Alex Marion
DIRECTOR, ENGINEERING
NUCLEAR GENERATION DIVISION

February 17, 2003

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

SUBJECT: Steam Generator Degradation Specific Management Database, Addendum 5

PROJECT NUMBER: 689

Enclosure 1 to this letter transmits Addendum 5 to the Steam Generator Degradation Specific Management Database. This addendum provides a 2002 update to the NP-7480-L Addendum 4 database report (2001) for outside diameter stress corrosion cracking (ODSCC) at tube support plates. The revised databases are used to update the alternate repair criteria (ARC) correlations for burst pressure, probability of leakage and steam line break leak rate as a function of bobbin coil voltage for both 3/4 and 7/8 inch diameter tubing.

The overall content of this addendum is significantly extended to incorporate essentially all applicable prior information on updates to NDE techniques, ARC analysis methods and ARC programmatic information. The intent is to maintain the addenda as a self-standing document for data and methods changes since the release of Addendum 1 and NRC Generic Letter 95-05. Sections 5 and 6 include all data and correlations even if not revised from a prior addendum.

The NRC recently approved exclusion of the French tube data from the ODSCC ARC correlations. This change resulted in significant changes to the correlations for 7/8 inch tubing. Due to the significance of the changes in the 7/8 inch probability of leakage and steam line break leak rate correlations, the 7/8 inch correlations should be implemented in all new ARC analyses beginning with the spring 2003 outages. The changes to the 3/4 inch correlations are insignificant, but should be implemented no later than the spring 2003 outages.

Section 1 of the attached report explains additional changes incorporated into Addendum 5.

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The proprietary information in Addendum 5 is supported by the signed affidavits in Enclosure 2. The affidavits set forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity, the consideration listed in paragraph (b)(4) of Section 2.790 of the Commission's regulations. Accordingly, we respectfully request that the information, which is proprietary to EPRI, be withheld from public disclosure in accordance with 10 CFR 2.790. A non- proprietary version of these guidelines is provided in Enclosure 3.

As has been the past practice, we believe any NRC staff review of the enclosed information is exempt from the fee recovery provision contained in 10 CFR Part 170. This submittal provides information that might be helpful to NRC staff when evaluating licensee submittals provided in response to Generic Letter 95-05. Such reviews are exempted under §170.21, Schedule of Facility Fees. Footnote 4 to the Special Projects provision of §170.21 states, "Fees will not be assessed for requests/reports submitted to the NRC...as means of exchanging information between industry organizations and the NRC for the purpose of supporting generic regulatory improvements or efforts."

We would be pleased to meet with you or provide any support necessary to expedite acceptance of the outstanding issues regarding the database. If you have any questions regarding the technical content of this letter, please contact Dr. Govinda Srikantiah of EPRI at (650) 855-2109.

Sincerely,

Alex Marion

Alex Marion

JHR/
Enclosures

c: Ms. Louise Lund, U. S. Nuclear Regulatory Commission
Mr. Kenneth Karwoski, U. S. Nuclear Regulatory Commission
Ms. Helen Cothron, TVA
Mr. Greg Kammerdeiner, Duquesne Light
Mr. Richard Pearson, NSP
Mr. Rick Mullins, Southern Co
Mr. Ron Baker, South Texas
Mr. Bob Exner, PG&E
Mr. John Arhar, PG&E
Mr. Steve Swilley, TU

Mr. John Jensen, AEP
Mr. Tim Olsen, WPS
Mr. Tom Pitterle, Westinghouse
Mr. Bob Keating, Westinghouse
Dr. Govinda Srikantiah, EPRI

Enclosure 2

SG Degradation Specific Management Database Addendum 5

Proprietary Affidavits

ELECTRIFY THE WORLD

February 12, 2003

Mr. Gene Carpenter
Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Carpenter:

Subject: "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002 (Addendum 5)"

This is a request under 10CFR2.790(a)(4) that the NRC withhold from public disclosure the information identified in the enclosed affidavit consisting of EPRI owned proprietary information as identified above (the "Information"). A copy of the Information and the affidavit in support of this request are enclosed.

EPRI desires to disclose the Information in confidence to the NRC for informational purposes to assist the NRC. EPRI would welcome any discussions with the NRC related to the Information that the NRC desires to conduct.

The Information is for the NRC's internal use and may be used only for the purposes for which it is disclosed by EPRI. The Information should not be otherwise used or disclosed to any person outside the NRC without prior written permission from EPRI.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (650) 855-2997. Technical questions on the contents of the Information should be directed to Dr. Govinda Srikantiah (650) 855-2109.

Sincerely,

Theodore U. Marston, Ph.D.
Vice President & Chief Nuclear Officer

Enclosure

c: Dr. Govinda Srikantiah

EPRI

AFFIDAVIT

RE: "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002 (Addendum 5)"

I, Theodore U. Marston, being duly sworn, depose and state as follows:

I am a Vice President at the Electric Power Research Institute (EPRI) and I have been specifically delegated responsibility for the information listed above that is sought under this affidavit to be withheld (the "Information") and authorized to apply for their withholding on behalf of EPRI. This affidavit is submitted to the Nuclear Regulatory Commission ("NRC") pursuant to 10 CFR 2.790 (a)(4) based on the fact that the Information consists of trade secrets of EPRI and that the NRC will receive the Information from EPRI under privilege and in confidence.

The basis for withholding such Information from the public is set forth below:

(i) The Information has been held in confidence by EPRI, its owner. All those accepting copies of the Information must agree to preserve the confidentiality of the Information.

(ii) The Information is a type customarily held in confidence by EPRI and there is a rational basis therefore. The Information is a type, which EPRI considers as a trade secret(s) and is held in confidence by EPRI because to disclose it would prevent EPRI from licensing the material provided in the Information at fees, which would allow EPRI to recover its investment. If consultants and/or other businesses providing services in the electric/nuclear power industry were able to publicly obtain the Information, they would be able to use it commercially for profit and avoid spending the large amount of money that EPRI was required to spend in preparation of the Information. The rational basis that EPRI has for classifying this/these Information(s) as a trade secret(s) is justified by the Uniform Trade Secrets Act, which California adopted in 1984 and which as been adopted by over twenty states. The Uniform Trade Secrets Act defines a "trade secret" as follows:

"Trade secret" means information, including a formula, pattern, compilation, program, device, method, technique, or process, that:

(1) Derives independent economic value, actual or potential from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
(2) Is the subject of effort that are reasonable under the circumstances to maintain its secrecy.

EPRI

(iii) The Information will be transmitted to the NRC in confidence.

(iv) The Information is not available in public sources. EPRI developed the Information only after making a determination that the Information was not available from public sources. It required a large expenditure of dollars for EPRI to develop the Information. In addition, EPRI was required to use a large amount of time of EPRI employees. The money spent, plus the value of EPRI's staff time in preparing the Information , show that the Information is highly valuable to EPRI. Finally, the Information was developed only after a long period of effort of at least several months.

(v) A public disclosure of the Information would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Information both domestically and internationally. The Information can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated therein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3412 Hillview Avenue, Palo Alto, California being the premises and place of business of the Electric Power Research Institute:

February 12, 2003

Theodore U. Marston

Subscribed and sworn before me this day: February 12, 2003

Nichole Alexandra Edraos, Notary Public

NICHOLE ALEXANDRA EDRAOS
Comm # 1295461
NOTARY PUBLIC CALIFORNIA
Santa Clara County
My Comm. Expires Feb 26, 2005

SUBSCRIBING WITNESS JURAT

State of California
County of Santa Clara } SS.

On 2/12/03 (DATE), before me, the undersigned, a notary public for the state, personally appeared Barbara Jeanne Ryan (SUBSCRIBING WITNESS'S NAME), personally known to me (or proved to me on the oath of ____________ (CREDIBLE WITNESS'S NAME), who is personally known to me) to be the person whose name is subscribed to the within instrument, as a witness there to, who, being by me duly sworn, deposed and said that he/she was present and saw Theodore O. Marston (NAME(S) OF PRINCIPAL(S)) the same person(s) described in and whose name(s) is/are subscribed to the within and annexed instrument in his/her/their authorized capacity(ies) as (a) party(ies) thereto, execute the same, and that said affiant subscribed his/her name to the within instrument as a witness at the request of

Theodore O. Marston.
NAME(S) OF PRINCIPAL(S)

NICHOLE ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC CALIFORNIA
Santa Clara County
My Comm Expires Feb 26, 2005

WITNESS my hand and official seal.

Nichole Alexandra Edraos
NOTARY'S SIGNATURE

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The information below is optional. However, it may prove valuable and could prevent fraudulent attachment of this form to an unauthorized document.

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- ☐ SUBSCRIBING WITNESS
- ☐ OTHER: ____________

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SCIENCE AND TECHNOLOGY

EPRI

Certificate of Conformance

Date:	February 13, 2003
Customer:	U.S. Nuclear Regulatory Commission
Reference:	N/A
Purchase Order or Agreement Number: N/A	

EPSC/C.Handy
Responsible for Delivery

Product: **EPRI Report #1007660:**
Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Data base for Alternate Repair Limits, Update 2002, NP-7480-L, Addendum 5, Interim Report, January 2003
(Prepared by Westinghouse Electric Company, LLC)

The above item(s) were procured or developed in compliance with the Quality Assurance requirements of the EPRI Quality Program. The current version of the EPRI Quality Program Manual is Revision 5, dated July 19, 2002. Past and current revisions of EPRI's Quality Program are in compliance with 10CFR50 Appendix B.

Certified by: Colette M. Handy for RWO
Dr. Richard Oehlberg, QA Manager

2-13-03
Date

Form 1.2 1
Revision 2
11/07/00

CORPORATE HEADQUARTERS
3412 Hillview Avenue | P.O Box 10412 | Palo Alto | CA | 94303-0813 | USA
Tel 650 855 2000 | www.epri com

Enclosure 3

SG Degradation Specific Management Database
Addendum 5

Non-Proprietary Version

NON-PROPRIETARY

EPRI

Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits

Update 2002

LICENSED MATERIAL

Technical Report

Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits

Update 2002

1007660

Interim Report, November 2002

EPRI Project Manager
G. Srikantiah

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ORGANIZATIONS THAT PREPARED THIS REPORT

WESTINGHOUSE ELECTRIC COMPANY LLC NUCLEAR SERVICES DIVISION

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Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (510) 934-4212. There is no charge for reports requested by EPRI member utilities.

CITATIONS

This report was prepared by

Westinghouse electric company, LLC
Nuclear service division
P.O. box 158
Madison, PA 15663

Principal Investigators
T. A. Pitterle
R. F. Keating
V. Srinivas

This report describes research sponsored by EPRI and was prepared in accordance with the applicable provisions of 10CFR50 Appendix B.

This report is a corporate document that should be cited in the literature in the following manner:

Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002, EPRI, Palo Alto, CA: 2002, 1007660.

REPORT SUMMARY

The Addendum 5 to the outside diameter stress corrosion cracking (ODSCC) of steam generator tubes at support plate intersections report (NP-7480-L) updates and extends the database previously reported in Addendum 4 of the report.

BACKGROUND

The database required to support the alternate repair limits for outside diameter stress corrosion cracking (ODSCC) of steam generator tubes at support plate intersections has been developed from pulled tube examination results and tests of specimens produced in model boilers. Leak rate and burst pressure correlations with bobbin coil voltage have been developed from overall data. The database extensions and correlations have been reported in Addenda 1, 2, 3 and 4 as additional tube pull data became available

OBJECTIVES

To extend the ODSCC database previously reported in Addendum 4 using pulled tube data from two plants for 7/8 inch tubing, and to update the correlations for burst pressure and probability of leak. An additional objective was to include in this addendum all the previously approved revisions to the ARC program, databases and analysis methods, and prior utility recommended updates to ARC analysis methods and data applications that were reported in the previous addenda.

APPROACH

Researchers evaluated pulled tube data from two plants with 7/8 inch diameter tubes against EPRI data exclusion criteria and added those data not excluded to the database. Using the modified database they updated correlations for burst pressure, probability of leakage and steam line break (SLB) leak rate. They evaluated the model boiler, Belgian and French datasets against the domestic pulled tube data to develop data exclusion criteria for evaluating datasets against the domestic pulled tube data relative to the potential for leakage at high voltages.

RESULTS

Researchers performed tests on pulled tube specimens and obtained burst pressure and leakage rate data. They evaluated the data against the EPRI exclusion criteria to select data that can be included for updating the database. They also updated the pulled tube database for field NDD indications, and the voltage-dependent probability of prior cycle detection (POPCD) by adding results from 7 additional inspection evaluations.

They developed a data exclusion criterion to compare the French data against domestic pulled tube data. Based on the NRC approval of this criterion, the French data could be excluded from the ARC correlations based on showing a much lower potential for leakage at high voltages (above 5 volts) than the domestic pulled tube data. ARC correlations with and without the French data are given in the report. Also included in this report is a documentation of the industry recommended program for tube pulls in support of the voltage based ARC as approved by the NRC.

EPRI PERSPECTIVE

Degradation of tubes at support plate intersections is one of the dominant tube degradation mechanisms in PWR steam generators. Alternate repair criteria were developed based upon eddy current data to replace the more restrictive criteria based on percent through-wall penetration of the degradation (EPRI TR-100407). The ODSCC database developed to support the alternate repair criteria is updated as more pulled tube data became available from the utilities using these criteria. The current report describes database update #5 and revised correlations based on the recent pulled tube data. An additional feature of this report is the inclusion of all the previously approved revisions to the ARC program, databases and analysis methods, as well as the prior utility recommended updates to ARC analysis methods and data applications.

The overall content of this addendum is significantly extended to incorporate essentially all applicable prior information on updates to NDE techniques, ARC analysis methods and ARC programmatic information. The intent is to maintain the addenda as a self-standing document for data and methods changes since the release of Addendum 1 and NRC Generic Letter 95-05.

ABSTRACT

This Addendum 5 to report NP-7480-L updates and extends the database for outside diameter stress corrosion cracking at tube support plates previously reported in Addendum 4 of the report. Pulled tube data from two plants for 7/8 inch tubing are added to the database, and the French data are removed from the 7/8 inch tubing database based on NRC approval for this data exclusion. The ARC correlations for burst pressure, probability of leakage and SLB leak rate are updated to reflect these changes. The updated 7/8 inch ARC correlations can be expected to significantly affect SLB leak rate analyses and to have a modest effect on burst probability analyses. There are no new pulled tube data for 3/4 inch tubing although the correlations are updated to remove a data point that should have previously been excluded from the correlations. The updated 3/4 inch correlations are not significantly different from the Addendum 4 correlations. In addition, the voltage-dependent probability of detection (POPCD) is updated by adding results from 8 additional inspection evaluations to include a total of 37 inspections. There is very little change in the resulting POD distribution.

The overall content of this addendum is significantly extended to incorporate essentially all applicable prior information on updates to NDE techniques, ARC analysis methods and ARC programmatic information. The intent is to maintain the addenda as a self-standing document for data and methods changes since the release of Addendum 1 and NRC Generic Letter 95-05. A new section is added to document NRC approved changes to the ARC databases, analysis methods and program. For example, this section includes the protocol for updating the ARC correlations, the tube removal requirements, changes to the database such as excluding the French data and revisions to the analysis methods such as techniques for leak rate analyses. A new section is also added to include industry recommended changes to the ARC databases, analysis methods and program that are either details below the level required for NRC approval or recommended only for sensitivity analyses. This section incorporates information from prior addenda and does not include new recommendations, which are included within the prior section format. Examples included in this section are techniques for calibrating NDE standards against the reference standard, methods for obtaining bobbin voltages for indications found by

RPC in less than 5 volt dents, growth rate data for deplugged tube indications and analysis methods for voltage dependent growth rates.

LIST OF ACRONYMS

ARC	Alternate Plugging Criteria
ASME	American Society of Mechanical Engineers
AVT	All Volatile Treatment
CSA	Cross-Sectional Area
DoF	Degrees of Freedom
EdF	Electricitie de France
EDM	Electro-Deposition Machining
EDS	Energy Dispersive Spectroscopy
EOC	End of Cycle
EPRI	Electric Power Research Institute
FDB	Flow Distribution Baffle
FS	Free Span
ICC	Intergranular Cellular Corrosion
IGA	Intergranular Attack
IGSCC	Intergranular Stress Corrosion Cracking
LTL	Lower Tolerance Limit
MBM	Manufacturing Buff Mark
NDE	Nondestructive Examination
NDD	No Degradation Detected
NRC	Nuclear Regulatory Commission
OD	Outside Diameter
ODSCC	Outside Diameter Stress Corrosion Cracking
POD	Probability of Detection
PoL	Probability of Leak
POPCD	Probability of Prior Cycle Detection
PoR	Probability of Rupture
RG	Regulatory Guide
RPC	Rotating Pancake Coil
RSS	Residual Sum of Squares
RT	Room Temperature
SEM	Scanning Electron Microscope
SD	Standard Deviation
SG	Steam Generator
SLB	Steam Line Burst
TEM	Transmission Electron Microscope

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1

INTRODUCTION

This addendum provides a 2002 update to the NP-7480-L Addendum 4 database report (2001) for outside diameter stress corrosion cracking at tube support plates. Specifically, the databases for 7/8 inch are significantly updated by this Addendum 5. In addition, the format of this addendum and future addenda is modified to establish each addendum as a self-standing document independent of prior addenda by including NRC approved changes to the ARC databases, methods and program as well as applicable information from prior addenda.

Pulled tube data from two plants with 7/8 inch tubes are added to the database (Sections 4 and 5). The data are evaluated against the EPRI data exclusion criteria and indications not excluded on this basis are included in the ARC database and correlations. The NRC has approved exclusion of the French data from the ARC correlations, which also leads to significant changes in the ARC correlations for 7/8 inch tubing. One 3/4 inch and one 7/8 inch indication are excluded from the database based on a 1997 NRC recommendation on interpretation of exclusion Criterion 2a that was inadvertently not previously applied to the database. Exclusion of these two indications had no significant impact on the correlations. No additional destructive examination results are available for intersections at TSPs that had no detectable degradation in the field inspection. No new test results have been obtained for the forces required for axial tensile tearing of cellular indications, and the correlations of Addendum 2 remain applicable for axial tensile tearing.

The revised databases are used to update the ARC correlations (Section 6) for burst pressure, probability of leakage and SLB leak rate as a function of bobbin coil voltage for both 3/4 and 7/8 inch diameter tubing. Due to the significance of the changes in the 7/8 inch probability of leakage and SLB leak rate correlations, the 7/8 inch correlations should be implemented in all new ARC analyses beginning with the fall 2002 outages. The changes to the 3/4 inch correlations are insignificant, but should be implemented no later than the spring 2003 outages.

