European Plugging Criteria for Defects at Tube Support Plates

NP-XXXX
Research Project S404-30

February 1991

Prepared by

DOMINION ENGINEERING, INC.
6862 Elm Street
McLean, Virginia 22101

Principal Investigator
J. A. Gorman

Prepared for

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94303

EPRI Project Managers
C. S. Welty and C. L. Williams

Steam Generator Reliability Program
Nuclear Power Division

ABSTRACT

The occurrence of intergranular attack and stress corrosion cracking (IGA/SCC) at tube outer surfaces in tube support plate (TSP) crevices is becoming more prevalent in certain types of PWR steam generators. There are concerns in the industry that this type of corrosion could affect significant numbers of tubes. It is also believed that the plugging criteria currently being used for such defects in the USA are unnecessarily restrictive and, unless revised, will result in the unnecessary repair of many tubes. The criteria in the USA typically require repair of tubes with defects over 40% of tube wall in depth, regardless of defect location or length.

Plugging criteria for IGA/SCC defects at TSPs in Europe are, in several cases, much less restrictive than in the USA. For example, this type of defect does not require repair of tubes in Belgium or France, regardless of defect depth. Alternate tube plugging criteria (ATPC) for defects at TSPs have also been developed in Sweden and Spain. These ATPC are in the process of being reviewed with national safety authorities and will allow, if approved, defects at TSPs up to 70 or 78% of the tube wall to remain without repair.

The purpose of this report is to document European practices and to serve as a reference for an EPRI coordinated committee in the USA that is developing alternate tube plugging criteria for defects at TSPs.

(blank page)

ACKNOWLEDGEMENTS

Thanks are extended to Belgatom, Electricité de France and Framatome, the Spanish Utilities, and the Swedish State Power Board for making the information upon which this report is based available, and for their reviews of this report

(blank Page)

CONTENTS

EXECUTIVE SUMMARY

PURPOSE

The purpose of this project is to document European experience with alternate tube plugging criteria (ATPC) for defects due to intergranular attack and stress corrosion cracking (IGA/SCC) at tube support plates (TSPs) of PWR steam generators. This information will serve as a reference for efforts in the USA directed at development and licensing of ATPC for this type of defect.

BACKGROUND

IGA/SCC at TSPs has recently become a significant concern to many utilities as a result of the increasing rate of occurrence of this type of defect. For example, it is a major factor in the recent decision by Spanish utilities to replace the steam generators at four PWRs starting in the mid 1990s (1).

Special concern about IGA/SCC at TSPs was generated by experience with a pulled tube from Farley 1 (2). A pulled tube that had, based on eddy current test (ECT), no detectable degradation, was found in laboratory examination to have IGA/SCC defects up to 62% of the tube wall thickness, which exceeded the plugging criteria of 40%. The NRC advised utilities (2) to take a conservative position with regard to interpretation of ECT signals for defects at TSPs, and to plug tubes with with questionable signals. This sequence of events raised serious concerns in the industry because it was believed that such conservative interpretation of ECT signals would result in plugging of many tubes, and was not warranted from either safety or reliability standpoints.

Because of the concerns about possible unnecessary plugging of many tubes due to IGA/SCC defects at TSPs, an EPRI coordinated effort was initiated to develop ATPC for such defects. The intent of these ATPC is to ensure that satisfactory safety and operability margins are maintained while not requiring plugging of small defects that do not pose safety or operability risks. There is confidence in the industry that margin exists such that defects well over the current 40% limit are not a concern. This confidence is based on pulled tube examinations and tests performed by Westinghouse for D. C. Cook (3, 4), and based on tests by Europeans that show that IGA/SCC type defects at TSPs do not reduce tube burst pressures, i.e., that tube burst occurs in the free span, away from the TSP area. The minimal effect of defects at TSPs on burst pressures is

attributed to the support provided to the tube by the TSP, which prevents opening up and propagation of the defects.

Several European countries have performed tests and developed ATPC for defects at TSPs, for similar reasons that they are being developed in the USA. The intent of this report is to document the European experience, so that the USA effort can build on this experience.

APPROACH

A team of EPRI and Dominion Engineering, Inc. (DEI) personnel visited utility and contractor personnel in Belgium, France, Spain, and Sweden in August and September 1990 to hold in-depth discussions regarding development and application of ATPC for IGA/SCC defects at TSPs. The results of these visits were documented in letter type reports and sent to the visited groups for review. After incorporating the resolution of comments into the reports, the letter type reports were issued to EPRI and the visited organizations. The information in these letter type reports is documented in this report. A draft of this report was also reviewed by all of the visited organizations, and all comments were resolved.

CURRENT STATUS OF ATPC FOR IGA/SCC DEFECTS AT TSPS IN EUROPE

In two countries, Belgium and France, current plugging criteria (as of September 1990) do not require defects of any depth at TSPs to be plugged. The main bases for these criteria are that tests have shown that tubes with severe simulated secondary side defects at TSPs do not have reduced tube burst strength, and that the tubes burst in free span areas, rather than at the TSPs.

In two other countries, Spain and Sweden, current plugging criteria (as of September 1990) for defects at TSPs are the same as for free span defects, i.e., 40% of tube wall in Spain and 50% in Sweden. However, in both of these countries, ATPC have been developed and proposed to safety authorities. These ATPC justify leaving defects up to 70% or 78% depth (in Sweden and Spain respectively) at TSPs without repair. The 70% and 78% values include allowances for defect growth and for inspection error. The Swedish and Spanish utilities hope to have the ATPC approved in the near future.

OCCURRENCE OF IGA/SCC AT TSPS

Examination of pulled tubes has shown the IGA/SCC at TSPs to mainly consist of axial cracks. The IGA/SCC cracks have almost always been located within the edges of the TSP. The one known exception occurred at a flow distribution baffle, not a TSP, where sludge was present on top of the baffle.

The severity of occurrence of IGA/SCC at TSPs in the countries visited varies. However, the numbers of units affected is increasing, and the numbers of tubes affected and the sizes of the defects at individual tubes are also increasing. In two countries this form of corrosion has been a significant factor in recent decisions regarding steam generator strategic planning: In Sweden, the operating temperature of one unit has been reduced in order to reduce the rate of increase of IGA/SCC as well as PWSCC. In Spain, IGA/SCC at TSPs was a factor in a recent decision to initiate replacement of steam generators at four units starting in 1994.

AREAS OF CONCERN AND INVESTIGATION

TSP Deflection

Possible deflection of TSPs during postulated accidents was identified as a significant issue in Sweden. The concern is that the TSP will be deflected during an accident out of its normal position, thus removing the support given by the TSP from the area with the defects. Because lower TSPs deflect less than higher ones, the Swedish intend to address the TSP deflection concern by applying ATPC to only the lower five TSPs.

Evaluation of TSP deflection in France has indicated that, for French Model 51 steam generators, TSP deflections are small (e.g., 2 mm (.08 in.) maximum), and are not a concern. It was noted that TSP deflection is dependent on specific design features, such as numbers of tie rods and their diameter, and that TSP deflection at other Model 51s could differ from that determined for French Model 51s.

Effects of the possible deflection of TSPs from hot full power positions caused by differential pressures across TSPs during accidents have not as yet been considered in Belgium or Spain. The work being performed as part of the EPRI technical support effort for ATPC is being relied upon to determine needs in this area.

Post Accident Leak Rates

As a result of work on ATPC for roll transitions in the USA, an issue has been identified regarding the amount of primary to secondary leakage that could occur subsequent to a postulated accident, such as a steam line break or a feedwater line break. The concern is that leakage through defects at roll transitions or at TSPs could, after the accident, exceed current limits if, as a result of the accident, the defects are opened up by exposure to the accident differential pressure of about 2650 psi (183 bar).

The approaches being taken regarding this concern differ in the various countries. The Swedish approach is to limit defect depths at TSPs to values that provide assurance that little post accident leakage could occur. In Belgium, limits on allowed post accident leakage are being increased by re-analysis. In France and Spain concerns about post accident leakage have not yet been addressed. The work being performed as part of the EPRI ATPC effort is being followed to determine needs in this area.

Quality Status of TSPs

In Sweden, a concern has been raised as to what needs to be done to allow credit to be taken for TSPs considering that they were not designed and built as safety grade equipment. This concern had not been addressed in any of the other countries visited.

