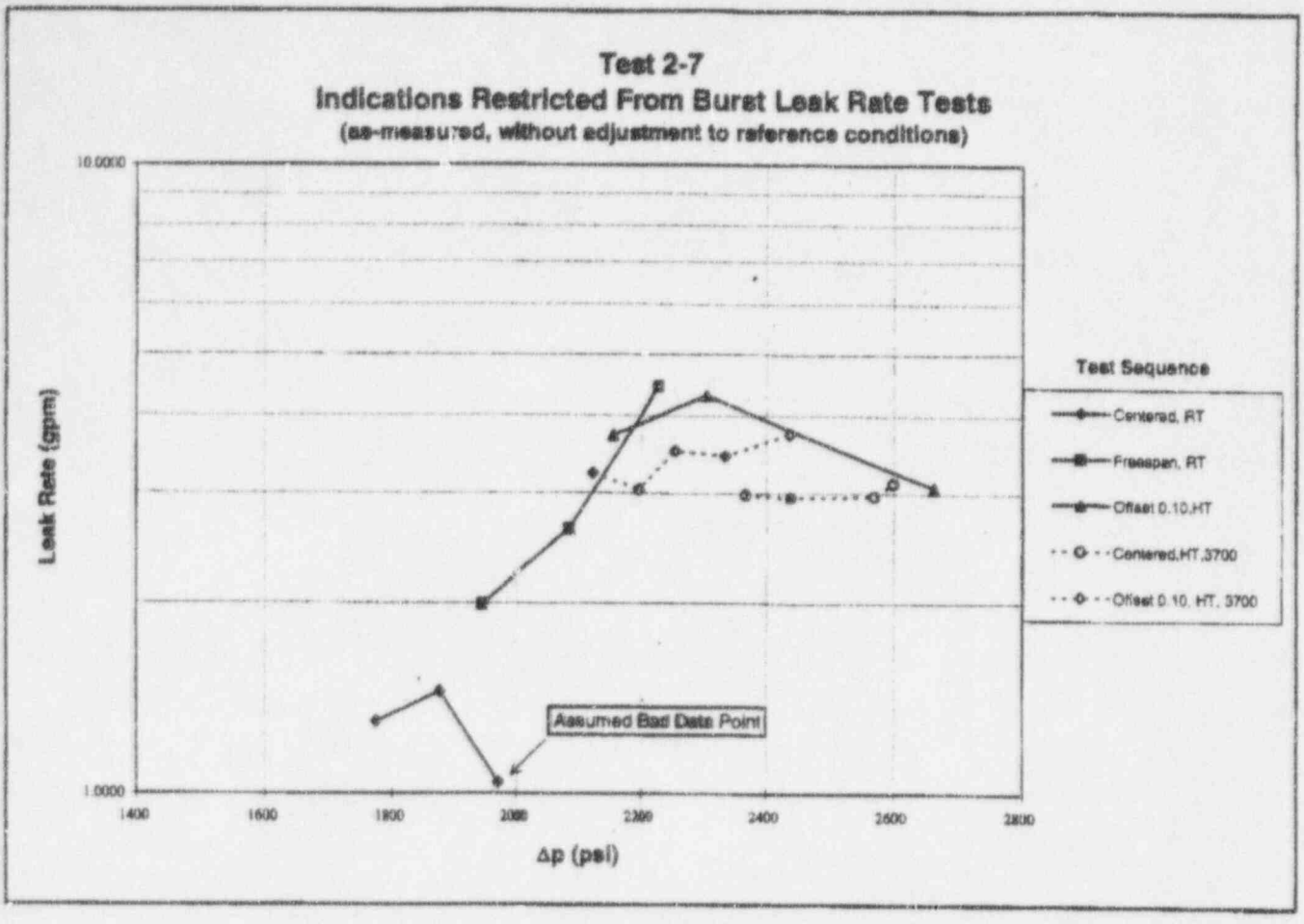
Test Plan for (IRBs)
Test 2-7

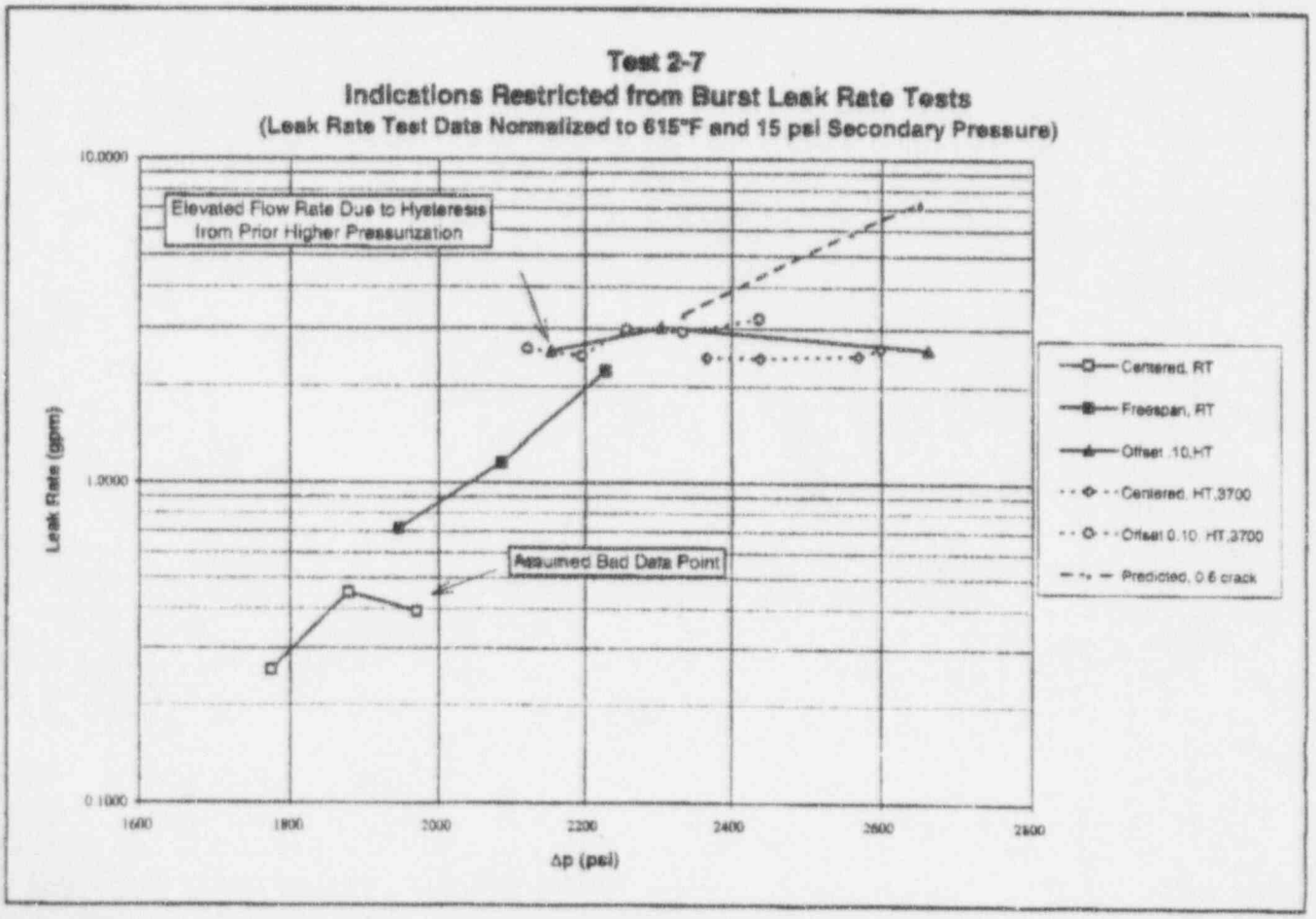
General Test Information

- Utilize large leak test facility testing
- Test 3/4" diameter, corrosion plus fatigue specimen 2051E
  - Original corrosion crack length: Silastic mold dye penetrant - 0.66" with 0.577" TW
  - Specimen fatigued to obtain ID TW length
- Leak test at room temperature with selected ≥ 615°F tests.
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. R.T. leak test with simulated crack inside TSP and crack tip at edge of TSP at 1800, 1900 and 2000 psi ΔP
B. R.T. free span leak test at 2000, 2150 and 2335 psi ΔP
C. Hot (615°F) leak test with crack tip 0.10" offset outside TSP at 2335, psi ΔP (adjust, if necessary, to the same ΔP as last test of Step C), 2560, 2700 psi ΔP and another higher ΔP at facility limit
D. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length).
E. With the crack tip 0.10" offset outside the TSP, pressurize to 3650 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.10" outside the TSP, adjust the specimen to obtain 0.10" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.10" offset and at the edge of the TSP.
   - Report whether the tube is tight or loose in TSP following pressurization.
F. Hot (615°F) test with crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
G. Hot (615°F) leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
H. R.T. leak test with crack tip 0.10" offset outside TSP at 2335 and 2560 psi ΔP
I. Measure corrosion throughwall length and length versus depth profile.


Test 2-7
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)
10.0000
1.0000
Leak Rate (gpm)
1400
1600
1800
2000
2200
2400
2600
2800
Δp (psi)
Assumed Bad Data Point
Test Sequence
Centered, RT
Freespan, RT
Offset 0.10,HT
Centered,HT,3700
Offset 0.10, HT, 3700


Test 2-7
Indications Restricted from Burst Leak Rate Tests
(Leak Rate Test Data Normalized to 615°F and 15 psi Secondary Pressure)
10.0000
1.0000
0.1000
Leak Rate (gpm)
1600
1800
2000
2200
2400
2600
2800
Δp (psi)
Elevated Flow Rate Due to Hysteresis from Prior Higher Pressurization
Assumed Bad Data Point
Centered, RT
Freespan, RT
Offset .10,HT
Centered, HT,3700
Offset 0.10, HT,3700
Predicted, 0.6 crack

Test 2-7. Summary of Test Results
Specimen 2051E, Tube Dia. = 0.749", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
None	0.0 Step A	0°	0.66[3]	0.577[3]	N.A.[2]	0.0	N.A.[2]	0.749	N.A.[2]	1775	1.30	R.T.
		180°	0.0	0.0[3]	-	-	-			1878	1.45	R.T.
										1970	1.04	R.T.
None	Free span Step B	0-180°	0.667[4]	0.515[4] (0.002W)	0.00090	0.0	0.0	0.756	0.748 0.749	1945	1.99	R.T.
		90-270°	0.0	-	-	-	-	0.746	0.748 0.746	2085	2.62	R.T.
										2228	4.44	R.T.
None	0.10 Steps C & D	0-180°								2155[5]	3.72?	638°F
		90-270°								2305[5]	4.30?	642°F
										2662	3.06	663°F
3700	0.0 Steps E & F	0-180°								2367[5]	2.98	655°F
		90-270°								2439[5]	2.95	668°F
										2570[5]	2.97	674°F
										2599[5]	3.11	672°F

Test 2-7. Summary of Test Results
Specimen 2051E, Tube Dia. = 0.749", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
3700	0.10 Step G	0-180°								2123[5]	3.23	633°F
		90-270°								2196	3.04	643°F
										2256[5]	3.51	620°F
										2335[5]	3.45	633°F
										2437	3.74	626°F

Notes:
1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.749" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Cracks are tight for specimens not pressurized with a bladder and TW area is not applicable.
3. Crack lengths from dye penetrant tests
4. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening ~0.001"
5. Single leak rate measurement. Other test results are an average of two measurements at comparable ΔPs.

TEST 2-10

Test 2-10: Summary of Test Results
