JUN 0 5 1992

R. P. McDonald, Chairman
Utility Steering Committee
EPRI Steam Generator Reliability Project
c/o Southern Nuclear Operating Company
P.O. Box 1295
Birmingham, Alabama 35201

SUBJECT: ALTERNATE TUBE PLUGGING LIMITS

Dear Mr. McDonald:

This letter transmits a summary of the meeting between the EPRI Steam Generator Reliability Project (SGRP) and the NRC staff on March 10, 1992, at NRC Headquarters in Rockville, Maryland (Enclosure 1). During that meeting, staff from the NRC Office of Nuclear Regulatory Research (RES) presented a number of questions pertaining to the proposed voltage-based alternate plugging limits. These questions are provided in Attachment B of Enclosure 1. The bases for these questions are provided in Enclosure 2 to this letter. These questions relate to the generic methodology used to develop the proposed voltage-based limits and, therefore, we request that the EPRI/SGRP coordinate the industry response to these questions. A response by August 28, 1992 is requested.

Sincerely,

James E. Richardson, Director
Division of Engineering Technology
Office of Nuclear Reactor Regulation

Enclosures:
As stated

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

MAY 0 7 1992

MEMORANDUM FOR: James E. Richardson, Director
Division of Engineering Technology

FROM: James T. Wiggins, Acting Chief
Materials and Chemical Engineering Branch
Division of Engineering Technology

SUBJECT: MEETING SUMMARY OF MARCH 10, 1992

A meeting was held on March 10, 1992, with representatives from the Nuclear Regulatory Commission (NRC), Electric Power Research Institute (EPRI) and several utilities to discuss on-going work in the Steam Generator Reliability Project (SGRP). The material presented by EPRI is included as Attachment A.

Steam Generator Programs managed by EPRI have existed since 1977. The programs managed by EPRI provide member PWR owners with information on the status of current research in the areas of steam generator (SG) degradation and methods to minimize this degradation. EPRIs SGRP, which has existed since 1987, has both U.S. and foreign utility participation.

The major objectives of the work in the area of SG reliability include: 1) reducing lost capacity due to SGs, 2) reducing repair and maintenance efforts associated with SGs, 3) reducing radiation exposure from work on SGs, 4) maximizing SG operational safety, and 5) extending SG life.

Evaluation of industry trends have shown that average capacity factor losses due to steam generator problems have decreased and that the average age of the SG at the time of replacement has increased. Additionally, SG tube plugging rates have remained steady although the dominant degradation mechanisms have changed. Based on the current rate of SG tube plugging, it is expected that the average service life of SGs in PWRs will be 20 to 25 years. A number of these improvements are due to research by both U.S. and foreign groups.

Research activities, including non-destructive examination methods for detecting and sizing of flaws, are currently on-going in the following areas of SG degradation: 1) primary water stress corrosion cracking (PWSCC) at roll transitions; 2) PWSCC of hot worked alloy 600; 3)intergranular attack (IGA) and stress corrosion cracking (SCC) at tube support plates (TSPs), in sludge piles, and in the free span of the tubes; 4) circumferential SCC; 5) anti-vibration bar (AVB) wear and fatigue; and 6) denting.

In order to mitigate the rate of SG degradation, research is also being performed in the area of secondary side water chemistry. The research includes the following programs: 1) alternate alloy tests, 2) electrochemical potential monitoring, 3) high hydrazine water chemistry, 4) IGA/SCC inhibitor testing, 5) alternate amines for AVT, and 6) CREV-SIM and MULTEQ computer codes. A draft revision to the EPRI PWR Secondary Water Chemistry Guidelines will be issued early in 1993 to reflect laboratory work and field experience in this area.

B/1

Since the dominant SG tube degradation mechanism has changed from wastage to SCC, utilities have begun to question whether or not the current depth based SG tube plugging limit is appropriate for all forms of degradation. Alternate tube repair limits are currently being proposed that utilize the relationship between SG tube degradation mechanism, structural integrity, remedial measures, operational leakage, and in-service inspection capability to define defect-specific repair criteria that maintain the safety margins contained in Regulatory Guide 1.121 and ASME Code Section III.

The industry is continuing its development of the SG Inspection Performance Demonstration Program in order to ensure a current knowledge base and demonstrated skill level by the analysts and to establish overall NDE system performance goals.

Staff from the NRC Office of Nuclear Regulatory Research presented a number of questions and concerns (Attachment B) regarding the details of the proposed alternate plugging criteria. A response to these concerns was requested.

/s/

James T. Wiggins, Acting Chief
Materials and Chemical Engineering Branch
Division of Engineering Technology
Office of Nuclear Reactor Regulation

Attachments:
A. NRC and SGRP handout
B. Alternate Plugging Criteria Concerns

cc: W. Russell
J. Partlow
R. Bosnak
R.P. McDonald
B.D. Liaw

FOR DISTRIBUTION SEE ATTACHED WP FILENAME: g:EPRIGRP.MTG

DET:EMCB	DET:EMCB	DET:EMCB	DET:EMCB	WTR
*KKarwoski:kk:tc:adl	*EMurphy	*GJohnson	JWiggins	NRR:ADT W. Russell
4/27/92	4/27/92	4/27/92	5/7/92	5/26/92

EPRI

ATTACHMENT A

INFORMATIONAL MEETING

NRC AND STEAM GENERATOR RELIABILITY PROJECT

March 10, 1992
ROCKVILLE, MARYLAND

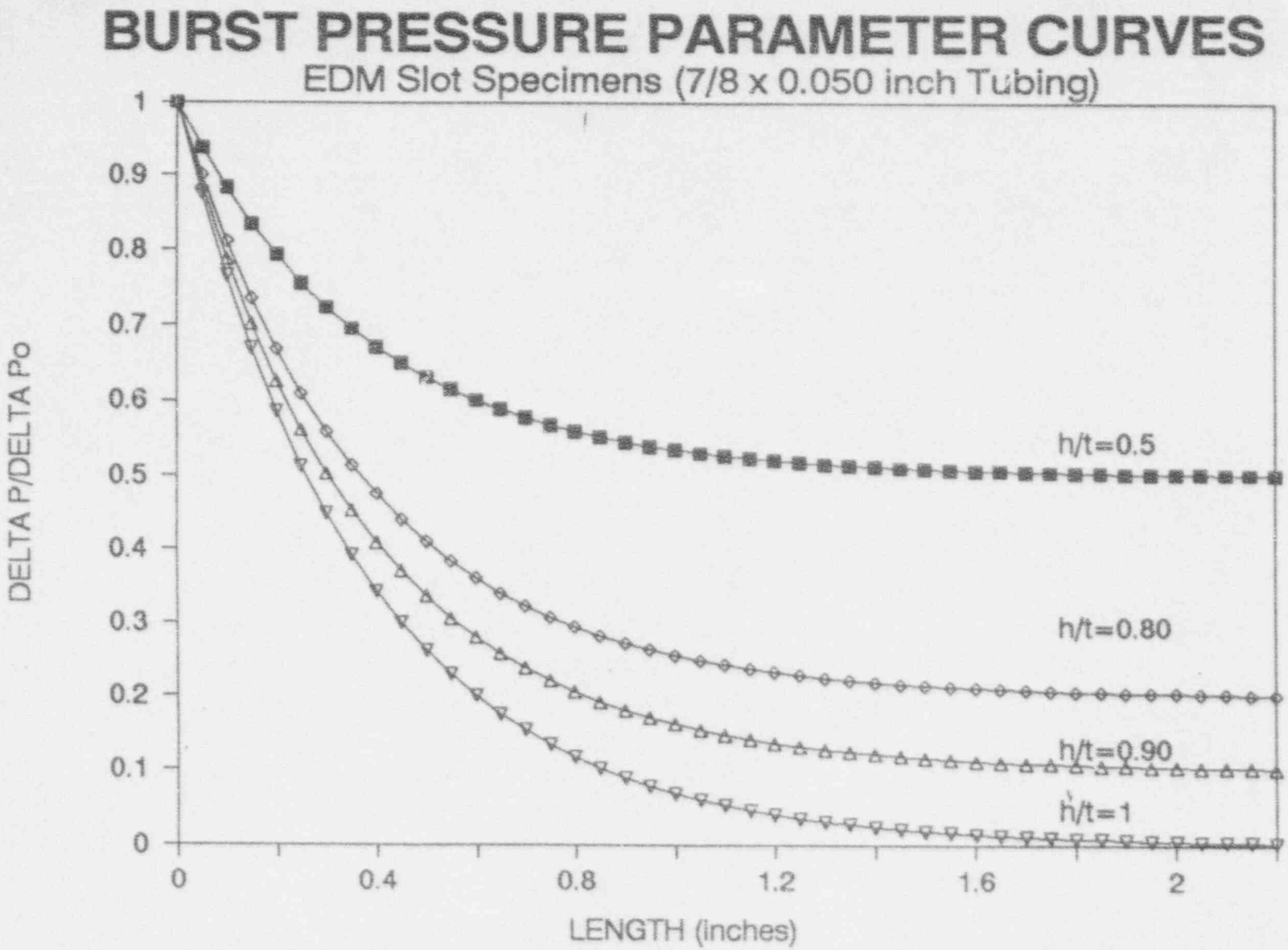


Figure 17 - Results from NRC Steam Generator Tube Integrity Program - Equations for Curves and Similar Plots Reported in NUREG/CR-0718

Figure 16 - Reproduced from EPRI Draft 3 Report, July 1991
"PWR Steam Generator Tube Repair - Technical Support Document for Outside Diameter Stress Corrosion Cracking at Tube Support Plates"

Comparison Between Predicted and Measured Leak Rates

Figure 15 - Reproduced from Westinghouse Report
WCAP-13129, Revision 1

Comparison of French Leak Test Data with Model Predictions Normal Operating Condition

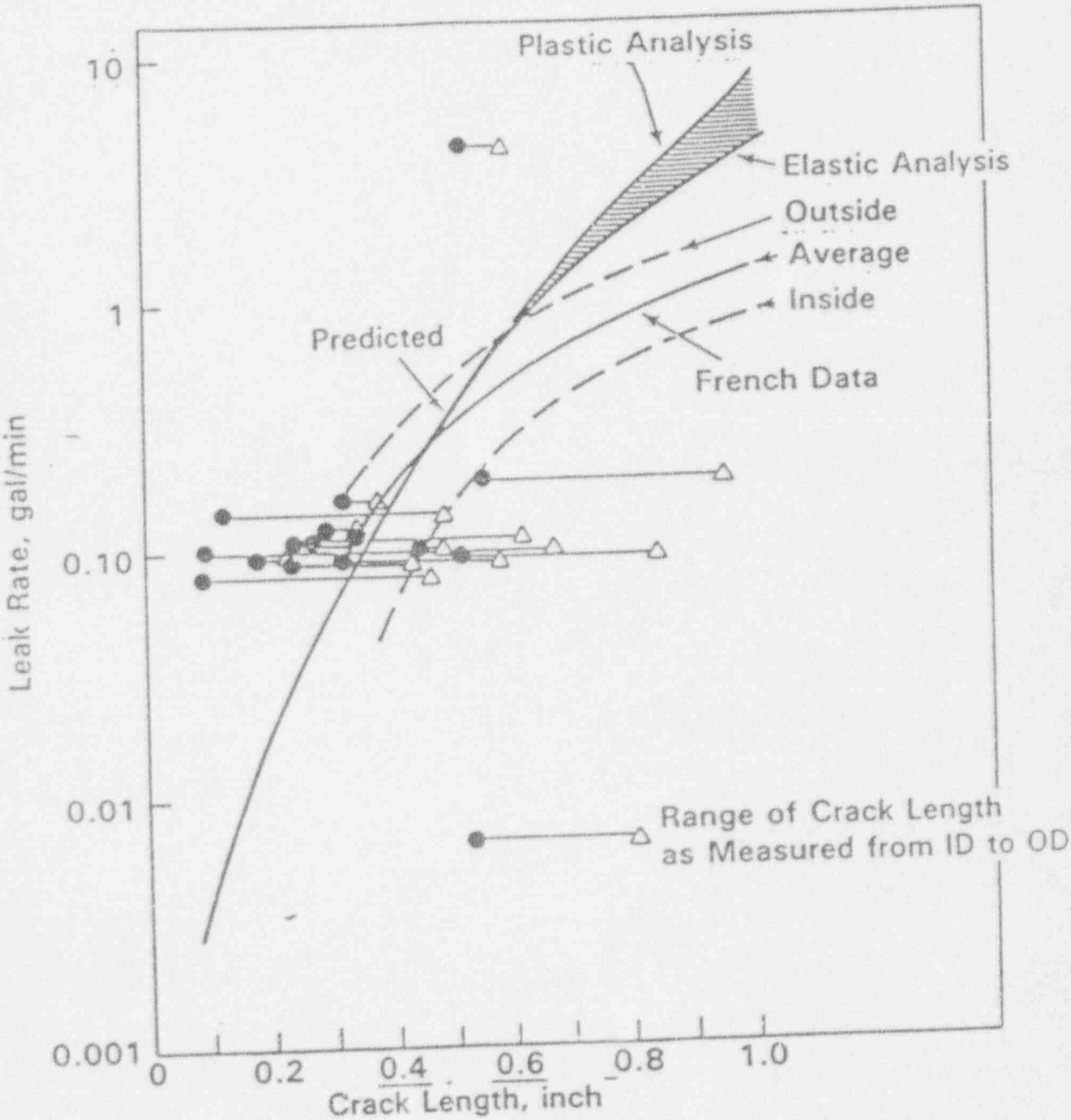


Figure 14 - Data taken from various sources, see NUREG/CR-2336 and NUREG/CR-5117

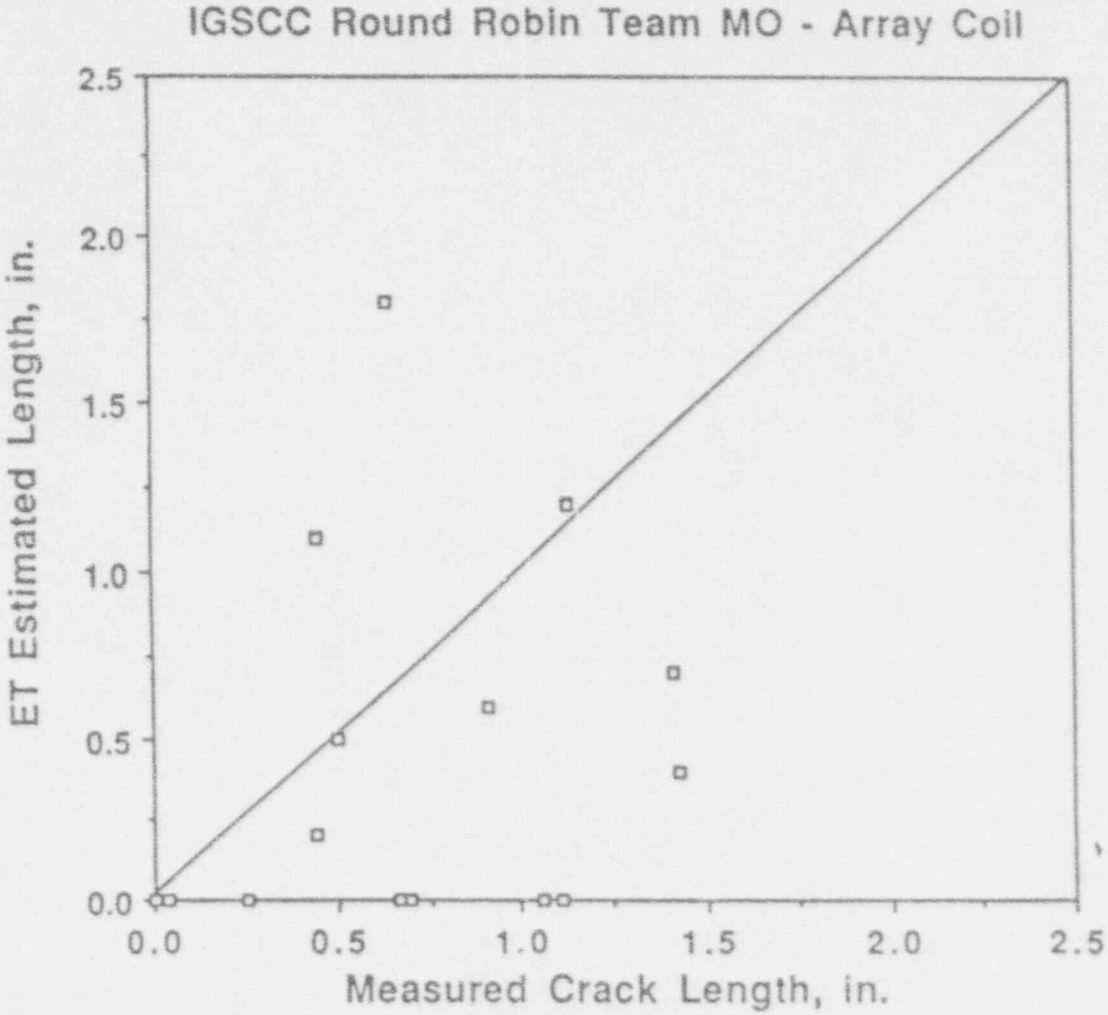


Figure 13 - Results from NRC Steam Generator Group Project Reported in NUREG/CR-2336 and NUREG/CR-5117