Inspection Criteria

The NDE methods used to quantify the amount of degradation present at a TSP due to IGA/SCC was reviewed at each of the countries visited. The groups visited indicated that they are supportive of the EPRI effort to develop an ATPC technical support document based on correlations of tube burst and leakage behavior with ECT signals (amplitude and phase angle), without attempting to measure quantitative depths or lengths of defects. However, until these results are available, two of the countries, Sweden and Spain, will continue to pursue their quantitative defect depth limit (70% and 78%) type of criteria rather than direct ECT signal criteria.

Need for Further Data

It was noted during the visits that part of the EPRI effort should include assembling information regarding the actual morphology of defects observed at TSPs, and the correlation of these defects with NDE results, especially bobbin coil ECT results.

REFERENCES

1. Minutes of Steam Generator Reliability Project Technical Advisory Group meeting, October 23-25, 1990, Palo Alto CA.

2. NRC Information Notice No. 90-49, "Stress Corrosion Cracking in PWR Steam Generator Tubes," USNRC, Washington, D. C., August 6, 1990

3. WCAP-11056, "NRC Presentation Report on Steam Generator Tube Integrity for D. C. Cook Unit 2, January 1986", Westinghouse Electric Corporation, Pittsburgh, PA, in NRC Public Document Room, ACN 8602130275, Date 860131, PDR ADOCK 05000316

4. WCAP-11330, "NRC Presentation Report on Steam Generator Tube Integrity for D. C. Cook Unit 2, September 1986", Westinghouse Electric Corporation, Pittsburgh, PA, in NRC Public Document Room, ACN 8612020058, Date 861124, PDR ADOCK 05000316

Section 1

INTRODUCTION

PURPOSE

The purpose of this project is to document European experience with alternate tube plugging criteria (ATPC) for defects due to intergranular attack and stress corrosion cracking (IGA/SCC) at tube support plates (TSPs) of PWR steam generators. This information will serve as a reference for efforts in the USA directed at development and licensing of ATPC for this type of defect.

BACKGROUND

IGA/SCC at TSPs has recently become a significant concern to many utilities as a result of the increasing rate of occurrence of this type of defect. For example, this type of defect was cited as a major reason that the Cook 2 steam generators were replaced, rather than repaired by sleeving (1). In addition, it has resulted in over 20% tubes being affected at three Japanese units, and is a major factor in the recent decision by Spanish utilities to replace the steam generators at four PWRs starting in the mid 1990s (2, 3).

IGA/SCC can occur in several secondary side locations. These include deep tube sheet crevices, in sludge piles, at eggcrate support grids, and in crevices at drilled hole tube support plates (TSPs). IGA/SCC at this last location is the focus of this report. The reasons for this focus are that IGA/SCC at drilled hole TSPs is of special concern to the industry because it is not as amenable to control or repair (e.g., by sleeving or removal of sludge piles) as are IGA/SCC at some of the other locations, and because it has begun to affect a large number of plants with high operating temperatures (e.g., over about 605°F (318°C), drilled hole TSPs, and mill annealed alloy 600 tubing.

Special concern about IGA/SCC was generated by experience with a pulled tube from Farley 1 (4). A pulled tube that had, based on eddy current test (ECT), no detectable degradation, was found in laboratory examination to have IGA/SCC defects up to 62% of the tube wall thickness, which exceeded the plugging criteria of 40%. The NRC advised utilities (4) to take a conservative position with regard to interpretation of ECT signals for defects at TSPs, and to plug tubes with with questionable signals. This sequence of events raised serious concerns in the industry because it was believed that such conservative

interpretation of ECT signals would result in plugging of many tubes that was not warranted from either safety or reliability standpoints.

Because of the concerns about possible unnecessary plugging of many tubes because of IGA/SCC defects at TSPs, an EPRI coordinated effort was initiated to develop alternate tube plugging criteria (ATPC) for such defects. The intent of these ATPC is to ensure that satisfactory safety and operability margins are maintained while not requiring plugging of small defects that do not pose safety or operability risks. There is confidence in the industry that margin exists such that defects well over the current 40% limit are not a concern. This confidence is based on pulled tube examinations and tests performed by Westinghouse for D. C. Cook (5, 6), and based on tests by Europeans that show that IGA/SCC type defects at TSPs do not reduce tube burst pressures, i.e., that tube burst occurs in the free span, away from the TSP area. The minimal effect of defects at TSPs is attributed to the support provided to the tube by the TSP, which prevents opening up and propagation of the defects.

Several European countries have performed tests and developed ATPC for defects at TSPs, for similar reasons that they are being developed in the USA. The intent of this report is to document the European experience, so that the USA effort can build on this experience.

APPROACH

A team of EPRI and Dominion Engineering, Inc. (DEI) personnel visited utility and contractor personnel in Belgium, France, Spain, and Sweden in August and September 1990 to hold in-depth discussions regarding development and application of ATPC for IGA/SCC defects at TSPs. The results of these visits were documented in letter type reports and sent to the visited groups for review. After incorporating the resolution of comments into the reports, the letter type reports were issued to EPRI and the visited organizations. The information in these letter type reports is documented in this report. A draft of this report was also reviewed by all of the visited organizations, and all comments were resolved.

TERMINOLOGY

Brief definitions of the terms and acronyms used in this report are given below.

ATPC. Alternate Tube Plugging Criteria.

ECT. Eddy current test.

IGA (Intergranular attack). Intergranular attack is corrosion attack at grain boundaries that tends to occur at all grain boundaries in the affected area. It can occur on either the secondary or primary side but, in this report, refers to attack on the secondary side.

IGA/SCC (Intergranular attack/stress corrosion cracking). Intergranular attack/stress corrosion cracking is corrosion attack on the secondary side that involves both intergranular attack and stress corrosion cracking. The stress corrosion cracking is typically intergranular, but is occasionally transgranular.

IGSCC (Intergranular stress corrosion cracking). Intergranular stress corrosion cracking is corrosion attack involving isolated cracks at grain boundaries propagating in regions with tensile stress. When it occurs on the primary side, it is called PWSCC; thus, the term IGSCC usually refers to attack on the secondary side.

Model D3. A Model D3 is a steam generator designed by Westinghouse that includes a split flow preheater.

Model 51. A Model 51 is a non preheat steam generator whose original design was developed by Westinghouse, but which was also built, with some design modifications, by licensees (Framatome and Mitsubishi).

NDE. Nondestructive examination.

PWSCC (Primary water stress corrosion cracking). Intergranular stress corrosion cracking that occurs in alloy 600 on the primary side.

RPC (Rotating pancake coil). This refers to a specialized eddy current test probe or method often used to obtain an improved characterization of tube degradation.

SSPB. Swedish State Power Board.

TSP. Tube support plate.

IWD (Through wall depth). This indicates the portion of the wall thickness of the tube that has been penetrated by a defect.

Section 2
SUMMARY OF INFORMATION OBTAINED

Detailed reports of the visits made to Sweden, Belgium, France and Spain are contained in Appendices A, B, C, and D respectively. A summary of the information obtained is given below.

CURRENT STATUS OF ATPC FOR IGA/SCC DEFECTS AT TSPS IN EUROPE

In two countries, Belgium and France, current plugging criteria (as of September 1990) do not require defects at TSPs to be plugged. The main bases for these criteria are that tests have shown that tubes with severe simulated secondary side defects at TSPs do not have reduced tube burst strength, and that the tubes with TSP defects burst in free span areas, rather than at the TSPs.

In two other countries, Spain and Sweden, current plugging criteria (as of September 1990) for defects at TSPs are the same as for free span defects, i.e., 40% TWD in Spain and 50% TWD in Sweden. In both of these countries, ATPC have been developed and proposed to safety authorities:

- At the time of the visit, September 1990, proposed ATPC had been submitted to, but not yet accepted by, Spanish safety authorities. The proposed criteria would allow defects up to 78% TWD to not be repaired. The main bases for the proposed criteria are that burst tests have shown 100% TWD defects that extend a short distance beyond the edges of the TSP do not reduce burst strength below accident pressures. For operational reliability reasons, it is desired to avoid development of leaks at TSPs. For this reason, an allowance of 7% for defect growth and 15% for defect depth measurement error are subtracted from 100% to arrive at the proposed limit of 78% TWD.