Status - June 17, 1995

Test Status

- 3/4" diameter specimen with 0.425" TW, 0.551" OD by dye penetrant at start of test
- Completed hot leak tests with crack at TSP edge and 0.10" offset and following bladder pressurization to the free span burst pressure
- Test complete except for post-pressurized cold test

Summary of Test Results

- The slope of the leak rate versus ΔP curve indicates essentially free span leak rates with no TSP interaction up to the maximum ΔP of 2300 psi tested under flow pressurization conditions
  - The maximum leak rate tested is about the limit of the small leak test facility used for this test
- The maximum measured leak rate for this 0.425" TW indication was about 0.85 gpm at 2300 psi which would extrapolate to about 1.2 gpm at 2560 psi
- Bladder pressurization to 3850 psi at 0.10" offset resulted in leak rates at SLB conditions of about 1.4 gpm with the crack inside the TSP. No increase in flow rate was observed with the crack offset 0.10" from the TSP.
- Following bladder pressurization at 0.10" offset to the free span burst pressure of 4960 psi, the SLB leak rate at the 0.10" offset condition was about 1.50 gpm
  - The increase in leak rates following bladder pressurization is typical for indications which do not show interaction with the TSP under flow pressurization conditions

Assessment of EPRI Cold Test to Reference Hot Conditions Leak Rate Adjustment Procedure

- Pressurization by primary flow pressure
  - Calculated cold test adjustment factor of 0.52 brings cold test results to slighly higher (about 5%) than the hot test results which indicates that the adjustment procedure is slightly conservative for adjusting cold test results to reference hot conditions

Overall Conclusions

- The initial TW crack length of 0.425", OD = 0.551" (Average length = 0.488") for this test does not result in interaction with the TSP ID at SLB conditions and the leak rates for the indication inside the TSP behave as free span indications with an SLB leak rate of about 1.2 gpm
- Although this indication would not burst at SLB conditions, bladder pressurization tests were performed to bound the leak rate at pressures of 3850 psi and 4960 psi (estimated free span burst pressure for this indication)
- The SLB leak rate for the 0.10" offset condition following bladder pressurization to the free span burst pressure was about 1.5 gpm, which is <10% higher than obtained for the crack within the TSP
- Bladder pressurization to the free span burst pressure resulted in SLB leak rates about 70% higher than obtained by flow pressurization, which is typical for the shorter indications for which the crack faces do not interact with the TSP under flow pressurization conditions

Test Plan for (IRBs)
Test 2-10

General Test Information

- Utilize small leak test facility followed by large leak test facility testing
- Test 3/4" diameter, corrosion specimen 2051B
  - Crack length: Silastic mold dye penetrant - 0.551" OD with 0.425" TW
- Leak test at ≥ 615° with selected room temperature tests
- Locate specimen relative to the TSP per requirements for crack locations within TSP and offset from TSP
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Hot (615°) leak test with simulated crack inside the TSP and the crack tip at edge of TSP at 1800, 1900 and 2000 psi ΔP
B. Hot (615°) free span leak test at 2000, 2150 and 2335 psi ΔP
C. Hot (615°) leak test with crack tip 0.10" offset outside TSP at 2335, 2560 and 2750 (or facility limit) psi ΔP

Note: If at any time during this test it appears that the facility limit for measuring leak rate is being approached, increase the ΔP to about the facility limit and terminate testing in the small loop. Testing will than be continued in the large loop.