An update to the Addendum 4 recommended probability of detection as a function of bobbin voltage is also developed in Section 7 for use in ARC supporting analyses for end of cycle voltage distribution projections. The recommended POD is developed from field inspection results since 1993 for inspections implementing the ARC for ODSCC at TSP intersections. The POD development uses results of one inspection to evaluate the POD at the prior inspection and is called the probability of prior cycle detection. Very little change is found in the updated POD which includes thirty-seven inspections from thirteen plants in contrast to the Addendum 4 twenty-nine inspections.

No new updates to methodology supporting ARC applications are recommended in this addendum. Section 8 of this addenda is provided only to maintain uniformity in the addenda format.

The overall content of this addendum is significantly extended to incorporate essentially all applicable prior information on updates to NDE techniques, ARC analysis methods and ARC programmatic information. The intent is to maintain the addenda as a self-standing document for data and methods changes since the release of Addendum 1 and NRC Generic Letter 95-05. Sections 5 and 6 include all data and correlations even if not revised from a prior addendum. Section 9 is a new section documenting NRC approved changes to the ARC databases, analysis methods and program. For example, this section includes the protocol for updating the ARC correlations, the tube removal requirements, changes to the database such as excluding the French data and revisions to the analysis methods such as techniques for leak rate analyses. Section 10 is a new section that includes industry recommended changes to the ARC databases, analysis methods and program that are either details below the level required for NRC approval or recommended only for sensitivity analyses. This section incorporates information from prior addenda and does not include new recommendations, which would be included in Section 8 when applicable. Examples of the industry recommendations below the level requiring NRC approval are techniques for calibrating NDE standards against the reference standard, methods for obtaining bobbin voltages for indications found by RPC in less than 5 volt dents and growth rate data for deplugged tube indications. ARC analysis methods for voltage dependent growth rates are provided for sensitivity analyses to assess the influence of voltage dependence if found in the growth rate data. Since voltage independent growth rate methods are defined in GL 95-05, NRC approval would be required to apply voltage dependent growth analyses for the reference ARC analyses in operational assessments.

2

SUMMARY AND CONCLUSIONS

2.1 Updated Database and Correlations for 3/4 Inch Diameter Tubing

The database report for 3/4 inch diameter tubing of Addendum 4 of NP 7480-L (Reference 2-1) was based on laboratory and pulled tube data available to 1999. No 3/4" diameter tubes were pulled for destructive examination since the preparation of Addendum 4. In a 1997 NRC request for additional information, the NRC recommended that EPRI data exclusion Criterion 2a be applied to all indications independent of the position of the burst pressure relative to the burst pressure regression line. In the response to this RAI, it was agreed that Criterion 2a would be applied independent of whether the burst pressure was high relative to the burst pressure correlation, and that the 1994 pulled tube indication from Plant AB-1, tube R20C07 TSP 5 would be excluded from the ARC database based on the revised interpretation of Criterion 2a. Inadvertently, this indication was not previously excluded from the database, but is excluded by this update to the database. All evaluations of pulled tube indications against exclusion Criterion 2a were reevaluated, and no additional 3/4" indications were found to be excluded per Criterion 2a. The 3/4" correlations in Section 6 are revised to exclude the R20C07 TSP 5 indication although there is no significant change to the correlations since the indication was on the regression line of the correlation.

2.2 Updated Database and Correlations for 7/8 Inch Diameter Tubing

This report updates the database for 7/8 inch diameter tubing given in Addendum 4 of NP 7480-L (Reference 2-1) and for the NRC approved exclusion of the French data from the correlations. One tube was pulled in 2001 from Plant P-1 and one tube in 2002 from Plant W-2. Voltages for the two indications from the Plant P-1 tubes included in the ARC correlations are 1.29 and 5.30 volts. Three indications removed from Plant W-2 had voltages of 0.44, 0.95 and 3.35 volts. No other 7/8" diameter tubes were pulled for destructive examination since the preparation of Addendum 4.

Each of the two pulled tubes had one indication with significant leakage for addition to the SLB leak rate correlations. The pulled tube data were incorporated into updated burst pressure, probability of leakage and leak rate versus bobbin coil voltage correlations for ARC applications. Evaluation of data for inclusion in the correlations is consistent with the EPRI data exclusion criteria. In addition, the NRC approved exclusion of the French data from the ARC database subject to updating the bases for excluding the data with each future addendum. In addition, the 7/8 inch data in prior addenda were reviewed against the revised interpretation of exclusion Criterion 2a as discussed in Section 2.1 above. This review led to the exclusion of Plant W-2, 1996 pulled tube indication R8C60 TSP-2 although this exclusion had no significant influence on the ARC correlations. Changes in the ARC correlations based on the additional pulled tube data and exclusion of the French data can be expected to significantly affect SLB leak rate analyses and to have a modest effect on burst probability analyses. The net effect of the changes on the SLB structural limit, including using 95%/95% lower tolerance limit material properties, is to decrease the limit from 9.09 volts in Addendum 4 to 7.67 volts with a safety factor of 1.4 applied to a SLB pressure differential of 2560 psi. For a SLB pressure differential of 2405 psi, the corresponding reduction in the structural limit is from 11.41 to 9.62 volts.

2.3 Supplemental Test Data

There is no new information on pulled tube destructive examination results for intersections at TSPs that had no reportable degradation (NDD) in the field inspection. No additional data has been obtained since Addendum 2 to update pulled tube test data for the forces required for axial tensile rupture of cellular ODSCC indications or for burst data on indications pressurized inside a TSP. The available data from prior addenda are included in Section 5 for complete documentation of the EPRI database.

The field NDD results are provided to demonstrate the size of indications that may not be detected in a field inspection. There are 259 field bobbin indications that have been destructively examined. The maximum crack depth of any field bobbin NDD indication is only 62%. These results strongly support adequate detection of ODSCC indications and imply a high POD at significant voltages, consistent with the voltage dependent POD developed in this report. Burst pressures were obtained with the lowest burst pressure of 9,063 psi which shows a negligible decrease compared to a typical value of about 10,500 psi for undegraded tubing.

2.4 Recommended Probability of Detection (POD)

The Addendum 4 recommended POD as a function of bobbin voltage is updated based on evaluation of additional inspection results from plants implementing the ARC for ODSCC at TSP intersections. This POD development utilizes extensive experience integrated over thirty-seven (increased from twenty-nine in Addendum 4) ARC inspections and thus uses historical ARC operating experience as the basis for the recommended POD. Inspection results from SGs with both 3/4 and 7/8 inch diameter tubing are used to obtain the POD. The development uses the POPCD based on the ratio of indications reported at the prior inspection to the total indications (reported in prior cycle plus new indications) found at the subsequent inspection. The resulting POD ranges from about 0.2 at 0.1 volt to about 0.9 at 1.4 volts and 1.0 at 3.5 volts. Although the database for evaluating POPCD has increased by about 35% for 7/8 inch tubing since the Addendum 4 evaluation, there is very little change in the resulting POD distribution from that in Addendum 4. The recommended POD is in good agreement with an EPRI POD developed using multiple analysts to evaluate a large number of field indications with "truth" for indications based on "expert" opinion.

2.5 NDE, Analysis Methods and Program Updates

Section 8 has no new recommendations on updates to NDE techniques or analysis methods supporting ARC applications, and Section 8 is included only to maintain the report format. New sections are added in this report to document NRC approved changes (Section 9) since GL 95-05 and to document industry recommended changes (Section 10) below the level requiring NRC approval, as previously reported in prior addenda. The NRC approved program changes include the protocol for updating the database and the tube pull requirements. NRC approved database changes include the EPRI data exclusion criteria and exclusion of the French data from the ARC database. NRC approved analysis methods include approval of the ARC Monte Carlo methods, clarification of the confidence level required for a correlation and methods for including the confidence level (p-value) for a correlation in the leak rate analyses. The industry recommendations in Section 10 include determination of bobbin voltages for indications detected only by RPC inspection, NDE techniques for cross calibration of ASME standards to the reference standard, voltage dependent growth rate methods and growth rate data for deplugged tubes returned to service. Section 10 is intended to maintain information from prior addenda and new industry recommendations would be included in Section 8.

2.6 References

2-1 NP-7480-L, Addendum 4, 2001 Database Update, "Steam Generator Tubing ODSCC at Tube Support Plates Database for Alternate Repair Limits, Database Update 2001" prepared for EPRI by Westinghouse (August 2001).

3

EVALUATION OF PULLED TUBE DATA FOR 3/4 INCH DIAMETER TUBING

This section is provided for updates to the 3/4" tubing database. There are no new pulled tubes since Addendum 4.

In the 1997 NRC request for additional information in Reference 3-1, the NRC recommended that EPRI data exclusion Criterion 2a be applied to all indications independent of the position of the burst pressure relative to the burst pressure regression line. In the Reference 3-2 response to this RAI, it was agreed that Criterion 2a would be applied independent of whether the burst pressure was high relative to the burst pressure correlation, and that the 1994 pulled tube indication from Plant AB-1, tube R20C07 TSP 5 would be excluded from the ARC database based on the revised interpretation of Criterion 2a. Inadvertently, this indication was not previously excluded from the database, but is excluded by this update to the database. All evaluations of pulled tube indications against exclusion Criterion 2a were reevaluated, and no additional 3/4" indications were found to be excluded per Criterion 2a. The 3/4" correlations in Section 6 are revised to exclude the R20C07 TSP 5 indication although there is no significant change to the correlations since the indication occurred on the regression line of the correlation.

References

3-1 NRC Letter, "Request for Additional Information Regarding NP 7480-L, Addendum 1, 'Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits, 1996 Database Update, November 1996," S. L. Magruder (NRC) to D. Modeen (NEI), January 24, 1997.

3-2 NEI Letter, "Phase I Response to Request for Additional Information Regarding NP 7480-L, Addendum 1, 'Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits, 1996 Database Update, November 1996," David J. Modeen (NEI) to Steward L. Magruder (NRC), April 2, 1997.

4

EVALUATION OF PULLED TUBE DATA FOR 7/8 INCH DIAMETER TUBING

This section provides an update of the database for 7/8″ diameter tubing based on pulled tube examinations completed since the preparation of Addendum 4 of this report. Additional pulled tube data were obtained from Plant P-1 and Plant W-2. In addition, NRC approval was obtained to exclude the French data, as described in Section 9.4 from the ARC correlations in Section 6.

In the 1997 NRC request for additional information in Reference 4-1, the NRC recommended that EPRI data exclusion Criterion 2a be applied to all indications independent of the position of the burst pressure relative to the burst pressure regression line. In the Reference 4-2 response to this RAI, it was agreed that Criterion 2a would be applied independent of whether the burst pressure was high relative to the burst pressure correlation. All evaluations of pulled tube indications against exclusion Criterion 2a were reevaluated. This reevaluation led to the need to exclude Plant W-2, pulled tube indication R8C60 TSP-2 from the ARC correlations, which is therefore excluded by this update to the database. The 7/8″ correlations in Section 6 are revised to exclude this indication.

4.1 Plant P-1 2001 Pulled Tube

4.1.1 Tube Examination Summary

A section of hot leg tube was removed from Plant P-1, R15 C62, SG C. The tube cut was located approximately 6″ below the 03H support, thus the TSP 1 and TSP 2 intersections were removed for examination. Bobbin DSI indications and +Pt axial OD indications were reported at both TSP intersections. The tube was pulled after chemical cleaning of the SGs that included both a bulk removal process targeted at removal of OD deposits on the tube freespan sections and top of tubesheet region and an additional process targeted towards cleaning of the TSP crevices. The principal results of the tube examination (Reference 4-3) are described in this section.

Non Destructive Examination

A summary of the field and laboratory eddy current results for this tube is provided in Table 4-1. Similar probes were used in the laboratory as in the field, namely a 0.720″ diameter bobbin probe and 0.720″ diameter +Pt probe. Reviews of the field analysis results produced essentially equal results as the original field calls with bobbin voltages for the TSP 1 indication ranging between 5.04 and the field call of 5.30 volts. The laboratory NDE of the post-pull tube sections indicated substantial flaw amplitude response increases for both the bobbin and +Pt coils. Figure 4-1 shows the field +Point terrain plot for the TSP 1 intersection. The intersection is dominated by a substantial axial indication with a second smaller parallel axial indication in close proximity to the dominant flaw. Figure 4-2 presents the field and laboratory +Point amplitude plot for the dominant TSP 1 flaw. The +Point profiles indicate that a significant flaw amplitude increase occurred at the lower end of the flaw, possibly due to damage that occurred during pulling of the tube. The reported pre-pull and post-pull +Point amplitudes are 2.94 volts and 4.55 volts, respectively. Figure 4-3 presents the field and laboratory depth plot for the dominant flaw based on NDE phase angle analyses and includes the corrosion depth profile from destructive examination. The pre-pull +Point NDE depth profile for the 01H elevation indicates a length of 0.65", maximum depth of 88%TW, and an average depth of 62%TW. The depth profile evaluation from SEM examination indicates a 100% TW length due to corrosion of 0.252". Using the depth from phase angle, the predicted pre-pull burst pressure for a flow stress of 76.73 ksi is 5612 psi. For the post-pull +Pt depth profile, the predicted burst pressure from phase is 4615 psi, which is in good agreement with the measured burst pressure as discussed below.

Figure 4-2 suggests that for the portion of the flaw above the centerline of the TSP, the pre-pull and post pull voltage plots are coincident, while below the centerline of the TSP, the voltage profiles are significantly different. The peak amplitude above the centerline of the TSP is consistent with 100%TW degradation; however, this area appears not to have been affected. Below the centerline of the TSP, the large amplitude increase (1.5 to 4.5 volts) at ≈ -0.13" may involve tearing of a <100%TW depth section, thus producing such a large change in response. The +Pt amplitude response is increased with increasing 100% TW length, however if only one throughwall crack were involved, the point of peak amplitude would be expected at the center of the flaw. In this case, the large amplitude response appears to have occurred at one end of the 100% TW length. Comparison of the pre-pull and post pull depth profiles in Figure 4-3 show that the depth estimates between about the TSP centerline and 0.25" below the TSP centerline are significantly increased for the post-pull case, again suggesting that a potential change in the 100% TW length of the flaw occurred. Figures 4-2 and 4-3 overlay the corrosion depth profile obtained from SEM analysis over the voltage and depth from phase plots. These figures show that the post-pull maximum +Point flaw amplitude and maximum depths are obtained outside of the corrosion depth profile indicating 100% TW degradation.

Figure 4-4 presents a photograph of the burst opening of the TSP 1 region of R15C62. The burst opening appears to be comprised principally of two offset axial cracks separated by a ligament in the circumferential direction. The dominant crack appears to extend downward from the top of the TSP by about 0.5", with a second parallel axial crack extending up from the bottom the TSP, and with a ligament separating the two cracks by about 25 mils. The ligament appears to be located at about 0.15" below the center of the TSP and appears to coincide with the peak +Point flaw amplitude observed in the post-pull eddy current data. Thus, this ligament was likely torn by the tube pull operation and led to the large increase in +Point flaw amplitude at this location.

Based on the significant drop in predicted burst pressure from pre-pull to post pull conditions using the phase/depth analysis profile, and the apparent increase in 100% TW length from pre-pull to post-pull conditions, it is probable that damage such as ligament tearing to the TSP 1 intersection occurred during the tube pull operations. Table 4-3 presents a summary of the above sizing data for the phase based model in comparison with the destructive examination results.

Destructive Examination

Following NDE of the as-received tube sections, elevated temperature (600°F) leakage testing was performed for the TSP 1 and TSP 2 intersections of R15 C62. The testing program included holds at the normal operating pressure differential, intermediate test pressure between normal operating pressure differential and SLB, and SLB pressure differential. For the TSP 2 indication, no leakage was reported for any test pressure. For the 01H intersection, leakage was reported at the normal operating pressure differential, although quite low, and for all test pressures beyond. Between about 2200 psi and 2480 psi, a ligament likely tore, thus producing an order of magnitude increase in leak rate for these two pressure differentials. Table 4-4 presents the leak rate test results for the elevated temperature leak rate testing of the TSP 1 intersection. The leak testing for the TSP 1 indication suggests that ductile tearing of a ligament likely occurred between 2200 and 2480 psi, resulting in a large leak rate increase from 0.013 gpm to 0.11 gpm. Table 4-5 provides the destructive exam depth profile and location of uncorroded ligaments. There are three uncorroded ligaments within the 100% deep section and another ligament near the 92% depth location. These ligaments, located near and below the TSP centerline, likely tore during the tube removal and leak testing operations.

Following elevated temperature leak testing, room temperature burst testing was conducted for the TSP 1 region, TSP 2 region, and freespan region of the tube. Pressurization rate was limited to 200 psi/second during the burst test. All burst testing was performed in a freespan mode, i.e., no TSP restraint was provided. The lowest burst pressure was reported for the TSP 1 region, at 4741 psi. The TSP 2 region burst at 8640 psi. The freespan burst pressure was greater than 10,000 psi. All burst openings were axially oriented.

The yield and ultimate strength values were determined using a tensile test for a freespan section of the pulled tube. The yield strength was 48.463 ksi, ultimate strength was 104.997 ksi, for a flow stress (sum of yield + ultimate divided by 2) of 76.73 ksi. The mean room temperature flow stress for 7/8" OD x 0.050" nominal wall mill annealed Alloy 600 tubing is 75.47 ksi, thus the flow stress of the pulled tube R15C62 is only 1.7% higher than the average flow stress for all 7/8" OD tubing.

Figure 4-5 provides sketches of the crack networks for the indications at TSPs 1 and 2. For the TSP 1 indication, the OD cracking was confined to one major patch area of the tube, extending essentially the entire axial length of the TSP and extending circumferentially for about 60 to 90° of arc. This patch was located azimuthally between about –45° to +45° from the designated 0° location. The burst opening of the TSP 1 indication was not located within areas of heavy deposits. The TSP 1 and TSP 2 crevice regions of SG C, R15C62 had OD intergranular corrosion. The predominant degradation mode is characterized as axial ODSCC. As seen in Figure 4-5, there are cellular corrosion components adjacent to the burst openings for both indications that include oblique cracking at depths less than the dominant axially oriented corrosion. Radial grinds were performed to assess the depth of the oblique cracking. For TSP 1, two sections were examined and the oblique cracking became negligible between the 20% and 44% depth grinds for one section and between the 60% and 80% depth grinds for the second section. For TSP 2, the oblique crack was negligible at a 26% depth grind.