- ATPC for TSPs were proposed in mid 1990 to Swedish safety authorities. These criteria are that defects up to 70% TWD were acceptable. The 70% value is based on ensuring that defects do not grow through wall during the next operating cycle, and include allowances of 10% for growth and 20% for NDE uncertainty. In 1990, Swedish safety authorities did not grant full approval of the proposed criteria, but did accept them for a limited number of tubes for one year. The Swedish safety authorities wanted more time for evaluation of the criteria. In addition, there were concerns with regard to possible TSP deflection during postulated

accidents, and concerns related to the TSPs not being safety grade equipment. Additional work addressing these issues has been performed subsequent to the initial submittal. SSPB indicated that they intend to resubmit the proposed criteria and hope to have them approved for use during the summer 1991 inspections of Ringhals 3

OCCURRENCE OF IGA/SCC AT TSPS

Examination of pulled tubes has shown the IGA/SCC at TSPs to mainly consist of axial cracks. The IGA/SCC cracks have essentially always been located within the edges of the TSP. The one known exception occurred at a flow distribution baffle, not a TSP, where sludge was present on top of the baffle. Due to the low elevation of the flow distribution baffle, which promotes accumulation of sludge, this experience is not considered applicable to TSPs. In addition, the Spanish indicate that, because of the larger holes in flow distribution baffles, application of ATPC to defects at flow distribution baffles is not justified.

The severity of occurrence of IGA/SCC at TSPs in the countries visited is as follows:

- In Sweden, the number of pluggable defects detected by ECT to date has been small. However, examination of pulled tubes has indicated that most tubes at Ringhals 3 and 4 have shallow IGA at TSPs, and that significant numbers of tubes in Ringhals 3 have SCC at TSPs that was not detectable by ECT (no tubes at Ringhals 4 have been found to have SCC at TSPs, even by examination of pulled tubes). Concerns about IGA/SCC, as well as with PWSCC, led to reducing the hot leg temperature of Ringhals 3 from 321°C (610°F) to 308.5°C (587°F).

- In Belgium two of seven units (Doel 4 and Tihange 1) have exhibited IGA/SCC at TSPs by ECT examination or by leakage. The amount of degradation is limited. Because of the limited extent of the attack, and since plugging criteria do not require such defects to be plugged, IGA/SCC at TSPs is not considered a serious problem in Belgium.

- In France, about 10 units were affected by IGA/SCC at TSPs as of September 1990, including three plants where it was confirmed by examination of pulled tubes. It was noted by EdF that the numbers of plants affected is steadily increasing, and the number and size of defects in individual plants is also steadily increasing. However, because plugging criteria do not require plugging of IGA/SCC at TSPs, it is not considered a serious problem in France.

- In Spain, all four units with Model D3 steam generators are experiencing significant amounts of IGA/SCC at TSPs. The amount of attack is increasing steadily at all four units. Current plugging criteria in Spain for these defects require them to be repaired if over 40% TWD. The increasing IGA/SCC at TSPs, together with PWSCC in the roll transition area, was a major factor in the decision to replace steam generators in these four units starting in 1994.

AREAS OF CONCERN AND INVESTIGATION

TSP Deflection

Possible deflection of TSPs during postulated accidents was identified as a significant issue in Sweden. The concern is that the TSP will be deflected during an accident out of its normal position, thus removing the support given by the TSP from the area with the defects. Evaluation of possible deflections of TSPs in the Model D3 steam generators in Sweden indicate that only the highest TSPs are deflected enough to be a concern (e.g., up to 13 mm (.5 in.) for the top support), and that the lower five TSPs are not sufficiently deflected to be a concern. As a result, the Swedish intended to apply ATPC to only the lower five TSPs.

Evaluation of TSP deflection in France has indicated that, for French Mo 51 steam generators, TSP deflections are small (e.g., 2 mm (.08 in.) maximum), and are not a concern. It was noted that TSP deflection is dependent on specific design features, such as numbers of tie rods and their diameter, and that TSP deflection at other Model 51s could differ from that determined for French Model 51s.

Effects of the possible deflection of TSPs from hot full power positions caused by differential pressures across TSPs during accidents have not as yet been considered in Belgium or Spain. The work being performed as part of the EPRI technical support effort for ATPC is being relied upon to determine needs in this area.

Post Accident Leak Rates

As a result of work on ATPC for roll transitions in the USA, an issue has been identified regarding the amount of primary to secondary leakage that could occur subsequent to a postulated accident, such as a steam line break or a feedwater line break. The concern is that leakage through defects at TSPs could, after the accident, exceed current limits if, as a result of the accident, the defects are opened up by exposure to the accident differential

pressure of about 2650 psi (183 bar). For example, the accident differential pressure could cause part depth defects at TSPs to penetrate through wall, even though full unstable rupture is prevented by the TSP. The through wall defects could increase leak rates significantly, as compared to pre-accident leak rates. Similar potential increases in leak rates have been identified for roll transition defects (Z), and the combined leakage from TSP and roll transition defects needs to be considered.

The approaches being taken regarding this concern are as follows:

- Sweden. The SSPB approach regarding leakage at TSPs during accidents is that defect depths at TSPs will be limited to values that assure that the number of defects is minimized that could become through wall during the operating cycle or could propagate through wall during an accident. As discussed earlier, this is the basis for the 70% TWD limit currently proposed for ATPC.

- Belgium. Analyses are underway to justify increasing allowed primary to secondary leakage during postulated accidents to higher values, such as 20 gpm. This may require lowering allowed radioactivity levels in the reactor coolant, which is considered practical because of good fuel performance. The leak rate limit would apply to total primary to secondary leakage from all causes, including roll transition cracks and cracks at TSPs.

- France. Leakage during accidents caused by defects at TSPs or roll transitions has not been evaluated to date. Should it be necessary, EdF considers that this evaluation should be based on a probabilistic method such as that developed by Laborelec for the EPRI roll transition ATPC document (Z).

- Spain. The possible contribution of leaks at TSPs to accident leak rates, and whether this might require additional limits on defects at TSPs, has not yet been considered. The work being performed as part of the EPRI ATPC effort is being followed to determine needs in this area.

As can be seen by the variability in the above approaches, resolution of this concern is still in the formative stages, and a standardized approach has not yet been worked out.

Quality Status of TSPs

In Sweden, a concern has been raised as to what needs to be done to allow credit to be taken for TSPs considering that they were not designed and built as safety grade equipment. For example, documented inspection reports may not be available to show that welds relied upon for strength were made with correct materials, were of the correct size, etc. Similarly, TSPs are not subjected to periodic inspections to verify that their structural integrity has remained intact.

This concern had not been addressed in any of the other countries visited.

Inspection Criteria

The NDE methods used to quantify the amount of degradation present at a TSP due to IGA/SCC were reviewed at each of the countries visited. Bobbin coil ECT is used by all the groups. RPC is used for confirmation in some countries. The groups visited indicated that they are supportive of the EPRI effort to develop an ATPC technical support document based on correlations of tube burst and leakage behavior with ECT signals (amplitude and phase angle), without attempting to measure quantitative depths or lengths of defects. However, until these results are available, two of the countries, Sweden and Spain, will continue to pursue their quantitative defect depth limit (70% and 78% TWD) type criteria.

Need for Further Data

It was noted during the visits that part of the EPRI effort should include assembling information regarding the actual morphology of defects observed at TSPs, and the correlation of these defects with NDE results, especially bobbin coil ECT results. This information is needed to continue to confirm that the morphology of cracks at TSPs is as expected, and to add to the data base demonstrating that bobbin coil signals provide a reliable way to detect unacceptable defects.

Swedish personnel indicated a desire for the EPRI work on ATPC for TSPs to include analyses for Model D steam generators, in addition to the work already underway for Model 51s.

Section 3
REFERENCES

1. T. G. Harshbarger, "Preparing to Replace the Lower Assemblies at Cook," Nuclear Engineering International, January 1988 ,pp. 26-27.

2. H. Takamatsu, "Japanese Steam Generator Operating Experiences and Results of Related R & D," presented at EPRI Reliability Project Technical Advisory Committee meeting, June 26-28, 1990, Philadelphia, PA.