D. Leak test at R.T. with crack tip 0.10" offset outside TSP at the 2750 ΔP psi or highest pressure obtained in Step C and increase the ΔP to the highest ΔP obtainable at room temperature.
E. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length).

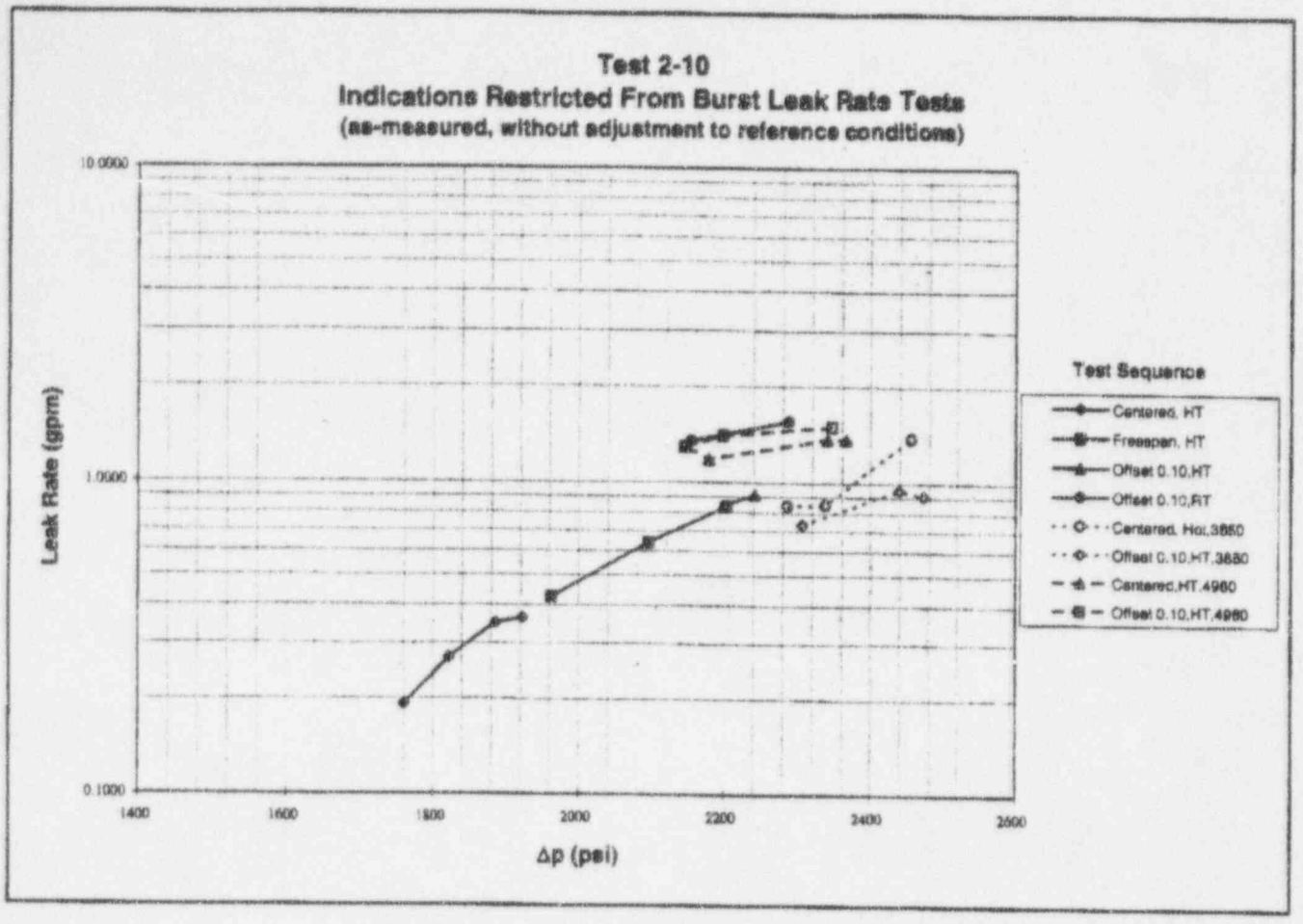
Decontaminate the specimen for later testing in large loop facility

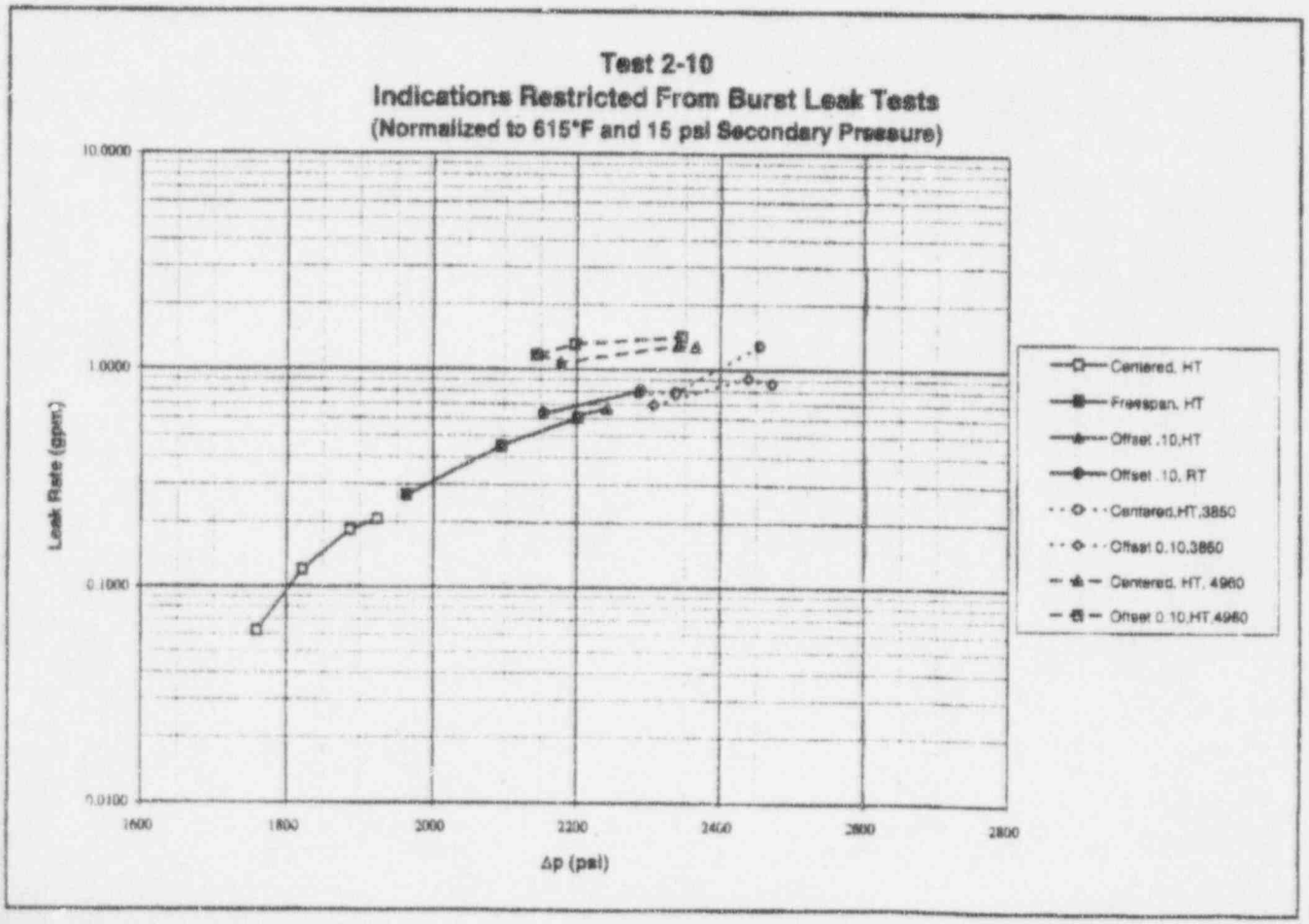
F. With the crack tip 0.10" offset outside the TSP, pressurize to 3800 psid with a bladder. If following pressurization, the corrosion crack tip is more than 0.10" outside the TSP, adjust the specimen to obtain 0.10" of the corrosion crack outside the TSP prior to the leak testing of Step G. Measure the total crack length, the through wall length/width, the exposed throughwall length/width and the tube diameter across the crack flanks including at least 5 points along the crack plus the locations of the edges of the TSP with the crack tip 0.10" offset and at the edge of the TSP.