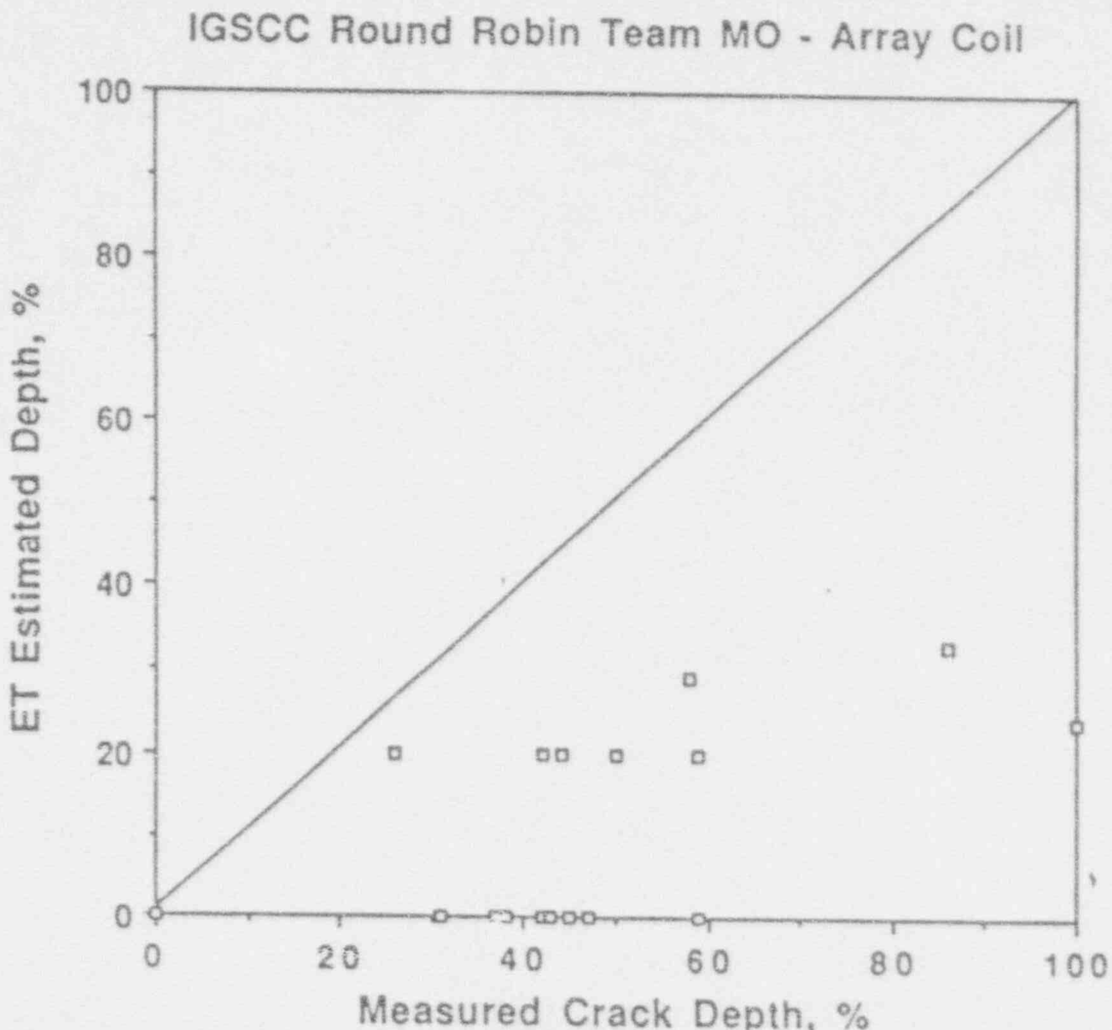


Figure 12 - Results from NRC Steam Generator Group Project Reported in NUREG/CR-2336 and NUREG/CR-5117

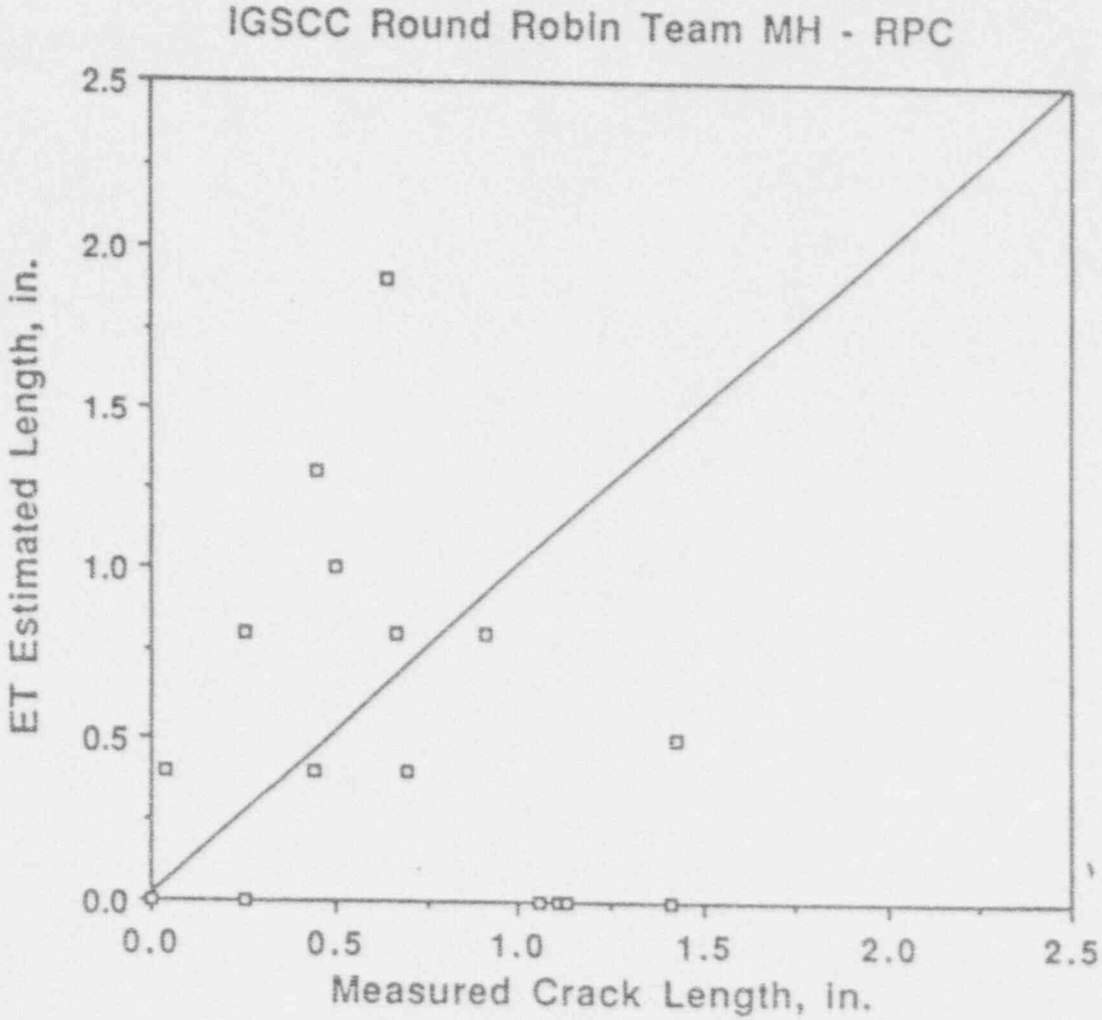


Figure 11 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-2336 and NUREG/CR-5117

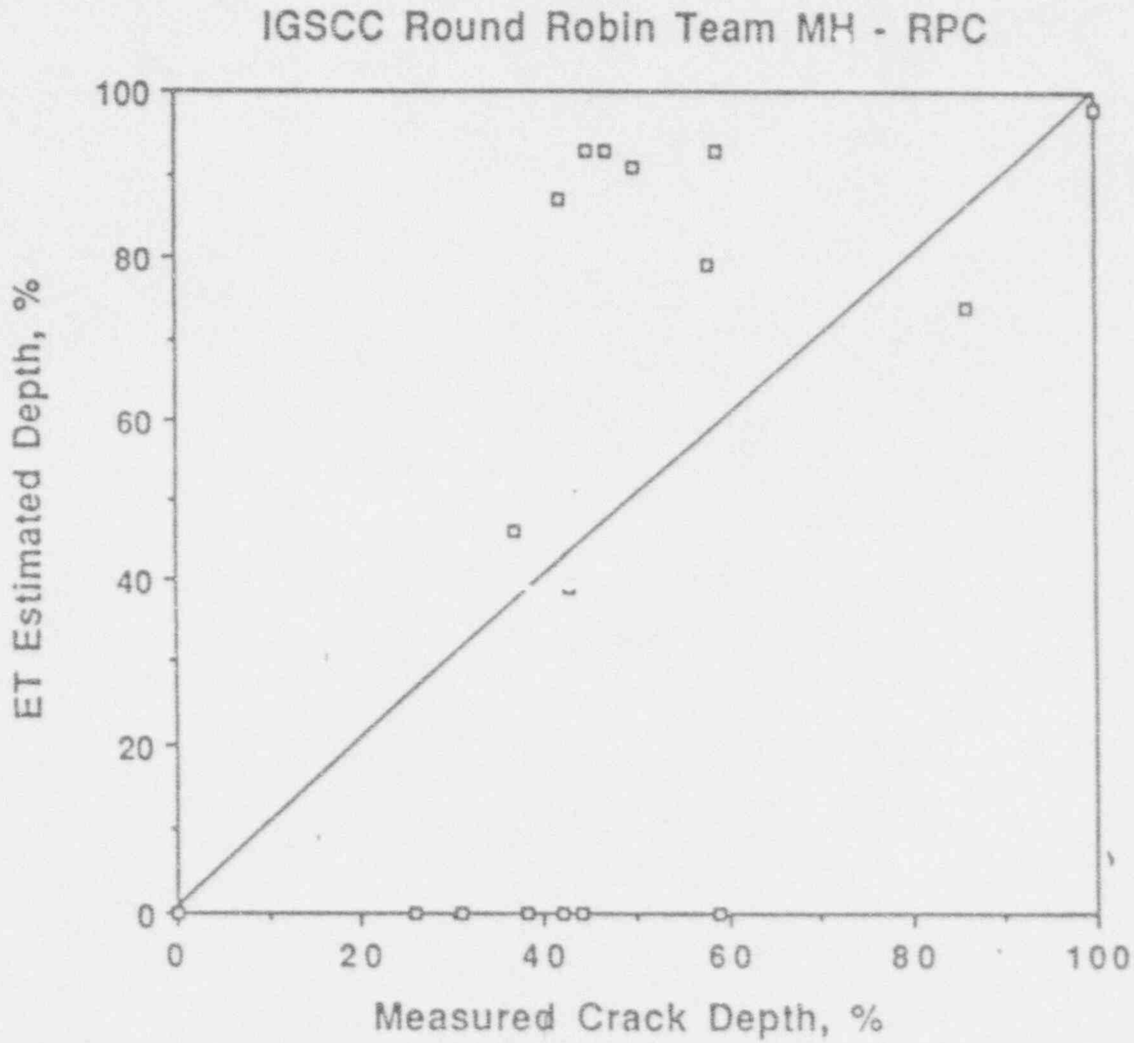


Figure 10 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-2336 and NUREG/CR-5117

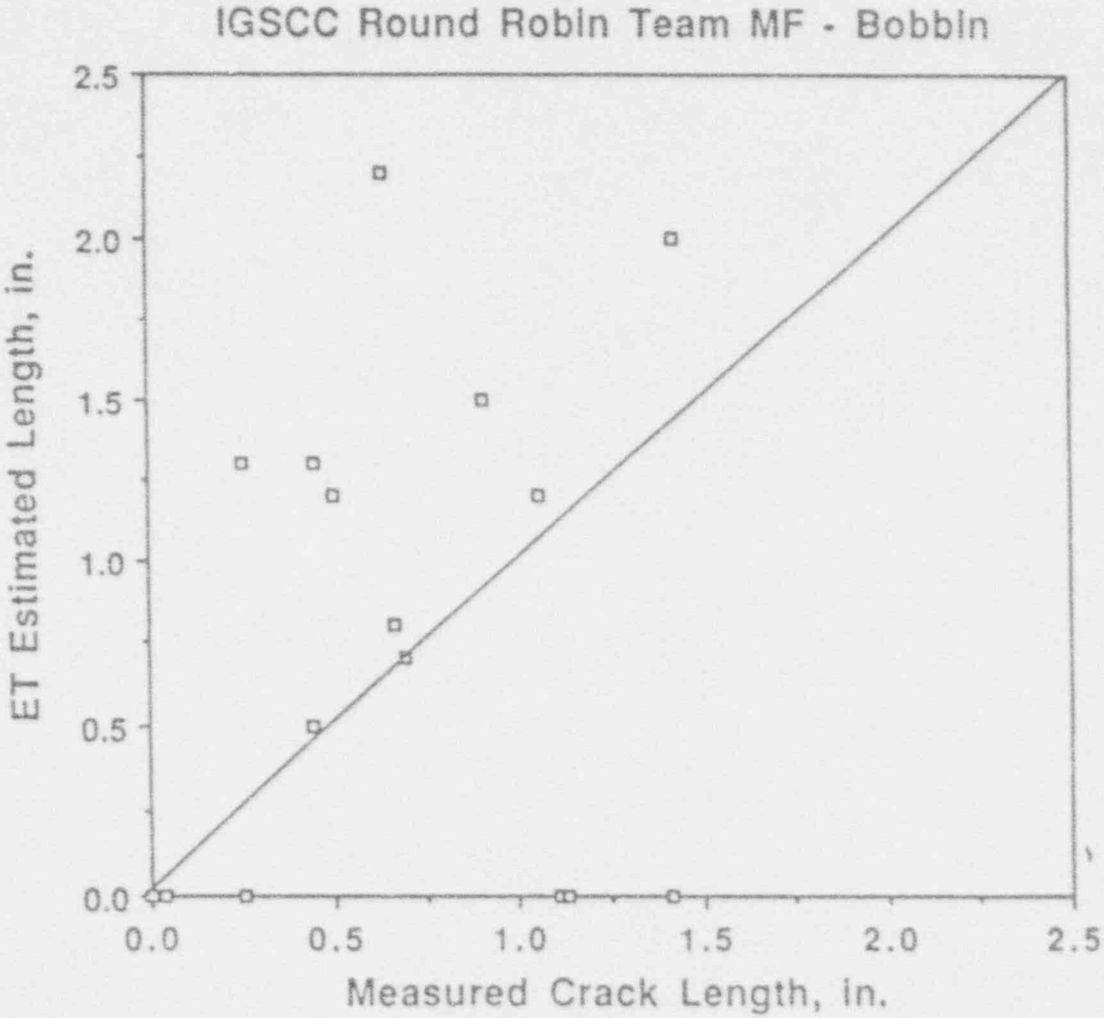


Figure 9 - Results from NRC Steam Generator Group Project Reported in NUREG/CR-2336 and NUREG/CR-5117

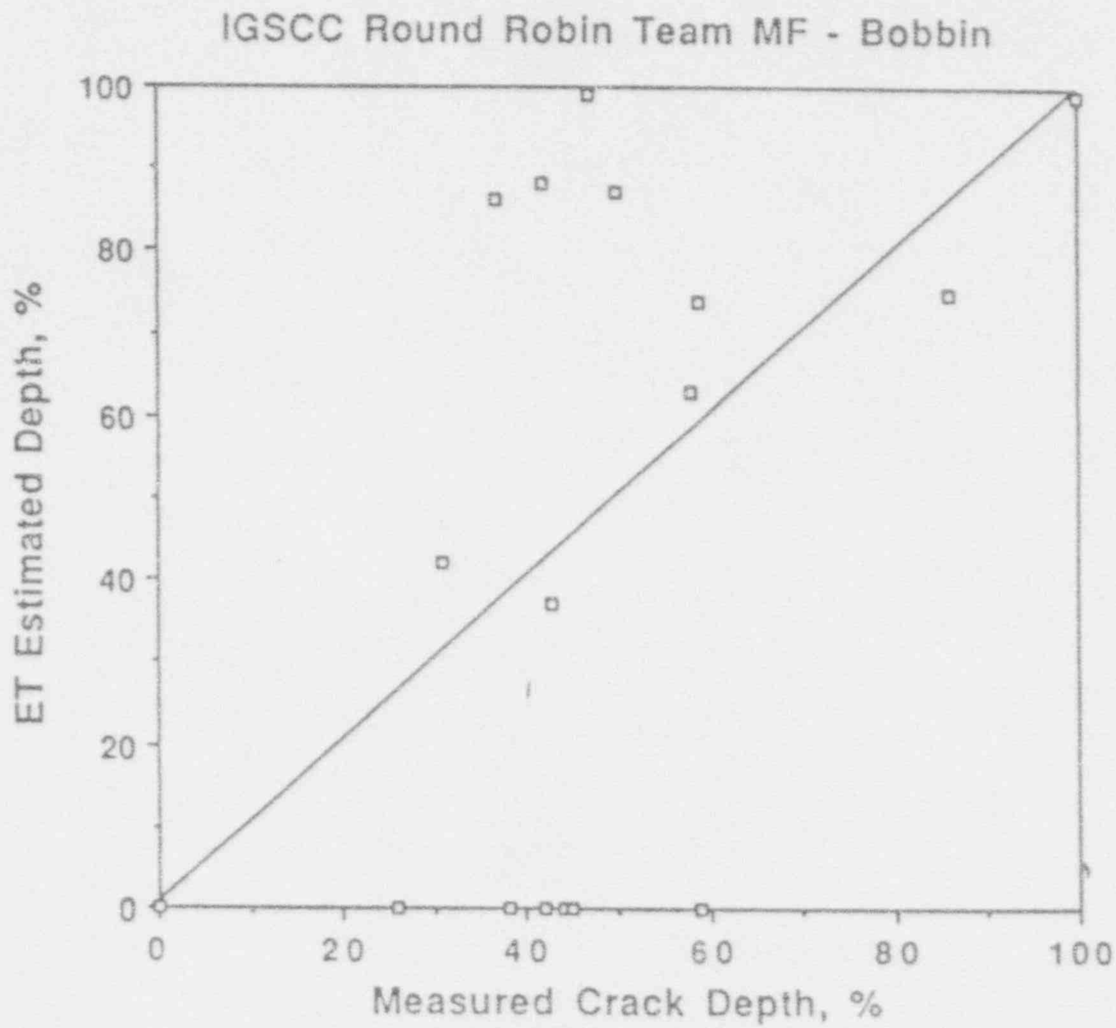


Figure 8 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-2336 and NUREG/CR-5117