3. Minutes of Steam Generator Reliability Project Technical Advisory Group meeting, October 23-25, 1990, Palo Alto CA.

4. NRC Information Notice No. 90-49, "Stress Corrosion Cracking in PWR Steam Generator Tubes," USNRC, Washington, D. C., August 6, 1990

5. WCAP-11056, "NRC Presentation Report on Steam Generator Tube Integrity for D. C. Cook Unit 2, January 1986", Westinghouse Electric Corporation, Pittsburgh, PA, in NRC Public Document Room, ACN 8602130275, Date 860131, PDR ADOCK 05000316

6. WCAP-11330, "NRC Presentation Report on Steam Generator Tube Integrity for D. C. Cook Unit 2, September 1986", Westinghouse Electric Corporation, Pittsburgh, PA, in NRC Public Document Room, ACN 8612020058, Date 861124, PDR ADOCK 05000316

7. PWR Steam Generator Tube-Plugging Limits: Technical Support Document for Expansion Zone PWSCC in Roll Transitions, EPRI NP-6864-L, December 1990

Appendix A

VISIT WITH SWEDISH STATE POWER BOARD

Dates: August 29, 1990

Place: Swedish State Power Board (SSPB) offices, Vällingby, Sweden

Subject: Alternate Tube Plugging Criteria for Defects at Tube Support Plates and Roll Transitions (ATPC-TSP and ATPC-RT)

Person contacted: Jan Engström, SSPB

Persons Making Visit: Jeff Gorman, DEI
Al McIlree, EPRI
Chuck Welty, EPRI

1.0 Purpose: The main purpose of this visit was to gather information related to development of alternate tube plugging criteria (ATPC) and associated plugging limits for intergranular attack/stress corrosion cracking (IGA/SCC) at tube support plates (ATPC-TSP). A second purpose of the visit was to review the current situation in Sweden regarding ATPC for primary water stress corrosion cracking (PWSCC) defects at roll transitions (ATPC-RT).

2.0 Summary

- Alternate tube plugging criteria for TSPs (ATPC-TSP) were recently proposed to Swedish safety authorities. These criteria were that defects up to 70% of through wall depth (TWD) were acceptable. The 70% value is based on ensuring that defects not grow through wall during the next operating cycle, and an allowance of 10% for growth and 20% for nondestructive examination (NDE) uncertainty. Safety authorities did not grant full approval of the criteria, but did accept them for a limited number of tubes for one year.

- SSPB's main concern regarding ATPC-TSP is that TSP deflection might occur during a postulated accident such as a steam line break, thus removing the constraining effect of the TSP for defects in the TSP area. Deflections up to 13 mm have been calculated for the top TSP. One approach being considered to resolve this concern is to limit

application of ATPC-TSP to the bottom five supports where deflections are smaller.

- SSPB's approach for resolving concerns regarding possible primary to secondary leakage during postulated accidents is to limit defect sizes at TSPs to values such that leakage during postulated accidents would be insignificant, even after allowance is made for defect growth and NDE error.

- SSPB intends to resubmit ATPC-TSP to Swedish safety authorities later this year, and hopes to have them approved in time for the mid-1991 inspections of Ringhals 3 and 4.

- SSPB supports the EPRI-SGRP effort on ATPC-TSP; however, they would like the current work to include Model D as well as Model 51 steam generators. They noted that items such as TSP deflection are dependent on design details, which vary from model to model.

- Swedish safety authorities were not willing to accept a recent proposal to increase the length of allowed cracks at roll transitions based on revised estimates for crack growth rate and for NDE uncertainty.

3.0 Discussion

3.1 Occurrence of IGA/SCC Defects at Tube Support Plates

IGSCC at TSPs has been detected by eddy current tests (ECT), consisting of bobbin coil inspections and followup rotating pancake coil (RPC) inspections at Ringhals 3, but had not been detected as of August 1990 at Ringhals 4. Axial IGSCC up to about 90% through wall depth (TWD) and 12 mm long has been confirmed by examination of pulled tubes at Ringhals 3. At Ringhals 4, no cracks have been revealed by examination of pulled tubes but, as also seen at Ringhals 3, IGA up to about 25 microns depth is commonly observed at TSP locations.

The amount of IGA/SCC detected by NDE at Ringhals 3 has been limited, with about 25 tubes (about 0.2%) having indications exceeding the current plugging limit of 50% TWD. As discussed later, a few of these tubes have been left in operation to gain crack growth information.

3.2 Current Tube Plugging Criteria for Defects at TSPs

Plugging criteria for defects at TSPs are that defects shall not have indicated depths exceeding 50% TWD. These criteria are the same as for free span defects. On a temporary basis, Swedish safety authorities have allowed a few tubes to remain in operation for one cycle with indicated defect depths up to 70% TWD. The purpose of this exception is to allow crack growth rate data to be obtained for a few deeper defects. Defect depths are determined using bobbin coil ECT.

3.3 Proposed Alternate Tube Plugging Criteria for Defects at TSPs.

SSPB has proposed to their safety authorities that plugging criteria for defects at TSPs be changed from 50% TWD to 70% TWD. The bases for the 70% value include the following: (1) burst test results that show that through wall cracks that extend the full height of the TSP, 19 mm, or a little more, do not result in tube rupture under accident conditions when supported by the TSP, and (2) a 10% allowance for growth and a 20% allowance for NDE uncertainty, with an objective of assuring no significant through wall penetration occurs during the next operating cycle (this will minimize leakage during normal operation and postulated accidents).

3.4 Status of ATPC-TSP Development

About November 1989, SSPB initiated work at Framatome directed at developing the bases for ATPC-TSP. This work included burst tests of tubes with defects located at TSPs. Cold and hot burst tests were performed, including tests using tubes with IGSCC defects generated using caustic. This work has shown that the presence of the TSP prevents rupture of tubes at the TSP for through wall or smaller defects located within the TSP. In addition, it was found that axial defects which extend less than about 10 to 11 mm beyond the edge of the TSP do not reduce tube burst strength.

Evaluation of the possible deflection of TSPs from hot full power positions was also performed. A steam line break (SLB) at hot shutdown conditions was determined to be the limiting case (causing the most TSP deflection), since initial secondary temperature and stored energy are greatest, and since thermal displacement of the TSPs is also the greatest.

Based on burst tests and related analyses, it was proposed to Swedish safety authorities that plugging criteria for defects at TSPs be increased from 50% to 70% TWD. With a value of 70%, which includes an allowance of 10% for growth and 20% for NDE uncertainty, it is expected that the possibility of tube rupture is

essentially eliminated and that leakage due to defects at TSPs would be insignificant following postulated accidents. Thus, this approach avoids the need for quantifying anu demonstrating the acceptability of leakage during accidents due to this cause.

Swedish safety authorities did not accept the proposed change except for a small group of tubes, which were allowed to have defects up to 70% TWD to obtain growth rate data. The main reason that the criteria were not approved for general use in 1990 was that Swedish safety authorities wanted time to determine what was being done in other countries. In addition, questions were raised with regard to the difficulty in assuring that the TSPs would be in position surrounding the tube defects during and after postulated accidents such as the SLB or feedwater line break (FLB), and with regard to quality assurance of the support structure.

Subsequent to making the ATPC-TSP proposal to Swedish safety authorities, Framatome has performed extensive additional evaluations of the potential for TSP deflection. SSPB is currently evaluating the Framatome analyses, and is evaluating what approach should be adopted for handling this issue. SSPB expects to re-apply for approval of ATPC-TSP, with further consideration given to TSP deflection, by early 1991, with the intent of having ATPC-TSP in effect for mid-1991 inspections.

3.5 TSP Deflection Considerations

Analyses performed by Framatome for SSPB have shown that, for the Ringhals 3 and 4 steam generators, the differential pressure (ΔP) that can develop across TSPs during postulated accidents varies from low values (about 1 psi) at low TSP elevations to about 5.5 psi at TSPs at the the top of the tube bundle. The controlling case is for a SLB or FLB from the hot shutdown condition, where starting temperature and stored energy on the secondary side are at a maximum. These calculated values of differential pressure (up to 5.5 psi) are large enough to cause deflections of upper TSPs up to 13 mm, if it is assumed that no resistance to deflection is provided by tube-TSP interaction. If it is also assumed that the TSP could stick in the deflected position, then the TSP deflection could effect tube rupture behavior, and/or have a significant effect on leak behavior..