- Report whether the tube is tight or loose in TSP following pressurization.

Move specimen to the large leak test facility for the following tests. Either the hot test sequence or the cold test sequence (lined out) are acceptable and selection of hot or cold testing should be based on most efficient completion of the tests.

G. Hot (615°F) test with crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
H. Hot (615°F) leak test with 0.10" offset outside TSP at 2335 and 2560 psi ΔP
I. Repeat Step F with a bladder pressurization of 4920 psid
J. Hot (615°F) test with crack tip located at the edge of the TSP at 2335 and 2560 psi ΔP
K. Hot (615°F) leak test with 0.10" offset outside TSP at 2335 and 2560 psi ΔP
L. R.T. leak test with 0.10" offset outside TSP at 2335 and 2560 psi ΔP
M. Measure corrosion throughwall length and length versus depth profile.


Test 2-10
Indications Restricted From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)
Leak Rate (gpm)
10.0000
1.0000
0.1000
1400
1600
1800
2000
2200
2400
2600
Δp (psi)
Test Sequence
Centered, HT
Freespan, HT
Offset 0.10,HT
Offset 0.10,RT
Centered, Hot,3650
Offset 0.10,HT,3650
Centered,HT,4960
Offset 0.10,HT,4960


Test 2-10
Indications Restricted From Burst Leak Tests
(Normalized to 615°F and 15 psi Secondary Pressure)
Leak Rate (gpm)
10.0000
1.0000
0.1000
0.0100
1600
1800
2000
2200
2400
2600
2800
Δp (psi)
Centered, HT
Freespan, HT
Offset .10,HT
Offset .10, RT
Centered,HT,3850
Offset 0.10,3850
Centered, HT, 4960
Offset 0.10,HT,4960

Test 2-10. Summary of Test Results
Specimen 2051B, Tube Dia. = 0.749", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
None	0.0 Step A	0°	0.551[3]	0.425[3]	N.A.[2]	0.0	N.A.[2]	0.750	0.748 0.749	1760[5]	0.19	540°F
		90°	0.0	0.0[3]	-	-	-	0.748	0.749 0.748	1823[5]	0.27	559°F
										1887[5]	0.35	561°F
										1924[5]	0.36	560°F
None	Free span Step B	-	-	-	-	-	-	-	-	1963[5]	0.42	553°F
										2095[5]	0.64	571°F
										2201[5]	0.84	584°F
None	0.10 Step C	-	-	-	-	~0.005	-	-	-	2198[5]	0.84	584°F
										2242[5]	0.91	586°F
None	0.10 Steps D & E	0°	0.554[3]	0.425[3]	N.A.[2]	~0.005	N.A.[2]	0.750	0.749 0.749	2154[5]	1.35	R.T.
		90°	0.0					0.748	0.748 0.748	2288[5]	1.56	R.T.

Test 2-10. Summary of Test Results
Specimen 2051B, Tube Dia. = 0.749", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
3850	0.0 Steps F&G	0°								2286[5]	0.84	634°F
		90°								2337[5]	0.85	648°F
										2455	1.39	636°F
3850	0.10 Step H	0°								2307	0.74	637°F
		90°								2439[5]	0.95	620°F
										2472[5]	0.91	630°F
4960	0.0 Steps I&J	0°								2146[5]	1.29	632°F
		90°								2178[5]	1.18	636°F
										2340[5]	1.37	619°F
										2366[5]	1.37	629°F
4960	0.10 Step K	0°								2145	1.29	636°F
		90°								2198[5]	1.40	611°F
										2346[5]	1.50	619°F

Test 2-10. Summary of Test Results
Specimen 2051B, Tube Dia. = 0.749", Gap = 0.025"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)

Notes:
1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.875" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Cracks are tight for specimens not pressurized with a bladder and TW area is not applicable.
3. Crack lengths from dye penetrant tests
4. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening ~0.001"
5. Single leak rate measurement. Other test results are an average of two measurements at comparable ΔPs.

TEST 4-1

Test 4-1: Summary of Test Results
Status - June 12, 1995

Test Status

- 7/8" diameter specimen with 0.24" TW, 0.67" OD by dye penetrant at start of test
  - After pressurization to approximate free span burst pressure of about 6000 psi, the specimen includes three TW cracks of lengths 0.606, 0.567 and 0.388 inch with maximum crack openings of about 0.020, 0.015 and 0.007 inch.
  - After pressurization to 8900 psi, the three TW lengths are 0.626, 0.603 and 0.408 inch with maximum crack openings of 0.022, 0.018 and 0.009 inch. The maximum tube diameters inside the TSP have nearly closed the entire tube to TSP gap.
- Test completed include cold leak tests following bladder pressurizations of 5800 psi (estimated free span burst pressure) with crack inside TSP, 6000 psi with 0.15" offset, and at 0.15" offset at pressures of 6800, 7725 and 8900 psi
- Tests to be performed are a hot leak test after 8900 psi pressurization and an attempt at another pressurization step at about 9900 psi although the indication could have a free span burst during this latter step.