4.1.2 Plant P-1 Pulled Tube Evaluation for ARC Applications

The pulled tube examination results were evaluated for application to the EPRI database for ARC applications. The data for incorporation into the EPRI database were then defined and reviewed against the EPRI data exclusion criteria to provide acceptability for the database.

Eddy Current Data Review

Table 4-1 provides a summary of the eddy current data evaluations for the Plant P-1 pulled tube. The field and laboratory reevaluations of the field bobbin data are in good agreement for the indications. The post-pull laboratory inspection results show a 71% increase in bobbin amplitude and a 52% increase in +Pt amplitude for the TSP 1 intersection. The TSP 2 intersection shows the bobbin amplitude was increased by nearly a factor of 3. As discussed above, these increases tend to indicate that some ligaments likely tore during the tube pulling operation.

Plant P-1 Data for ARC Applications

The pulled tube leak test, burst test and destructive examination results are summarized in Table 4-2. The leak rate data in Table 4-2 are adjusted to reference SLB conditions based on applying the EPRI leak rate adjustment procedure of Reference 4-4 to the measured data of Table 4-4.

The Plant P-1 pulled tube results were evaluated against the EPRI data exclusion criteria of Section 9.3 for potential exclusions from the database. Criteria 1a to 1e apply primarily to unacceptable voltage, burst or leak rate measurements and indications without leak test measurements. Data exclusion Criterion 1d provides for tube damage from tube pull forces, but requires that supporting analyses show that the uncorroded ligaments would not have torn under SLB conditions. The uncorroded ligaments for the TSP 1 indication are shown in Table 4-5. It is expected that the ligaments within and near the 100% TW section tore during the tube removal and leak testing operations. Figure 4-4 shows that the indication was slightly oblique (i.e., not completely axial). During the tube pull, a 35 ksi break away force was required to pull the tube, which is 73% of the yield strength of the tubing. It is likely that the tube pull forces would have damaged some of the 10 ligaments that were present in the crack. However, it is not possible to demonstrate that the uncorroded ligaments would not have torn under SLB conditions, and the indication cannot be excluded from the database. Similarly, there is no basis to exclude the TSP 2 indication based on the exclusion Criterion 1d. Criterion 2a applies to atypical ligament morphology and states that indications with ≤ 2 uncorroded ligaments in shallow cracks < 60% deep shall be excluded from the database. Table 4-2 identifies the number of remaining ligaments and the maximum depths for the indications. The TSP 1 indication is too deep for application of Criterion 2a. The TSP 2 indication is 60% deep with 2 uncorroded ligaments. Since the TSP 2 indication depth is 60% rather than < 60%, exclusion criterion 2a is marginally not applicable to these pulled tube specimens. Criterion 3 applies to potential errors in the leakage measurements and is not applicable to the indications since there are no known issues associated with the leakage measurements.

As shown in the last column of Table 4-2, the TSP 1 indication of R15C62 is to be included in the probability of leakage, leak rate and burst correlations. The TSP 2 indication of R15C62 is to be included in the probability of leakage and burst correlations.

4.2 Plant W-2 2002 Pulled Tube

4.2.1 Tube Examination Summary

One tube was removed from the hot leg side of SG-4 of Plant W-2 (R12C45) and examined (Reference 4-5) at the Westinghouse Science and Technology Center in support of the 2 volt ARC application. The examination was conducted to characterize corrosion at the steam generator TSP crevice locations. The first, second and third TSP crevice regions (TSP 1 to TSP 3) were removed from R12C45. Field eddy current inspection prior to the tube removal identified an OD indications by both the bobbin and +Point coils at all three TSP intersections.

Non Destructive Examination

A summary of the field and laboratory eddy current results for this tube is provided in Table 4-6. Similar probes were used in the laboratory as in the field, namely a 0.720" diameter bobbin probe and 0.720" diameter +Pt probe. The reevaluated bobbin coils were made to eliminate contributions from the mixed residuals, and resulted in slightly lower bobbin voltages than the field calls for the first two TSPs. The field calls are more typical of the ARC peak-to-peak voltage analysis guidelines and are used for the ARC database. For the +Point analyses, the principal difference between the field and field reanalysis is that the reanalysis identified more indications around the circumference of the tube. The terrain plots for the +Point and pancake coils from the field data are shown in Figure 4-6. The pancake coil response shows an overall sine wave pattern that is attributable to variations in the wall thickness resulting from eccentricity in the tube. The OD variation is only about 3 mils but the variation in the ID is about 8 mils leading to corresponding variations in the wall thickness. This wall thickness variation is much larger than generally found in Westinghouse tubing and may have had some influence on burst and leakage test results.

The laboratory NDE of the post-pull TSP 1 intersection shows flaw amplitude response increases by a factor of two for both the bobbin and +Pt coils. The laboratory +Point response shows more characteristics of cellular corrosion than the field data, which suggests opening of cellular corrosion by the axial stresses from the tube removal operations. The post-pull bobbin data for TSP 2 was distorted by a tube removal artifact and a meaningful voltage could not be assigned to the indication although the flaw was detectable.

Destructive Examination

Following NDE of the as-received tube sections, the three TSP intersections were helium leak tested at 400 psi. Only the TSP 1 intersection was found to leak in the helium leak tests. Based on these results together with the low voltages and NDE depths for the TSP 2 and TSP 3 intersections, only the TSP 1 intersection was leak tested at operating temperature conditions. The conclusion that leak testing was not required for TSPs 2 and 3 is supported by the maximum depths found by destructive examination of 71% and 62%, respectively. The testing program included holds at the normal operating pressure differential, intermediate test pressure between normal operating pressure differential and SLB, and SLB pressure differential. For the TSP 1 intersection, leakage was reported at the normal operating pressure differential, although quite low, with the leak rates tending to increase exponentially with increasing pressure differential. Table 4-8 presents the leak rate test results for the elevated temperature leak rate testing of the TSP 1 intersection.

Following elevated temperature leak testing, room temperature burst testing was conducted for the 01H, 02H, 03H and freespan regions of the tube. Pressurization rate was limited to 200 psi/second during the burst test. All burst testing was performed in a freespan mode, i.e., no TSP restraint was provided. The lowest burst pressure was reported for the TSP 1 region, at 5391 psi. The TSP 2 and TSP 3 regions burst at 6579 and 8237 psi, respectively. The freespan burst pressure was greater than 11,000 psi. All burst openings were axially oriented.

The yield and ultimate strength values were determined based on two tensile tests for freespan sections of the pulled tube. The two measurements, with differences of less than 1.5 ksi, were average to obtain the recommended material properties. The room temperature yield strength was 58.5 ksi, ultimate strength was 110.2 ksi, for a flow stress (sum of yield + ultimate divided by 2) of 84.35 ksi. The mean room temperature flow stress for 7/8" OD x 0.050" nominal wall mill annealed Alloy 600 tubing is 75.47 ksi, thus the flow stress of the pulled tube R15C62 is about 12% higher than the average flow stress for all 7/8" OD tubing.

Following the burst testing, the visible OD crack networks were sketched as shown in Figure 4-7 for TSPs 1 to 3. The crack networks show axial and cellular corrosion patches around the burst openings. The burst opening for the TSP 1 indication shows that a second crack (referred to as left face in later discussion) was opened over the upper half of the TSP as a result of the burst test pressurization. The presence of two, very closely spaced cracks may have contributed to the lower than expected burst pressure for the 3.35 volt indication at TSP 1. The sketch for TSP 3 shows slight cracking within the TSP at installation scratches that extended outside the TSP. The gray area for TSP 3 in the figure represents deposits that remained after the burst tests.

Crack depths were obtained by fractography for the burst openings. Both of the indications contributing to the burst opening for TSP 1 were depth profiled with the profiles given in Tables 4-9 (left face) and 4-10 (right face). The depth profile for the left face of the TSP 1 indication has a total crack length of 0.625 inch that includes a throughwall length of about 0.197 inch starting just below the centerline of the TSP. The right face with a total crack length of 0.619 inch has two throughwall lengths of about 0.084 and 0.071 inch length. Both crack faces were found to have five uncorroded ligaments with one ligament within the 100% depth location. If the uncorroded ligaments within the 100% depth region tore during the tube pull, the tearing of the ligaments would help to explain the large voltage increase between the pre-pull and post-pull voltages. The ligaments within the 100% depth region can be expected to have torn prior to SLB conditions in the leak test in order to contribute to the relatively large leak rate found for this indication. The measured leak rates are much larger (about a factor of 10) than expected as a sum of leakage for both cracks assuming that all depths > 90% were throughwall by the time the specimen reached SLB conditions. The measured leak rates are even larger than calculated assuming that the length between the throughwall sections of the right crack face (Table 4-10) tore at SLB conditions.

The maximum depths for the TSP2 and TSP 3 indications were 71% and 62%, respectively. Both indications had 10 uncorroded ligaments within the burst opening length. The crack lengths were 0.750 inch for TSP 2 and 0.743 inch for TSP 2. Both of these indications appear, based on best estimates for the TSP edge locations, to extend up to the edges of the TSP but remain within the TSP.

In summary, all of the burst macrocracks were composed of numerous axial intergranular microcracks with at numerous ledges separating the microcracks having ductile features, indicating their tearing during the burst test if not during the tube pull or leak testing. The OD intergranular corrosion present at the TSP locations was typical of that in the EPRI database gathered in support of ARC.

4.2.2 Plant W-2 Pulled Tube Evaluation for ARC Applications

The pulled tube examination results were evaluated for application to the EPRI database for ARC applications. The eddy current data were reviewed, including reevaluation of the field data, to finalize the voltages assigned to the indications. The data for incorporation into the EPRI database were then defined and reviewed against the EPRI data exclusion criteria to provide acceptability for the database.

Eddy Current Data Review

Table 4-6 provides a summary of the eddy current data evaluations for the Plant P-1 pulled tube. The field and laboratory reevaluations of the field bobbin data are in good agreement for the indications. The post-pull laboratory inspection results show factors of two increases in the bobbin and +Point amplitudes for the TSP 1 intersection. No significant increases in the amplitudes were found in the post-pull data for the TSPs 2 and 3 indications that had no throughwall corrosion. As discussed above, the amplitude increases for TSP 1 tend to indicate that some ligaments likely tore during the tube pulling operation.

Plant W-2 Data for ARC Applications

The pulled tube leak test, burst test and destructive examination results are summarized in Table 4-7. The leak rate data in Table 4-7 are adjusted to reference SLB conditions based on applying the EPRI leak rate adjustment procedure of Reference 4-4 to the measured data of Table 4-8.

The Plant W-2 pulled tube results were evaluated against the EPRI data exclusion criteria of Section 9.3 for potential exclusions from the database. Criteria 1a to 1e apply primarily to unacceptable voltage, burst or leak rate measurements and indications without leak test measurements. Data exclusion Criterion 1d provides for tube damage from tube pull forces, but requires that supporting analyses show that the uncorroded ligaments would not have torn under SLB conditions. The uncorroded ligaments for the 01H indications are shown in Tables 4-9 and 4-10. It is expected that the ligaments within and near the 100% TW sections tore during the tube removal to contribute to the large voltage increase for the post-pull data. Figure 4-6 shows that the burst opening included slightly oblique (i.e., not completely axial) cracking. It is likely that the tube pull forces would have damaged some of the ligaments that were present in the crack. However, it is not possible to demonstrate that the uncorroded ligaments would not have torn under SLB conditions, and the indication cannot be excluded from the database. Similarly, there is no basis to exclude the TSP 1 and TSP 2 indications based on the exclusion Criterion 1d. Criterion 2a applies to atypical ligament morphology and states that indications with ≤ 2 uncorroded ligaments in shallow cracks < 60% deep shall be excluded from the database. Table 4-6 identifies the number of remaining ligaments and the maximum depths for the indications. The TSP 1 and TSP 2 indications are too deep for application of Criterion 2a. The shallower TSP 3 indication is 62% deep with 10 uncorroded ligaments, and exclusion Criterion 2a is not applicable to these pulled tube specimens. Criterion 3 applies to potential errors in the leakage measurements and is not applicable to the indications since there are no known issues associated with the leakage measurements.

As shown in the last column of Table 4-6, the TSP 1 indication of R15C62 is to be included in the probability of leakage, leak rate and burst pressure correlations. The TSP 1 and TSP 2 indications of R12C45 are to be included in the probability of leakage and burst correlations.

4.3 References

4-1. NRC Letter, "Request for Additional Information Regarding NP 7480-L, Addendum 1, 'Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits, 1996 Database Update, November 1996," S. L. Magruder (NRC) to D. Modeen (NEI), January 24, 1997.

4-2. NEI Letter, "Phase I Response to Request for Additional Information Regarding NP 7480-L, Addendum 1, 'Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits, 1996 Database Update, November 1996," David J. Modeen (NEI) to Steward L. Magruder (NRC), April 2, 1997.

4-3. SG-SGDA-02-19, "Beaver Valley Unit 1 Steam Generator Tube Examination", April 2002, Westinghouse Electric Company

4-4. EPRI Report NP-7480-L, Volume 1, Revision 2, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates – Database for Alternate Repair Limits, Volume 1: 7/8 Inch Diameter Tubing", Appendix B, August 1996

4-5. Magee, T. P., Westinghouse, Private Communication, Tube Examination Report in Progress

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Tube	TSP	[redacted]		[redacted]			[redacted]	
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Table 4-2. Plant P-1 2001 Pulled Tube Data for ARC Applications

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Table 4-5

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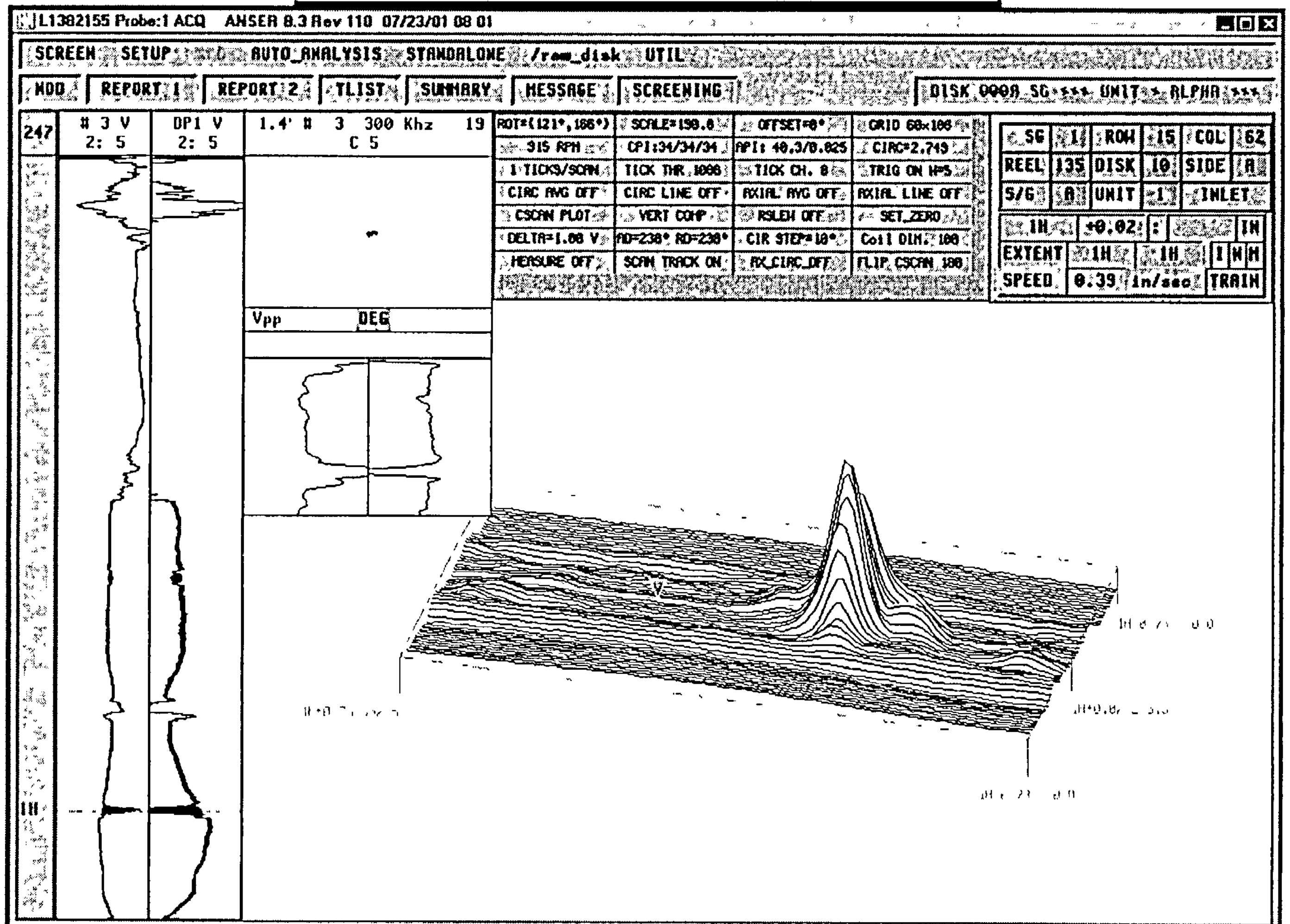
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Figure 4-2

Figure 4-3

Figure 4-4
Post Burst Photograph of R15 C62, 01H TSP

Figure 4-5. Sketches of Visible OD Cracking at TSPs 1 and 2 of Plant P-1 Pulled Tube R15C62

Figure 4-6
Field +Point Coil (Upper Figure) and 115 Pancake Coil (Lower Figure) Terrain Plots for R12C45, 01H TSP, SG 4

Figure 4-7. Sketches of Visible OD Cracking at TSPs 1 to 3 of Pulled Tube R12C45

5

UPDATED ARC DATABASES

This section presents updated databases obtained by adding the pulled tube specimen data obtained in 2001 and 2002 to the Addendum 4 database presented in Reference 5-1. The databases for 3/4" diameter tubes and 7/8" diameter are discussed separately below. The new data added to the database are described in detail in Sections 3 and 4. The updated database presented have been utilized to develop updated ARC correlations for probability of leakage, leak rate, tube burst probability and axial rupture force presented in the next section (Section 6).