One approach for limiting concerns regarding TSP deflection would be to limit application of ATPC-TSP to lower TSPs, e.g., TSPs 1 through 5, where support

from the preheater structure is the greatest and predicted deflections are relatively small.

SSPB/Framatome analyses of TSP deflection have shown that the amount of deflection is design dependant and is a function of features such as tie rod design (location and diameter), type of welds at wedge blocks used to connect the TSPs to the wrapper (e.g., whether welds are present at both the top and bottom of the joint, or just at the top), flow patterns, presence of pre-heater, etc. Further, in evaluating the question of TSP deflection, it was found difficult to justify assuming that TSPs could not move freely past tubes, and quantitative credit for TSP to tube friction was not taken. It was also difficult to develop assurance that the TSP would return to its original position, since slip-stick behavior appears to be possible. Thus, TSP deflection evaluations are based on assumptions of zero tube to TSP sliding resistance force, together with possible sticking of the TSP in the fully deflected position.

An additional factor of concern regarding TSP deflections and reliance on TSP structural integrity is that the TSP structure was not originally a nuclear safety (Q-list) component, and the amount of QC/QA verification performed during fabrication to assure that the structure was manufactured and installed per design (correct materials used, welds installed and inspected, etc.) was probably limited.

3.6 Accident Leakage Limits

The SSPB approach regarding leakage at TSPs during accidents is that defect depths at TSPs will be limited to values that assure that the number of defects is minimized that could become through wall during the operating cycle or could propagate through wall during an accident. As discussed earlier, this is the basis for the 70% TWD limit currently proposed for ATPC-TSP.

Burst tests in cold conditions have shown that the pres[illegible]e of the TSP does not affect (i.e., does not prevent) the rupture of the remaining ligament of part depth defects. The test results indicate that cracks of the typical maximum length observed in TSPs of about 12 to 13 mm, and with depths over about 82% TWD, are likely to propagate through wall during postulated accidents, and to result in some primary to secondary leakage after the accident. Larger cracks could propagate at lower pressures. SSPB intends that their proposed 70% TWD

plugging criteria limit the number of defects that could grow through wall before or during an accident to an insignificant number.

3.7 EPRI ATPC-TSP Technical Support

SSPB indicated that they are supportive of the EPRI effort to develop an ATPC-TSP technical support document based on correlations of tube burst and leakage behavior with ECT signals. However, until these results are available, they will continue to pursue the 70% TWD limit discussed above.

The EPRI ATPC-TSP effort is currently focused on Model 51 steam generators. SSPB would like the EPRI effort to also develop information for Model D steam generators of the type used in Sweden, in parallel with work on Model 51s. SSPB noted that some important parts of the bases for ATPC-TSP are dependent on steam generator design details, such as tie rod location and diameter, and that these details can differ from design to design.

It was agreed that part of the EPRI effort should include assembling information regarding the actual morphology of defects observed at TSPs, and the correlation of these defects with NDE results, especially bobbin coil ECT results. This is because:

- Continuing support will be required for the assumptions that the TSP defects are mainly axial cracks, and do not involve significant general degradation, such as IGA.

- Support is needed to demonstrate that use of bobbin coil data provides reliable detection of defects that are structurally significant (likely to burst at or below accident pressures), and also provides reliable detection of defects that increase the probability of developing significant leakage during postulated accidents.

4.0 Discussion of ATPC-RT

Swedish plugging criteria for roll transition PWSCC cracks currently limit the lengths of cracks extending up from the top of the tube sheet to 7.5 mm (there are additional criteria covering cracks that have both ends above the top of the tube sheet: 5 mm if close to the tube sheet, and 3 mm if the top is 16 mm or more above the tube sheet). Based on correlations of RPC measured defect lengths with lengths determined by metallurgical examination of pulled tubes, SSPB recently proposed reducing the allowance for NDE uncertainty from 3 to 1

mm, and also proposed that a more realistic basis for setting the allowance for crack growth, to that expected for a 4 mm long crack, be used. The proposed changes would support changing the criteria such that cracks a few mm longer than the current 7.5 mm limit would not require repair. However, Swedish safety authorities took the position that sufficient experience is not available to justify such changes. For example, one expressed concern is that link up of short cracks could result in increased apparent growth rates. SSPB intends to continue pursuing obtaining relaxation of the ATPC-RT.

Jeffrey A. Gorman
Dominion Engineering, Inc.

Appendix B

VISIT WITH BELGATOM

Report of Visit

Date: September 3, 1990

Place: Laborelec offices, Linkebeek, Belgium

Subject: Alternate Tube Plugging Criteria for Defects at Tube Support Plates and Roll Transitions (ATPC-TSP and ATPC-RT)

Person contacted: Paul Hernalsteen, Laborelec

Persons Making Visit: Jeff Gorman, DEI
Al McIlree, EPRI
Chuck Welty, EPRI

1.0 Purpose: The main purpose of this visit was to gather information related to development of alternate tube plugging criteria (ATPC) and associated plugging limits for intergranular attack/stress corrosion cracking (IGA/SCC) at tube support plates (ATPC-TSP). A second purpose of the visit was to review the current situation in Belgium regarding ATPC for primary water stress corrosion cracking (PWSCC) defects at roll transitions (ATPC-RT).

2.0 Summary

- The occurrence of IGA/SCC at TSPs has been relatively minor in Belgium, with only two units affected (Tihange 1 and Doel 4), and with only a limited number of tubes affected at these units.

- Current plugging criteria in Belgium do not require defects located within the TSP edges to be plugged.

- Analyses are underway to justify increasing allowed primary to secondary leakage during postulated accidents to higher values, such as 20 gpm. This may require lowering allowed radioactivity levels in the reactor coolant, which is considered practical because of good fuel performance. The leak rate limit would apply to total primary to

secondary leakage from all causes, including roll transition cracks and cracks at TSPs.

- The EPRI-SGRP effort for ATPC-TSP is being relied upon to develop guidance relative to questions regarding TSP deflection during accidents, and correlation of bobbin coil signals and the leakage performance of tubes at TSPs.

- No significant circumferential cracks have been found at roll transitions in Belgian plants, despite extensive inspections using sensitive methods. Plugging criteria have been approved that allow circumferential cracks of limited sizes to remain in place. However, in practice, tubes with circumferential cracks will probably be plugged when circumferential cracks are combined with multiple axial cracks.

3.0 Discussion

3.1 Occurrence of IGA/SCC Defects at Tube Support Plates

IGA/SCC defects at TSPs have been detected by bobbin coil inspections and by examination of pulled tubes at Tihange 1, and by leakage and subsequent bobbin coil inspections and follow-up ultrasonic inspections at Doel 4. IGA/SCC at TSPs has not been detected by bobbin coil inspections or by leakage at Doel 1, 2, or 3, or at Tihange 2 or 3. The IGA/SCC at TSPs in Tihange 1 has been increasing slowly for several years, and about 69 tubes are now affected. Examination of a pulled tube indicates that the IGA/SCC consists of axial intergranular and transgranular cracks that are fully within the TSP edges. The Doel 4 IGA/SCC has only recently been detected, in about 5 or 6 tubes. Ultrasonic inspections and leak tests indicated that the largest defects consist of through wall axial cracks 11 to 12 mm long.

3.2 Current Tube Plugging Criteria for Defects at TSPs

Belgian tube plugging criteria permit operation with axial through wall cracks with lengths completely within the edges of the TSP, i.e., do not require tubes with such cracks to be plugged. These criteria are based on results of burst tests which show that such axial cracks do not reduce the burst pressure; i.e., the tube bursts in the free span area, away from the TSP.

3.3 Status of Tube Support Plate Alternate Tube Plugging Criteria (ATPC-TSP) Development and Review

As noted above, ATPC-TSP already exist which permit through wall axial cracks contained within the TSP to remain without repair. However, the possible effects on leakage during a postulated accident such as a steam line break (SLB) or a feedwater line break (FLB) are recognized and are being addressed by Belgatom. This leakage could add to the leakage from roll transition cracks, and may lead to the need to limit the number and/or depth of cracks at TSPs. Belgatom is not doing any separate research regarding quantification of possible leakage at TSPs, but rather is participating in the EPRI-SGRP ATPC-TSP effort, which is being relied upon to develop needed technical support for the alternate criteria.