Summary of Test Results

- Leak rates with the crack within the TSP decrease significantly (about 2.2 gpm at 5800 psi bladder pressure to about 0.8 gpm after 8900 psi at SLB ΔP = 2560 psid) with increasing bladder pressure as the increasing pressures progressively close the tube to TSP gap due to plastic deformation of the tube while crack opening areas only modestly increase.
  - After pressurization to 8900 psi, the crack faces contact the TSP ID over close to 0.6" of the 0.626" TW length. The two largest cracks are 180° from each other and both are bulged such that the gap flow area within the TSP is reduced for both cracks
- Leak rates with the crack offset 0.15" outside the TSP do not significantly change (slight decrease) with increasing bladder pressure
- Leak rates with 0.15" offset are about 3.3 gpm at SLB conditions or about 50% higher than for the crack within the TSP
  - Two throughwall cracks are exposed outside the TSP and contribute to the higher leak rate with the 0.15" offset
- The crack opening TW area following pressurization is less than the geometric minimum flow area from the tube in the TSP as developed in WCAP-14273
  - Tube to TSP contact at the crack face limits the crack opening area
  - Leak rate governed more by crack area than geometry - maximum TW width is 0.022" compared to geometrically possible $\pi \cdot c$ = 0.072"

Test 4-1: Summary of Test Results
Status - June 12, 1995

Overall Conclusions

- SLB leak rates for this indication with multiple throughwall cracks up to 0.61" TW after bladder pressurization to about the free span burst pressure are bounded by about 3.3 gpm with 0.15" offset and about 2.2 gpm for the crack within the TSP
- Crack opening areas are limited by the tube to TSP gap following contact of the crack face with the TSP ID and the associated areas are less than the minimum geometric flow area formed by the gap
  - WCAP-14273 model overestimates the flow area and leak rate
- Bladder pressurizations above the free span burst pressure do not result in increasing leak rates
  - Therefore, it is not necessary to include bladder pressurizations above the free span burst pressure in tests following Test 4-1
  - The principal effect of further increases in bladder pressure is to close the tube to TSP gap within the TSP due to plastic deformation of the tube diameter

Test Plan for (IRBs)
Test 4-1

General Test Information

- Utilize large leak test facility
- Test 7/8" diameter specimen 4B 214
  - Crack length: Dye Penetrant - 0.67" with 0.24" TW; UT - 0.74" with 0.50" TW
- Leak test at room temperature except as specifically noted
- Tube to TSP diametral gap of 0.025" except per adjustments noted
- Tubes shall be free to move within TSP during pressurization or, as a minimum, the tube shall contact the TSP hole at 180° from the crack being leak tested.

Test Sequence

A. Pressurize to 5800 psid with a bladder
- If tube is loose in TSP following pressurization, replace TSP to obtain about 0.001" diametral clearance between the maximum diameter of the crack opening and the TSP hole. This requirement applies following all bladder pressurizations of this test sequence.

B. Room temperature leak test at 2335, 2560 psi ΔP

C. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length). Estimate corrosion throughwall length.

D. Move crack to 0.15" outside TSP and pressurize to the same pressure as step A
- Move tube by 0.15" relative to the TSP

E. Room temperature leak test at 2335, 2560 psi ΔP. If high temperature facility is available, repeat leak test at 615°F.

F. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length).

G. With the 0.15" crack position, pressurize with a bladder (and foil if necessary) to about 1000 psi above the prior pressurization step

H. Room temperature leak test at 2335, 2560 psi ΔP

I. Repeat steps G and H with increases in bladder pressure of 1000 psi increments until bladder/foil pressurization of about 9000 psi is achieved

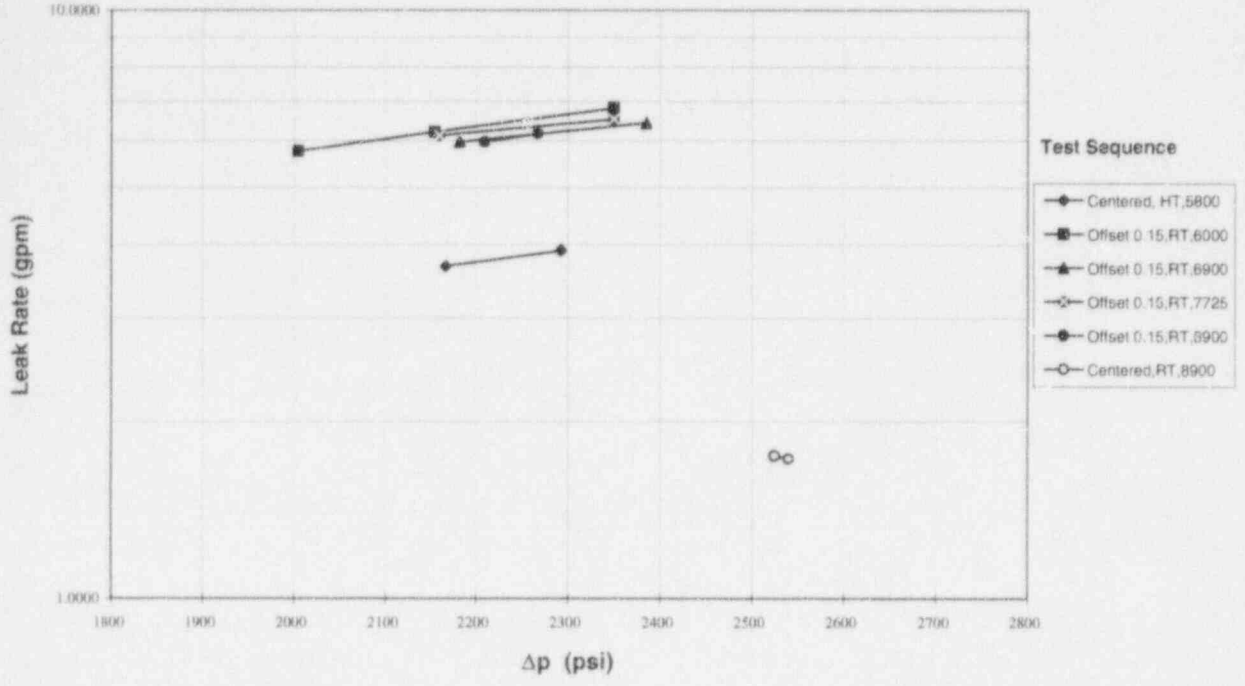
J. At bladder pressurization of about 8900 psi, also perform R.T. leak test with crack centered in the TSP

K. At bladder pressurization of about 8900 psi, perform hot (≥615°F) leak test with crack tip 0.15 inch offset from the edge of the TSP