The database shows adjusted leak rates corresponding to two Δps: 2405 psi and 2560 psi. The data at 2405 psi Δp are applicable to a plant whose Tech Spec allows credit for operability of SG power operated relief valve (PORV) under accident conditions in accordance with GL 95-05. As in the past data, leak rates at 2560 psi Δp are applicable when no credit can be taken for SG PORV operability.

5.1 3/4" Data

The database for 3/4" diameter tubes has been revised in Table 5-1 to exclude the 1994 pulled tube indication for Plant AB-1, R20C07 TSP 5 as described in Section 3. This change affects (negligible changes) only the burst pressure and probability of leak correlations.

The database shown in Table 5-1 includes adjusted leak rate at two accident condition pressure differentials of 2405 psi and 2650 psi. The leak rate values were obtained using the same leak rate adjustment procedure as described in Reference 5-3. Leak rate data at 2405 psi Δp are applicable to plants for which credit can be taken for operability of SG PORV in the design-basis accident analyses.

5.2 7/8" Data

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5.3 Data for Burst Inside the TSP

No new tests have performed since 1995 to measure burst pressure for crack indications inside the TSP. Therefore, no changes are needed to the current version of this database since Addendum 1, Reference 5-2. The data from Addendum 1 are included as Table 5-3.

5.4 Data for Axial Tensile Tearing

No new data have become available for axial tensile tearing of cellular corrosion at TSP intersections. A summary of all of the applicable data through Addendum 4 (Reference 5-1) is provided in Table 5-4.

5.5 Summary of Field NDD Data

No new indications that were called NDD in the field have been obtained since Addendum 4. The Addendum 4 database for field NDD indications is included as Table 5-5. The total number of indications in the database is 259. The maximum crack depth for the database is 62%, and the lowest measured burst pressure in the database is 9,063 psi. The database strongly supports the conclusion that ODSCC indications at TSP intersections not detected by the bobbin inspection are not structurally significant and would not contribute to SLB leakage or burst probability.

5.6 References

5-1 Addendum to EPRI Report NP-7480-L (Report TR-113861), "Steam Generator Tubing ODSCC at Tube Support Plates for Alternate Repair Limits, Database Update 2001", August 2002.

5-2 Addendum 1 to EPRI Report, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates – Database for Alternate Repair Limits, NP-7480-L, August 1996.

Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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Table 5-1
3/4 Inch Diameter Pulled and Model Boiler Tube Leak Rate and Burst Pressure Measurements

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6

UPDATED ARC CORRELATIONS

This section reports on evaluations performed of results obtained from leak rate and burst testing of tubes removed from operating SGs at utility sites after the publication of Addendum 4 to the ARC database in 2001. The original database for the structural and leak analyses of ODSCC indications was documented in References 6-1 and 6-2 for 7/8" and 3/4" diameter SG tubes respectively. Modifications and additions to the database for both sizes of tubes were reported in References 6-3, -4, -5 and -6 (Addenda 1, 2, 3 and 4), and further in Sections 3, 4 and 5 of this report. The specific use of the data is also delineated in Section 5 of this report. Table 6-1 provides the number of additional pulled tube data points obtained since Addendum 4 of this report was issued in 2001. In addition, one 3/4" and one 7/8" pulled tube indications were excluded based on applying the NRC recommended interpretation of exclusion Criterion 2a as discussed in Sections 3 and 4. In summary, separate correlations are developed for Westinghouse designed SGs with drilled hole TSPs which employ 3/4 and 7/8" nominal diameter tubes which relate the burst pressure, the probability of leak (POL), and the leak rate to the bobbin inspection amplitude for ODSCC at locations where degradation has occurred. It has also been postulated that axial tensile tearing of the tube could be of concern if the extent of the degradation were to become extreme in the circumferential direction. For this reason, a correlation has been developed between the axial tensile tearing strength and the magnitude of the bobbin amplitude. Each of the correlations is discussed in the following sections.

Reference Database of 3/4" Diameter SG Tubes. There were no new data for nominal 3/4" diameter SG tubes. However, pulled tube indication from Plant AB1, tube R20C7 TSP5 was excluded based on Criterion 2a as discussed in Section 3. The parameters for the regression correlation equations are updated to reflect this change in the database.

Reference Database of 7/8" Diameter SG Tubes. A discussion of the additional data for 7/8" diameter tubes is provided in Section 4 of this report. The reference database for 7/8" diameter SG tubes is that of Addendum 4, Reference 6-6. [redacted]

[redacted]

Reference Database of Axial Tensile Tearing. The database has not been changed from that which was documented in Addendum 2 to References 6-1 and 6-2 as no additional data have been obtained since then. Therefore, the axial, or tensile, tearing correlation. reported in Addendum 2 remain valid.

6.1 3/4" Diameter Tubes Data Analysis

This section reports on the evaluations of data obtained from leak and burst testing of Alloy 600 MA SG tubes with a nominal OD of 3/4" and a nominal thickness of 0.043".

6.1.1 Free Span Burst Correlation for 3/4" Tubes

The only change to the 3/4" burst pressure database is the exclusion of Plant AB1, tube R20C7 TSP 5 based on application of the NRC recommended interpretation of exclusion Criterion 2a to the prior database.. Figure 6-1 shows all of the burst pressure data in the database for 3/4" tubes along with the latest burst pressure correlation and the lower 95th percentile prediction line. The regression parameters for the latest burst correlation are shown in Table 6-2.

The current SLB structural limits based on 95%/95% lower tolerance limit material properties are shown in Figure 6-1. The structural limit for a SLB differential pressure of 2405 psi is 5.67 volts. The corresponding limit for a SLB differential pressure of 2560 psi is 4.85 volts. Figure 6-2 shows the probability of burst distribution for the above two SLB differential pressure values.

6.1.2 Probability of Leak Correlation for 3/4" Tubes

The only change to the 3/4" burst pressure database is the exclusion of Plant AB1, tube R20C7 TSP 5 based on application of the NRC recommended interpretation of exclusion Criterion 2a to the prior database. Figure 6-3 shows all of the data used to establish the current POL distribution for 3/4" tubes. Also shown in this figure are the latest POL correlation based on a *Generalized Linear Model* and the lower 90th percentile confidence line. The regression parameters for the latest POL correlation for 3/4" tubes are shown in Table 6-3.

6.1.3 Free Span SLB Leak Rate Correlation for 3/4" Tubes

There were no data added to the leak rate database since Addendum-3 report (Reference 6-5) was issued. Hence, the leak rate data and correlation parameters presented here for 3/4" tubes are same as those in Reference 6.5. Figure 6-4 shows all of the data used to establish the latest leak rate correlation for a SLB differential pressure of 2560 psi, and Figure 6-5 shows the corresponding data for 2405 psi SLB differential pressure. The regression parameters for the latest leak rate correlations for 3/4" tubes are shown in Tables 6-4 (2560 psi) and 6-5 (2405 psi)

6.1.4 General Conclusions Regarding 3/4" Data

The changes to the correlation parameters due to the exclusion of one data point are negligible.

6.2 7/8" Diameter Tubes Data Analysis

This section reports on the evaluations of data obtained from leak and burst testing of Alloy 600 MA SG tubes with a nominal diameter of 0.875" and a nominal thickness of 0.050".

6.2.1 Free Span Burst Correlation for 7/8" Tubes

The reference burst pressure database used in this report for 7/8" tubes consisted of the data from Addendum 4 (Reference 6-6) excluding the pulled tube indication from Plant W2, R8C60 TSP 2 based on applying the NRC recommended interpretation of exclusion Criterion 2a as discussed in Section 4. There are no EdF data in the Addendum 4 burst pressure correlation. The results from the five (5) additional burst tests (see Table 6-1) performed on tube specimens that exhibited non-zero bobbin amplitude at a TSP elevation location, were evaluated. A plot of the burst pressures of the additional specimens is depicted on Figure 6-6 relative to the burst pressure correlation developed using the reference database and relative to a two-sided tolerance band to contain 90% of the population of burst pressures (leaving 5% in each of the upper and lower tails) at a confidence level of 95%.

A visual examination of the data relative to the EPRI database indicates that the burst pressures measured fall within the scatter band defined by the Addendum 4 data. However, one data point from Plant P1 and the three data points from Plant W2 fall along the lower bound of the data. The other P1 data point is in the middle of the data. Four of the five new data points fall below the 90%/95% tolerance interval about the regression line.

[redacted]

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[1] Prediction bounds bracket a specified number of future observations while tolerance bounds bracket a specified portion of the population.

Although slightly lower than the expected value, there is no significant implication associated with the values, and they were quite repeatable.

In addition to the statistical evaluation, the prior data from both plants were examined to further address the potential implication that a departure from the reference database might be indicated. These are also illustrated on [redacted]. It is clear from the visual examination of that data that there is no systematic behavior indicated for the tubes from either plant. It was also judged that comparison on a SG by SG basis would not be meaningful.

Since the additional burst pressure data were not indicated to be from a separate population from the reference data, the regression analysis of the burst pressure on the common logarithm of the bobbin amplitude was repeated with the additional data included. A comparison of the regression results obtained by including these data in the regression analysis is provided in [redacted]6. Regression predictions obtained by including these data in the regression analysis are shown on Figure 6-7. A summary of the changes to the burst pressure correlation is as follows:

1. [redacted]

[redacted]

[redacted]

The scatter of the residuals relative to the predicted values continues to be nondescript and a standard normal plot of the residuals does not indicate a departure from normality. Neither of these are illustrated herein because the purpose is only to verify that the assumptions inherent in performing the regression analysis are not violated.

The net effect of the changes on the SLB structural limit ($1.4 \cdot \Delta P_{SLB}$), using 95%/95% lower tolerance limit material properties, is to lower it by 15%, i.e., from 9.05 to 7.67 V for a SLB differential pressure of 2560 psi. The corresponding structural limit for a SLB differential pressure of 2405 psi decreased from 11.34 to 9.62 V. Since the decrease is mainly due to the increase in the standard error, the probability of burst would be expected to increase. The probability of burst of a single indication was calculated as a function of bobbin amplitude using the reference database and the updated database. The results of the calculation are illustrated on [redacted]8 and [redacted]9 for SLB differential pressures of 2560 and 2405 psi respectively. It may be observed from these figures that the probability of burst is increased very slightly for all indications.

6.2.2 Probability of Leak Correlation

The additional data were examined relative to the reference correlation for the POL as a function of the common logarithm of the bobbin amplitude. The comparison is based on excluding the EdF data from both correlations to make the comparisons meaningful. The effect of the EdF data on the POL function was significant as described in Reference 6-6. [redacted]10 illustrates the new data relative to the reference correlation where the reference correlation is the Addendum 4 correlation without the EdF data and excluding the W2 R8C60 TSP 2 indication based on exclusion Criterion 2a. The specimens exhibited POL behavior commensurate with their bobbin amplitudes. Examination of the figure leads to the conclusion that the three smaller indications would not be expected to leak during a postulated SLB event. Two of the indications had a signal amplitude of < 1V and the third had an amplitude of 1.3V with a POL of about 0.01. None of these indications exhibited leakage. The largest indication had a amplitude of 5.3V with an Addendum 4 POL of nearly 0.5 and it did exhibit leakage. The next to the largest indication had an amplitude of 3.35V with an attendant POL of 0.17. This indication exhibited leakage. The probabilities are such that there is no indication of irregular results, i.e., outlying behavior is not indicated. The addition of the data slightly increases the POL for all indications, i.e., bring the left tail of the curve up.

In order to assess the quantitative effect of the new data on the correlation curve, the database was expanded to include the data from tubes removed from the aforementioned plants. A *Generalized Linear Model* regression of the POL on the common logarithm of the bobbin amplitude was performed. A comparison of the correlation parameters with those for the reference database is shown in [redacted]8. These results indicate:

1. [redacted]

[redacted]

6.2.3 Free Span SLB Leak Rate Correlation for 7/8" Tubes

As discussed previously and noted in Table 6-1, the effect of excluding the EdF data decreases the leak rate database by two specimens. Two of the newly added indications leaked, increasing the data base by two specimens. In order to understand the effect of the new leak rate results on the correlations the Addendum 4 data were reanalyzed with the EdF data omitted. The results are referred to as Addendum 4.1 in the tabular results, e.g., see the column headings in [redacted]9. Both of the indications leaked at rates significantly more than expected and the net effect is significant. Analyses were performed for SLB differential pressures of 2560 and 2405 psi. This is because most of the remaining affected plants have taken steps to be able to count on the operation of the PORVs preventing the SLB pressure from exceeding 2405 psi. The results of the analyses are listed in [redacted]9 and [redacted]10 for differential pressures of 2560 and 2405 psi respectively, and are illustrated on Figure 6-13 through [redacted]18.

The effect of excluding the EdF data on the leak rate correlation for a differential pressure of 2560 psi was to reduce the *p* value to 0.9%. This is essentially the probability of the observed correlation being due to random chance when there really is no correlation. The addition of the Plant P1 and W2 data increases the *p* value to 7.6%. The effect on the correlation is to reduce the slope by 43% and to increase the standard deviation of the errors by 8%. This can result in a significant increase in the predicted total leak rate at 95% confidence. Similar changes occurred to the correlation parameters for a SLB differential pressure of 2405 psi. The *p* value increased from 0.3 to 2.3%, the slope decreased by 34% and the standard deviation of the prediction errors increased by 7%.

[redacted]

6.2.4 General Conclusions Regarding 7/8" Tubes

The review of the effect of the additional burst data indicates that the SLB structural limit burst pressure is lowered by about 15% for both SLB differential pressure values of 2560 psi and 2405 psi. However, the decrease is mainly due to the increase in the standard error, and the probability of burst is increased only very slightly for all indications.

The inclusion of new leak data for 7/8 inch tubing in the probability of leak correlation increases POL for indications below 10 volts. The new leak data also results in an increase in the leak rate predicted by the SLB leak rate correlation at both SLB differential pressures of 2560 psi and 2405 psi. The joint effect of the changes in the POL and leak rate correlations is to increase the expected leak rate for a 2 volt indication by a factor of about 7 and 6, respectively, at SLB differential pressure of 2560 psi and 2405 psi.

6.3 Consideration of EdF Data

The results of an extensive statistical analysis of the EdF data and its effect on the ODSCC correlations were presented in Addendum 1 to the database, Reference 6-3. A recommendation was made to exclude the EdF data for statistical reasons, but no criterion was formulated for dealing with errant datasets based on a proposed rule. A criterion was developed and presented in Addendum 4, Reference 6-6, which would have resulted in excluding the EdF data from consideration based on cracking morphology differences. The NRC Staff developed a number of queries, referred to as requests for additional information (RAIs), regarding the proposed exclusion criterion. The final set of RAIs requested that a repeat of the statistical analyses be performed considering US data added to the database subsequent to the original analysis, Reference 6-7, to assess whether or not the original findings were still valid, and that a discussion be provided giving physical insight on the EdF data relative to the crack morphology differences as the cause for the different leakage behavior compared to domestic indications. Responses to those RAIs were provided in Reference 6-8, and NRC concurrence with the recommendation to exclude the EdF data was provided in Reference 6-9. A commitment was made in Reference 6-8 that future updates to the ODSCC database would include the reporting of results of similar analyses regarding the EdF data. This commitment is defined in Section 9.4.

6.3.1 Free Span Burst Correlation for 7/8" Diameter Tubes

The statistical analysis for Comparison 2 of Table 1 of Reference 6-8 is to be repeated for each new addendum for the ARC database where data for 7/8" diameter tubes is added. The values from that analysis are provided in Table 6-7. Comparison 2 is an evaluation of the significance of treating the EdF data as having an intercept distinctly different from the US data. The F statistic in Table 6-7 indicates that the likelihood that the EdF and US data share a common intercept is only 0.004. Since this value is less than 0.05, the conclusion that the EdF data should be excluded from the correlation analyses is confirmed.

6.3.2 Probability of Leak Correlation for 7/8" Diameter Tubes

Since the comparison of the intercepts from the burst correlation resulted in an *F* statistic with a random probability of 0.004 of occurrence, no specific statistical analysis of the POL data is required to support the conclusion that the EdF data may be excluded from the correlation analyses

6.4 Axial Tensile Tearing Correlation

Section 6.3 of Addendum 2, Reference 6-4, presents axial strength information for cellular corrosion based on a correlation of the remaining cross section area (CSA) of the tube as a function of the bobbin amplitude of the TSP ODSCC. There have been no additional tests performed since Addendum 2 was issued and no changes to the analysis of the Addendum 2 data. The database for the axial tensile tearing correlation was unaffected by the excluding the EdF data, because there were no EdF data in the axial tearing analysis.

6.5 Summary/Conclusions

[redacted]

6.6 References

6-1. NP-7480-L, Volume 1, Revision 2, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates – Database for Alternate Repair Limits, Volume 1: 7/8 Inch Diameter Tubing," Prepared for EPRI by Westinghouse (August, 1996).

6-2. NP-7480-L, Volume 2, Revision 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates – Database for Alternate Repair Limits, Volume 2: 3/4 Inch Diameter Tubing," Prepared for EPRI by Westinghouse (August, 1996).

6-3. NP-7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," EPRI, Palo Alto, CA (November, 1996).

6-4. NP-7480-L, Addendum 2, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1998 Database Update," EPRI, Palo Alto, CA (April, 1998).

6-5. NP-7480-L, Addendum 3, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1999 Database Update," EPRI, Palo Alto, CA (November, 1999).

6-6. "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2001," EPRI, Palo Alto, CA (August, 2001), 1006255 (Also known as Addendum 4)

6-7. Letter, "Request for Additional Information Regarding Exclusion of French Data from the Steam Generator Degradation Specific Database," W. Bateman (USNRC) to D. Modeen (Nuclear Energy Institute), Rockville, MD (August 14, 2002).

6-8. Letter, "Exclusion of French Data from the Steam Generator Degradation Specific Management Database (Generic Letter 95-05)," D. Modeen (NEI) to B. Sheron (NRC), Nuclear Energy Institute, Washington, DC (October 4, 2002).

6-9. Letter, "Exclusion of French Data from the Steam Generator Degradation Specific Management Database," W. Bateman (NRC) to A. Marion (NEI), Office of Nuclear Reactor Regulation, USNRC, Rockville, MD (October 8, 2002).