3.4 TSP Deflection Considerations

Belgatom has no separate work underway at this time regarding evaluation of possible TSP deflection during postulated accidents and, as above, is participating in the EPRI ATPC-TSP effort, which is being relied upon to develop needed information.

3.5 EPRI ATPC-TSP Technical Support

Belgatom is cooperating with EPRI in the development of an ATPC-TSP technical support document and, as noted above, is relying on the EPRI project to develop any needed information regarding TSP deflection and leakage due to defects at TSPs. The Belgian perspective with regard to one of the main thrusts of the EPRI effort, correlation of ECT signals with structural capability, was discussed. They indicated:

- They agree with the general concept of correlating bobbin coil ECT signals at TSPs to leakage behavior, without attempting to measure quantitative depths or lengths of defects, subject to the following reservations.

- They are not confident that meaningful information can be obtained from bobbin coil phase angle data. In addition, they noted that there are large effects of probe location (wobble) on the amplitude of bobbin coil signals generated by a defect at one circumferential location. For example, the variation in amplitude of the signal generated by an ASME defect as the probe is moved from one side to the other of a tube is 68% to 197%, where a 100% signal is developed by the centered probe.

Despite these difficulties, they concur that no better approach is presently available, since bobbin coil inspections are considered to be the only practical way of monitoring tube conditions at TSPs.

3.6 Circumferential Cracks at Roll Transitions

No significant circumferential cracks have been detected at roll transitions in Belgian plants. One very short (0.5 mm) crack was seen in a pulled tube from Doel 2 in 1983, and several short segments (maximum length of 3.5 mm) were seen in a pulled tube from Doel 3 in 1986. The absence of significant circumferential cracking has been confirmed by RPC examinations of all tubes in Doel 3 and Tihange 2 for several years, and by examination using sensitive ultrasonic test (UT) methods of 250 tubes in the sludge pile region of one steam generator in Doel 3 for two years. The UT method is considered capable of detecting circumferential through wall cracks of 2 to 3 mm length. The RPC method is considered capable of detecting circumferential through wall cracks of 6 to 8 mm length if not combined with axial cracks at the same location.

Burst tests have been performed that indicate that circumferential cracks 6 mm or shorter which intersect axial cracks do not significantly affect tube burst behavior, i.e., do not excessively reduce burst pressures below the values set by the axial cracks.

ATPC for circumferential cracks have been developed, and have been accepted by Belgian safety authorities (16 mm limit for 7/8" tubes and 14 mm limit for 3/4" tubes). If circumferential cracks are detected, then inspections with increased sensitivity will probably be performed, e.g., 100% inspection using an axially oriented UT signal. In addition, if necessary based on the types of crack patterns observed, plugging criteria would be re-evaluated and revised as appropriate.

3.7 Accident Leakage Limits

Belgatom is in the process of re-evaluating allowable leakage during postulated accidents such as a steam line break (SLB) or a feedwater line break (FLB). Site dose rate limits are more stringent in Belgium than in the USA, which tends to limit the allowable leakage. However, fuel performance has been very good, and reactor coolant activity limits may be reduced to take advantage of this good experience. It is anticipated that total accident leak rates of 20 gpm

will be shown to be permissible. These leak rates will apply to the sum of leakage from roll transition and TSP defects.

Jeffrey A. Gorman
Dominion Engineering, Inc.

Appendix C

VISIT WITH ELECTICITE DE FRANCE AND FRAMATOME

Report of Visit

Dates: September 4 and 5, 1990

Places: Electricité de France offices in St. Denis and La Defense and Framatome offices in La Defense

Subject: Alternate Tube Plugging Criteria for Defects at Tube Support Plates and Roll Transitions (ATPC-TSP and ATPC-RT)

Persons contacted:
Libin Bernard, Framatome
Jean Paul Billoue, Framatome
Robert Comby, EdF
John Esposito, Westinghouse
Bruno Flesch, EdF
Angel Gelpi, Framatome
Bob Gold, Westinghouse
Don Harrod, Westinghouse
Pierre Nicot, EdF
Francis Nordmann, EdF
Jean-Marie Pecout, EdF
Georges Slama, Framatome

Persons Making Visit:
Jeff Gorman, DEI
Al McIlree, EPRI
Chuck Welty, EPRI

1.0 Purpose: The main purpose of this visit was to gather information related to development of alternate tube plugging criteria (ATPC) and associated plugging limits for intergranular attack/stress corrosion cracking (IGA/SCC) at tube support plates (ATPC-TSP). A second purpose of the visit was to review the current situation in France regarding ATPC for primary water stress corrosion cracking (PWSCC) defects at roll transitions (ATPC-RT).

2.0 Summary

- The number of units experiencing IGA/SCC at TSPs, and the numbers of tubes affected in these units, are gradually increasing as plants age. About 10 units are now affected, and the number of tubes affected increases by about a factor of 2 to 2-1/2 per fuel cycle in those plants affected to the greatest degree. However, there is no requirement to plug or repair indications at TSPs, and the sizes of the eddy current test (ECT) indications seen in plants are much less than the sizes that laboratory tests indicate could significantly affect tube burst strength. Accordingly, IGA/SCC at TSPs is not considered a serious problem in France.

- TSP deflection during accidents has been evaluated and determined to not be a problem for French steam generators.

- Leakage during accidents caused by defects at TSPs or roll transitions has not been evaluated to date. Should it be necessary, EdF considers that this evaluation should be based on a probabilistic method such as that developed by Laborelec for the EPRI ATPC-RT guidelines.

- EdF has recently adopted a length based criterion (13 mm limit) for PWSCC at roll transitions, as opposed to the previous leak before risk of break (LBRB) criterion. EdF plans to perform rotating pancake coil (RPC) inspections of 100% of the tubes in affected steam generators, with initial inspections of all affected steam generators (over 5% tubes affected) being completed over a two year period.

3.0 Discussion

3.1 Occurrence of IGA/SCC Defects at Tube Support Plates

IGA/SCC defects at TSPs were first discovered in French plants at Fessenheim 1 in 1986. Since that time, TSP defects have been identified in about 10 other units. Because these defects are not considered to be significant with regard to safety, inspections to identify and trend such defects have generally been limited to the relatively small inspection samples used to monitor the general condition of the steam generator and to monitor special areas, such as row 1 and 2 U-bends and areas subject to antivibration bar (AVB) wear. Also, the threshold used to determine whether signals at TSPs should be reported has been subject to some change with time. As a result, limited information is available

on the occurrence and progression/growth of defects at TSPs. Nevertheless, some general observations can be made:

- The number of plants affected has been increasing slowly but steadily as plants age. About 10 plants are now listed as having experienced some degree of detectable secondary side attack at hot leg TSPs.

- At plants with measurable/reportable amount of attack, the number of TSP intersections with ECT signals over a given threshold voltage tends to increase by a factor of about 2 to 2-1/2 per annual cycle.

3.2 Results of Pulled Tube Examinations

Three tubes with IGA/SCC defects at TSPs were removed from Fessenheim 1 in 1986, one from St. Laurent B1 in 1987, and one from Bugey 5 in 1989. Examination of these tubes showed the defects to be primarily axial IGSCC. All of the defects were confined within the borders of the TSPs.

3.3 Results of Burst Tests

An extensive series of burst tests was performed subsequent to the discovery of IGA/SCC at TSPs in Fessenheim 1 in 1986. These tests were performed using specimens with IGA generated by sodium tetrathionate attack of sensitized tubing. The tests showed that even very severe degradation of the tube (about 60% of tube wall severely attacked for its full circumference) does not cause reduction of the tube burst strength, as long as the degradation is fully confined within the borders of the TSP.

3.4 Plugging Criteria for TSPs

Based on the results of the burst tests described above, it has been concluded that the type of IGA/SCC degradation observed in French plants does not impact tube burst properties and is therefore not a safety concern. Accordingly, there are no requirements for plugging tubes as a result of detection of IGA/SCC defects at TSPs. These criteria are not documented in a formal report. Rather, they are based on an agreement with French safety authorities and, in the event that significantly different types of defects are discovered, the criteria will be re-evaluated. However, it was noted that the voltage signals from the severely degraded test tubes, that did not experience reduced burst pressure as a result of the degradation, were about a factor of ten greater than the largest signals detected in plants (e.g., 18 volts versus 1.8 volts). Thus, there is a

large margin between the observed conditions and those that would require reevaluation of the need for plugging criteria for IGA/SCC defects at TSPs.