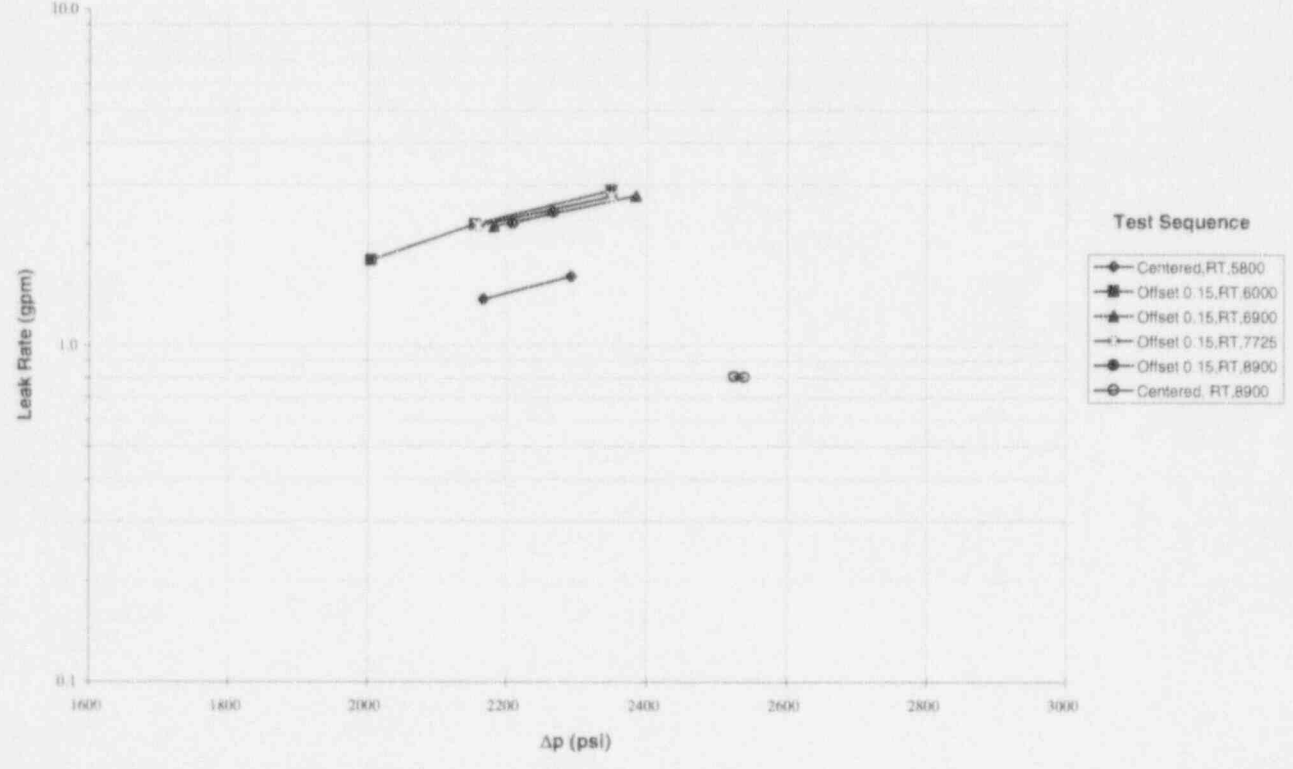
L. Continue bladder pressurization increases in about 1000 psi increments (initially about 9900 psi) and perform either room temperature or hot leak tests (option to increase facility efficiency) at 2335 and 2560 psi with 0.15 inch offset following each pressurization step. Terminate testing when the indication bursts outside the TSP.

M. Measure crack opening length, diameter, area and evaluate crack tearing extension (beyond corrosion crack length). Measure throughwall corrosion length and corrosion depth verus length profile.

Test 4-1
Indications Restrained From Burst Leak Rate Tests
(as-measured, without adjustment to reference conditions)



Test 4-1
Indications Restricted From Burst Leak Rate Tests
(Normalized to Tp=615°F and ps=15 psia Conditions)



Test 4-1 Summary of Test Results
Specimen 4B-214, Tube Dia. = 0.876", Gap = 0.023"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
5800	0 0	90°	0.650[2]	0.0	Tight	0.0	0.0	0.901	0.875 0.878	2168	3.68	R.T.
		270°	0.670[2]	0.24[2]	Tight	0.0	0.0			2293	3.91	R.T.
		0°	0.610[2]	0.0		0.0	0.0	0.893	0.882 0.883			
		180°	0.590[2]	0.0		0.0	0.0					
		45°-225°	Crack lengths following bladder pressurization are approximately the same as those measured after 0.15" offset test					0.897	0.885 0.887			
		135°-315°						0.896	0.886 0.886			
6000	0.15	90°	0.665	0.606 (0.020W)	0.0099	0.099 (0.013W)	0.0011	0.901	>0.875 0.871	2155	6.21	R.T.
		270°	0.676	0.567 (0.015W)	0.0067	0.112 (0.009W)	0.0008			2350	6.81	R.T.
		0°	0.606	0.388 (0.007W)	0.0022	0.0	0.0	0.893	>0.882 0.881			
		180°	0.583	0.0	0.0	0.0	0.0					
		45°-225°						0.897	>0.885 0.881			
		135°-315°						0.896	>0.886 0.881			
6800	0.15	Not Measured								2183	5.97	R.T.

Test 4-1 Summary of Test Results
Specimen 4B-214, Tube Dia. = 0.876", Gap = 0.023"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
										2385	6.44	R.T.
7725	0.15	Not Measured								2160	6.12	R.T.
										2350	6.54	R.T.
8900	0.15	90°	0.668	0.626 (0.022W)	0.0125	0.133 (0.013W)	0.0017	0.901	0.898 0.877	2210	5.97	R.T.
		270°	0.680	0.603 (0.018W)	0.0090	0.122 (0.010W)	0.0010			2403	6.18	R.T.
		0°	0.717	0.408 (0.009W)	0.0030	0.0	0.0	0.895	0.895 0.888			
		180°	0.583	0.0	0.0	0.0	0.0					
		45°-225°						0.899	0.896 0.884			
		135°-315°						0.900	0.897 0.887			
8900	0.0	90°	Same as for 8900 psi bladder pressure with 0.015" offset			0.0	0.0	0.901	0.879 0.880	2335	1.66	R.T.
		270°				0.0	0.0			2533	1.75	R.T.
		0°				0.0	0.0	0.895	0.889 0.888			
		180°				0.0	0.0					
		45°-225°						0.899	0.890 0.889			

Test 4-1 Summary of Test Results
Specimen 4B-214, Tube Dia. = 0.876", Gap = 0.023"

Bladder Pressure (psi)	Tube Offset (in.)	Angle	Total Crack Length (in.)	Total TW Length (Max. Width) (in.)	Total TW Area (in^2)	Exposed TW Length (Max. Width) (in.)	Exposed TW Area (in^2)	Max. Dia. (in.)	Min. Dia. (in.) Note 1	Leak Rate Test Results		
										ΔP (psi)	Rate (gpm)	Temp. (°F)
		135°-315°						0.900	0.894 0.893			
8900	0.015	Same as above for 8900 psi bladder pressure with 0.15" offset								2005	1.48	615°F
										2560	1.94	615°F
										2335		Adj. to Ref. ΔP @ 615°F
										2560		
										2335		R.T. adj. to 615° Note 2
										2560		

Notes: 1. Diameters given are approximately the values at the two edges of the TSP. Diameters greater than the initial 0.876" diameter indicate bulging of the tube at the edges of the TSP as a result of the tube pressurization.
2. Crack lengths from dye penetrant measurements prior to bladder pressurization.
3. Crack lengths from toolmaker's microscope. Minimum measurable TW crack opening -0.001".