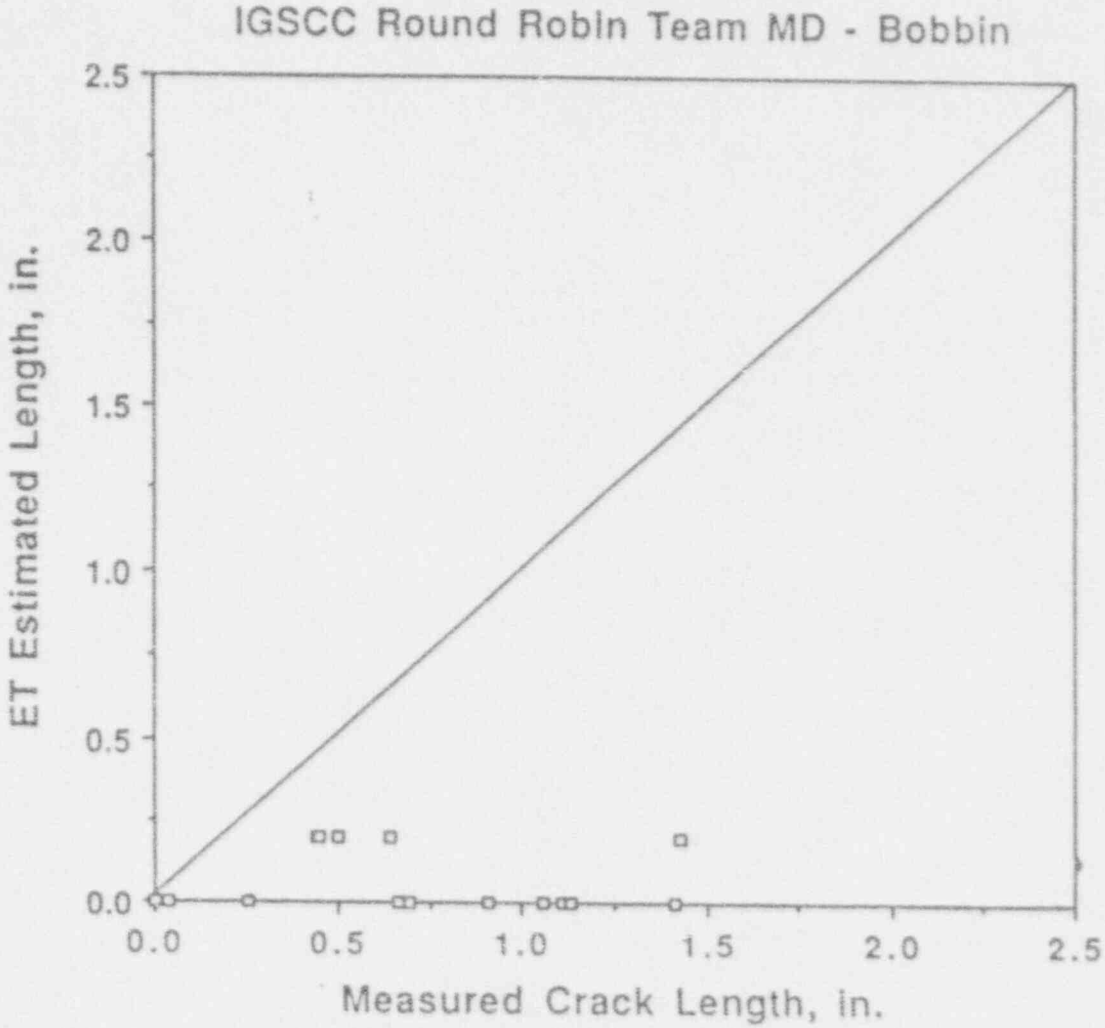


Figure 7 - Results from NRC Steam Generator Group Project Reported in NUREG/CR-2336 and NUREG/CR-5117

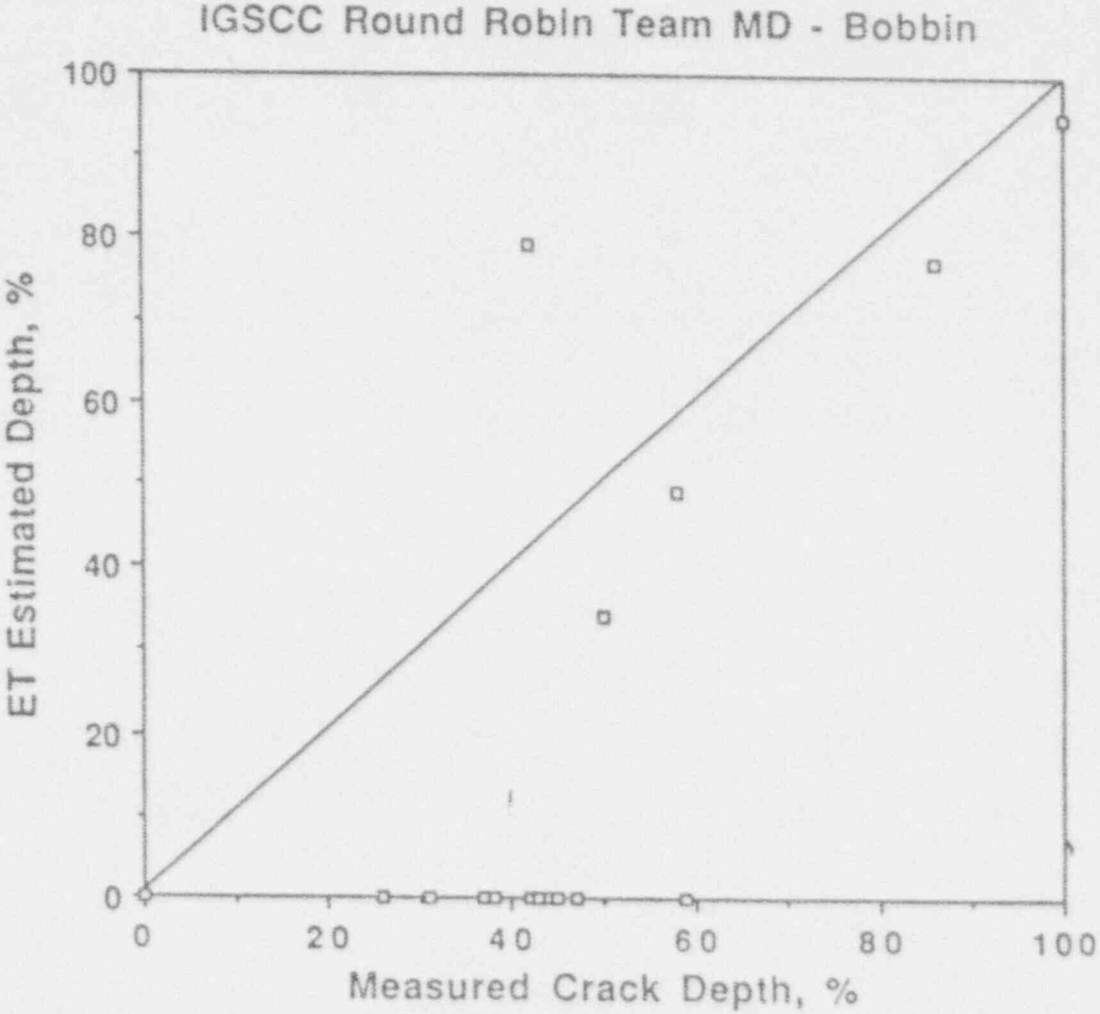


Figure 6 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-2336 and NUREG/CR-5117

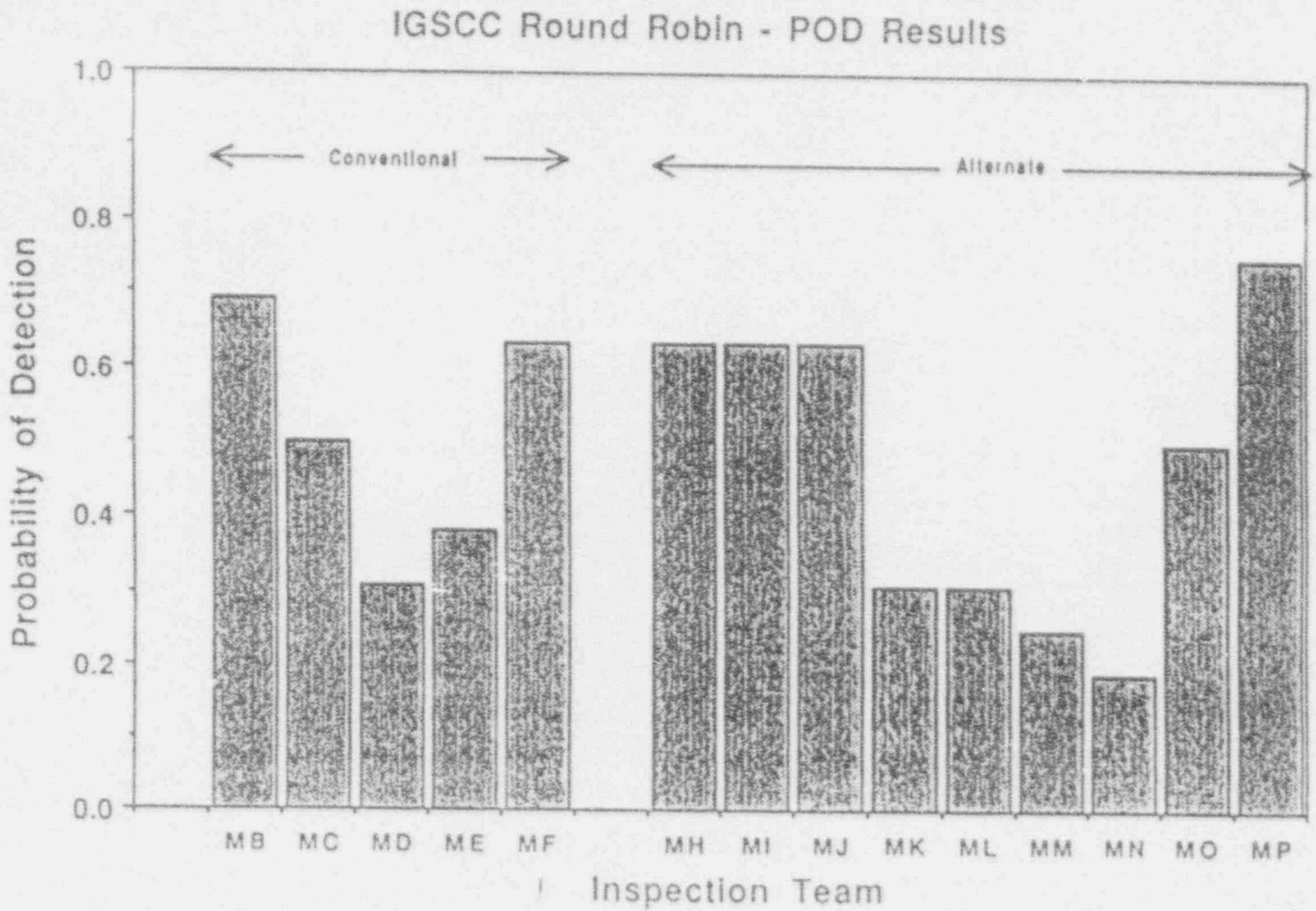


Figure 5 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-5117

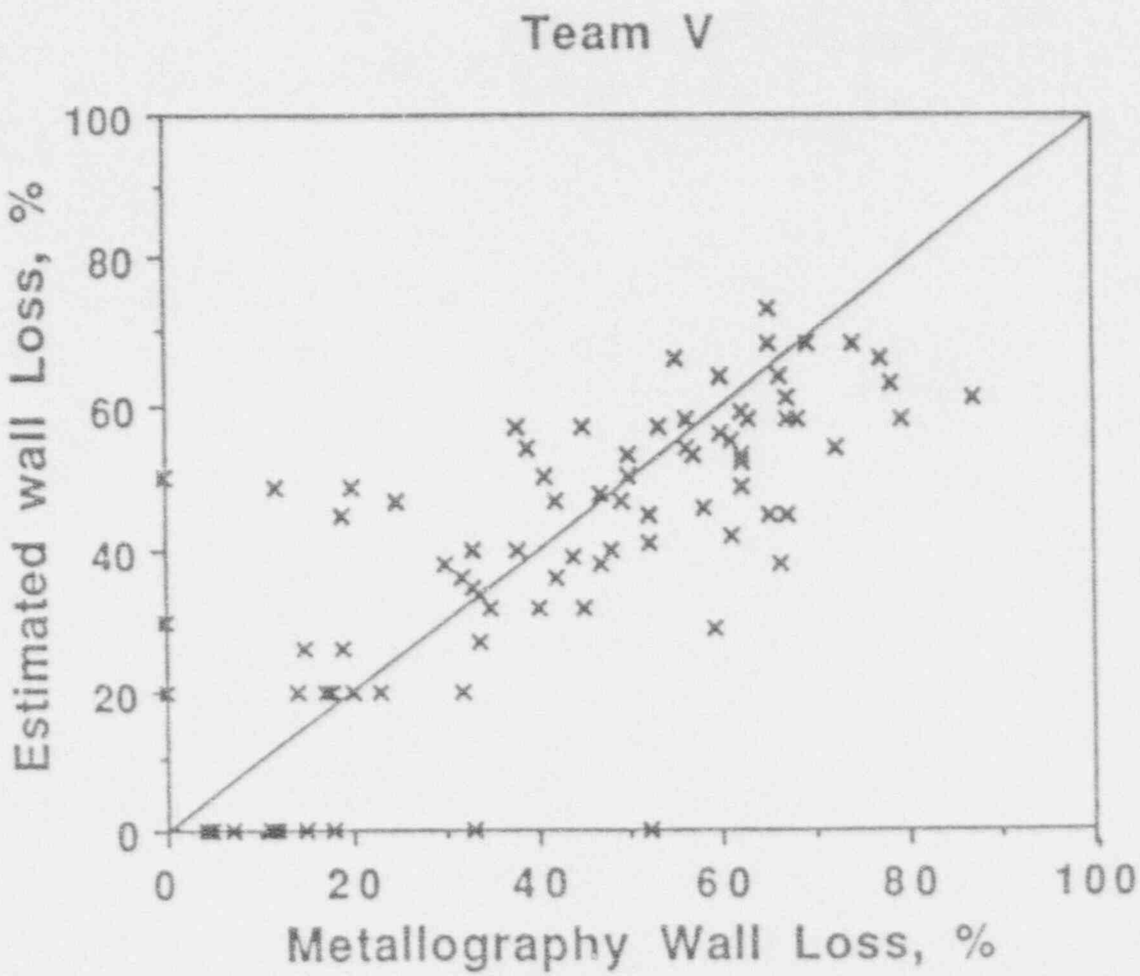


Figure 4 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-5117 and NUREG/CR-5185