The possible effects of IGA/SCC defects at TSPs on leak rate following postulated accidents, such as a steam line break (SLB) or a feedwater line break (FLB), were discussed. EPRI indicated that the need to limit the leak rate due to its impact on site boundary doses was considered in the USA as a probable reason for limiting the number and size of defects at TSPs, as well as at roll transitions. EdF indicated that there are no plugging criteria in existence in France as a result of this particular effect; however, the subject is currently being evaluated by EdF. In this regard, EdF noted that:

- Previous evaluations of acceptable primary to secondary side leakage during postulated accidents associated with defects at antivibration bars (AVBs) indicated that maximum leak rates in the neighborhood of 15 cubic meters per hour (66 gpm) are acceptable, and that similar limits are expected to apply to the sum of leakage from all defects, including TSP and roll transition defects. It was noted that the leak rate rate limits for defects at AVBs were established by core flow considerations, rather than by site boundary dose considerations, which generally control accident leak rate limits in the USA.

- The presence of the TSP is not expected to limit the growth through wall during a postulated accident of defects that are nearly through wall prior to the accident. Such growth is the result of the high differential pressure expected during postulated accidents, and because the support provided by the TSP does not become effective until the tube experiences significant plastic deformation. Thus, the occurrence of a postulated accident could result in an increase in the number of through wall defects and an increase in the primary to secondary leak rate. EdF considers that such possibilities of crack growth and increased leakage should be addressed using statistical models for crack growth and leakage behavior, similar to that developed by Laborelec for roll transition cracks.

3.5 TSP Deflection

Evaluations of possible TSP deflections during postulated accidents have been performed. Detailed results were not available during the meeting, but maximum deflections of about 2 mm were determined for the highest TSP for French Model

51 steam generators; these values reflect the specific design features of the French units, e.g., number and size of tie rods. These deflections are not considered to be significant.

3.6 EPRI ATPC-TSP Technical Support Effort

EPRI indicated that the EPRI technical support document is directed at establishing a correlation between bobbin coil signals at TSPs and tube structural and leakage performance. EdF described some of their experiences with correlation of bobbin coil ECT signals with defects at TSPs.

- As described above regarding burst tests, EdF has found that tubes with bobbin coil voltage signals about ten times as large as the largest signal seen in plants have not significantly reduced burst strengths.

- EdF provided EPRI with their data correlating TSP signals and defect size at TSPs based on examination of pulled tubes. Correlation of defect depth with signal amplitude has not been good, but correlation with phase angle has been better. However, the number of pulled tubes has been limited, and EdF considers that it is not possible to draw firm conclusions regarding the ability of ECT to monitor defect depths.

3.7 Discussion of ATPC-RI

- EdF has recently adopted a length based plugging limit of 13 mm for axial cracks for all tubes. Previously, this limit applied only to the sludge pile region, and leak before risk of break (LBRB) criteria were used for non sludge pile regions. EdF considers LBRB to still be valid for non sludge pile regions, but has adopted the inspection based approach for regulatory reasons.

- EdF has started performing RPC inspections of the roll transition region of 100% of the tubes in affected steam generators, i.e., steam generators with over 5% of the tubes affected by PWSCC at roll transitions. This is a change from the previous practice of performing 100% RPC inspections of sludge pile areas, and limiting RPC inspections of tubes in other areas to tubes with helium leaks or unusual bobbin coil signals. The 100% inspections of all affected plants will be completed during a two year time frame.

- A leak rate limit of 5 L/h per steam generator continues to be used for 900 MWe plants that are significantly affected by roll transition PWSCC, despite the adoption of a length based limit and 100% RPC inspection. A leak rate limit of 3 L/h is being used for 1300 MWe plants. These leak rate limits have not been found to be unduly burdensome. N-16 monitors on steam lines are used to provide rapid on-line indication of primary to secondary leak rates.

- About 70 tubes in the sludge pile region are being preventively plugged in steam generators in which one or more circumferential cracks in the sludge pile region have been detected (about 13 steam generators in 5 units).

- The growth rate of PWSCC cracks in many roll transitions in France appears to be very low or zero. However, recent measurements in one steam generator of Dampierre 3 (fourth cycle after peening) indicate that average crack growth rates of about 1 mm per fuel cycle occurred, similar to values measured in Belgium. Growth rates decreased as crack length increased, with essentially zero crack growth for the longest cracks. The decision to use 100% RPC inspections of roll transitions is expected to provide additional useful data on this subject in the near future.

- EdF's position regarding circumferential cracks at roll transitions was discussed, and includes:

  - EdF plugs all tubes in which circumferential cracks are detected.

  - EdF considers that the inspection sensitivity of RPC is such that any significant circumferential crack (i.e., a crack that would have a marked impact on burst strength) will be detected by the 100% RPC examination that has recently been instituted.

- The situation regarding effects of roll transition PWSCC on leakage during postulated accidents (e.g., SLB and FLB) is the same as previously discussed for TSP defects, i.e., EdF has not had to meet specific requirements up to the present, but is currently evaluating this concern.

Jeffrey A. Gorman
Dominion Engineering, Inc.

Appendix D

VISIT WITH SPANISH UTILITIES

Report of Visit

Dates: September 18 and 19, 1990

Places: Offices of Centro Investigaciones Energeticas, Medioambientales Y Tecnologicas (CIEMAT) and Central Nuclear de Almaraz (CNA), Madrid, Spain

Subject: Alternate Tube Plugging Criteria for Defects at Tube Support Plates and Roll Transitions

Persons contacted: Gustavo Bollini, Tecnatom-PWR Project
Dolores Gomez Briceno, CIEMAT
Julian Gorosarri, CNA
Anna Marie Lancha Hernandez, CIEMAT
Emilio Lopez Toribio, Asco
Jauquin Lozano, Asco
Jose Pelaez Martinez, CIEMAT
Jose Maria Zamarron, CNA

Persons Making Visit: Jeff Gorman, DEI
Al McIlree, EPRI
Chuck Welty, EPRI

1.0 Purpose: The main purpose of this visit was to gather information related to development of alternate tube plugging criteria (ATPC) and associated plugging limits for intergranular attack/stress corrosion cracking (IGA/SCC) at tube support plates (ATPC-TSP). A second purpose of the visit was to review the current situation in Spain regarding ATPC for primary water stress corrosion cracking (PWSCC) defects at roll transitions (ATPC-RT).

2.0 Summary

- IGA/SCC defects are occurring in increasing rates at Almaraz 1 and 2 and at Asco 1 and 2. The defects are mostly axial in orientation, can be up to 100% in through wall depth (TWD), and generally do not extend beyond the edge of the TSP. In one case, defects at the flow

distribution baffle (FDB) did extend beyond the edge of the FDB; however, this was associated with sludge being present on top of the FDB and to sodium from initial operation of polishers, and is not considered applicable to IGA/SCC at TSPs. In another case, bobbin coil inspection indicated that a primary side defect at a dented TSP extended beyond the edge of the TSP; however, this defect was not confirmed by RPC.

- Current tube plugging criteria for defects at TSPs are the same as for free span defects, 40% TWD. Proposed ATPC-TSP have been submitted to, but not yet accepted by, Spanish safety authorities. The proposed criteria would allow defects up to 78% TWD to not be repaired. The main bases for the criteria are that burst tests have shown 100% TWD defects that extend a short distance beyond the edges of the TSP to not reduce burst strength below accident pressures. For operational reliability reasons, it is desired to avoid development of leaks at TSPs. For this reason, an allowance of 7% for defect growth and 15% for defect depth measurement error are subtracted from 100% to arrive at the proposed limit of 78% TWD.

- The EPRI-SGRP ATPC-TSP effort is being relied upon to identify any needed actions on ATPC-TSP regarding effects of TSP deflection and possible primary to secondary side leakage during accidents.

- The Spanish utilities are supportive of the EPRI-SGRP ATPC-TSP approach of correlating bobbin coil signals with tube burst and leakage behavior, without quantifying defect depth or length. However, until the EPRI criteria are available, the Spanish will continue to pursue the 78% TWD limit discussed above.