References

1. M. Lynch letter to D. Farrar dated March 24, 1995, transmitting the Nuclear Regulatory Commission comments on Commonwealth Edison's Company Proposed Test Program for Steam Generator Tube Indications Restricted from Burst.

2. D. Saccomando letter to NRC dated March 20, 1995, transmitting Information Regarding Questions Pertaining to Increased Interim Plugging Criteria.

3. D. Saccomando letter to the Nuclear Regulatory Commission dated March 15, 1995, transmitting Commonwealth Edison's response to the Nuclear Regulatory Commission Concerns as Documented in Meeting Summary dated March 14, 1995.

4. M. Lynch letter to D. Farrar dated March 14, 1995, transmitting a Meeting Summary from the February 23, 1995, NRC/ComEd Meeting.

5. WCAP-14273 (Proprietary), "Technical Support for Alternate Plugging Criteria with Tube Expansion at Tube Support Plate Intersections for Braidwood-1 and Byron-1 Model D-4 Steam Generators, " Westinghouse Electric Corporation, February 1995.

6. D. Saccomando letter to NRC dated April 3, 1995, transmitting ComEd's proposed test program for IRB testing.

7. D. Saccomando letter to NRC dated May 25, 1995, transmitting information regarding leak rate test program.

Attachment 2

Leak Rate Methodology

Comparison of Freespan and IRB Leak Rates

The information contained in this Attachment supersedes information contained in Sections 9.7 and 9.8 of WCAP-14273, Reference 1. Information has been previously presented to the NRC (ComEd/NRC meetings on April 11, 1995 and May 9, 1995) on the effect of including *indication restricted from burst* (IRB) leak rates in the 95% confidence estimate for the total leak rate to be expected from TSP indications in a SG experiencing a postulated SLB event at the end of the operating cycle. The conclusion of comparisons of simulations with and without consideration of IRBs is that the expected total leak rates at a 95% confidence level are very similar. The effect of IRBs with a 3.0 volts repair limit was also evaluated until the time of SG replacement (Braidwood 1 in the Fall of 1998, and Byron 1 in the Spring of 1999), and the results indicate a trend of similar total leak rates, i.e., the inclusion of consideration of IRBs has a small effect on the predicted total leak rate. Although this may seem to be inconsistent with the concept of an IRB, it is not. The explanation for this phenomenon is discussed in the following paragraphs.

Figure 1 illustrates the correlations of the median and average (adjusted for the PoL) leak rates to indication bobbin amplitudes for 3/4" diameter Alloy 600 SG tubes in Westinghouse type SGs. Also illustrated is a plot of the regression equation one-sided prediction bound leak rate at a prediction level equal to the probability that the indication does not experience a burst, i.e., one minus the probability of burst (PoB), as a function of the bobbin amplitude. Finally, the limiting fixed, i.e., independent of voltage, leak rate for IRBs, as supported by the results of the current leak testing program, is also illustrated (the heavy horizontal line at 1067 lph). A comparison of the latter two curves indicates that it is more likely to simulate higher leak rates for high voltage indications from the leak rate to volts correlation than it is by using the IRB leak rate in conjunction with the probability of burst. Also, from Figure 1, the average free span leak rate from a 22 volt indication is equal to the bounding IRB leak rate.

The probability of burst used in this comparison is deterministically estimated as described in Reference 1, i.e., the statistic

$$t_{SLB} = \frac{P_B - P_{SLB}}{\sigma_P}, \qquad (1)$$

is assumed to be distributed as a Student's t distribution, where P_B is the estimated burst pressure from the regression of burst pressure on bobbin amplitude, P_{SLB} is the steam line break pressure (2560 psi), and σ_P is the standard error of the predicted burst pressure obtained from the standard error of the regression and the standard deviation of the material properties. The probability of burst is then

obtained as

$$\mathrm{PoB} = \Pr\{t \geq t_{SLB} \mid dof\}. \tag{2}$$

where *dof* is the degrees for freedom from the regression of the burst pressure on the bobbin amplitude. The *expected* leak rate from each potential IRB, with the *predicted* leak rate for an IRB being Q_0, is,

$$Q_{IRB} = \mathrm{PoB} \cdot Q_0, \qquad \textit{(Expected)} \tag{3}$$

where Q_0 is estimated for IRBs from the leak rate testing. The expected leak rate from a *potential* IRB, which includes the effect of PoB, is considered to be conservative, even though it is based on a deterministic estimate rather than on the Monte Carlo simulations, per the discussion in Section 9.4 of Reference 1.

For a specific indication amplitude, the predicted and expected leak rates from a burst tube can be compared to the corresponding leak rates from the free span correlation at the same probability level. Using the degrees of freedom, ν, from the leak rate as a function of volts correlation, a (1-PoB)·100 % prediction bound on the leak rate from an indication that leaks is obtained as,

$$Q_{1-\mathrm{PoB}} = Q_{\mu} \cdot 10^{t_{1-\mathrm{PoB},\nu}\,\sigma_e}, \tag{4}$$

where Q_μ is the predicted leak rate from the regression equation, and σ_e is the effective standard error of the regression (adjusted for the standard error of the coefficients of the regression). The predicted (1-PoB)·100% leak rate from the indication would be $\mathrm{PoL}\cdot Q_{1-\mathrm{PoB}}$, and the expected, or average, leak rate from each indication of a large number of indications at the same voltage level is then found as,

$$Q_{FS} = \mathrm{PoB} \cdot \mathrm{PoL} \cdot Q_{1-\mathrm{PoB}}, \qquad \textit{(Expected)} \tag{5}$$

where PoL is the probability of leak of the indication. For example, the probability of burst of a 6 volt indication is conservatively estimated as 0.0027. For a constant predicted IRB leak rate, Q_0, of 1067 lph (4.7 gpm), the expected leak rate from the indication is 2.85 lph. The probability that the tube does not burst is 0.9973. A 99.73% prediction bound on the leak rate from a single indication that leaks is 949 lph. The probability of leak of the same indication is 0.822, thus the predicted leak rate from the indication is 780 lph. Since the likelihood of experiencing a leak rate greater than or equal to this value is 0.0027, the expected leak rate from the indication is estimated as 2.08 lph. Table 1 and Table 2 list the predicted and expected IRB leak rates, Q_{IRB}, and the expected correlation leak rates, Q_{FS}, for

several indication bobbin amplitudes. Figure 2 illustrates a comparison of the correlation expected leak rate as a function of the IRB expected leak rate for a range of bobbin amplitudes from 4.75 volts to approximately 63 volts. From Table 1, the predicted leak rate from a 7.8 volt IRB is 1067 lph, while. from Table 2, the expected leak rate from a 7.8 volt indication is 7.8 lph. The expected freespan leak rate at the same probability of occurrence as a burst, 0.0073, is also 7.8 lph. Thus, for a 7.8 volt indication, a predicted leak rate of 1067 lph is as likely to occur as a result of predicting the leak rate from the correlation of leak rate to bobbin amplitude as it is from predicting the leak rate based on the likelihood of experiencing an IRB.