Estimated and Actual Wall Loss for Baseline and DAARR Teams

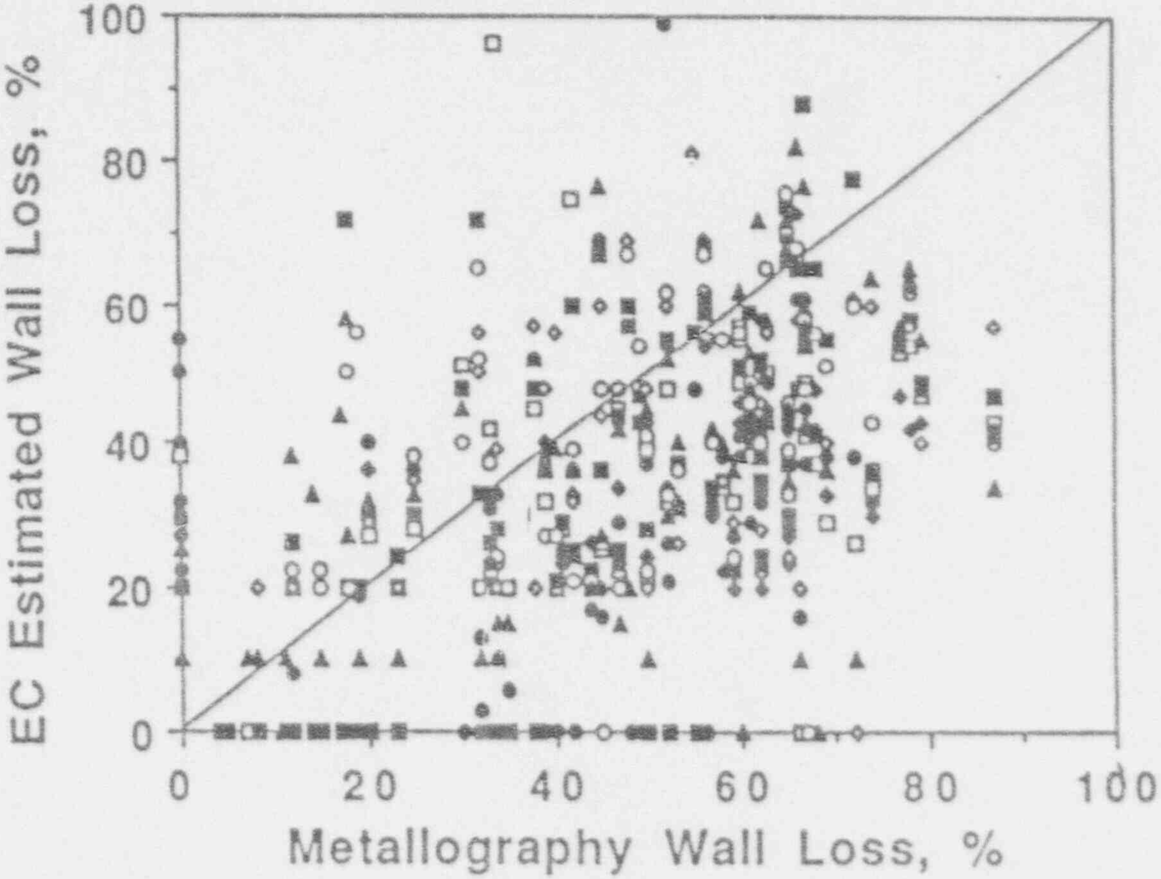


Figure 3 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-5185

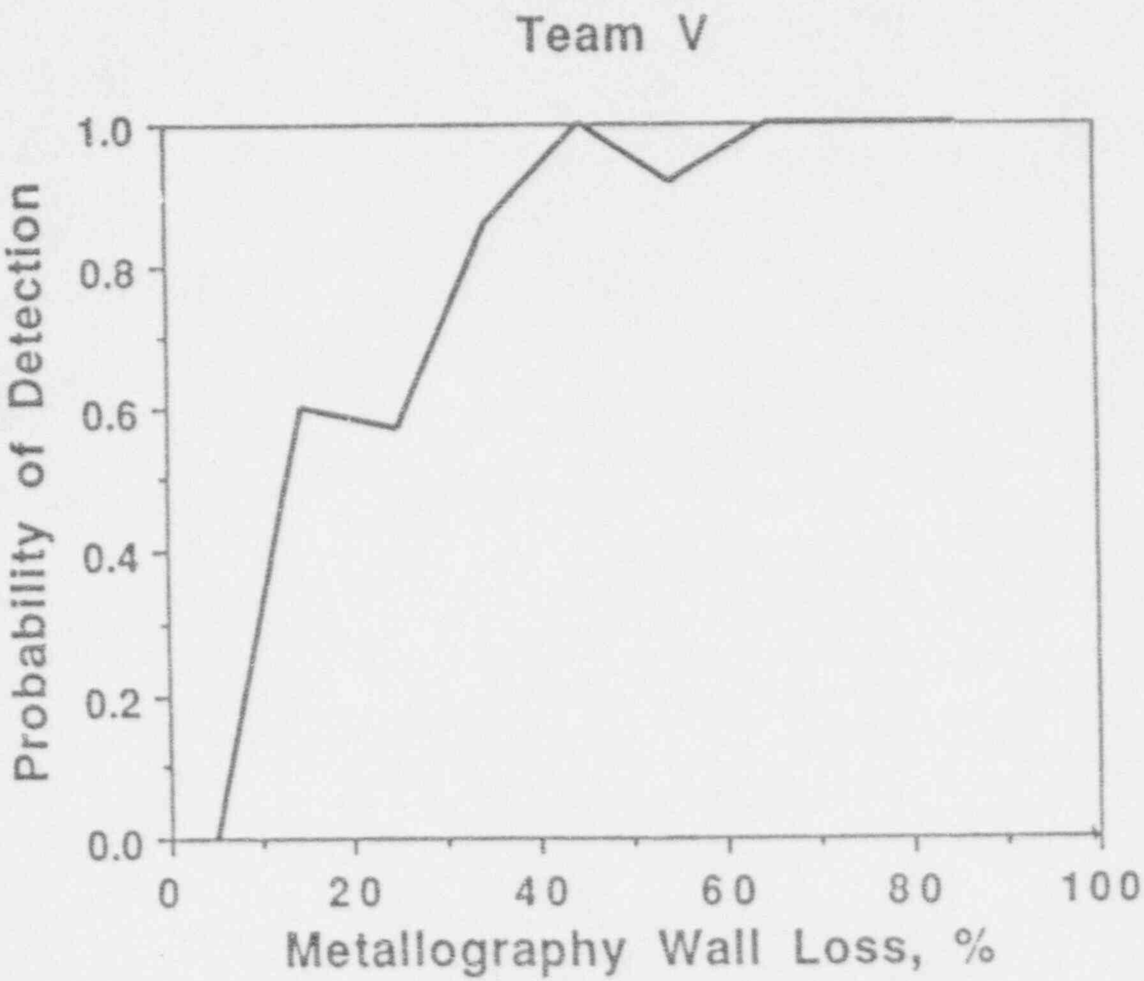


Figure 2 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-5185

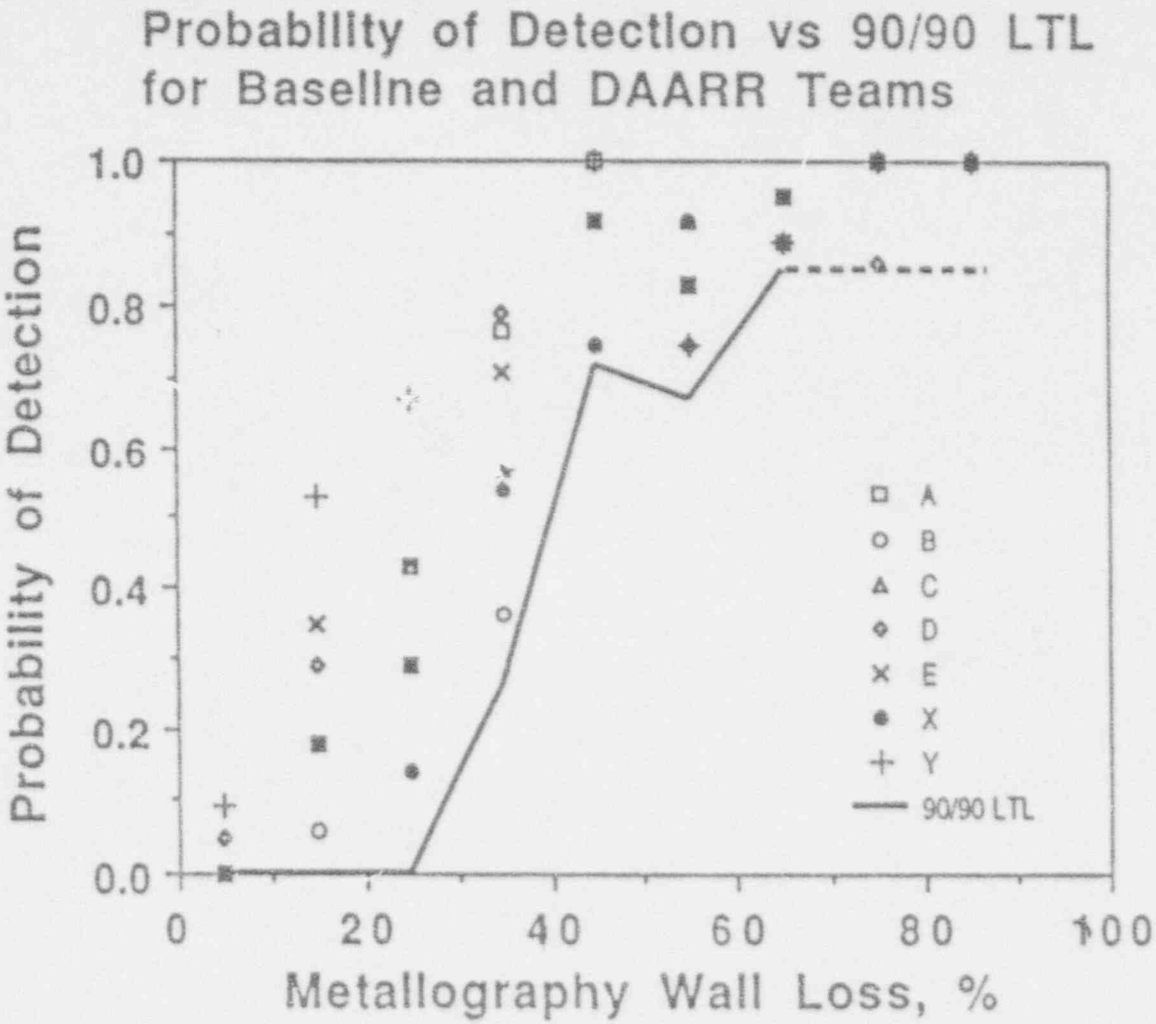


Figure 1 - Results from NRC Steam Generator Group Project
Reported in NUREG/CR-5117 and NUREG/CR-5185

TABLE 1. ODSCC Flaw Dimensions and Bobbin Voltages*

Specimen Number	Maximum Depth, %	OD Surface Length, In.	Raw Bobbin Voltage, Volts	Renormalized Voltage, Volts
B-63-08	26	1.41	0.32	1.16
B-46-02	31	1.06	1.00	3.61
F-10	37	0.25	1.62	5.85
F-15	38	0.25	2.38	8.59
B-30-10	38	0.53	1.37	4.95
B-61-07	42	0.25	0.43	1.55
B-07	43	0.66	1.48	5.34
B-63-01	44	1.14	0.46	1.66
B-62-08	42	1.43	2.04	7.36
B-61-03	47	0.69	0.62	2.24
E-11-05	50	0.64	1.31	4.73
E-07-07	58	0.45	3.44	12.42
B-62-02	61	0.50	1.71	6.17
B-46-04	58	0.70	0.37	1.34
B-55-04	59	0.91	1.92	6.93
B-63-06	59	1.11	1.82	6.57
B-59-07	76	0.81	2.22	8.01
E-11-03	86	0.44	4.57	16.50
B-10-08	99	1.09	7.24	26.14

* Data from NRC Steam Generator Tube Integrity Program-Phase II

Points of interest are that longer (above 0.8") through-wall flaws exhibit low burst pressures and even relatively short but deeper flaws also exhibit low burst pressures. Figure 17 shows for example that a tube with 0.4-inch long through-wall flaw can withstand about 3,500 PSI pressure but a 0.8-inch long through-wall flaw would withstand only about 1200 PSI pressure. A tube with a 0.5-inch long flaw at 50 percent through-wall penetration would withstand about 6,500 PSI pressure at 80 percent through-wall, 4,000 PSI at 90 percent through-wall, 3,400 PSI and the 0.5-inch long flaw, 100 percent through-wall, would withstand approximately 2,500 PSI.

Because voltage does not directly relate to crack length and depth for crack morphologies of interest, a good correlation between voltage and burst pressure is not expected. For example, short tight cracks (deep or through-wall) would produce a low voltage and a high burst pressure, however, a long tight crack (deep or through-wall) could produce a low voltage but also a low burst pressure. Similarly, a series of short tight cracks, axially aligned, with short ligaments in between would produce low voltage and low burst pressure. Figure 18 shows a plot of voltage vs burst pressure used by industry in support of alternate tube plugging criteria. The 95 percent lower tolerance limit on the data is shown. Besides the large variability of a factor of two in burst pressure and one to two orders of magnitude in the voltage, the plot lacks data for the tight long flaws or tight short flaws, axially aligned that could produce low voltages and low burst pressure.

Leak Rate/Crack Size Predictions and Variabilities

Assuming for a moment that a) through wall cracks can be reliably detected and their length accurately sized b) the amount of crack growth, any changes in cracking mechanism and morphology, and growth outside of original zones can be reliably predicted and c) particular cracks will not approach critical sizes during the next operating cycle and are left in service, then these cracks must be monitored during operation to assure that they will not approach critical size. To accomplish this monitoring, leak rate measurements and specifications are established. Unfortunately, for the types of cracks of interest, correlations of leak rates to crack sizes and measured leak rates vs. predicted leak rates (from fluid flow and fracture mechanics models) show approximately two orders of magnitude variabilities, Figures 14 and 15. PLEASE NOTE THE PROPRIETARY NATURE OF FIGURE 15. The variability is due to several unknown or uncontrollable factors. The length of cracks varies from the inside surface to the outside surface, these lengths are not always known or easily measured in service; the leak path for IGSCC is variable and highly tortuous; cracks can be very tight and of variable tightness. Further, in service, cracks can become fouled with small particles and/or corrosion products and may be surrounded by support structures and corrosion products. Under these conditions it is difficult to relate leak rate to crack length (to assure it is below critical length). Furthermore, through-wall cracked tubes in steam generators leak very little inservice whether the cracks are short or long because of tightness, fouling, and constriction by corrosion products or support structures. So, critical cracks cannot be distinguished from subcritical ones based on observed leak rates. Furthermore, the approach of cracks growing to critical sizes cannot be determined since very small changes in leak rates are expected in service. Finally, when hundreds or even thousands of tubes may be leaking a very small amount, how does one distinguish those tubes that have cracks of, or approaching critical size under MSLB conditions? How many are there? Small leakage does not necessarily mean short cracks.

A recent draft EPRI report attempts to show correlations between leak rate and EC probe voltage, Figure 16. These correlations are used in submittals to support alternate tube plugging criteria. The log - log plot of Figure 16 shows very little correlation of voltage with leak rate. Five orders of magnitude variability is shown for leak rates at a given voltage and one to two orders of magnitude variability in voltage for a given leak rate. The correlation coefficient for this plot is reported as 0.73 which also indicates very poor correlation. This plot also lacks data for cracked SG tubes which produce low voltages.

Burst Pressure vs. Degradation

The NRC tube integrity results indicate that tubes with short flaws exhibit more strength than tubes with longer flaws of the same depth, also tubes with shallow flaws can withstand considerably more pressure. Figure 17 shows plots from an empirical equation derived from the data for EDM notches and validated by testing of stress corrosion cracks. It is not surprising that tubes removed from service have exhibited high burst pressures; this can be predicted for short through-wall flaws or for other reasonably deep flaws.

Uniform intergranular attack has been experienced which essentially produces a thinning from an integrity point-of-view. Other uniform intergranular attack progresses to a given depth, then is accompanied by cracking through additional depth in the tube. Still another form, cellular intergranular attack, is a network of axial intergranular cracking connected by circumferential cracking. At different plants and within the same generators, axial and circumferential cracks have been found. In the tube support plate region, cracks have occurred in tubes within the thickness of the tube support plate but have also grown beyond the support plate region and axial cracks have also been accompanied by circumferential cracks. Although, at first, cracks may be noticed only within the tube support plate region, cracks may grow beyond the support plate region in time. Research studies have shown that even for materials that are difficult to crack, once cracks are initiated their growth is sustained and the crack growth rates are similar to those for materials that are more susceptible to crack initiation. To varying degrees, the crack itself may act as a crevice and growth is sustained. Therefore, cracks that initiated in the tube support plate crevice region could grow beyond the original crevice. After the different cracks are observed, the modes of cracking are recognized; however these cracking phenomena have not been predicted nor their occurrence easily controlled. The various mechanisms, causative factors and synergism between important parameters are not well understood. Even if the effect of some of the important parameters such as chemistry were well understood, their control in crucial locations such as in crevices is difficult if not impossible to achieve. Concentration factors, of different species under different conditions, from the bulk to the crevice as high as 10^6 to 10^9 can be expected.

To summarize the above discussion, several modes of cracking have been experienced in U.S. steam generators and several modes can be experienced in a given unit. The cracking modes can change with time and cracking that might have initiated in a given region, tube support plate for example, can extend beyond that region. The mechanisms, interactions and causative factors are not well understood or controllable and the cracking phenomena were not predicted a priori. Laboratory testing of the same heat of material under the same environment and loading conditions produce crack growth rates differing by an order of magnitude. Conditions in an operating plant are not so well known or controlled and even higher variability in growth rates can be expected. Thus, changes in mechanisms, growth of cracks beyond given regions and crack growth rates cannot be reliably predicted. Therefore no assurance can be provided for cracks found during an inspection (even if accurately sized) that they will not reach critical size during the next operating cycle.

Recent proposals try to use a "voltage growth rate" obtained from consecutive eddy current ISIs as a measure of crack growth rate. As discussed previously, for the cracks and crack morphologies of interest, there is no unique correlation between the voltage and the crack length or depth (parameters of interest to structural integrity) therefore the voltage growth rate cannot be used as a measure of crack growth rate.

phase angle for detection and sizing of flaws. Recently a parameter has been emerging, the voltage (or amplitude), as a measure of tube integrity. This parameter does not uniquely measure the length or depth of flaws, the critical parameters from a structural integrity point of view. Table 1 shows data from laboratory produced part-through-wall stress corrosion cracks. For various crack morphologies of interest the voltage is not expected to relate to tube integrity for the following reasons: 1) For flaws of given width and depth a correlation exists of increasing voltage with length up to a flaw length of approximately 0.5 inch. Longer flaws will not produce a larger voltage than this saturation level; this saturation of voltage for approximately 0.5 inch long flaws and longer is based on the coil design. 2) The voltage produced can be related to the tightness of the cracks; if the cracks are tight enough, and conductivity paths exist, low voltage response is expected whether the cracks are short or long. Of course from a structural point of view the larger flaws are more important and the voltage parameter would not distinguish between them. 3) The voltage produced is insensitive to critical crack morphologies. For example a number of short, tight cracks (deep or through wall) axially aligned with short ligaments between them would produce a small voltage indicative of the tight short segments of the cracking. From a structural point of view such cracking would behave like a long crack i.e. tubes would have low pressure holding capability; under pressure the ligaments would join to produce critical length cracks and high leak rates. The voltage response from such cracking would not predict the structural integrity.