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$$Q = 10^{[b_3 + b_4 \log(Volts)]}$$

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$$Q = 10^{[b_3 + b_4 \log(Volts)]}$$

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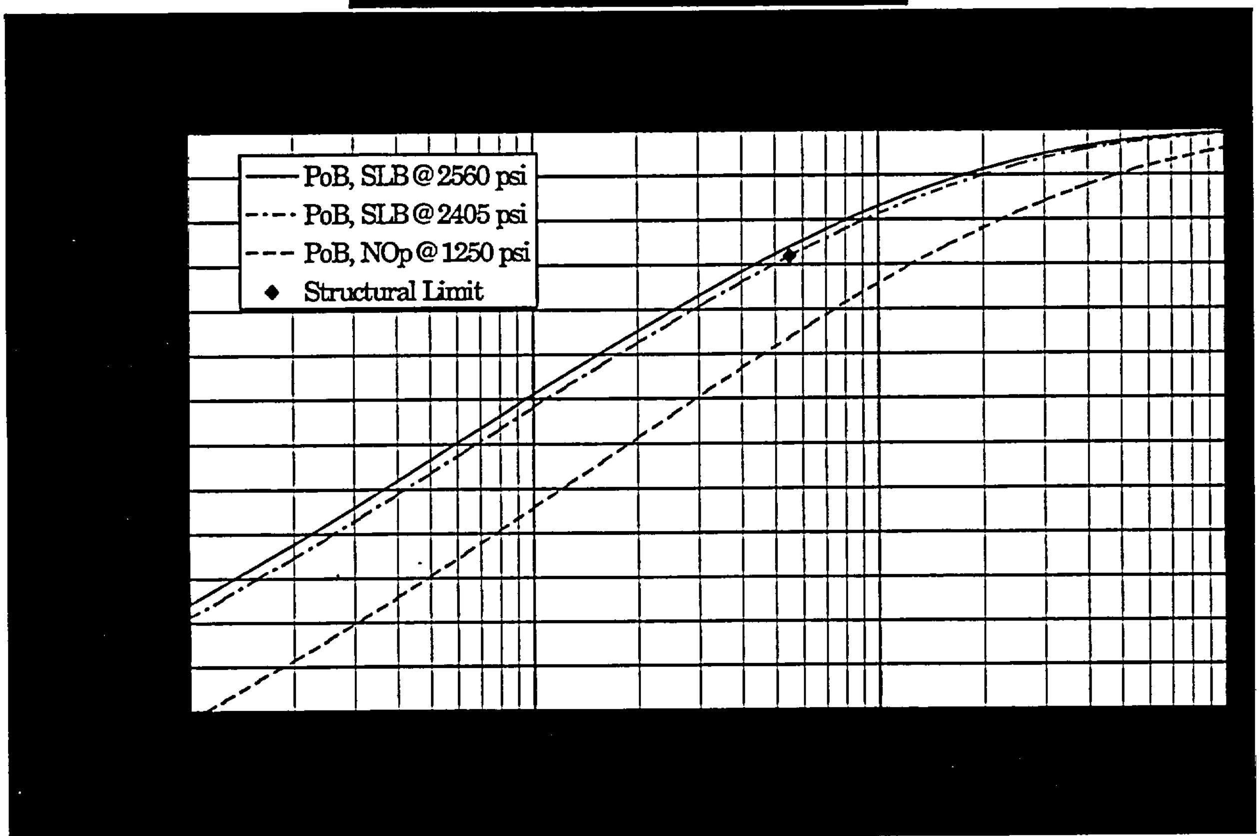

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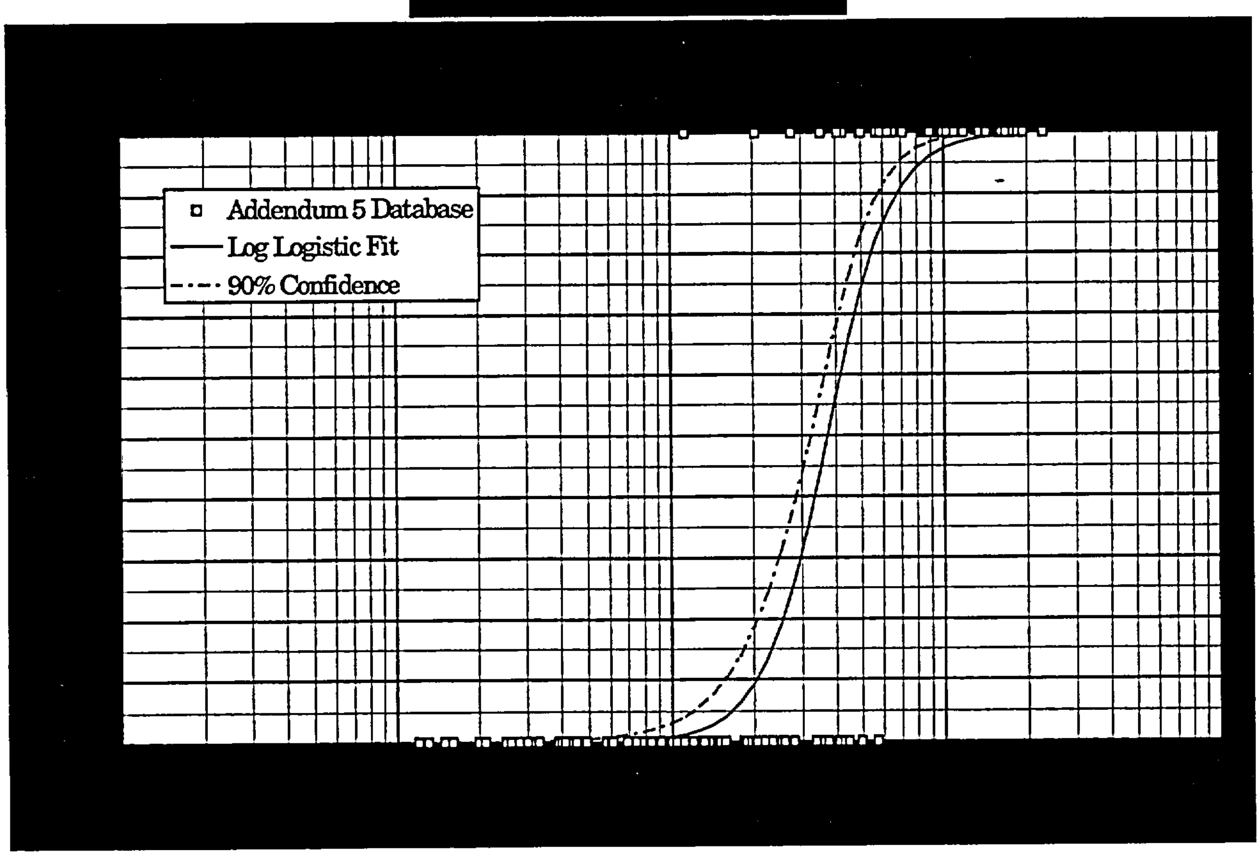

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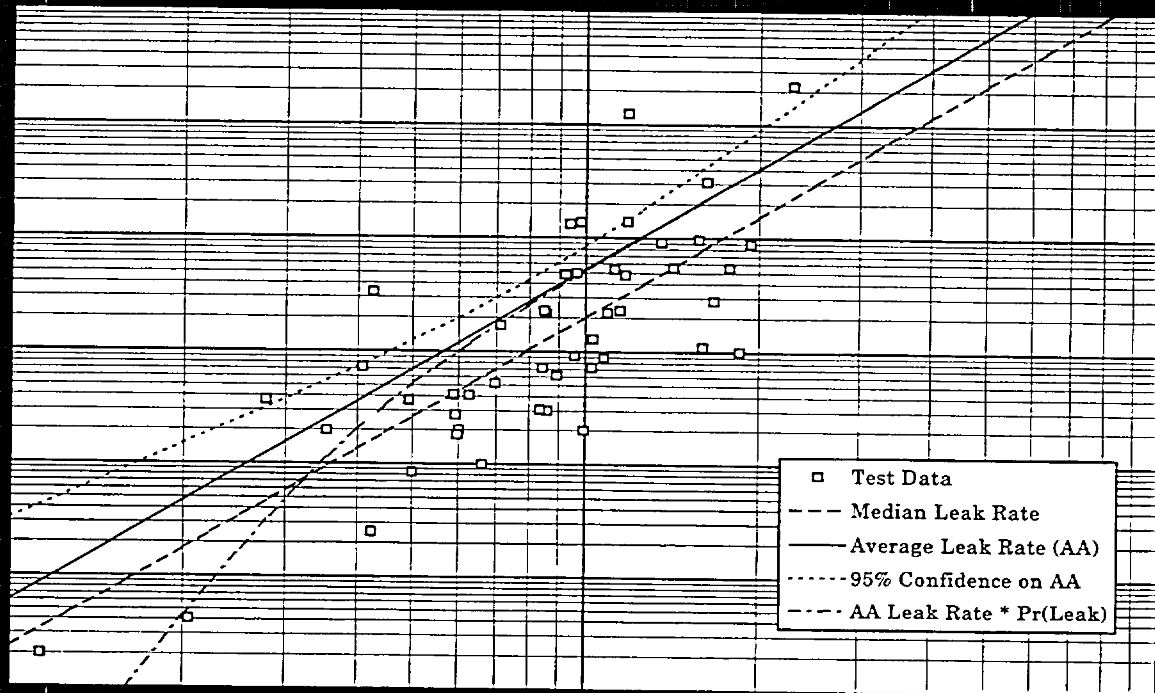

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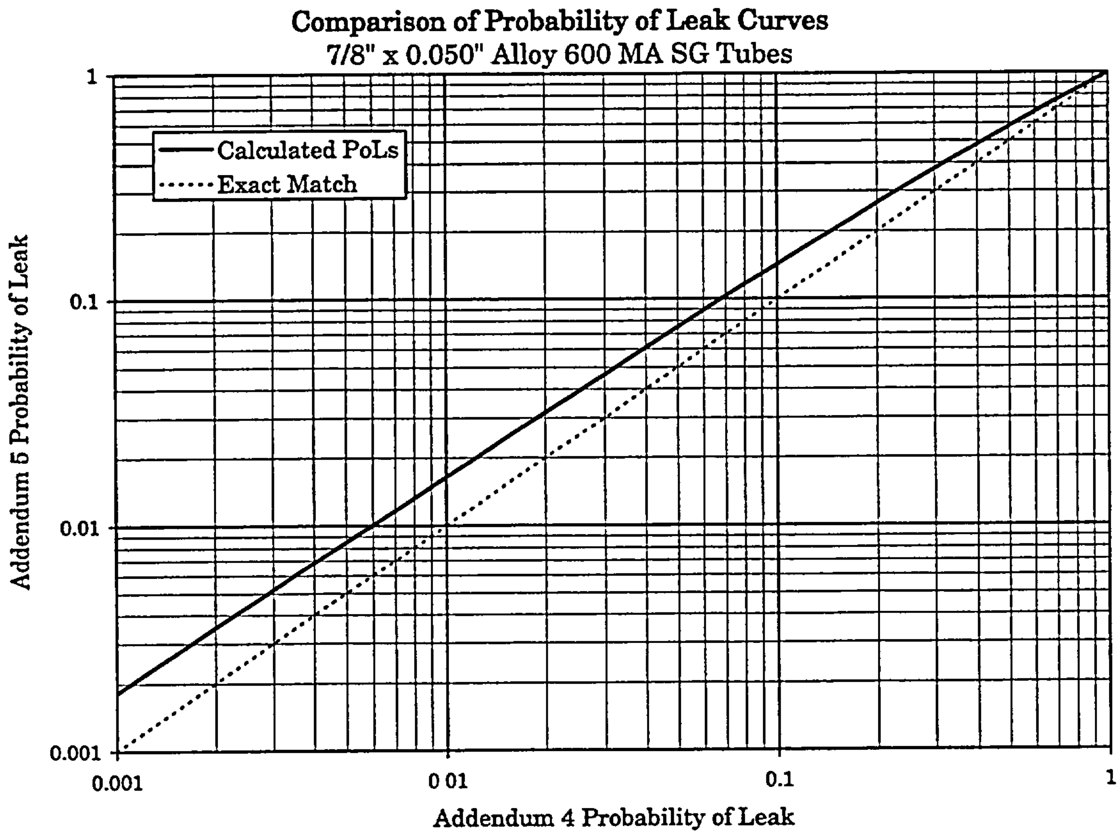

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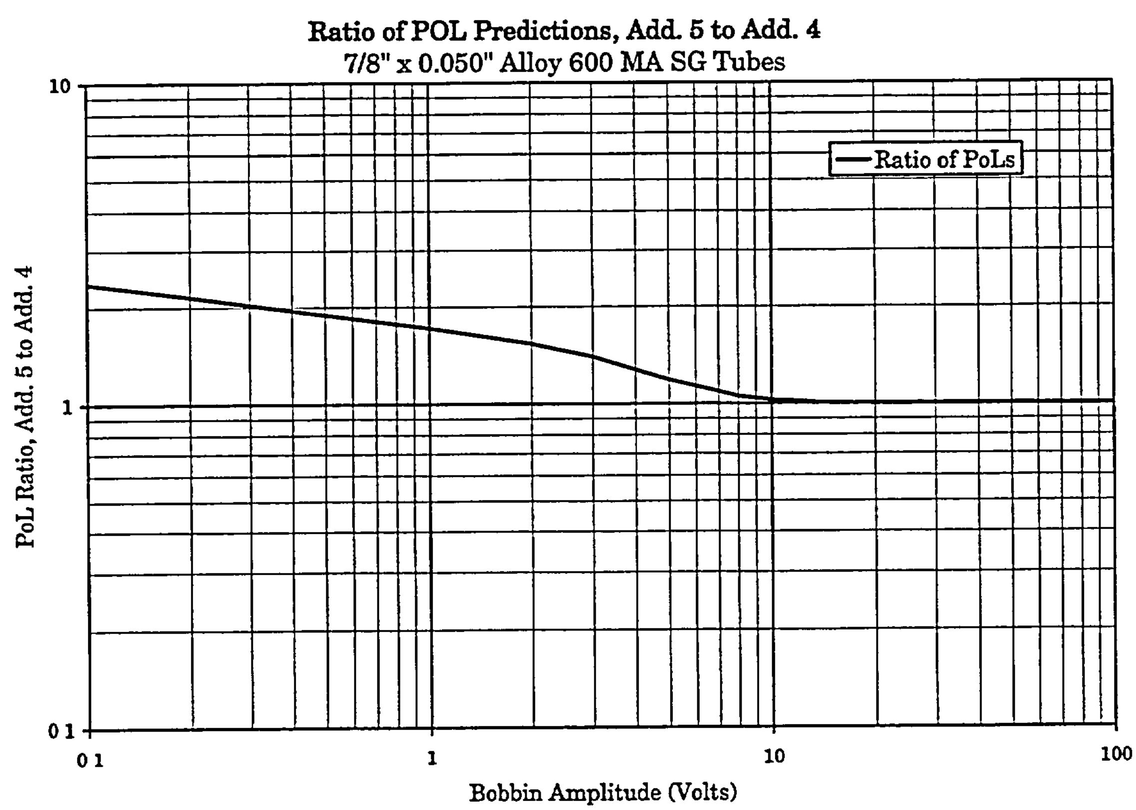

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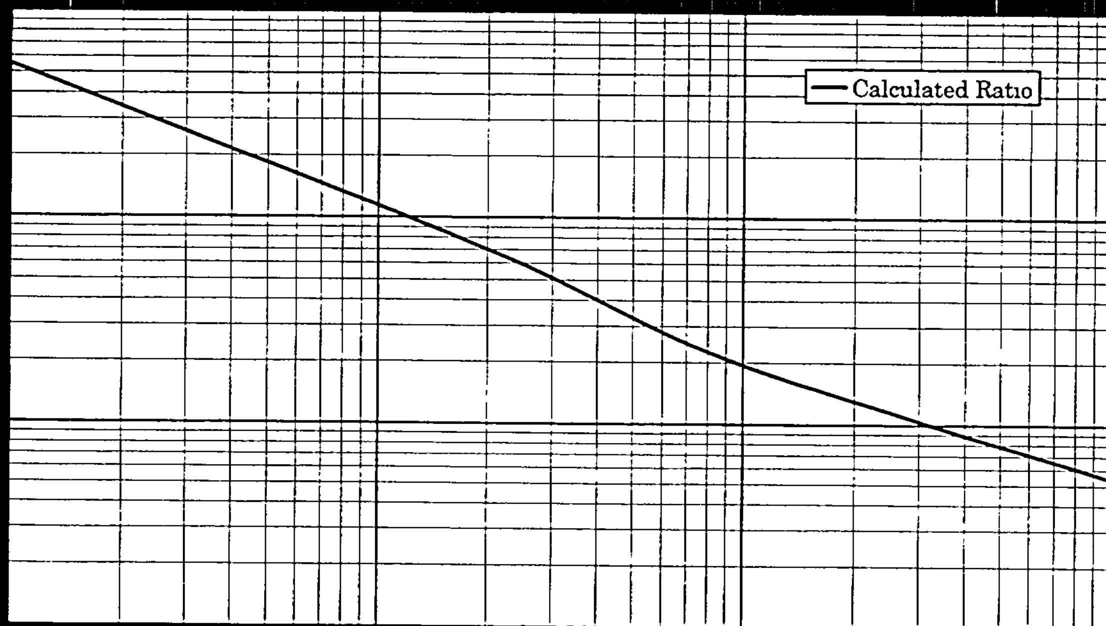