- During the summer 1990 inspection at Asco 1, 41 tubes were found to have ID circumferential cracks at the roll transitior. In earlier tube pulls at Asco and Almaraz, OD circumferential cracks have been found. The occurrence of circumferential cracks has required re-evaluation of the ATPC-RT for Almaraz 1 and 2 (they have never been accepted for Asco 1 and 2). Based on burst tests which show that circumferential cracks to not degrade burst test performance if they are located below the top of the tube sheet (TTS), and based on experience which indicates that circumferential cracks occur at roll transitions, revised criteria have

been proposed to Spanish safety authorities that allow current ATPC-RT to be applied to tubes with roll transitions located below the TTS, but require plugging of tubes with roll transitions located above the TTS if any axial or circumferential defects are detected above the TTS.

3.0 Discussion

3.1 Occurrence of IGA/SCC Defects at TSPs

IGA/SCC defects at TSPs and flow distribution baffles (FDBs) have been detected for several years by bobbin coil inspections in Almaraz 1 and 2 and Asco 1 and 2. The defects have been confirmed by examination of pulled tubes from all four units. They have also been confirmed in many cases using rotating pancake coil (RPC) methods. The number of IGA/SCC defects has been increasing at a significant rate at all four units. The bobbin coil indications at TSPs have been growing in amplitude by about 0.5 volts per fuel cycle, and in indicated depth (by phase angle) of about 7 to 9% TWD per fuel cycle.

Examination of pulled tubes has shown the defects to mostly be axially oriented IGSCC. Defect depths at TSPs have ranged up to 100% TWD. Most of the IGA/SCC has been confined within the TSP.

In a few cases defects have been noted extending beyond the edges of tube supports and flow distribution baffles, or the cracks have had an off-axial component. For example:

- A large leak occurred at Almaraz 1 in July 1988 and was found to be caused by IGSCC above the FDB. The IGSCC appeared to be associated with the presence of sludge deposited on top of the FDB and was caused by sodium input during initial operation of polishers; thus, this IGSCC is not considered to be representative of IGA/SCC at TSPs. Also, as noted later, ATPC-TSP in Spain are not considered applicable to the FDB area, so that the occurrence of these defects above the FDB is not relevant to the question of ATPC-TSP.

- Bobbin coil examination in 1990 at Asco 1 identified a possible primary side crack extending beyond the edge of the TSP (the defect was not confirmed by RPC). The tube was dented at the TSP. Since this cracking occurred on the primary side, it is not directly applicable to ATPC-TSP for secondary side IGA/SCC. However, it illustrates the need

for ATPC-TSP to consider the possibility of primary side attack at TSPs if dents are present.

- A pulled tube from Asco was found to have IGA/SCC at a TSP with cracks running at a small angle to the tube axis. No denting was detected, and the reason for the off-axial orientation is not known.

3.2 Current Tube Plugging Criteria for Defects at TSPs

Current plugging criteria for defects at TSPs are that defects shall not have indicated depths exceeding 40% TWD, and are the same limits as for free span defects.

3.3 Proposed ATPC-TSP

The Spanish utilities have recently proposed to their safety authorities that plugging limits for defects at TSPs be changed from 40% TWD to 78% TWD. The bases for the 78% value are:

- A 100% TWD axial IGSCC defect at a TSP is not considered to be a safety concern from a tube rupture standpoint. This is based on burst tests that have shown that defects that are 100% TWD and extend the full width (thickness) of the TSP, and up to three mm beyond the edge of the TSP, do not reduce tube burst pressure to values close to accident values.

- For operational reliability reasons, it is desired to avoid significant leakage at TSPs during the operating cycle following a given inspection. Accordingly, an allowance of 7% for defect growth and an allowance of 15% for NDE uncertainty are subtracted from the 100% TWD value that is considered acceptable from a safety point of view. The 7% growth value is an average one for IGA/SCC at TSPs, and the 15% NDE uncertainty comes from comparison between ECT data and pulled tube results.

3.4 Status of ATPC-TSP Development

A significant amount of work has been performed to develop and support ATPC-TSP. This work has included development of specimens with OD IGSCC for use in leak tests, performance of an array of burst tests using specimens with electrodischarge machined (EDM) notches, performance of leak tests, and supporting analyses. This work indicated that:

- Clearances in FDB holes are so large that the FDB does not provide effective support against rupture. Thus, ATPC-TSP cannot be applied to defects at the FDB.

- Tube burst pressures with through wall defects that are fully contained within the TSP are much higher than the burst pressures for the same defect located in free span areas, and are much higher than accident pressures.

- Extension of defects 3 mm beyond the edges of the TSP only causes a 10 to 20% reduction in burst pressure, and the resulting burst pressure is still much higher than accident pressures.

The proposed ATPC-TSP described in 3.3 were recently submitted to Spanish safety authorities. A rapid response is not expected, because of attention currently being given to resolution of questions regarding roll transition alternate tube plugging criteria (ATPC-RT) raised by detection of circumferential cracks at Asco.

Effects of the possible deflection of TSPs from hot full power positions caused by differential pressures across TSPs during accidents have not as yet been considered. The work being performed as part of the EPRI ATPC-TSP technical support effort is being relied upon to determine needs in this area.

The possible contribution of leaks at TSPs to accident leak rates, and whether this might require additional limits on defects at TSPs, has not yet been considered. The work being performed as part of the EPRI ATPC-TSP effort is being followed to determine needs in this area.

3.7 EPRI ATPC-TSP Technical Support Effort

The Spanish utilities indicated that they are supportive of the EPRI effort to develop ATPC-TSP based on correlations of tube burst and leakage behavior with ECT signals. However, until these criteria are available, they will continue to pursue the 78% TWD limit discussed above.

4.0 Discussion of ATPC-RT

Spanish plugging criteria for roll transition PWSCC cracks currently limit the lengths of axial cracks extending up from the last point of contact between the

tube and tube sheet to about 7 mm. These criteria are based on the assumed absence of circumferential cracks. Recent ECT inspections and pulled tube results have revealed the presence of significant numbers of primary side initiated circumferential cracks at Asco 1. In addition, a number of pulled tubes (6 of 12 pulled tubes) from Asco and Almaraz over the past three years have revealed the presence of OD circumferential cracks. Because of the possible presence of circumferential cracks, revised ATPC-RT were recently prepared and submitted to Spanish safety authorities for use in the refueling outage just started at Almaraz 1. In summary, these criteria are as follows:

- A 100% bobbin coil inspection and a 25% RPC inspection (plus RPC of any tubes with bobbin coil indications) will be performed of the hot leg roll transition area of each steam generator. If no circumferential cracks are detected, then the normal ATPC-RT will be used (axial crack length limited to about 7 mm).

- Steam generators in which circumferential cracks are detected will be inspected 100% by RPC. All tubes with defects above the top of the tube sheet will be identified. For these tubes:

  - Tubes with axial cracks only (no circumferential cracks detected) and with the roll transition below the top of the tube sheet will be treated using the normal ATPC-RT.

  - Tubes with the roll transition located above the top of the tube sheet and with either longitudinal or circumferential defects located above the top of the tube sheet will be plugged.

Some of the considerations that went into the above criteria are as follows:

- Analyses based on experience at Spanish and foreign plants indicate that isolated circumferential cracks do not grow sufficiently in one fuel cycle to grow from an undetected size (e.g., 7.5 mm long) to an unacceptable size (critical length of 45 mm).

- Recently performed burst tests show that circumferential cracks below the top of the tube sheet do not degrade the rupture behavior of critical length axial cracks located above the top of the tube sheet.

- Recently performed burst tests show that circumferential cracks located above the top of the tube sheet can significantly reduce the rupture strength of tubes with intersecting axial cracks, and can lead to large leakage configurations, before rupture, as a result of flaps or corners bending where axial and circumferential cracks intersect. Because the presence of roll transitions located above the top of the tube sheet increases risks of undetected circumferential cracks above the the top of the tube sheet, tubes with roll transitions above the top of the tube sheet are subject to more strict criteria than tubes with roll transitions below the top of the tube sheet.

Jeffrey A. Gorman
Dominion engineering, Inc.