Cracking Mechanisms and Growth Rate Variabilities

The discussion on crack detection and sizing reliability indicates that important cracks can be easily missed and those that are detected cannot be adequately sized. Even if important flaws were adequately detected and sized, the crack growth rates, both in terms of depth and length, are required in order to estimate the crack sizes at the end of the operating cycle, before the next inspection, to assure that accepted cracks remain below the critical size by a reasonable margin. Research results show that variabilities of one order of magnitude can be easily expected in crack initiation times and growth rates for environmentally assisted cracking even under test conditions where samples of the same material are exposed to the same environment, temperatures, stresses, etc. Much variation in the operating environment of steam generators exists for the power plants in the U.S. Conditions of water chemistries, temperatures and thermal hydraulics can differ from plant-to-plant; geometries, crevice conditions, heat of material, temperatures, water chemistries, stresses, etc. can vary even within the same steam generator. As a consequence, many different types of cracks have been experienced at different U.S. steam generators and even within the same steam generator. Primary and secondary side cracking has been experienced. Cracks in tubes at various locations has occurred such as in the tube sheet crevice, at top of tube sheet, in free span zones, within the tube support plate regions, at U-bends etc. Fatigue cracks, intergranular corrosion cracks, intergranular attack and crevice corrosion cracks have been experienced. Some of the intergranular cracking is associated with stress such as at dented regions, other intergranular cracking is not associated with any significant stress such as at crevices in undented regions. Several forms of intergranular attack and combinations of intergranular attack and cracking have occurred.

to ensure maintenance of structural integrity in cracked steam generator tubes, cracks must not exceed certain sizes during operation and tubes with cracks above these sizes must be removed from service. Cracks present in tubes during a given inspection must not reach critical sizes during operation before the next ISI. This requires that cracks must be reliably detected and accurately sized, that the sizing errors are known and that crack growth rates (both in depth and length) are known for the wide spectrum of conditions and mechanisms that occur in steam generators. Furthermore, if cracks are accepted they must be monitored during operation to ensure that their sizes do not approach critical sizes which would place the tubes at risk of large leak or rupture during a MSLB. The information from the monitoring must relate directly to crack size. No single factor mentioned above by itself can assure maintenance of structural integrity, these must be applied together. Reliable crack detection and sizing is required along with accurate estimates of crack growth rates and reliable leak rate/crack size correlations for monitoring crack evolution and stability during operation. Discussions related to these capabilities follow.

Crack Detection and Sizing Uncertainty

Some of the most extensive research conducted to evaluate flaw detection probability (as a function of flaw size) and flaw sizing accuracy was the inspection of the Surry generator removed from service. Figures 1-4 show the flaw detection probability as a function of flaw size and flaw sizing accuracy obtained from EC ISI teams. Plots for all the teams and for the best team are shown. These data are for flaws found in the Surry generator i.e. wastage and combinations of wastage and pitting. These flaws are considered to be large volume flaws and easier to detect and size than small volume flaws such as cracks. It is expected that the performance for cracks would be even less reliable. To supplement the data from Surry, a round robin was conducted on a 18-tube box containing laboratory produced stress corrosion cracks. Sixteen tubes contained cracks of various lengths and depths. The depth of four cracks ranged from 25 to 40 percent through-wall, the remaining 12 ranged from 40 percent to through wall. The lengths varied up to 1.5 inches long. Although the total number of flaws in this test is relatively small, some trends are evident from the results. Four organizations inspected these tubes using several techniques a) the standard field practice techniques that met code and regulatory guide requirements and b) alternate techniques to represent the organization's best efforts and techniques. Figures 5-13 show some typical results. The probability of detection for these flaws ranged from 0.2 to 0.75 and on the average was approximately 0.5 for either conventional or alternate techniques; the conventional technique used the bobbin coil while the alternate techniques included rotating pancake coil, array coil and an alternate bobbin coil design. Sizing accuracy was poor. The through wall flaw was sometimes missed and other times reported as a shallow flaw. Of particular interest was the poor length sizing ability even with the alternate techniques, where flaws up to 1.5 inches long were missed or sized at 0.2 to 0.5 inches. Note that some of these cracks are of critical length or longer and the EC would classify them shorter than critical length.

The above discussion on flaw detection and sizing is based on techniques and parameters in common use. Multifrequency procedures, using amplitude and

Enclosure (2)

STEAM GENERATOR TUBE INSPECTION, INTEGRITY AND PLUGGING ISSUES

The following discussion addresses issues related to operation of steam generators with through-wall cracked (leaking) tubes. Two general areas are discussed; 1) engineering design philosophy and the policy of defense-in-depth and 2) technical issues related to assurance of maintaining tube integrity of cracked steam generator tubes during reactor operation.

Engineering Design Philosophy and Defense-in-Depth

General Design Criteria (GDC) of Appendix A to 10CFR50 require that the reactor coolant pressure boundary (RCPB) have an extremely low probability of abnormal leakage, of rapidly propagating failure and of gross rupture. Further, the RCPB is to be designed to permit periodic inspection and testing to assess the structural and leak-tight integrity. Using materials that exhibit leak-before-break behavior, maintaining leak-tightness of the RCPB and conducting inservice inspection (ISI) to assess structural and leak-tight integrity are important elements of defense-in-depth for maintaining safety and are not meant to allow operation with a leaking RCPB. The GDC indicate and the NRC staff has interpreted that through wall cracks in the RCPB are not acceptable. Several recent actions attest to this interpretation: 1) GDC 4 on exclusion of dynamic effects from ruptured pipes does not apply to materials susceptible to degradation; 2) ASME and NRC rules for evaluation of cracked stainless steel pipe do not allow operation with pipes containing through-wall cracks even though these pipes may exhibit leak-before-break. Pipes with cracks deeper than 75 percent through-wall must be repaired; 3) NRC guidance for leak monitoring of RCPB allows for a small amount of unidentified leakage, however, if leakage is from a through wall crack, the component must be repaired; 4) NRR comments from review of a proposed revision to Regulatory Guide 1.121 required the guide to state that through-wall flaws of any type and identified cracks of any size are unacceptable. Since the steam generator tubes comprise over 50 percent of the RCPB surface area and hundreds, even thousands of tubes could be leaking with an alternate tube plugging criteria, it is important to adhere to the policy of non-penetration of the RCPB.

TECHNICAL ISSUES

If it is decided that it is acceptable to operate a nuclear power plant with the primary pressure boundary violated, i.e. with through-wall cracked steam generator tubes for the situation under discussion here, then a strong engineering case needs to be made and actions taken to assure maintenance of structural integrity. The important parameters relating to the structural integrity of steam generator tubes are the crack length for through-wall cracked tubes and the crack length and depth for other cracks. Cracked tubes can exhibit no leakage, small leakage or large leakage and burst behavior under normal operating and accident conditions. For through-wall cracked tubes, with axial cracks, the crack-length at which large leakage or burst occurs (critical crack length) under MSLB condition is approximately one-inch. Various combinations of crack lengths and depths for part-through-wall flaws can lead to burst under normal operating or MSLB conditions. Therefore,

6. How well do we understand the various mechanisms of cracking? What are the causative factors and synergisms? What assurance is there that cracking mechanisms will not change during operating cycles? Why wouldn't existing cracks grow beyond the initial locations, i.e. outside of support plates for crevice corrosion cracking? What are the crack growth rates to be applied to estimate crack length (or depth) at the end of operating cycle?

7. What reliable correlations exist between crack length and measured or predicted leak rates? How do leak rates measured inservice relate to crack length considering corrosion products, fouling, residual stresses, etc. which tend to restrict leakage? What changes in leak rates are expected and can be measured as cracks approach critical lengths?

8. In the Monte Carlo evaluations used to predict expected leak rates under normal operating and accident conditions, how are non-detections of through-wall cracked tubes considered?

CONCERNS REGARDING THE ALTERNATE PLUGGING CRITERIA

If it is decided that it is acceptable to operate SGs with through-wall cracked tubing, thereby eliminating the leak tight integrity of the Reactor Coolant Pressure Boundary (RCPB) as a very important element in defense-in-depth for maintaining safety, then a strong engineering case needs to be made to assure maintenance of structural integrity during operation. To maintain structural integrity, flaw length must remain below a critical length. Key issues in assuring structural integrity are knowledge of:

a) the through-wall flaws present
b) the crack length and accuracy of measurement
c) the cracking mechanism and crack growth rate
d) the crack size and progression from leak rate monitoring

Questions and comments related to these issues are as follows:

1. What is the probability of detection (POD) for deep and through-wall cracks as a function of crack length? Past experience and results indicate a low POD.

2. What is the accuracy of length and depth sizing?

3. If voltage is used as a measure of tube integrity, how is voltage related to length (and depth for deep flaws)?

   - Voltage saturates as a function of length below the critical length.
   - What is the voltage response for tight cracks - even if long?
   - What voltage response and variation is expected for effectively long cracks made up from a series of short cracks axially aligned with small ligaments in between?

4. Tubes with short cracks, even if through-wall, will exhibit high burst pressures. However, tubes with deep partially through-wall flaws (85 percent and greater) and through-wall flaws approximately 0.6 inches long will exhibit burst pressures below the differential pressure experienced during a Main Steam Line Break (MSLB).

   - Again, from the voltage, what is the flaw size for these flaws?
   - In the burst pressure versus voltage correlation, were effectively long, tight cracks (expected of producing low voltage and low burst pressure) considered?

5. Regarding voltage versus leak rate, considering five orders of magnitude scatter in the data and correlation factors of 0.7 to 0.8, is it considered that a reasonable correlation exists?

EPRI / NPD

Samples

- Survey of Existing Samples
- Review of Database of Pulled Tubes
- Development of Sample Matrix
- Specification of Fabrication
  - -- NDE Verifiable, Direct or Indirect Method (Short term, October 1992)
    - Pitting, Thinning, Wear, Impingement
  - -- Requiring Metallurgical or Qualified Sizing Technique (Longer Term, 1993)
    - PWSCC, IGA / ODSCC

SGRP

EPRI / NPD

Status of Implementation Program Development

- Appendices G & H Completed 9/91, approved by SGRP Tech. Advisory Group 11/91
- Implementation approach developed 11/91 and efforts at the NDE Center started 12/91
- Survey of available SG tube samples completed 1/92
- Development of IDB is underway
- Development of training materials is underway
- Development of interactive software shell for PD program integration is under contract negotiation

SGRP

EPRI/NPD

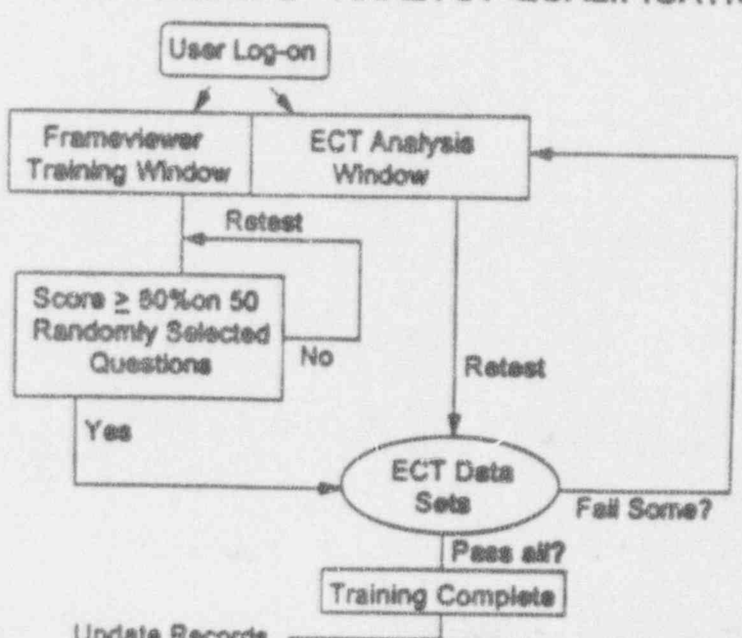
What's a QDA?

- o Analyst trained in all NSSS Vendor Plant Experience & data acquisition/analysis techniques
  - Text Material
  - Laboratory ECT data sets
- o Demonstrated Analysis Skills
  - Tested on all damage mechanisms
    - o Thinning
    - o Wear
    - o IGA/SCC
    - o Impingement damage
    - o Pitting
    - o PWSCC

NDEC 2/92

EPRI/NPD

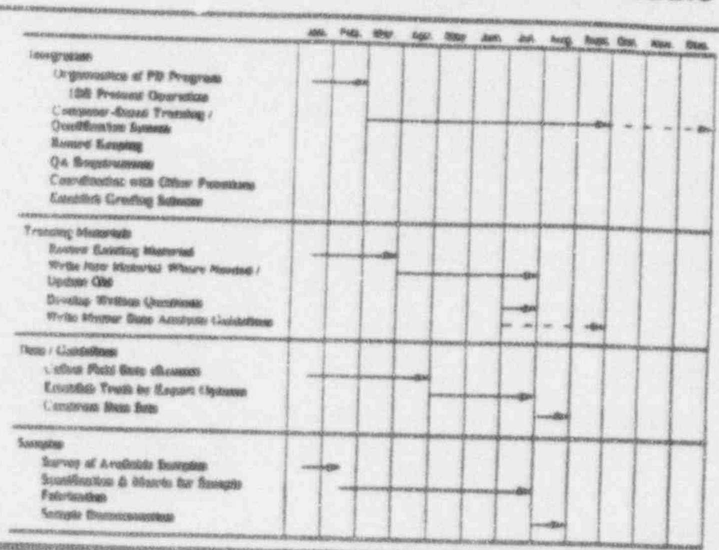
APPENDIX G - ANALYST QUALIFICATION



NDEC 2/92

EPRI / NPD

S.G. Performance Demonstration Schedule



SGRP

EPRI/NP

Defect Mechanism Specific Tube Repair Limits are not new to U.S. Industry

- Site specific applications already exist at some plants
  - P*, L*, F* Criterion. Some relaxation if cracks are at a specified distance below top of tube sheet.
  - Pitting degradation, justifies a plugging limit of 63% allowable wall loss for tubes experiencing pitting.
  - Wastage, justifies a 47% plugging repair limit for steam generator tube thinning.

NRC 3/92

DAS-NRC-3/92-III.7

EPRI/NP

Defect Mechanism Specific Tube Repair Limits are Thoroughly Investigated and Applied in Europe

- In general, criteria may, depending on defect mechanism and SG defect location, involve:
  - Reliance originally based on "leak before break" (LBB) argument for safety
  - Reliance on additional constraint afforded by surrounding tubesheet or tube support plate.
  - Reduced Tech Spec leak limit
  - Inspect for steam generator reliability and plug tubes at a defect length that might be a problem during next cycle (i.e., account for growth rate)
    - -- Special inspection procedures and techniques may be used.
  - Demonstrate that tube burst capability is not compromised including degradation of >40% thru-wall.
  - Now moving towards simply a crack length based limit or even through wall cracks - no absolute reliance on LBB.

NRC 3/92

DAS-NRC-3/92-III.8

EPRI/NP

Alternate Tube Repair Limits

INDUSTRY RESPONSE

- Utilize the relationship between tube degradation mechanism, structural integrity, remedial measures, operational leakage, and in-service inspection capability to define defect-specific repair criteria that maintain Reg. Guide 1.121 and ASME Section III margins.

NRC 3/92

DAS-NRC-3/92-B1.5

EPRI/NP

Plant Operational Advantages of Defect Mechanism Specific Tube Repair Limits for Steam Generators

- Avoid premature/unnecessary tube plugging
- Optimize steam generator availability
- ALARA principle considerations
- Maintain flexibility for long-term repair options
- Maximize the available heat transfer area
- Optimizing the cost-effectiveness of the steam generator repair and inspection program

NRC 3/92

DAS-NRC-3/92-B1.6

EPRI/NP

Status of Generic Defect Mechanism Specific Tube Repair Limit Documents

- PWR Steam Generator Tube-Plugging Limits:Technical Support Document for Expansion Zone PWSCC in Roll Transitions - issued December 1990, deals with multiple axial cracks
  - Updated (Rev. 1) to include the possibility that circumferential cracking can occur - issued December 1991.
- Alternate Repair Limits for OD SCC at TSPs, deals predominantly with axial cracking, to be issued by March 18, 1992..

NRC 3/92

DAS-NRC-3/92-8.11

EPRI/NP

Alternate Steam Generator Tube Repair Limits for Certain Defect Mechanisms Focus on True Measure of Structural Integrity

For Example:

- Eddy current voltage based plugging criterion for OD SCC at tube support plates mandates action be taken in a voltage range which can be accurately measured and depth is not a consideration
  - Voltage range is dictated by burst pressure capability of the tube and leakage considerations with Reg. Guide 1.121 and ASME Section III Conservatism Incorporated
- Crack length based repair limit also ignores depth parameter and deals with that which directly influences tube burst

NRC 3/92

DAS-NRC-3/92-8.12

EPRI/NP

U.S. Utility Industry Takes Initiative to Define Generic Defect Mechanism Specific Tube Repair Limits

- Prepare industry reviewed and supported documents published by EPRI for Alternate Repair Limits for specific defect mechanisms in susceptible PWR plants
  - Document would be used with site-specific submittal to NRC with appropriate modifications where needed (individual utilities will submit shortly)
  - They are "living documents" being reviewed and updated by industry
  - Utility group will in the near future formally submit a request for a Tech. Spec. change to allow application of defect specific repair criteria as reviewed and approved by NRC
    - Methodology for development of defect specific repair criteria presented in Tech. Spec.
- Coordination for document preparation and updating performed by the Steam Generator Project Office of EPRI

NRC 3/92

DAS-NRC-3/92-Sl.9

EPRI/NP

Industry "Ad-Hoc" Committee for Alternate Repair Limits for EZ PWSCC

[illegible]

NRC 3/92

DAS-NRC 3/92-Sl 10

EPRI/NP

Alternate Repair Limit for Tube Support Intersections Incurring Predominantly Axial OD Stress Corrosion Cracking (ODSCC)

Tube Repair Limit

- Tubes with bobbin coil indications exceeding 4.5 volts will be repaired

SLB Leakage Criterion

- Predicted SLB leak rates from tubes left in service must be less than 55 gpm for each S/G, including considerations for NDE uncertainties and ODSCC growth rates
  - Either a deterministic or probabilistic leak rate analysis may be performed

NRC 3/92

DAB-NRC-3/92-B.15

EPRI/NP

Alternate Repair Limit for Tube Support Intersections Incurring Predominantly Axial OD Stress Corrosion Cracking (Cont.)