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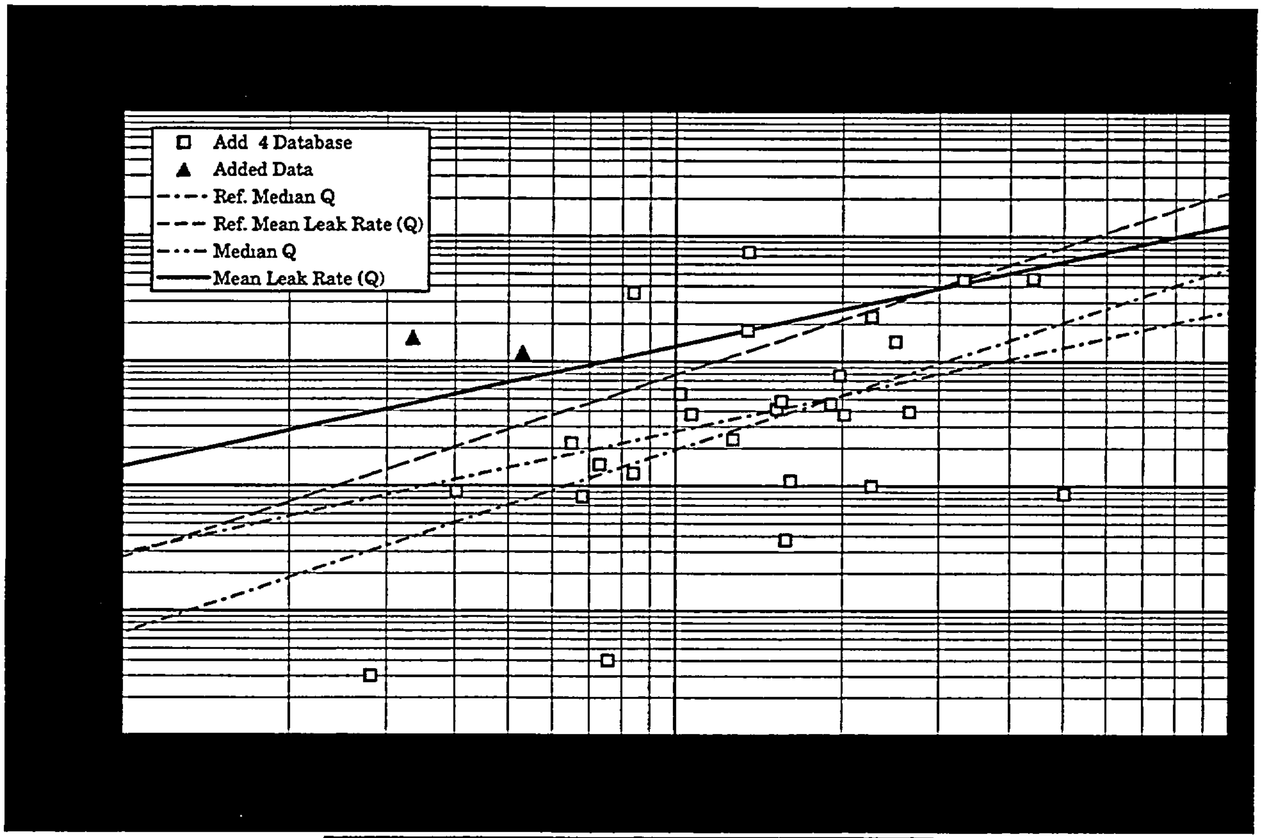

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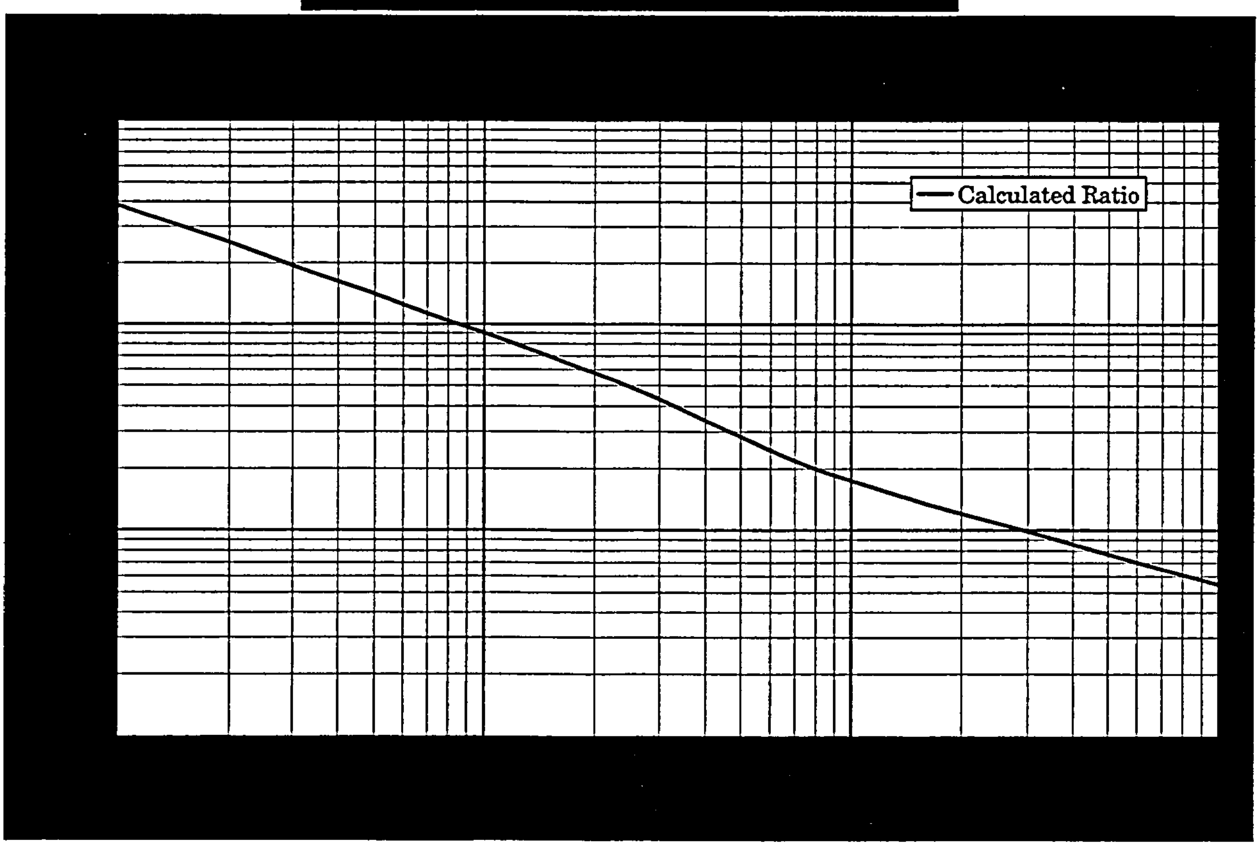

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7

PROBABILITY OF DETECTION DATA EVALUATION

This section presents the updated data for probability of prior cycle detection (POPCD). This is the fourth update to the original POPCD data presented in Reference 7-1. The earlier three updates are documented in the previous addenda (References 7-2 to 7-4). The present update adds data from 8 additional inspections. The POPCD database now includes data from evaluations for 37 inspections in 13 plants.

Briefly, POPCD is calculated as the ratio of indications reported at the prior inspection to the total indications found at the subsequent inspection (all indications reported in the prior cycle plus new indications). POPCD for the n^{th} inspection (EOC_n) is defined as follows.

$$\text{POPCD}\ (EOC_n) = \frac{\begin{array}{c}EOC_{n+1}\text{ RPC confirmed and detected at }EOC_n + EOC_n\text{ RPC confirmed and repaired at }EOC_n\end{array}}{\{\text{Numerator}\} + \text{New }EOC_{n+1}\text{ RPC confirmed indications (i.e., not detected at }EOC_n)}$$

The above definition for POPCD is based on the premise that all indications that can contribute significantly to leak rate calculations for voltage-based repair criteria application can be confirmed by RPC. However, since only a fraction of the bobbin indications are RPC inspected, a more realistic definition of POPCD is obtained by replacing EOC_{n+1} RPC confirmed indications with EOC_{n+1} RPC confirmed plus not inspected indications. A more detailed description of POPCD calculation is presented in Reference 7-1. As in the prior addenda, both POPCD values based on EOC_{n+1} RPC confirmed indications as well as EOC_{n+1} RPC confirmed plus not inspected indications are presented in this report.

7.1 Updated POPCD Data

Since the last update of the POPCD database reported in Addendum-4 (Reference 7-4), data are available from 8 additional inspections, all from plants with 7/8" diameter tubing. With the present update, the POPCD database now includes results from 37 evaluations. All of the inspections considered for POPCD evaluations are inspections performed after 1992 that utilized a voltage-based repair criterion per Generic Letter 95-05.

Figure 7-1 (data of Table 7-1) shows the latest POPCD data for plants with 3/4" tubing. There was no additional data for 3/4" diameter tubing since last update; therefore, the data shown here is same as that presented in Addendum-4 (Reference 7-4). The EPRI POD shown in the figure was developed using multiple analysts to evaluate a large number of field indications in 3/4" diameter tubing with "truth" for indications based on "expert" opinion.

Figure 7-2 (data of Table 7-2) shows the updated POPCD data for plants with 7/8" diameter tubing. It is based on results from 27 inspections performed since 1992. The present update increases the database size by about 35%. In spite of a substantial increase in the database size, the updated POPCD values for RPC confirmed and not inspected indications in all voltage bins are within 2% of the last update, which indicates that the database is sufficiently mature and truly represents the plant experience. The updated POPCD values are slightly higher than those reported in the last update for all voltages except indications 0.2 volt or lower for which POPCD values decrease by about 0.007, which is not significant. The average POPCD independent of voltage changed insignificantly (changed from 0.736 to 0.734). As with the original data and subsequent three updates, the present data also support a POD approaching unity above 3 volts.

The combined POPCD data for 37 inspections since 1992 are given in Table 7-3, and the results based on the RPC confirmed plus not inspected indications are illustrated in Figure 7-3. The updated POPCD distribution is very similar to the distributions shown in Addenda-1 through 4. It is also in good agreement with an EPRI POD developed using multiple analysts to evaluate a large number of field indications with "truth" for indications based on "expert" opinion. POPCD supports a POD approaching unity at about 3.5 volts while the EPRI POD is about 0.98 at 2 volts and unity at 3 volts. Figure 7-3 also includes POPCD evaluated at the lower 95% confidence limit on the data for individual voltage bins. The data of Table 7-3 show 900 to 20115 indications in all voltage bins below 2 volts, nearly 460 indications between 2.0 and 3.2 volts and about 69 indications above 3.2 volts. Thus, the collective data provide a substantial database for defining a POD.

The POPCD evaluations shown in Figures 7-1 to 7-3 are based on the definition of "truth" as RPC confirmed plus not RPC inspected indications. Since many of the indications not RPC inspected would be expected to be found NDD if inspected, this represents a lower bound POPCD evaluation. Figure 7-4 shows the POPCD evaluation for all 37 inspections since 1992 based only on RPC confirmed indications. The differences between the POPCD values calculated considering RPC confirmed indications only (Figure 7-4) and those based on RPC confirmed and not inspected indications (Figure7-3) are not as significant as for the original data in Reference 7-1. However, the data based on RPC confirmed indications only still show a slight increase in POPCD below 1.5 volts.

7.2 Recommended POD Distribution

As with the data presented in prior addenda, the results of Figure 7-3 clearly support an increase in the POD for voltage-based repair criteria applications above the POD = 0.6, independent of voltage, required by the NRC Generic Letter 95-05. For indications above 1.0 volt, the POD exceeds 0.85 and is about 0.94 at 2.0 volts. A POD of 0.6 is only applicable to indications below about 0.6 volts.

[redacted]

The POPCD evaluations for 37 inspections since 1992 provide a database for updating the NRC generic letter requirements on POD. The POD of Figure 7-5 is recommended for voltage-based repair criteria applications as a replacement for the constant POD of 0.6. In response to a RAI (Reference 7-5), results of a detailed evaluation to demonstrate conservatism in the EOC voltage, leak rate and burst probability projection results based on POPCD have been provided to the NRC. Per NRC GL 95-05, formal NRC approval of the recommended POD is required before application of POPCD to voltage-based repair criteria analyses.

7.3 References

7-1 NP-7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," EPRI, Palo Alto, CA (November, 1996).

7-2 NP-7480-L, Addendum 2, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1998 Database Update," EPRI, Palo Alto, CA (April, 1998).

7-3 NP-7480-L, Addendum 3, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1999 Database Update," EPRI, Palo Alto, CA (November, 1999).

7-4 "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2001," EPRI, Palo Alto, CA (August, 2001), 1006255 (Also known as Addendum 4).

7-5 Letter from S. L. Magruder, Nuclear Regulatory Commission, to D. Modeen, Nuclear Energy Institute, January 24, 1997.

Table 7-1
Evaluation for POPCD for Plants with 3/4" SG Tubes
Combined Data from 10 Post-92 ('93 and later) Inspections

Voltage Bin	New Indications		Bobbin Call in Both Inspections		First Inspection	POPCD			
	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	17	2089	2	1077	32	0.667	34 / 51	0.347	1109 / 3198
0.2 - 0.4	126	6498	38	5390	321	0.740	359 / 485	0.468	5711 / 12209
0.4 - 0.6	145	3861	184	5842	296	0.768	480 / 625	0.614	6138 / 9999
0.6 -0 .8	123	1426	396	4075	201	0.829	597 / 720	0.750	4276 / 5702
0.8 - 1.0	116	535	507	2450	139	0.848	646 / 762	0.829	2589 / 3124
1.0 - 1.2	63	160	216	849	909	0.947	1125 / 1188	0.917	1758 / 1918
1.2 - 1.6	44	87	250	487	797	0.960	1047 / 1091	0.937	1284 / 1371
1.6 - 2.0	6	9	82	87	251	0.982	333 / 339	0.974	338 / 347
2.0 - 2.5	4	4	26	26	99	0.969	125 / 129	0.969	125 / 129
2 5 - 3 2	2	2	9	9	69	0.975	78 / 80	0.975	78 / 80
3.2 - 3.5#	0	0	0	0	5	1.0	5 / 5	1.0	5 / 5
TOTAL	646	14671	1710	20292	3119				
Total > 1V	119	262	583	1458	2130				

\# The database also includes 33 indications above 3.5 volts for which POD=1.

Table 7-2
Evaluation for POPCD for Plants with 7/8" SG Tubes
Combined Data from 27 Post-92 ('93 and later) Inspections

Voltage Bin	New Indications		Bobbin Call in Both Inspections		First Inspection	POPCD			
	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed	RPC Confirmed plus not Inspected	Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
>0 - 0.2	284	1095	19	648	11	0.096	30 / 314	0.376	659 / 1754
0.2 - 0.4	222	3151	123	4654	101	0.502	224 / 446	0.601	4755 / 7906
0.4 - 0.6	198	2295	218	6193	197	0.677	415 / 613	0.736	6390 / 8685
0.6 -0 .8	130	1297	307	5032	169	0.785	476 / 606	0.800	5201 / 6498
0.8 - 1.0	83	622	395	3303	131	0.864	526 / 609	0.847	3434 / 4056
1.0 - 1.2	57	318	429	2000	123	0.906	552 / 609	0.870	2123 / 2441
1.2 - 1.6	62	238	668	1738	137	0.928	805 / 867	0.887	1875 / 2113
1.6 - 2.0	34	67	254	420	66	0.904	320 / 354	0.879	486 / 553
2.0 - 2.5	15	16	22	22	139	0.915	161 / 176	0.910	161 / 177
2.5 - 3.2	4	4	6	6	55	0.938	61 / 65	0.938	61 / 65
3.2 - 3.5#	0	0	0	0	3	1.000	3 / 3	1.000	3 / 3
TOTAL	1089	9103	2441	24016	1132				
Total > 1V	172	643	1379	4186	523				

\# The database also includes 26 indications above 3.5 volts and for all but one of them POD=1.

Table 7-3
Combined POPCD Evaluation for 37 Assessments Conducted After 1992
POPCD Based on RPC Confirmed Plus Not Inspected Indications

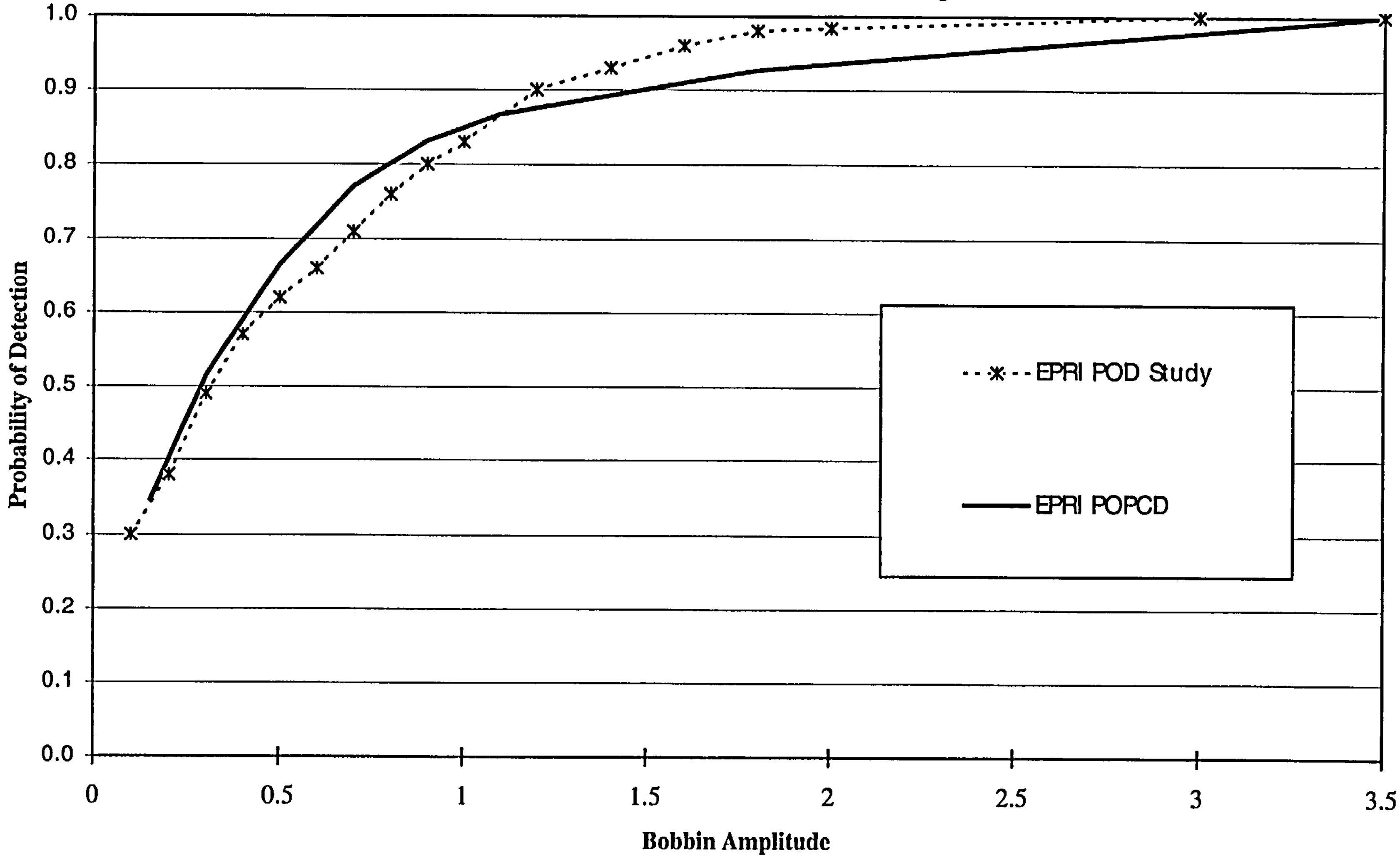
Voltage Bin	New Indications		Bobbin Call in Both Inspections		First Inspection	POPCD			
	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	301	3184	21	1725	43	0.175	64 / 365	0.357	1768 / 4952
0 2 - 0 4	348	9649	161	10044	422	0.626	583 / 931	0.520	10466 / 20115
0.4 - 0.6	343	6156	402	12035	493	0.723	895 / 1238	0.671	12528 / 18684
0 6 -0 .8	253	2723	703	9107	370	0.809	1073 / 1326	0 777	9477 / 12200
0 8 - 1 0	199	1157	902	5753	270	0.855	1172 / 1371	0 839	6023 / 7180
1.0 - 1.2	120	478	645	2849	1032	0.933	1677 / 1797	0.890	3881 / 4359
1 2 - 1 6	106	325	918	2225	934	0.946	1852 / 1958	0 907	3159 / 3484
1.6 - 2.0	40	76	336	507	317	0.942	653 / 693	0.916	824 / 900
2 0 - 2 5	19	20	48	48	238	0.938	286 / 305	0.935	286 / 306
2.5 - 3.2	6	6	15	15	124	0.959	139 / 145	0.959	139 / 145
3 2 - 3 5	0	0	0	0	8	1.000	8 / 8	1.000	8 / 8
TOTAL	1735	23774	4151	44308	4251				
Total > 1V	291	905	1962	5644	2653				