It could be argued, if the probability of predicting large leak rates from single indications using the free span correlation is approximately the same as the probability of predicting large leak rates from IRBs, then the simulation of many such indications should lead to an approximate doubling of the expected leak rate. Hence, it would be expected that simulation leak rates based on including special provisions for IRBs would be significantly higher than simulation rates without those provisions. However, recall that in the above comparison the PoB is being overestimated, perhaps by an order of magnitude at the lower voltage. Thus, the probability of not bursting is being underestimated, hence the (1-PoB)·100 % prediction bound from the correlation leak rate is also being underestimated. This means that a *true* comparison curve a la Figure 2 would be shifted to the left if also plotted on Figure 2. Hence the likelihood of predicting large leak rates based on the free span correlation is greater than the likelihood of predicting a large leak rate from an IRB. This reduces the effect of the contribution of leak rates from IRBs on the total leak rate. The Monte Carlo simulations have demonstrated this effect to be on the order of ~20% for the distribution of indications in the Braidwood 1 and Byron 1 SGs. For the application of IPC, this difference is not significant when comparing the predicted total leak rate at 95% confidence to the allowable leak rate based on radiological considerations. The implication of the comparison of the two curves is also that as the median amplitude of the population of indications increases, the absolute magnitude of the difference would be expected to be about the same, thus the relative magnitude of the difference would be expected to diminish. The trend of results from simulation projections supports this supposition. Hence, the inclusion of special provisions for the simulation of leak rates from IRBs is not necessary.

In conclusion, end of cycle 95% confidence bound total leak rates can be satisfactorily predicted using the free span leak rate correlation to the bobbin amplitude of the indications for the Braidwood 1 and Byron 1 SGs.

It is to be noted that this conclusion could be affected if the burst pressure as a function of volts and/or the leak rate as a function of volts correlation(s) changes significantly with regard to the regression curve parameters or the standard error of the regression. The most significant reason why the free span leak rate predic-

tions can exceed the IRB leak rate predictions is probably the magnitude of the standard error of the common logarithm of the leak rate about the regression line. Moreover, this evaluation would have to be revisited if any significant changes in the correlations' parameters changed.

References

1. WCAP-14273 (Proprietary), "Technical Support for Alternate Plugging Criteria with Tube Expansion at Tube Support Plate Intersections for Braidwood-1 and Byron-1 Model D4 Steam Generators," Westinghouse Electric Corporation, February, 1995.

TABLE 1: COMPARISON OF PREDICTED LEAK RATE FROM IRBS AND FREE SPAN ODSCC INDICATIONS						
Bobbin Volts	P_b (ksi)	PoB	Q_{IRB} (lph)	PoL	$Q_{1\text{-}PoB}$ (lph)	Q_{FS} (lph)
4.75	5.453	0.0010	1067	0.663	802	531
6.0	5.150	0.0027	1067	0.822	949	780
7.0	4.951	0.0049	1067	0.890	1065	948
7.8	4.811	0.0073	1067	0.923	1157	1070
10.0	4.488	0.0175	1067	0.968	1412	1367

TABLE 2: COMPARISON OF EXPECTED LEAK RATE FROM IRBS AND FREE SPAN ODSCC INDICATIONS						
Bobbin Volts	P_b (ksi)	PoB	Q_{IRB} (lph)	PoL	$Q_{1\text{-}PoB}$ (lph)	Q_{FS} (lph)
4.75	Values are the same as provided in Table 1		1.10	Values are the same as provided in Table 1		0.55
6.0			2.85			2.08
7.0			5.20			4.61
7.8			7.79			7.79
10.0			18.7			23.9

Figure 1: SLB Leak Rate vs. Bobbin Amplitude
3/4" x 0.043" Alloy 600 SG Tubes @ 650°F, ΔP = 2560 psi

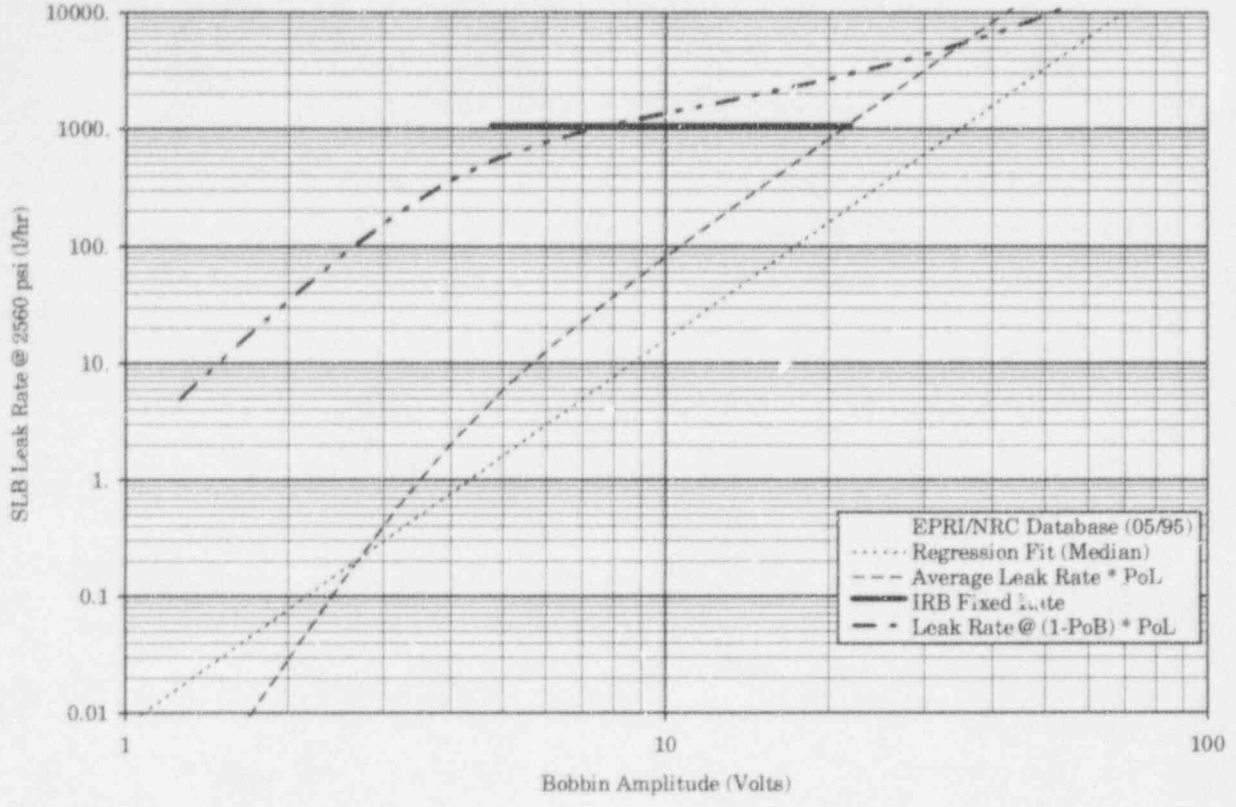


Figure 2: Correlation Leak Rate at (1-PoB) Prediction vs. the Fixed IRB Leak Rate Times the Probability of Burst