Inspection Requirements

- A 100% bobbin coil inspection shall be performed for all hot leg TSP intersections and all cold leg intersections down to the lowest cold leg TSP with ODSCC indications

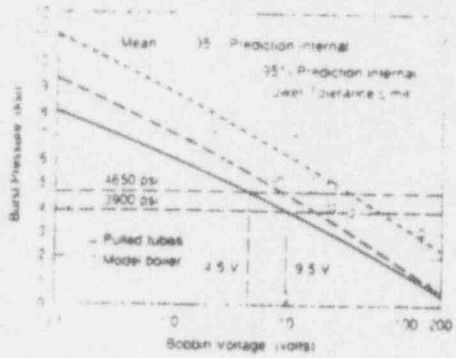
- All tubes with bobbin coil indications >1.5 volts at TSP intersections shall be inspected using RPC probes. The RPC results shall be evaluated to support ODSCC as the dominant degradation mechanism.

NRC 3/92

DAB-NRC-3/92-B.16

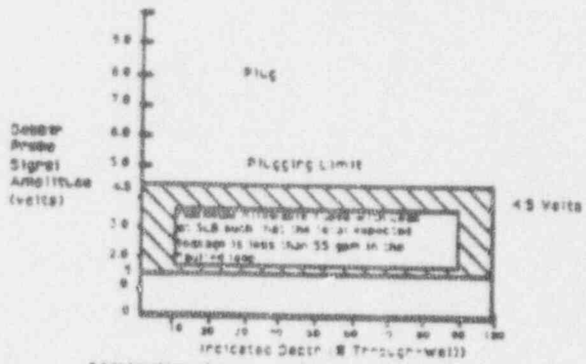
EPRI/NP

Tube Burst Test Results



EPRI/NP

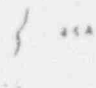
Alternate Repair Limit for Tube Support Intersections Incurring Predominantly Axial OD Stress Corrosion Cracking



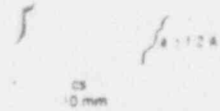
*Application of Alternate Repair Limits confined to within thickness of tube support plates

EPRI/NP

EZ-PWSCC Axial Crack Configurations Acceptable for Continued Service per the Guidance in this Document



Predominately axial cracks (a≥c) where the axial length is less than or equal to the allowable crack length (a≤A)



Multiple axial cracks with spacing between adjacent axial cracks greater than or equal to 10 mm (0.4 in.) (cs≥10 mm) and axial length less than or equal to the allowable crack length (a≤A)

Multiple axial cracks with spacing between adjacent axial cracks less than 10 mm (0.4 in.) (cs<10 mm) and axial length less than or equal to 1/2 the allowable crack length (a≤1/2A)

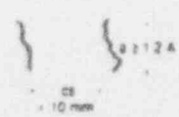
NRC 3/92

DAS-NRC-3/92-SI 19

EPRI/NP

EZ-PWSCC Axial Crack Configurations That Should be Repaired Per The Guidance in This document

Predominately axial cracks (a≥c) where the axial length is greater than the allowable crack length (a>A)



Multiple axial cracks with spacing between adjacent axial cracks less than 10 mm (0.4 in.) (cs<10 mm) and axial length greater than 1/2 the allowable crack length (a≤1/2A)

NRC 3/92

DAS-NRC-3/92-SI 20

EPRI/NP

Alternate Repair Limit for Tube Support Intersections Incurring Predominantly Axial OD Stress Corrosion Cracking (Cont.)

Operating Leakage Limits

- Plant shutdown will be implemented if normal operating leakage exceeds 150 gpd per S/G

Exclusions from Tube Repair Limit

- Tubes with RPC indications not attributable to ODSCC and circumferential indications shall be evaluated for tube repair based on a 40% depth limit.

NRC 3/92

DAB-NRC-3/92-B.17

EPRI/NP

Alternate Tube Repair Limits Established for Expansion Zone Primary Water Stress Corrosion Cracking at Roll Transitions (EZ PWSCC)

- EPRI Report NP-6864-L, Rev. 1 (December 1991)
- Repair Limit based on crack length (not depth)
  - Based on published tube burst data
  - Axial cracks only
  - Repair if circumferential crack is indicated
  - Restrict spacing between adjacent axial cracks
- Enhanced Inspection
  - 100% rotating pancake coil (RPC) in affected areas
  - Allowance for RPC uncertainty
  - Allowance for crack growth between inspections
- Reduced primary to secondary leak rate limit (0.1 gpm) to enhance leak-before-break
- Limit number of cracked tubes in service to limit leakage for postulated accidents
- Developed for full-depth roll transitions
  - Correction for tubesheet constraint
  - Applicable, but over-conservative, for partial depth roll transitions
- Application of NRC Reg. Guide 1.121 safety factors

NRC 3/92

DAB-NRC-3/92-B.18

EPRI/NP

Future Actions

- Complete 3/4 inch tube testing and data report (June 1992)
  - Only 3/4 inch data
  - Combined 3/4 and 7/8 inch data
- Complete 3/4 inch generic support document (June 1992)
  - Not yet planned
- Initiate work for other mechanism-specific degradation forms (September 1992)
  - IGA with some SCC
  - Cracking at dented intersections
  - Free span cracking (e.g., in sludge pile)

NRC 3/92

DAS-NRC-3/92-B.21

EPRI / NPD

Program Objectives

- Establish an industry-wide data analyst and training and qualification program to ensure a current knowledge base and demonstrated skill level

- Establish NDE system performance e.g., procedure (technique), instrumentation, and individual analyst - using a performance demonstration methodology - for all damage mechanisms

EPRI / NPD

Development of Capability To Implement SG ECT Performance Demonstration Appendices G & H

- The industry is developing source materials and implementation protocol through EPRI at the EPRI NDE Center.

- This capability (source materials) will be transportable and intended for program implementation by utilities or other third party providers of qualification services.

EPRI / NPD

Status of Industry SG Inspection Performance Demonstration Program

Mohamad Behravesh

Steam Generator Reliability Project
Annual Meeting With The NRC
NRC Offices, Rockville, Maryland
March 10, 1992

SGRP

EPRI / NPD

Background

- The industry program for SG NDE Personnel Qualification and Performance Demonstration was last presented to the NRC on October 1, 1991
- The program was developed by an industry group representing utilities, NSSS, and ISI vendors and it is described in two Appendices to the SG ISI Guidelines;
  - Appendix G, Personnel Qualification
  - Appendix H, Performance Demonstration

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Implementation Task Groups Membership

J. Benson, NEU
B. Curtis, ANA
R. Ingraham, W
R. Marlow, CONAM
D. Mayes, Duke
T. Richards, B&W

G. Boyer, FP&L
H. Houserman, Zetec
D. Malinowski, W
R. Maurer, ABB CE
S. Redner, NSP
K. Wachter, RG&E

Chuck Welty, EPRI
Gary Henry, EPRI NDE Center
Steve Brown, EPRI Consultant
Doug Harris, EPRI Consultant
Mohamad Behravesh, EPRI Project Manager

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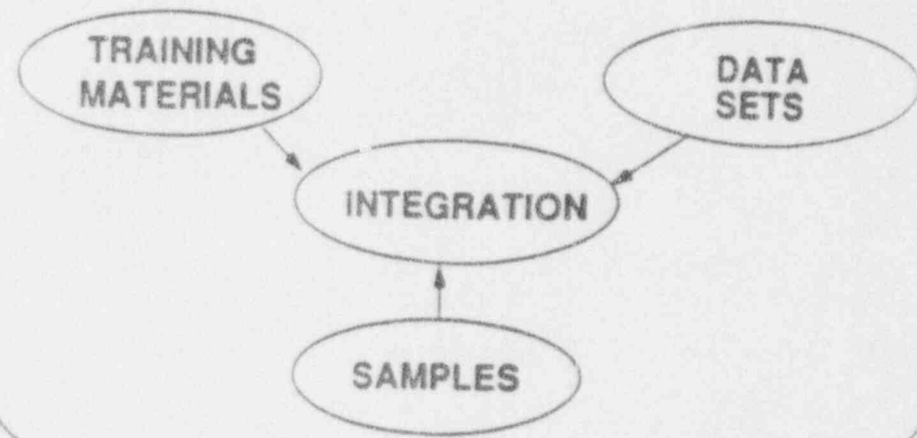
EPRI/NPD

Industry Data Base

- Centralized Data Base
  - Purpose is to provide uniform training and examination source material for *employer implemented* data analyst qualification and technique qualification using protocols established in Appendices G & H.
- IDB *initialized* using EPRI developed source material with continued updates e.g., *IDB maintenance*, on a yearly basis
- User Responsibilities
  - Implementation (training & qualification)
  - Certification
  - Record keeping (non-centralized)

EPRI / NPD

SG Eddy Current Inspection Performance Demonstration



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Utility Oversight and Technical Input / Review

- Overall guidance and oversight provided by SGRP Technical Advisory Group's Subcommittee Chairmen
- Technical input and review are given by individual industry experts through participation in various Task Groups and contracted efforts

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EPRI / NPD

Interim System

- Computer -Based Analysis
- Manual Training (Book)
  - -- Design and Operating Experiences (CE, W, & B&W)
  - -- Acquisition & Analysis Techniques (CE, W, & B&W)
  - -- Pulled Tube Experiences

SGRP

EPRI/NPD

Shell Software

Functions

o Integration

- Text material
- Written questions
- ECT data sets

o User Friendly

- Menu driven system access

o Security

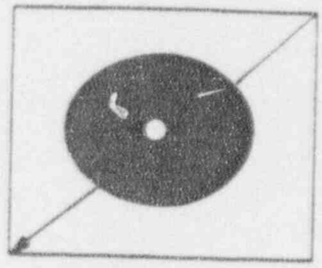
- Limits access to written questions and practical examination data sets

NDEC 2/92

EPRI/NPD

Industry Data Base

- o System built around Zetec HP/UX Eddynet system with optical networking & storage
- o EPRI Prepared Source Material
  - Descriptive test for training
  - Written Questions
  - ECT data sets for training & qualification



Optical Disk

NDEC 2/92

EPRI / NPD

Overview of Appendix G Implementation

Goal:

To Be In Place By October 1992

Approach for Industry Database (IDB):

Interactive Computer-Based Training System (HP &/or IMB) Fully Integrated by 1993

- **Training Data Sets: CE, W, & B&W**
- **Qualification Data Sets: CE, W, & B&W**
- **Retest Data Sets: CE, W, & B&W**

SGRP

EPRI/NP

Alternate Steam Generator Tube Repair Limits

An Industry Initiative

David A. Steininger

Technical Advisor
Steam Generator Project Office
Electric Power Research Institute

NRC 3/92

DAS-NRC-3/92-B.1

EPRI/NP

Steam Generator Tubes are Experiencing Multiple Defect Mechanisms

- Primary water stress corrosion cracking, (e.g., within the tubesheet region, i.e., EZ PWSCC), axial and circumferential
- Secondary side stress corrosion cracking (ODSCC), axial and circumferential
  - @ at tube support plate intersections, and
  - @ tube sheet region
- Intergranular attack (IGA), a volumetric form of attack (i.e., not crack like)
- Fretting and wear
- Secondary side wastage
- Denting
- Fatigue

NRC 3/92

DAS-NRC-3/92-B.2

EPRI/NP

U.S. Plugging Practice To Date In General Consists Of:

- Plug @ >40% thru wall degradation (i.e., depth) as indicated by eddy current using "bobbin coil" phase relationship
  - Originated during the days of steam generator "tube wastage" as the tube defect mechanism
- Plug all "crack-like" indications as indicated by RPC interrogation
  - PC inspection "triggered" by a bobbin coil distorted phase signal
- No special mandated inspection technique other than bobbin coil
  - a 3% sample plan is indicated
- No change in "Tech Spec" leak limi

NRC 3/92

DAS-NRC-3/92-BL3

EPRI/NP

Multiple Defect Mechanisms Have Resulted in NDE "False Calls" and Excessive Tube Repair

PROBLEM:

- For some tube degradation on mechanisms (e.g., short, axial stress corrosion cracks, IGA), the 40% repair criterion challenges current NDE technology. Moreover, tube burst tests inc ate that, for these forms of tubing degradation, integrity argins are maintained will beyond the 40% thru-wall limit
- Can lead to extended inspection campaigns and to tubes being removed from service unnecessarily (e.g., recent experience of Portland General Electric at their Trojan plant)

NRC 3/92

DAS-NRC-3/92-BL4

EPRI/NPD

Alternate Tubing Alloy Comparison - Update -

- Results
  - Almost + 100 references have been identified. Most references dealt with SCC testing in 10-50% caustic, pure/primary or AVT water, and pitting environments.
  - >11 of the references had comparative results for alloy 690 TT vs. 800 mod. for 12 of the 19 corrosion issues.
  - >18 of the references had comparative results for 690 MA or TT vs. 800 MA or Mod. for 15 of the 19 corrosion issues.
  - Corrosion issues of pitting in chlorides and wastage in sulphates previously thought to be unsupported by data were found to have some references.

NRC-3/92

Relative Ranking of the Corrosion Resistance of Alloys 600, 690, 800 and Stainless Steel

Corrosion Issue	Alloy 600 MA	Alloy 600 TT	Alloy 690 TT	Alloy 800 MOD	S S
A. Stress Corrosion Cracking					
1. Chloride					
· Acid	1	1	1	3	(4)
· Acid (SO4 [illegible])	1	1	1	(1)	(3)
· Neutral (or AVT)	1	1	1	2	5
2. Caustic					
· Below 6%	3	2	1	2	5
· 10-50%	4	2	2	3	5
3. Water					
· Pure,primary, & AVT w/H2	4	2-3	1	1	1
· Pure w/O2	4	3	1	(2)	5
4. Sulphur compounds					
· Acid sulphate	3	2	1	3	5
· Alkaline sulphate	1	1	1	(1)	(2)
· Acid reduced compounds					
· Alka.reduced compounds	2	(3)	3	3	(5)
5. Lead					
· Acid	4	(4)	1	3	(4)
· Neutral (or AVT)	3-4	(3)	1	1	1
· Alkaline	3-4	(3)	4-5	5	5
B. Intergranular Corrosion					
1. Acid	3-4	2-3	1-2	(4-5)	(4-5)
2. Alkaline	4	(3)	1	4	(5)
C. Pitting in Chlorides	3-4	3-4	2	3	4
D. Wastage					
1. Phosphates	(3)	U	(2)	(2)	(3)
2. Sulphates	2	3	2	(2)	(1)

Rankings: 1 - Best; 5 - Worst; () Estimates; U-Unknown
MA = Mill Annealed; TT = Thermally Treated

EPRI/NPD

Planned Secondary Chemistry Guidelines Revision

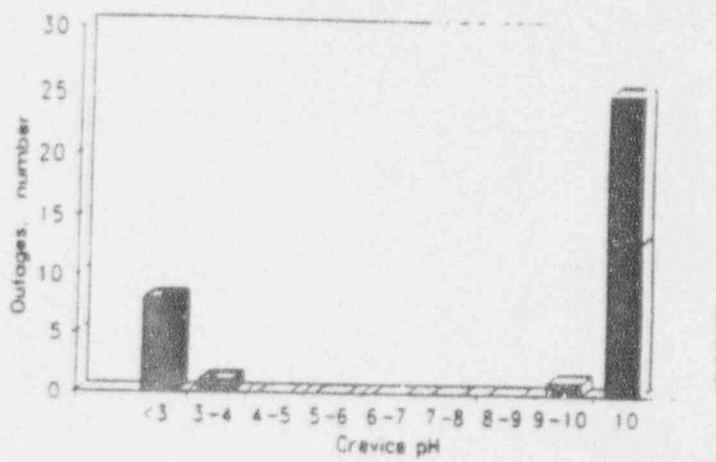
- Laboratory work and field experience warrants another revision
- Items to consider include:
  - Use of advanced/alternate amines for iron minimization
  - Anion-to-cation ratio as a crevice pH indicator
  - Use of plant chemistry modeling to develop site-specific limits
  - Oxygen vs. ECP of feedwater
  - Other monitoring improvements
  - Elevated hydrazine operation
  - Optimization of hideout return processes
  - Sodium phosphate chemistry treatment possible AVT - phosphate conversion
  - Modifications to boric acid treatment practice
- Draft should be available by 1/93

NRC-3/92

EPRI/NPD

Crevice pH vs Number of Outages

(Cumulative Prompt Hideout Return)