Table 7-4
Comparison of EPRI POPCD with EPRI POD Study

Voltage Bin	EPRI# POD Study	EPRI POPCD	
		NP-7480-L Addendum-4	Updated
0.1	0.30	0.29	0.29
0.2	0.38	0.40	0.40
0.3	0.49	0.50	0.51
0.4	0.57	0.57	0.59
0.5	0.62	0.65	0.66
0.6	0.66	0.70	0.72
0.7	0.71	0.76	0.77
0.8	0.76	0.79	0.80
0.9	0.80	0.83	0.83
1	0.83	0.85	0.85
1.2	0.90	0.88	0.88
1.4	0.93	0.89	0.89
1.6	0.96	0.91	0.91
1.8	0.98	0.92	0.93
2	0.98	0.93	0.94
3	1.00	0.98	0.98
3.5	1.00	1.0	1.0

Dual analyst detection probability study

Figure 7-6
Comparison POPCD with EPRI POD Study
POPCD Based on RPC Confirmed Plus Not Inspected Indications



8

RECOMMENDED NEW UPDATES TO NDE, ANALYSIS METHODS AND PROGRAMS

This section provides recommended new updates to NDE and analysis methods applied in applications of the ARC for ODSCC at TSP intersections. NRC approved updates are given in Section 9, and prior industry updates recommended for ARC implementation are included in Section 10.

No new updates to the NDE methods, analysis methods or ARC program requirements are recommended as part of Addendum 5. This section number is maintained in order to establish a continuing format for the addendum reports.

9

NRC APPROVED REVISIONS TO ARC PROGRAM, DATABASES, AND ANALYSIS METHODS

This section documents NRC approved revisions to the ARC program requirements, databases and analysis methods applied in applications of the ARC for ODSCC at TSP intersections. The ARC program requirements include the protocol for updating the database and the tube pull requirements. ARC database changes include the NRC approved EPRI data exclusion criteria and exclusion of the French data from the ARC database. Analysis methods updates include revisions to the leak rate analysis methods based on clarification of the confidence level required for a correlation and the methods for including the confidence level for a correlation in the leak rate analyses.

The requirements for pulling tubes in Section 9-2 includes Table 9-2, which identifies the number of indications needed to complete voltage bins for the leak rate data. This table is updated for this addendum and will be further updated for future addenda. The remaining information in this section is not expected to change between addenda. Any future NRC approved changes will be added as additional subsections to this section.

9.1 NRC/Industry SGDSM Database Protocol

The NRC/industry SGDSM database protocol for updating the ARC database is given in Table 9-1. Items 1 and 2 were developed when annual updates to the database were anticipated. Due to the reduced number of plants implementing the ARC, the addenda updates are issued only when required due to additional pulled tubes. Item 2 should therefore be interpreted as plants in an outage season when a new addenda is issued have the option of using the prior addenda provided there is not a significant, non-conservative shift in the ARC correlations. Item 3 provides for requesting NRC approval of changes to the exclusion criteria of Section 9.3 or exclusions of data, such as described in Section 9.4. If issuing of an addendum update to the correlations does not include any request for changes to the exclusion criteria or data exclusions, NRC approval of the updated correlations is not required for plant implementation. Item 4 provides for excluding data from the database only when applying the NRC approved data exclusion criteria given in Section 9.3. Item 5 provides the requirements for issuing interim ARC correlations in the event that new pulled data leads to significant non-conservative changes to the correlations.

Items 1 to 5 were submitted to the NRC by NEI in Reference 9-3 and items 1 to 4 were approved by the NRC in Reference 9-4. Item 5 was submitted by Reference 9-1 and approved by the NRC in Reference 9-2.

9.2 Requirements for Pulling Tubes in Support of the Voltage Based Repair Limits

The industry recommended requirements for pulling tubes were initially defined in Addendum 3 and updated to incorporate the NRC approval with comments in Reference 9-5. The NRC comments were incorporated and transmitted to the NRC in Reference 9-6. To maintain important documentation supporting the ARC, the NRC approved tube pull requirements are given below, as previously reported in Addendum 4.

9.2.1 Description of the Issue

The pulled tube database supporting the voltage based repair limits has been significantly increased since the issuance of GL 95-05. It is therefore appropriate to update the requirements for pulling tubes in support of the ARC. This section describes industry recommended and NRC approved requirements for pulling tubes.

Pulled tubes are required to characterize the crack morphology as dominantly axial ODSCC for consistency with that of the EPRI database and to increase the pulled tube database supporting the ARC. There have been no pulled tubes for which the ODSCC crack morphology differs from that found in the initial EPRI database prior to issuance of GL 95-05. The morphology is dominantly axial ODSCC with differences between pulled tubes being principally in the degree of cellular corrosion found at a given intersection. The cellular involvement can differ between TSP intersections on the same tube as much as differences between SGs or plants. The only morphology difference from the EPRI database found in the pulled tubes has been one case of combined local wall thinning with ODSCC, which was identified as a volumetric indication in the field inspection and was pulled to clarify the morphology of the indication. Tubes pulled with RPC axial ODSCC field calls have had morphologies consistent with the EPRI database. Consequently, removal of tubes specifically for morphology verification can be a low priority for tube removal. As a result of this consistent morphology experience, it is acceptable to delay the initial tube pull for morphology confirmation to the end of the first cycle following ARC implementation if this delay can improve the value of the pulled tube data to the database.

The principal objective for the tube pulls should be to support the database where the database has limited data. The burst pressure versus bobbin voltage correlation has not changed significantly with additional pulled tube data since before issuance of GL 95-05 in 1995. The additional data have resulted in changes in the structural limit by about half a volt or less. Changes in the leak rate versus voltage correlation have been more significant due to the smaller database on leaking tubes. Thus the primary objective for pulling tubes should be to increase the leak rate database. The tubes should have a large enough voltage to have a significant likelihood of leaking. The correlations of Section 6 show that to obtain a 30% probability of leakage, both the 3/4 inch and 7/8 inch (excluding French data) tubes should have bobbin voltages > 3.2 volts. These considerations lead to emphasis on pulling tubes based on having large enough voltages to contribute to the leak rate database.

The GL 95-05 requirements for tube removal can be summarized as follows:

1. Number and Frequency of Tube Pulls

- Two pulled tubes with a minimum of four intersections should be obtained during the plant SG inspection outage implementing the ARC or a preceding outage.
- Additional tube pulls with a minimum of two intersections should be obtained at the refueling outage following accumulation of 34 EFPM of operation following the previous tube pull.

2. Selection Criteria

- The emphasis should be on removing tube intersections with large voltage indications
- Where possible, the removed intersections should cover a range of voltages, including intersections with no detectable degradation.
- Selected intersections should include a representative number of intersections with RPC signatures of a single dominant crack as compared to intersections with two or more dominant RPC signatures around the circumference.

The following provides the NRC approved changes to the above requirements for tube removal.

9.2.2 Bases for Tube Removal Guidelines

Based on the above considerations, the primary emphasis for pulled tubes should be to support the leak rate correlation, while also obtaining information on crack morphology. Table 9-2 summarizes the number of ODSCC indications pulled and destructively examined and the number of intersections that had leak rates contributing to the correlations for both 3/4 and 7/8 inch diameter tubing. Table 9-2 has been updated to the Addendum 5 database and will be updated with each future addendum update. It is seen that 136 out of a total of 183 indications (excluding the French data) had voltages less than 2 volts. This voltage range, which is typical of indications found during the first outage implementing the ARC, has more data than needed and emphasis for tube removal should be on higher voltage indications. In this low voltage region, crack morphology features typically are not well established and the data provide only OD cracking as a morphology confirmation. Therefore, the tube removal requirements should be defined to minimize the need for pulling low voltage indications.

For 3/4 inch tubing, indications greater than about 3 volts would have a 30% probability of leakage and would likely contribute to the leak rate correlation database. As seen in Table 9-2, the existing leak rate database for ¾ inch tubing is extensive and only 4 indications are needed to complete a database of 2 indications in each one volt bin up to 12 volts. For 7/8 inch tubing, indications less than about 3 volts have a very low leakage probability with only 1 small leaking indication in 34 pulled tube indications between 1 and 3 volts. The probability of leakage correlation shows < 20% leakage potential at 3 volts. Therefore, indications > 3 volts are desirable to have a reasonable likelihood of contributing to the leak rate database. It is therefore recommended that tube pulls be targeted toward obtaining a leak rate database of 2 indications in each one volt range above a minimum of 2 volts for ¾ inch tubing and above 3 volts for 7/8 inch tubing.

9.2.3 Criteria for Tube Removal and Examination/Testing

Implementation of the voltage based repair criteria should include a program of tube removals for testing and examination as described below. The purposes of this program, in order of priority, are: 1) to provide additional data to enhance the conditional leak rate, burst pressure and probability of leakage correlations; 2) to verify axial ODSCC as the dominant degradation mechanism at or near the time of ARC implementation; 3) to assess inspection capability; and 4) to monitor the degradation mechanism over time.

The principal database goal to support the ARC correlations is to enhance the leak rate correlation. Table 9-2 identifies voltage ranges for additional leaking indications (target number) to work toward a leak rate database that includes at least two indications with leakage in one volt intervals for which leakage is reasonably expected. Tube removals should be targeted toward satisfying the target number of indications. As noted below, the required times for tube pulls may optionally (utility option) be delayed up to one fuel cycle if no pullable tube indications are found that satisfy the target indication voltage ranges. The data of Table 9-2, including target indications, shall be updated and included in the EPRI ARC database addenda so that the target indications reflect the latest available pulled tube results.

The following criteria for tube removal and examination shall be followed.

<u>Number and Frequency of Tube Pulls</u>

- Two pulled tube specimens with an objective of retrieving as many intersections as is practical (a minimum of four intersections) should be obtained for each plant either during the SG inspection outage that implements the voltage based repair criteria or during an inspection outage preceding initial application of these criteria. However, if no pullable tube indications are found in this inspection that would satisfy the industry database target indications, the tube removal may be delayed (utility option) to the next planned inspection with the goal of obtaining indications satisfying the database target. The tube pulls may not be delayed more than one planned outage following implementation of the repair criteria.

- On an ongoing basis, an additional (follow-up) pulled tube specimen with an objective of retrieving as many intersections as is practical (minimum of two intersections) should be obtained at the refueling outage following accumulation of three operating cycles following the previous tube pull. However, if no pullable tube indications are found in this inspection that would satisfy the industry database target indications, the tube removal may be delayed (utility option) to the next planned inspection with the goal of obtaining indications satisfying the database target. The tube pulls may not be delayed more than one planned outage following the required time for an additional pulled tube specimen. Consequently, the maximum interval between tube removals is four operating cycles to provide a periodic confirmation of crack morphology.

- If the above time requirements for a pulled tube specimen coincide with the plant's last scheduled outage before SG replacement, the requirement for a tube pull is waived. However, this waiver does not apply if the plant has not previously pulled tubes to support the ARC database. For example, if the last scheduled outage is the first or second outage implementing the ARC, the waiver does not apply where tube pull specimens have not been obtained during the plant SG inspection outage that implements the voltage based repair criteria or during an inspection outage preceding initial application of these criteria.

- If indications with unanticipated voltage levels substantially higher than the structural limit (for example, > 10 volts) from the burst correlation are found in an inspection, the indication should be considered for removal and destructive examination if the test results are likely to determine whether or not condition monitoring or operational assessment results would satisfy acceptance limits.

Tube Removal Selection Criteria

- The primary emphasis for selecting an intersection for removal should be an indication that satisfies the target indication voltages of Table 9-2. If the target voltage range cannot be satisfied, the emphasis should be on intersections with large voltage indications.

- Where possible, the removed tube intersections should cover a range of voltages, including intersections with no detectable degradation.

- For selection between indications of comparable voltage levels, the preference for removal should be intersections with RPC (or equivalent probe) signatures indicative of a single dominant crack as compared to intersections with RPC signatures indicative of two or more dominant cracks about the circumference.

Pulled Tube Examination and Testing

- Removed tube intersections should be subjected to leak and burst tests under simulated MSLB conditions to confirm that the failure mode is axial and to permit enhancement of the supporting data sets for the burst pressure and leakage correlations. The systems for leak testing should accommodate and permit measurements of leak rates as high as practical including leak rates that may be in the upper tail of the leak rate distribution for a given voltage. Leak rate data should be collected at temperature for the differential pressure loadings associated with the maximum postulated MSLB. When it is not practical to perform hot temperature leak tests, room temperature leak rate testing may be performed as an alternative. Burst testing may be performed at room temperature. The burst and leak rate correlations and/or data should be normalized to reflect the appropriate pressure and temperature assumptions for a postulated MSLB.

- Subsequent to burst testing, the intersections should be destructively examined to confirm that the degradation morphology is consistent with the EPRI database morphology for ODSCC at tube to TSP intersections. The destructive examination techniques should include techniques such as metallography and scanning electron microscope (SEM) fractography as necessary to characterize the degradation morphology (e.g., axial ODSCC, circumferential ODSCC, IGA involvement, cellular IGA and combinations thereof) and to characterize the largest crack networks with regard to their orientation, length, depth and ligaments. For uncorroded ligaments, the following information should be reported: location within the elevation of the overall macrocrack; angular orientation (approximate degrees) relative to the primary direction of the macrocrack; and size of the ligament such as uncorroded ligament area. The purpose of these examinations is to verify that the degradation morphology is consistent with the assumptions made in NRC GL 95-05 as well as that included in the EPRI database.

9.3 Data Exclusion Criteria

9.3.1 Introduction

This section describes the criteria for excluding data from the Alternate Repair Criteria (ARC) database supporting the burst, probability of leakage and leak rate correlations. The criteria are applied to identify specimens to be excluded from the correlations. Exclusion Criteria 1 and 2 submitted by References 9-7 and 9-8 are consistent with NRC guidelines given in Paragraph 2.b.3(2) of Generic Letter 95-05. In addition, the NRC has accepted a modification to Criterion 3a as originally drafted in Reference 9-9. The NRC acceptance (References 9-10 and 9-11) of Criterion 3a is based on increasing the confidence level for application of this criterion from 95% to 99%. Criterion 3a then excludes leak rate data that is outside the lower 99% prediction interval on both the leak rate versus voltage and leak rate versus crack length correlations. In the NRC RAI of Reference 9-12, the NRC provided a staff position on exclusion Criterion 2a that this criterion should be applied to all data rather than the original criterion application to data that had high burst pressures. This change is included in Criterion 2a.

Reference 9-11 provided approval of the ARC database in Addendum 2 as an update to the database approved in GL 95-05. The approval of Criterion 3a led to exclusion from the leak rate database of model boiler specimens 598-3 and 604-2. Reference 9-11 also approved a revision of the SLB leak rate for Plant S Tube R28C41 from 2496 l/hr to 1250 l/hr as a revision to GL 95-05 Paragraph 2.b.3(2) requirements.

The complete data exclusion criteria, as approved by the NRC, are given in this section. Criterion 3b of Reference 9-9 was not accepted by the NRC and is not included in this section. Data resulting from application of these criteria form the database for the ARC correlations. Evaluations of new data against these exclusion criteria are given in Sections 3 and 4 of each ARC database addendum.

9.3.2 Data Exclusion Criteria

NRC guidelines for acceptance of data used in developing the correlations are based on accepting all data that do not satisfy specific criteria for exclusion from the database. The NRC's general guidelines for exclusion of data from the database are:

1. Data associated with an invalid test.
2. Data associated with atypical morphology must be based on morphology criteria which are rigorously defined and applied to all data.
3. Data exclusion criteria must be able to be unambiguously applied by an independent observer.
4. Data can be excluded if it results in conservatism associated with application of the affected correlation.

Specific criteria developed for exclusion of data following the above guidelines and approved by the NRC are:

<u>Criterion 1. Invalid or Inadequate Test</u>

An invalid test is associated with unacceptable test specimens or invalid test measurements as exemplified by one of the following situations:

1a. *Eddy current signal corruption.* This condition results in the data point not being used in any of the three correlations. Examples of this condition are tube specimens that have been severely damaged for reasons other than the operating corrosion, specimens exhibiting extraneous eddy current signal effects (e.g., due to proximity of the degradation to a specimen weld), both of which result in inappropriate or excessive eddy current voltage response.

1b. *Inadequate or inappropriate burst test.* This condition results in the data point not being used in the burst correlation. Examples of this condition are: tube specimens that did not attain a true burst condition (e.g., caused by the specimen's internal re-enforcing bladder leaking), a test fixture malfunction with inability to retest and specimens tested for other purposes (e.g., specimen burst tested inside a support plate).

1c. *Inadequate leak test.* This condition results in the data point not being used in the leak rate correlation. Examples of this condition are: insufficient test loop flow capacity to reach the specimen's leak rate for SLB conditions and test malfunction with inability to retest.