NRC-3/92

EPRI/NPD

Status of Alternate Inhibitor Work for OD IGA/SCC

- Boric Acid laboratory work is finished
  - Field effectiveness is a matter of major concern
- Titanium compound studies have passed the screening tests for inhibition of IGSCC, and are now being tested for solubility, stability and will shortly be tested in heat transfer devices
- Other inhibitors: are still undergoing screening tests
  - Modes of Application Being Considered
  - Off-line soaking with more concentrated solutions
  - On-line additions
  - Colloidal dispersions

NRC-3/92

EPRI/NPD

First Model Boiler Test of Titania-Silica Gel Compound

- 25 day test, caustic with titania-silica inhibitor
  - white deposits in each crevice and in sludge
  - distribution and composition of crevice deposits

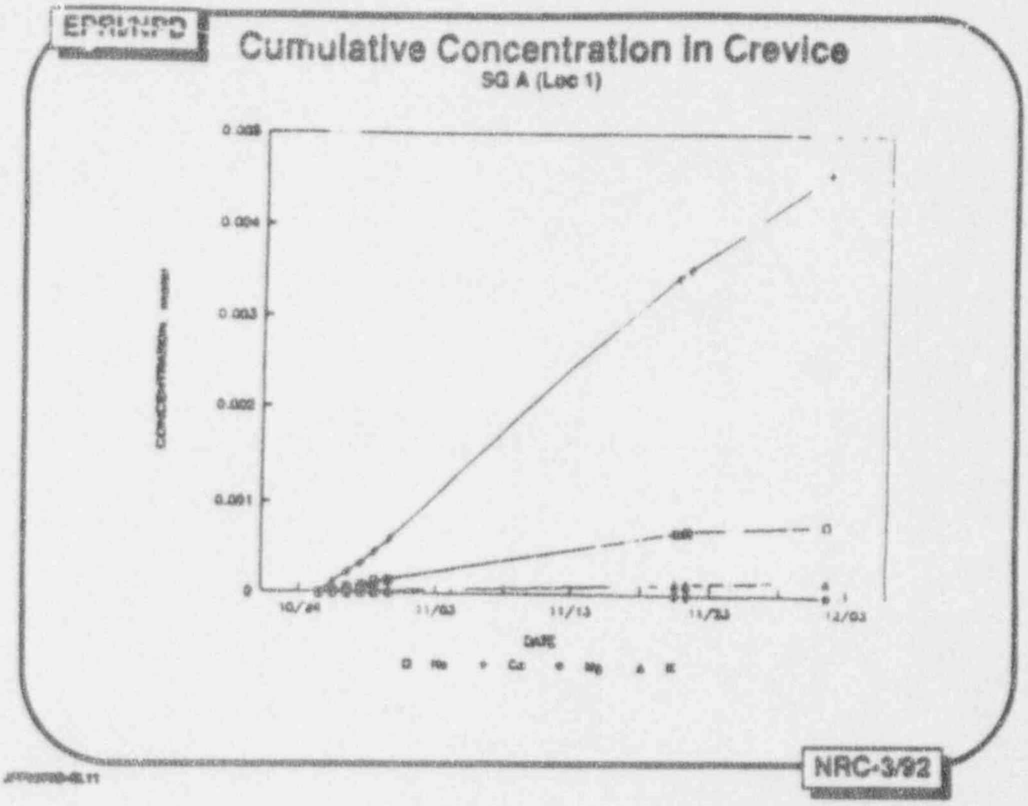
Weight %	Top 1/3	Middle	Bottom 1/3
Ti	0.66	0.36	0.29
SiO_2	3.2	2.8	3.2
Na	0.18	0.84	0.18

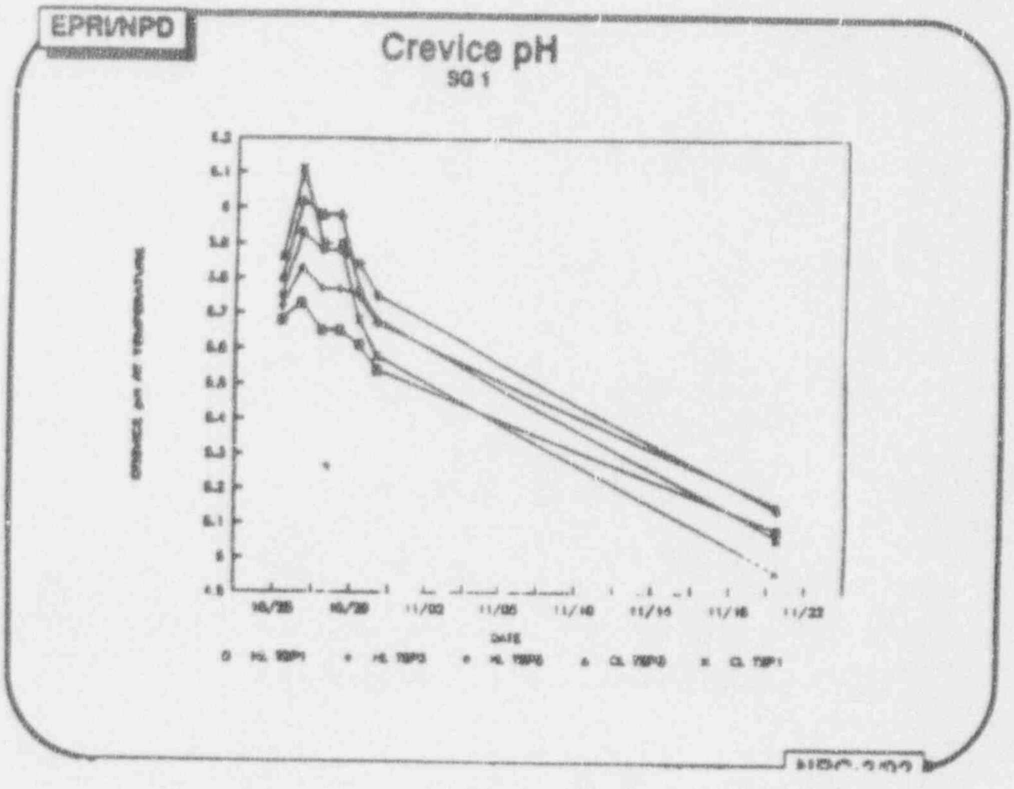
  - Titania has sufficient solubility to penetrate packed or eccentric crevices.
  - no degradation observed on tube surface

EPRI/NPD

Alternate Tubing Alloy Comparison - Update -

- Approach
  - Review/record all personal and EPRI references
  - Review/record all KWU Laborelec and Clemat provided documentation
  - Create new corrosion issue categories on table if required
  - Assign literature reference numbers to each of 19 corrosion issues/alloy categories
  - Confirm whether each category is or is not supported by references, and then attempt objective ranking of alloys


EPRI/NPD
Cumulative Concentration in Crevice
SG A (Loc 1)
0.005
0.004
0.003
0.002
0.001
0
11/03
11/13
11/23
12/03
DATE
NRC-3/92


EPRI/NPD
Crevice pH
SG 1
10/29
11/02
11/05
11/10
11/22
DATE

EPRI/NPD

CREV-SIM & MULTEQ Cycle Chemistry

PROGRAM OBJECTIVE:

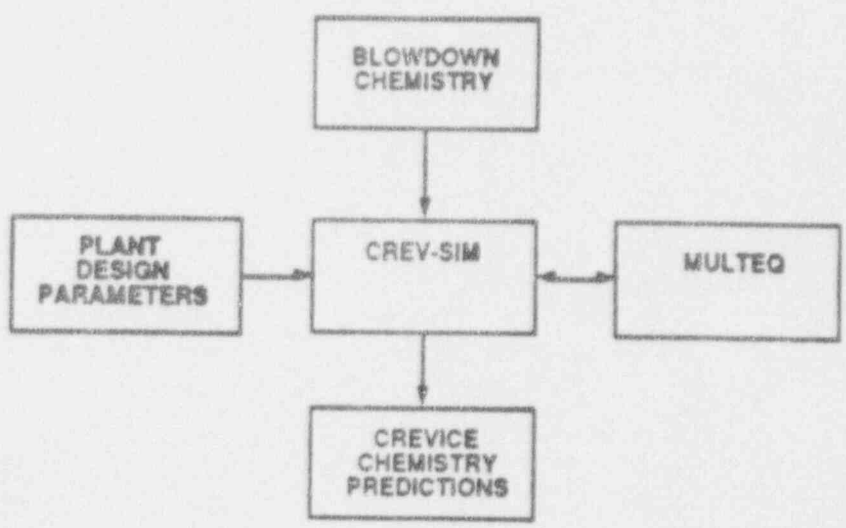
- Develop an approach for making real-time crevice chemistry predictions from routinely measured blowdown chemistry parameters, leading to improved prediction of corrosion mode and providing the basis for correlating blowdown chemistry to corrosion damage.

TECHNICAL APPROACH

- Assume crevice hideout is controlled by local boiling rate in crevices
- Total crevice hideout rate is known from tracer injection tests and is proportional to blowdown concentration.
- Distribute total hideout to crevices based on available superheat
- Integrate crevice inventory over time
- Calculate and trend local pH using MULTEQ
- Correct inputs based on observed hideout return

NRC-3/92

EPRI/NPD



NRC-3/92

EPRI/NPD

Alternate Amines for AVT

Program Objective

- To reduce iron transport and erosion corrosion in single and two-phase flow
- To provide laboratory and loop test data showing the beneficial and side effects of advanced AVT using low-volatility amines

Results Achieved

- Morpholine-AVT in wide spread use. Has reduced iron transport by 2-3 times in U.S. PWR's.
- Five loop tested amines appear to be acceptable substitutes for ammonia or morpholine
- Ethanolamine best of the five available commercially
- 1, 2 diamino ethane best for copper-free cycles - but tends to strip sodium from condensate polishers

Status

- Limited field trials expected late 1992 or 1993

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Summary of Amine Properties from Loop Tests

Amine	Mol.Wt	PPM @ 9.1	Steam/Liq Ratio in loop	% Decomp @ 285°C/hr
ETA	61	2	~0.36	~2
DAE	60	0.9	~0.41	~30
AMP	89	1.1	~1.2	~80
3-OHQ	127	2.4	~0.2	~7
MPA	89	1.2	~1.6	~8
MORPH	87	5.2	~1.2	~9
NH_3	17	0.6	~3.5	0

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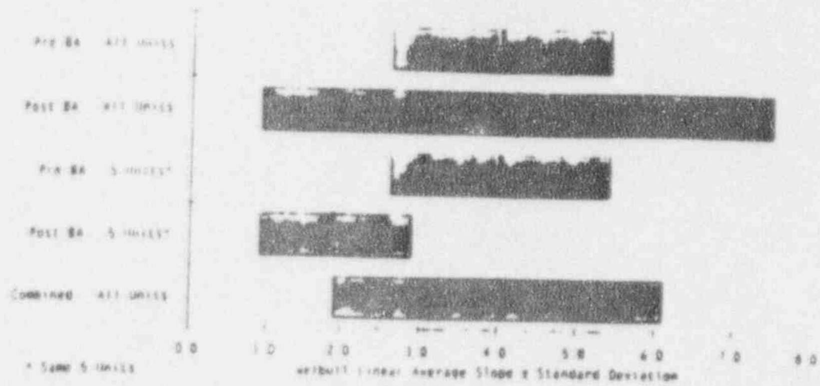

Linear Average Weibull Slope and Standard Deviation for Various Sets of Data Considered

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EPRI/NPD

Boric Acid Effectiveness

- Boric acid continues to be recommended to mitigate secondary side caustic induced IGSCC and denting
- In order to maximize boric acid effectiveness steps to minimize and lower SG corrosion potential are still recommended
  - Elevate feedwater hydrazine to 50-100 ppb if possible
  - Physically remove all copper components and chemically clean residual copper from secondary system
  - Raise feedwater pH as high as practical to minimize transport of hematite and magnetite
- Tube's should be removed from the SG's to regularly assess tube bundle condition.

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Boric Acid Effectiveness Survey

PARTICIPATION OF SURVEYED PLANTS

Unit	Returned Completed Survey	Primary Source of Data
Almaraz 1	YES	Survey
Almaraz 2	YES	Survey
Asco 1	YES	Survey
Asco 2	YES	Survey
Calvert Cliffs 1	YES	Survey
Calvert Cliffs 2	YES	Survey
Cook 1	NO	Public Sources (1)
Cook 2	NO	Public Sources
Farley 1	YES	Survey
Farley 2	YES	Survey
Genkai 1	NO	Public Sources
Kewaunee	YES (2)	Survey/Pub. Sources
Krsko	NO	(3)
North Anna 1	NO	Public Sources
North Anna 2	NO	Public Sources (1)
Ohi 1	NO	Public Sources
Ringhals 3	YES	Survey
Ringhals 4	YES	Survey
St. Lucie 1	YES	Survey
St. Lucie 2	YES	Survey
Takahama 2	NO	Public Sources
Trojan	YES	Survey

(1) Sufficient ECT data were not available
(2) ECT data were not given, so publicly available sources were used
(3) Not included in study because sufficient data were not available

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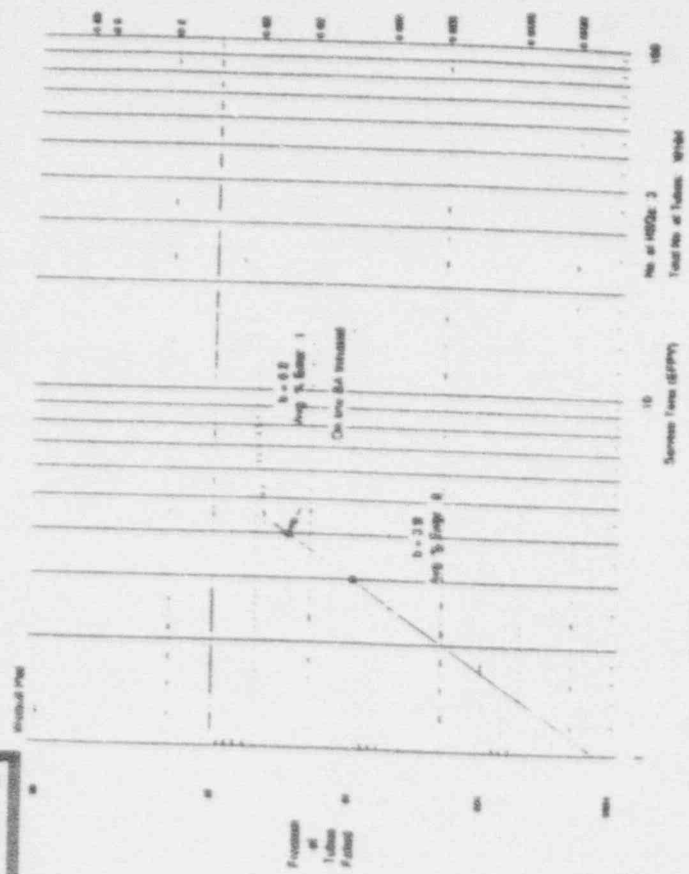

Factor 2 Re-evaluated Pre and Post Boric Acid Plugged Tube Weibull Slopes - TSP

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PWR Steam Generators Secondary Side Chemistry, Corrosion & Materials Issues

J P N Paine
A R McIlree
T. O. Passell
C. R. Wood
P. J. Millett

EPRI-NRC Meeting
March 10, 1992

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Secondary Side Topics

- Boric Acid Effectiveness - survey results
- Alternate amine treatment update
- CREV-SIM and MULTEQ Experience
- Status of work on Alternate inhibitors
- Alternate tubing alloy studies
- Planned secondary chemistry guidelines revision

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SECONDARY SIDE CHEMISTRY ISSUES

IGA/SCC Inhibitor Testing

- Inhibitors testing is following EPRI and U.S. lead.
- Boric acid and sodium phosphate being tested.
- Model boilers are being readied for use in Sweden and Spain
- Side stream model boiler at Ohi (Kansai) is providing chemistry data that has been used to validate high temperature computer codes.

JPP SL15

NRC/3/92

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SUMMARY

- EPRI's on-going world-wide information exchanges provide considerable insight into SG PWR operations.

JPP SL16

NRC/3/92

EPRI/NPD

SECONDARY SIDE CHEMISTRY ISSUES

Electrochemical Potential Monitoring

- Test programs in Germany, Sweden and Finland.
- PWR Power plant installations at Biblis, Ringhals, Lovisa, and at many BWR's.

Conclusions:

- Probe life about one cycle.
- Valuable insights into oxidizing transients. Can be much more effective than O_2 monitors.
- ECP measurements suggest need for higher hydrazine operation.
- VTT probe combines ECP, pH and high temperature conductivity.

EPRI-Utility tests are planned for late 1992.

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JPP 05.13

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SECONDARY SIDE CHEMISTRY ISSUES

High Hydrazine Water Chemistry

- KWU recommends 70 -- 100 ppb Hydrazine in blowdown based on field and laboratory ECP measurements.
- Studsvik recommends high hydrazine, but level can be plant specific. Ringhals 3 and 4 operate with 70 and 50 ppb hydrazine in feedwater respectively.
- Almaraz operates with about 100 ppb hydrazine in feedwater.
- Japanese Units: 400-500 ppb hydrazine in feedwater at Ohi Takahama, Genkai sites.
- KWU and SSPB recommend high hydrazine-high ammonia to protect against erosion corrosion. Much simpler than amines chemistry and claimed as effective.

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JPP 05.14

EPRI/NPD

AVB WEAR/Fatigue

- Not a serious problem in Europe, but has led to AVB replacement in Belgium and plans for replacement in one Spanish unit.
- EDF has measured average wear growth rates of 2% of wall per year. In one tube growth rate was measured at 14%.
- AVB wear is serious concern for Japanese units. After Mihama 2 event all units have had or will shortly have AVB's replaced with a new MHI-Westinghouse design.
- Tube fatigue is primary cause for replacement at Mihama 2.
- Tube fatigue is a major concern for Ontario Hydro at the Candu Bruce station. Fatigue cracks grow slower at Bruce than in PWR S.G.s. Reason not understood.

JPP SL11 NRC/3/92

EPRI/NPD

OCCURRENCE OF AND REMEDIAL MEASURES FOR:

DENTING

- Denting is continuing in several Japanese, Korean, Belgian and Spanish units.
- ID or OD Cracking at dented intersections has been very minimal.
- PWSCC in alloy 600 TT in dented tubes has been observed in new French 1300 MW units.

JPP SL12 NRC/3/92

EPRI/NPD

IGA/SCC at TSP's, in SLUDGE PILES, on FREE SPAN TUBES (CONT)

- Remedial actions:
  - In Japan, Spain and Sweden: Use of boric acid, increased hydrazine levels and modifications to chemistry control systems. Effectiveness not apparent in some cases.
  - Chemical cleaning has been used and sludge lancing is used. Effectiveness not apparent in some cases.
  - In France: Tighter blowdown limits on sodium, more efficient sludge lancing. Full height chemical cleaning and use of boric acid are being evaluated.
  - In Belgium: Tighter limits on impurity ingress and periodic sludge lancing. Chemical cleaning of Tihange 1 several years ago and of Doel 4 planned. Use of sodium phosphate is being considered.
  - Japanese still believe that SG's with early exposure to sodium phosphate are much less susceptible to IGA/SCC.

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JPP 7.15

EPRI/NPD

OD CIRCUMFERENTIAL SCC

- Affecting two units in Belgium, three units in Spain and several units in France
- Normally encountered in the roll transition but also in the free span at Doel 4.
- May limit SG life in some units.

ISI Activities in Europe:

- Serious concern with IGA/SCC in sludge pile. Extensive and frequent inspections. Belgium and France using absolute mode methods since detection is very difficult with differential mode bobbin coil or RPC.
- Alternate plugging criteria are in place, based of correlations between absolute mode voltages and burst strength

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JPP 65.16

EPRI/NPD

IGA/SCC at TSP's, in Sludge Piles, on Free Span Tubes

- Growing problem at many units in Spain, France, Belgium, Sweden and Japan.
  - Affecting 17 of 20 French units with LTMA tubing and drilled hole supports.
- At supports: a major problem only for drilled hole units.

Replacements:

- Primary cause of planned Genkai 1, Ohi 1 & Takahama 2 replacements.
- Primary cause of St. Laurent B1 possible replacement.
- Primary cause of Tihange 1 possible replacement.
- Significant cause in Almaraz 1 & 2 and Asco 1 & 2 planned replacements.
- Significant cause in Ringhals 3 possible replacement.

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EPRI/NPD

IGA/SCC at TSP's, in Sludge Piles, on Free Span Tubes

ISI Activities in Europe:

- Extensive inspections, no safety problems at supports. Revised plugging criteria based on an allowed depth of 70% and a threshold bobbin coil voltage in Sweden.
- In France and Belgium plugging criteria based on bobbin coil voltages and pulled tube burst strength. Take credit for TSP.

Cause of attack not known in a majority of cases

- Assumed caustic in France, with lead involvement in several cases. Hideout return chemistry data is not available for prior years examination.
- Lead involvement shown at Ontario Hydro
- At Doel 4, local chemistry still questioned but lead is present.
- In Spain, tube examinations have shown evidence for acid or alkali at different units.
- Japanese assume caustic for initiation in all cases.

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PWSCC at roll transitions (cont.)

Remedial Actions:

- Roto and shot peening performed after initial start up is believed to have slowed occurrence with alloy 600 LTMA but not to have halted it.
- Due to cracking with kiss rolled alloy 600 TT tubing, EDF is shot peening their newer SGs.
- Thot Reduction at Ringhals 3. Growth rate reduced. Detection rate apparently not affected.
- For part-depth roll units: Japanese hydraulic + roll re-expansion and shot peened has been successful (several cycles)
- For part-depth roll units: At Doel 2, re-expansion followed by nickel plating on ID have been satisfactory too date. (one cycle)
- Nickel plating appears successful to prevent initiation and growth. (several cycles)
- Sleeving is seldom used in Europe: expensive, interferes with inspections, can't repair above the sleeve. In Japan sleeving is common at several elevations in each sleeved tube.
- Stress relief heat treatment of u-bends appears successful to date.

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PWSCC of hot worked alloy 600

- PWSCC of hot worked alloy 600 has occurred in
  - Mechanical tube plugs
  - Pressurizer nozzles
  - Control rod drive mechanisms
- Studies are being initiated to explore crack growth rates.
  - Rank susceptibility of different heats
  - Finite element analysis (CRDM cases)

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SECONDARY SIDE CHEMISTRY ISSUES

- Alternate alloys tests
- Electrochemical potential monitoring
- High hydrazine water chemistry
- IGA/SCC inhibitor testing

JPP 93.3

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EPRI/NPD

PWSCC at roll transitions

- Major problem at many units in France, Belgium, Sweden and Japan
- Especially a problem for plants with kiss rolls.
  - Several plants operate with 20% or more of tubes with roll transitions cracked through wall.
- Replacements:
  - Primary cause of Dampierre 1 replacement.
  - Primary cause of Doel 3 and Bugey 5 planned replacements.
  - Major cause of Ringhals 3 possible replacement.
  - Significant cause in Almaraz 1 & 2 and Asco 1 & 2 planned replacements.
- ISI Activities in Europe:
  - Extensive and frequent RPC inspections, no safety problems, using defect specific plugging criteria.

JPP 93.4

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Recent Steam Generator Experience
Europe - Canada - Asia

Year End: 1991

NRC - EPRI Status Meeting

March 10, 1992

NRC/3/92

JPP 93.1

EPRI/NPD

SUBJECTS COVERED

OCCURRENCE OF AND REMEDIAL MEASURES FOR:

- PWSCC at roll transitions
- PWSCC of hot worked alloy 600
- IGA/SCC at TSP's, in sludge piles, on free span tubes
- Circumferential SCC
- AVB wear/Fatigue
- Denting

NRC/3/92

JPP 93.2

Major Tasks and Key Contacts

EPRI Contact	Task Description	Utility Contact
R. Jones (415-855-2790)	Strategic Direction and Management	R. P. McDonald (205-868-5540) J. Blomgren (708-515-7215)
P. Paine (415-855-2076)	Materials and Corrosion	K. Craig (407-694-4206)
C. Wood (415-855-2379)	Cycle Chemistry	R. Eaker (704-373-4373)
G. Srikantiah (415-855-2108)	Thermal-Hydraulics and Vibration	R. Pearson (612-388-1121)
M. Behravesh (415-855-2388)	Inservice Inspection	J. Smith (716-546-2700)
D. Steininger (415-855-2019)	Assessment, Repair and Replacement	P. Bauer (919-546-7754)

EPRI/NPD

Assessment

- Based on current plugging rates, the average service life of original equipment steam generators in PWRs worldwide is projected to be 20 to 25 years. The average age of the original equipment units in U.S. plants is now ~13 years
  - Most original equipment steam generators will have to be replaced within the plant life. Many U.S. units will have to be replaced within the next 10 to 15 years.

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Planned R&D Response

- To minimize future industry costs, additional R&D is planned aimed at the development and delivery of technology to
  - Further extend the life and increase the reliability of original equipment steam generators
  - Reduce the duration of replacement outages and the associated radiation exposures
  - Assure that replacement units can meet utilities' life and reliability goals

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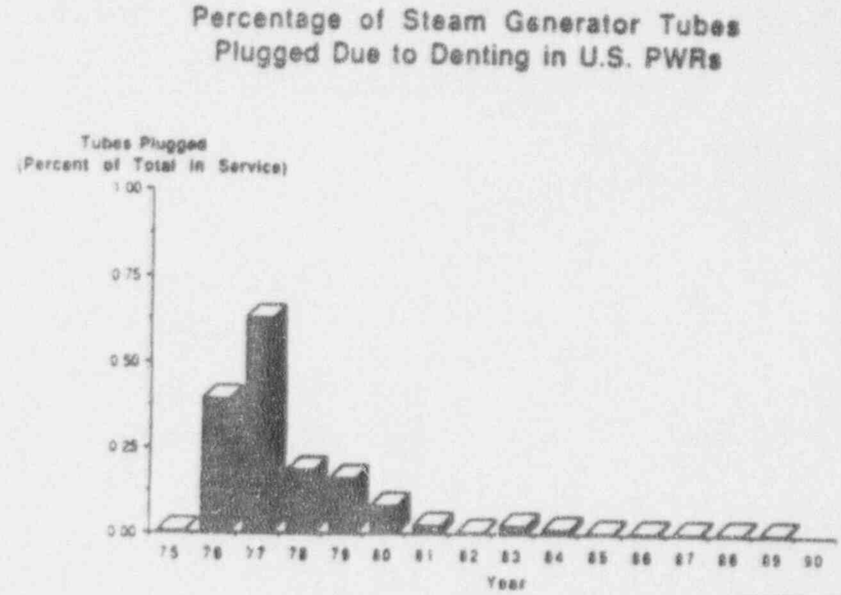
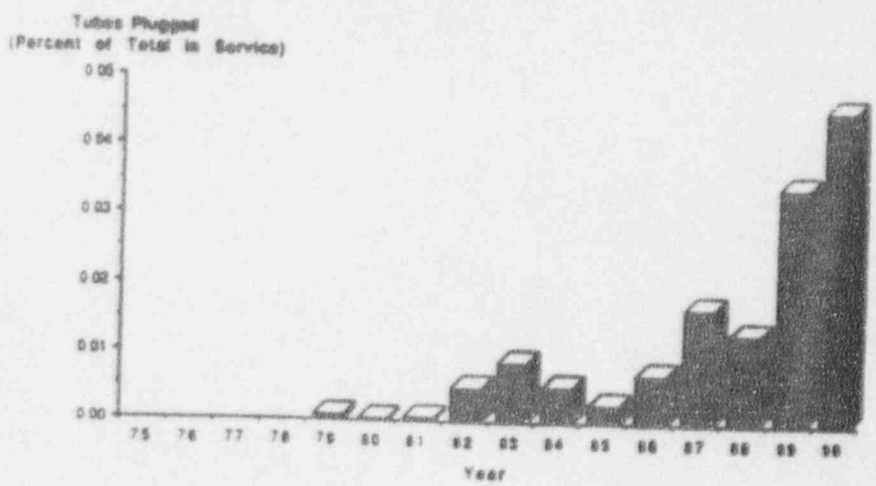
EPRI/NPD

Percentage of Steam Generator Tubes Plugged Due to Denting in U.S. PWRs



EPRI/NPD

Percentage of Steam Generator Tubes Plugged Due to OD SCC/IGA at Support Plates in U.S. PWRs



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Steam Generator Experience Trends

- Average capacity factor losses have decreased from 5.3% (1979-1984) to 2.5% (1985-1990) and the average age of units that have had to be replaced has increased from 10.4 years (replacements thru' 1984) to 13.4 years (replacements since 1985)

- Steam generator tube plugging rates have remained steady for several years but the dominant degradation mechanisms have continued to change
  - Some problems (e.g., denting) have been solved but other problems (e.g., stress corrosion cracking at tube support plate intersections) have emerged and are rapidly increasing in importance.

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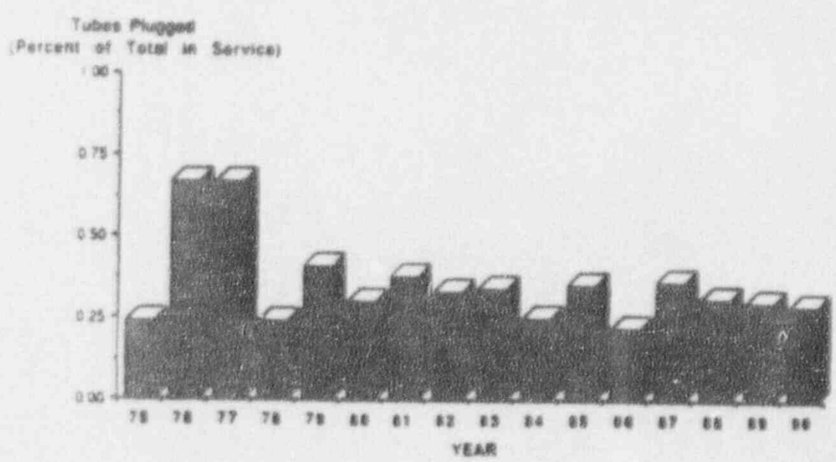
Percentage of Steam Generator Tubes Plugged in U.S. PWRs



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SGRP Scope

Mechanism Management (Preventive Maintenance)

1. Define Causes
2. Develop Remedies
   a. W/C G/L
   b. Sludge Control
   c. Stress Improvement
   d. FIV Models

Defect Management (Near-Term Corrective Maintenance)

1. Remove only those tubes from service that are required to be removed (for reliability and/or safety) and no others
   a. ISI/NDE
   b. Plugging Criteria
   c. Leak Detection
   d. Progression Rate
2. Assess Consequences

Repair/Replacement (Long-Term Corrective Maintenance)

1. Develop Long Range Planning
   a. Repair/Replace Decision
2. Develop Improved Design
   a. Materials
   b. Configuration
3. Improve Replacement/Repair Activities
   a. Time
   b. Man-rem

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SGRP Performance Measures

- Number of tubes plugged/year
- Number of tube leak outages/year
- SG related capacity loss/year
- Number of tube ruptures/year
- SG age at replacement
- Replacement outage duration and radiation exposure
- Service life of replacement generators

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EPRI/NPD

Summary of SGRP Scope and Plans

R. L. Jones

RLJ-NRC-395-SL1

SGRP-NRC

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Objectives of the Work on Steam Generator Reliability

- Reduce lost capacity due to steam generators
- Reduce repair and maintenance efforts
- Reduce radiation exposure
- Maximize steam generator operational safety
- Extend steam generator life

RLJ-NRC-395-SL2

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Foreign Utility Participation Technical Exchange Agreements

Utility

CEGB
CRIEPI
EdF
Electronucleaire
Ontario Hydro
Spanish Utilities
Swedish State Power Board

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SGRP-NRC MEETINGS

- Annual Meetings on Program Status (5/13/91)
- Special Topical Meetings
  - ISI Performance Demonstration (10/1/91)
  - Tube Repair Criteria - ACRS (11/6/91)

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U.S. Utility Participants in SGRP

- All EPRI - member PWR Owners (33)
  - Current EPRI non-members are:
    - American Electric Power
    - Consumers Power
    - Southern California Edison
    - Virginia Power

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Executive Group

Grant Bassion	Northeast Utilities
R. P. McDonald (Chairman)	Alabama Power
Steve Rosen	Houston Lighting & Power
Donald Schnell	Union Electric Company
Robert Smith (Vice Chairman)	Rochester Gas & Electric
Bart Withers	Wolf Creek Nuclear Operating Corp.
James Zach	Wisconsin Electric Power

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Budget

Steam Generator Reliability Project

Year	Budget $ Millions
1987	4.4
1988	4.4
1989	5.2
1990	4.7
1991	4.3
1992	4.4

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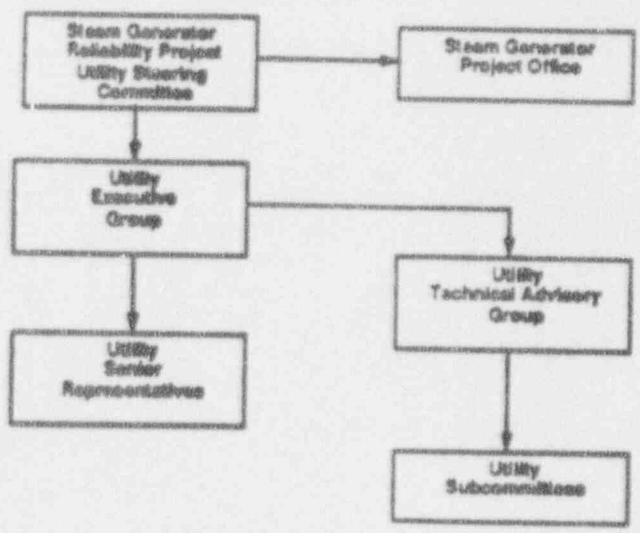
EPRI/NPD

Steam Generator Reliability Project



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Steam Generator Reliability Project

Introduction

R. P. McDonald

SGRP-NRC

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EPRI Managed Steam Generator Programs

	SGOG I	SGOG II	EPRI	EPRI	EPRI
Period	'77-'82	'83-'86	'77-'86	'87-'92	'93-'97
R&D Effort ($M)	36	26	31	30	43*
Utility Members	24	48	35	33	33

*To be approved

SGRP-NRC

Steam Generator Reliability Project
Annual Meeting with NRC
NRC Offices
One White Flint North
11555 Rockville Pike, Rockville, Maryland

March 10, 1992

AGENDA

1:00 PM	Introductory Remarks	R.P. McDonald/NRC
1:10	Summary of SGRP Scope and Plans	R.L. Jones
1:20	Overview of NRC Plans for SG-Related Work	NRC
1:30	Secondary Chemistry Modeling and Improvement	J.P.N. Paine
2:00	Status of Generic Damage-Form Specific Alternate Tube Repair Criteria Documents	D.A. Steininger
2:30	Comments on Generic Alternate Tube Repair Criteria	NRC
2:50	Status of Industry SG Inspection Performance Demonstration Program	M.M. Behravesh
3:20	Comments on Industry Program and Status of SG Mockup and ISI Reg. Guide	NRC
3:50	Closing Remarks	R.P. McDonald/NRC
4:00	Adjourn-	