1d. *Tube damage from field induced tube pull forces.* This condition results in the data point not being used in the leak rate correlation. It may be used in the probability of leak correlation if justified by analysis. An example of this condition is radial ligament tearing as indicated by excessive post-pull measured voltage for the field obtained specimen and higher than expected leak rates at or below normal operating conditions. Supporting analyses must show that the uncorroded ligament would not have torn to increase the leak rate under SLB conditions.

1e. *Unavailable test information for estimating probability of leakage.* This condition results in the data point not being used in the probability and leak rate correlation. An example of this situation is a number of tube specimens for which no leak rate tests were performed and the specimens exhibit short throughwall crack lengths (less than 0.1") for which experience shows they do not leak. An additional example is a specimen with no leak test and no destructive exam data to estimate whether or not the indication would leak at SLB conditions.

Criterion 2. Morphology Related Criteria

These criteria identify atypical degradation that if incorporated into the database would inappropriately bias the correlations over the range of interest. Pulled tube specimens with this atypical degradation do not invalidate the application of the correlations to the plants from which the tubes were pulled. The specific criteria are as follows:

2a. *Atypical degradation ligament morphology.* This condition results in the data not being used in any of the three correlations. The morphology for exclusion is defined to be degradation with less then or equal to 2 ligaments within the macrocrack and the maximum corrosion depth is less than 60%. This criterion is to be applied irregardless of the magnitude of the burst pressure (i.e., such as a high burst pressure) associated with the indication. Experience indicates that this degradation results in tubes exhibiting relative high bobbin voltages but maintaining relatively high burst pressures close to that of undegraded tubing. Such degradation is atypical of the dominant ODSCC degradation in the database for which the ARC correlations are developed and would be considered an inappropriate bias to the correlation if incorporated into the database. The correlation uncertainty distribution is associated with random effects (e.g., due to non-quantifiable changes in the degradation morphology) about the correlation mean. However, data for atypical degradation exhibits a non random effect that is physically definable and different from the dominant ODSCC morphology.

Removal of data under this criterion from the correlation's database results in a conservative shift of, for example, the mean of the burst correlation. Since the removed data are positioned in the tail of the correlation's uncertainty distribution, their removal from the database may decrease the distribution's variance. This effect is acceptable because scientific argument does not suggest that the existence of these data located on one side of the uncertainty distribution dictates an equal probability of some type of effect on the other side of the distribution.

2b. *Severe degradation.* This condition results in the data point not being used in any of the correlations. The condition is defined to be a data point that has a voltage measurement more than 20 volts higher than the next adjacent point located at the high voltage boundary of the data. Note that this criterion applies only to one side of the correlation, specifically to the high voltage region of the correlation. Such data is far removed from the voltage range of interest over which the correlation is applied. It is not appropriate to allow one data point, which represents an extreme form of degradation compared to the majority of the data, to have a significant influence on the linear regression correlation. If additional data is obtained in this very high voltage region, such that there is a more uniform distribution of data in this extreme voltage region, review of all data will be performed with consideration of incorporating data previously filtered from the correlation by this criterion. Exclusion of such data has a varied effect on the correlation mean. Its effect is dependent on the voltage range of interest. Removal of the data point could for example, add conservatism in the high voltage region from which the data is excluded, with a reduction in conservatism in the low voltage region because of the linear nature of the regression.

<u>Criterion 3. Probable Test Error in Leakage Measurement</u>

Criterion 3 is intended to exclude leakage measurements exhibiting extreme behavior, such as a very low measurement, although the specific cause for the probable test measurement error cannot be identified. In the performance of leak tests, the crack can become plugged by deposits resulting in abnormally low leak rates or a measurement error (e.g., piping leakage between specimen and leakage collection tank, collection time error, etc.) could occur. For these cases, the cause for the measurement error is not as apparent as for Category 1 and the test results must be evaluated for probable errors. It is not appropriate to include the spread in leak rates resulting from plugging of cracks during leak tests in the leak rate correlation and each leak rate measurement should be evaluated against Criterion 3 before including the data in the database. Criterion 3a provides for excluding SLB leak rates much lower than expected for the throughwall crack length found by destructive examination.

3a. *Probable Test Error in Leakage Measurements.* Data with throughwall crack length measurements are excluded from the leak rate correlation if the measured leak rate is below the lower, one-sided 99% prediction interval from regression analyses for correlations of both SLB leak rate versus corrosion throughwall length and SLB leak rate versus bobbin voltage as obtained without including the suspect data point in the regression analysis. For application of this criterion, the throughwall crack length must have no remaining uncorroded ligaments over the throughwall length. Uncorroded ligaments, if present, could contribute to the lower than expected leak rate.

Basis for Criterion 3a

The potential for plugging of a crack due to deposits in a leak rate test has existed and will continue to exist in leak rate measurements. Prototypic borated primary water, as used in the earlier database tests, is being eliminated in future tests to reduce the potential for deposits in the cracks. Indications that have extremely low leakage, based on quantified lower 99% prediction intervals on the voltage correlation for leak rates are candidates for further evaluation. The leak rate versus voltage correlation, by itself, does not adequately identify probable deposits affecting the leak rate since the voltage could be influenced by crack morphologies or distortions in the bobbin response. Thus, when crack length measurements are available from destructive examination of the specimen, the indication must be a low outlier on both the voltage and the crack length correlations. The use of the 99% prediction interval conservatively exceeds other applications such as the burst correlation and acceptance levels for leak rates.

An increased physical insight into the potential for plugging of a crack can be obtained by evaluating the data point based on leak rate data as a function of throughwall crack length. Leak rate versus crack length can be expected to have a smaller uncertainty spread than the voltage correlation at a given throughwall crack length since this relation is physically based and more analytically predictable. In this case, leak rates significantly higher than the regression line can be expected due to tearing of ligaments but leak rates for cracks with no ligaments that are much lower than the population have no known physical basis other than blockage of the crack or a measurement error. Thus high outliers can be expected for this correlation but very low outliers are unlikely without an additional influence such as deposits. An unusually high crack tortuosity can lead to a lower leak rate than the mean but would not realistically reduce the leak rate below the 99% confidence bound on the data. A conservative and quantifiable measure for much lower than the database is obtained by requiring that the leak rate lie below the lower 99% confidence level obtained from a regression analysis of leak rate versus crack length. If the leak rate is lower than the 99% confidence levels for both the voltage and crack length correlations, it can be reasonably assured that the leak rate was strongly influenced by blockage of the crack or the measurement was erroneous. Criterion 3a thus provides a well quantified criterion for excluding unacceptable leakage from the leak rate correlation and requires a very low leak rate on both the voltage and crack length correlations. Since it is known that the specimen leaks, the data point is included in the probability of leakage correlation as a leaker.

Criterion 3a applies only to specimens that leak and does not exclude specimens with throughwall cracks but zero measured leakage. A few specimens with short throughwall cracks, such as 3/4" specimen 595-2 (throughwall length of 0.17") and 7/8" specimen 509-3 (throughwall length of 0.16"), had no measured leakage. In this case, the specimens are included in the probability of leakage correlation as non-leakers and are not considered for the SLB leak rate correlation. This application of non-leakers with throughwall cracks is not inconsistent with data exclusion Criterion 3a. Abnormally low leakers (zero or slightly greater than zero) are excluded from the leak rate correlation but retained in the POL correlation based on whether or not any leakage was measured, independent of the leakage magnitude.

The specific effects causing lower than expected variation in leak rates are remaining ligaments in the crack face, tortuosity (oblique steps in the crack, surface irregularities) and presence of deposits. These effects tend to lower leakage for modest throughwall crack lengths. All three effects become smaller as crack length increases and crack opening increases. Longer throughwall cracks tend to have lost the ligaments by corrosion; the wider crack openings reduce the influence of surface irregularities and reduce the potential for deposits plugging the crack. From the database, "long" cracks appear to be about > 0.3" throughwall as above this length, the variability from predicted leak rates as a function of length appears to be smaller. For 0.3" throughwall cracks, the crack width is about 1 mil at 2560 psi and increases to about 10 mils for a 0.5" long crack. Thus, crack lengths < 0.3" are more susceptible to plugging from deposits. The presence of ligaments is a valid cause for low leakage and Criterion 3a (destructive exam data available) requires that the throughwall length have no remaining uncorroded ligaments.

9.4 Exclusion of the French Data from the ARC Database

In the initial evaluation of the French data in Addendum 1, it was recommended that the French data not be included in the ARC database due to significant differences in crack morphology and leakage behavior from the domestic data. The recommendation included a statistical evaluation that concluded that the French data had a low likelihood of being from the same population as the balance of the EPRI database. In Reference 9-13, the NRC staff commented that they did not concur that there was conclusive physical evidence to demonstrate that the French data should be separated from domestic plant data, hence, the remaining statistical analyses alone did not provide a basis for excluding the French data. Addendum 4 proposed a new data exclusion Criterion 2c for atypical deep crack degradation morphology that also led to a recommendation to exclude the French data. Additional physical evidence and updated statistical evaluations supporting exclusion of the French data were provided to the NRC (References 9-14 and 9-15) in response to the requests for additional information. The NRC then approved exclusion of the French data from the ARC database in Reference 9-16 although exclusion Criterion 2c was not approved. The industry submittal of Reference 9-15 and the NRC approval of Reference 9-16 require that each ARC database addendum update provide confirmatory analyses to demonstrate that the French data remain statistically and physically different from the domestic data.

The specific industry commitments for updating the assessments of the French data are:

- The statistical analysis for Comparison 2 of Table 9-3 (Table 1 of Reference 9-15) will be updated for each new addenda for the ARC database in NP-7480-L.
- If the probability, Pr(F Statistic) in Table 9-3 that the null hypothesis for common regression lines (model 4) is true increases to 5% (the current value is 0.4%), the statistical analyses for Tables 9-3 and 9-4 (Table 5 of Reference 9-15) addressing both the burst and POL correlations will be updated.
- If the burst correlation probability increases to 5% and the POL correlation test statistic (e.g., 0.54 in Table 9-4) decreases to less than or equal to the critical value at the 5% level of significance (e.g., 0.25 in Table 9-4), the EdF data would be included in the burst, POL and leak rate correlations issued for the new addenda. The EdF data would not be included in the correlations unless supported by the statistical analyses for both the burst pressure correlation and the POL correlation.

The required updates to the statistical analysis, including Tables 9-3 and 9-4, in the RAI response of Reference 9-15 are included in Section 6 of this addendum.

9.5 Revisions to Leak Rate Analysis Methods

One clarification of the GL 95-05 p-value requirements and one change to the leak rate analyses have been approved by the NRC.

In Reference 9-17, industry representatives recommended that the GL 95-05 requirement for a 95% confidence interval on the p-value for the slope parameter of the leak rate correlation be clarified to apply as a one-sided confidence level. At the Reference 9-17 meeting and by Reference 9-2, the NRC concurred that the one-sided p-test for the leak rate correlation is appropriate. This approval permits the leak rate correlation with voltage to be applied when the one side p-value for the correlation slope parameter is less than 5%.

By Reference 9-18, the NRC approved an updated method for accounting for the p-value in Monte Carlo leak rate calculations as submitted in Reference 9-19. This method determines whether a correlation should be applied during each Monte Carlo simulation of the generator. After simulating a potential value for the population slope, the value defines the leak rate correlation to be applied. If the population slope is less than or equal to zero, then no correlation is assumed and the simulation of the leak rate is based on the mean and standard deviation of the leak rate data. If the population slope is greater than zero, the correlation is applicable and the leak rate is based on the regression line slope and intercept. This analysis method is required to be implemented in all ARC leak rate analyses after September 23, 2002.

9.6 References

9-1 Letter from R. Clive Callaway (NEI) to Mr. Edmund J. Sullivan (NRC), "Steam Generator Degradation Specific Management Tube Pull Database Addendum and Protocol (Project No. 689)", dated October 28, 1997

9-2 Letter from Mr. Edmund J. Sullivan (NRC) to David J. Modeen (NEI), "EPRI Report: Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, NP-7480-L, Addendum 1, November 1996", dated January 20, 1998

9-3 Letter from David J. Modeen (NEI) to Gus C. Lainas (NRC), "Steam Generator Degradation Specific Management Tube (SGDSM) Database Protocol (Project No. 689)", dated January 15, 1997

9-4 Letter from Brian W. Sheron (NRC) to D. Modeen (NEI), dated April 10, 1997

9-5 Letter from Jack Strosnider (NRC) to D. Modeen (NEI), "Industry Recommended Steam Generator Tube Pull Program," dated January 31, 2000

9-6 Letter from David J. Modeen to Document Control Desk, USNRC, Project Number 689, "Steam Generator Degradation Specific Management Database, Addendum 3", June 2, 2000

9-7 Letter from David A. Steininger, EPRI, to Jack Strosnider, NRC, "Exclusion of Data from Alternate Repair Crieria (ARC) Databases Associated with 7/8 Inch Tubing Exhibiting ODSCC", April 22, 1994

9-8 Letter from David J. Modeen (NEI) to Brian Sheron (NRC), June 9, 1994

9-9 EPRI Report NPL-7480-L, Volume 2, Revision 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Volume 2: 3/4 Inch Diameter Tubing" August 1996

9-10 NRC letter from Thomas H. Essig to David J. Modeen (NEI), "EPRI Report: Proposed Data Exclusion Criteria and Adjustments to Measure Leak Rate for Tube R28C41 (Plant S), February 26, 1996

9-11 NRC letter from Gus C. Lainas to David J. Modeen (NEI), "Evaluation of Proposed Update to SGDSM Database and Modifications to the Methodology to Assess Steam Generator Tubing Outside Diameter Stress Corrosion Cracking", November 20, 1998

9-12 NRC Letter, "Request for Additional Information Regarding NP 7480-L, Addendum 1, 'Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits,' 1996 Database Update, November 1996," S. L. Magruder (NRC) to D. Modeen (NEI), January 24, 1997.

9-13 NRC letter to David J. Modeen, NEI, "EPRI Report: Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Limits, NP-7480-L, Addendum 1, November 1996", January 20, 1998

9-14 NEI letter from A. Marion to Brian W. Sheron, "Exclusion of French Data from the Steam Generator Degradation specific Management Database (Generic Letter 95-05), July 25, 2002

9-15 NEI letter from A. Marion to Brian W. Sheron, "Exclusion of French Data from the Steam Generator Degradation specific Management Database (Generic Letter 95-05), October 4, 2002

9-16 NRC letter from William H. Bateman to Alexander Marion, "Exclusion of French Data from the Steam Generator Degradation Specific Management Database", October 8, 2002

9-17 Public meeting between industry and NRC staff representatives on the subject of statistical methods for the regression analysis of ARC data (December 3, 1997)

9-18 NRC letter from William H. Bateman to Alex Marion (NEI), "Refining the Leak Rate Sampling Methodology for Generic Letter 95-05 Voltage-Based Alternate Repair Criteria Application", March 27, 2002

9-19 NEI letter from A. Marion to Brian W. Sheron (NRC), "Refining the Leak Rate Sampling Methodology for ODSCC ARC Applications (Generic Letter 95-05)", March 15, 2002

Table 9-1. NRC/Industry SGDSM Database Protocol

1. The pulled tube database will be updated each March to add additional data from the prior calendar year for steam generator tubes which have been burst, leak, and metallurgically tested, as necessary. This updated database will include updated correlations and a list of plants which provided pulled tube data (including the number of intersections).

2. Utilities with spring outages commencing prior to June 1 will have the option of using the latest database and correlations submitted as an information copy to the NRC (by the end of March) or the prior version of the database and correlations, providing there is not a significant, non-conservative shift in the correlations submitted as an information copy to the NRC (by the end of March) or the prior version of the database and correlations, providing there is not a significant, non-conservative shift in the correlations as discussed in item 5 below. This approach is necessary to ensure sufficient time is available to finalize plant-specific procedures and conduct analyst training prior to the outage.

3. Utilities may request NRC approval of modifications to the database and correlations in accordance with the guidance contained in Generic Letter (GL) 95-05. Examples which would require specific approval include questionable data, application of revised exclusion criteria, or use of a revised probability of detection. The annual update of the correlations discussed in item 1 above will occur regardless of specific requests for NRC approval of changes to the database or correlations. If specific approval of modifications to the database or correlations is requested from the NRC staff, the modifications will not be used until the NRC approves the correlations.

4. Data may be excluded as appropriate under the approved exclusion criteria referenced in GL 95-05. Exclusion of data will be reported in the individual utility 90-day reports and in the pull tube database.

5. If any domestic, pulled tube data fall outside the 95% prediction interval using the latest, approved correlations, the data will be identified to the NRC staff in accordance with Generic Letter (GL) 95-05 by the appropriate utility in the required 90 day report. If the inclusion of the new data results in a non-conservative and significant shift in the correlation predictions, industry representatives will discuss potential database changes with the NRC staff and/or issue a new database and associated correlations. If a revision to the correlations is required, the NRC will be notified, and it will be issued and effective within three (3) months of submittal of the 90 day report.

   A nonconservative shift in the correlations is one that results in a lowering of the structural limit, thereby increasing the probability of burst, or an increase in the

Table 9-1. NRC/Industry SGDSM Database Protocol

probability of leak as a function of bobbin amplitude (voltage) associated with an ODSCC indication, or an increase in the predicted leak rate as a function of indication voltage.

Significant is a term relative to the approved limits of operation and that involves the application of good engineering practice. For example, if the overall probability of burst increases from $1 \cdot 10^{-4}$ to $2 \cdot 10^{-4}$, , while the absolute change is 100% of the original value, the change relative to the GL 95-05 reporting threshold is inconsequential and would not be considered significant if it was suspected that an order of magnitude change in the value associated with indications at a plant previously determined to have an ed of cycle (EOC) probability on the order of $1 \cdot 10^{-3}$ could result in the calculated probability of burst exceeding the GL 95-05 limit. The term significant relative to leakage (i.e., probability of leak and leak rate correlations) should be viewed in a similar manner as discussed above for burst pressure. Because the requirements for EOC leakage are plant specific, consideration should be given to the relative margin between the plant specific calculated leak rate and the leak rate limit.

Significant is also to be interpreted relative to the change histories of the correlations. If the change associated with the inclusion of a new data set is on the order of twice that of the largest change associated with a previous data set with a like number of indications, the inclusion of the additional data will be considered to be significant.

Table 9-2
Summary of Current (October 2002) Number and Target Number for Pulled Tube Intersections with Leakage – Excludes French Data

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PRIOR INDUSTRY RECOMMENDED UPDATES TO ARC ANALYSIS METHODS AND DATA APPLICATIONS