May 1, 2002

Mr. Gregory M. Rueger
Senior Vice President, Generation and
Chief Nuclear Officer
Pacific Gas and Electric Company
Diablo Canyon Nuclear Power Plant
P. O. Box 3
Avila Beach, CA 93424

SUBJECT: DIABLO CANYON NUCLEAR POWER PLANT, UNIT NOS. 1 AND 2 - ISSUANCE OF AMENDMENT RE: ALTERNATE REPAIR CRITERIA FOR AXIAL PRIMARY WATER STRESS CORROSION CRACKING AT DENTED INTERSECTIONS IN STEAM GENERATOR TUBING (TAC NOS. MB3392 AND MB3393)

Dear Mr. Rueger:

The Commission has issued the enclosed Amendment No. 152 to Facility Operating License No. DPR-80 and Amendment No.152 to Facility Operating License No. DPR-82 for the Diablo Canyon Nuclear Power Plant (DCPP), Unit Nos. 1 and 2, respectively. The amendments consist of changes to the Technical Specifications (TSs) in response to your application dated November 13, 2001, as supplemented by letters dated February 26, 2002, March 11, 2002, and April 18, 2002.

The amendments revise the TS to incorporate a new alternate repair criteria (ARC) for steam generator (SG) tubes with axial primary water stress corrosion cracking (PWSCC) at dented tube support plate (TSP) intersections. These amendments will apply to the future operating cycles of DCPP Unit Nos. 1 and 2.

A copy of the related Safety Evaluation is enclosed. The Notice of Issuance will be included in the Commission's next regular biweekly *Federal Register* notice.

Sincerely,
/RA/

Girija S. Shukla, Project Manager, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-275
and 50-323

Enclosures:
1. Amendment No. 152 to DPR-80
2. Amendment No. 152 to DPR-82
3. Safety Evaluation

cc w/encls: See next page

May 1, 2002

Mr. Gregory M. Rueger
Senior Vice President, Generation and
Chief Nuclear Officer
Pacific Gas and Electric Company
Diablo Canyon Nuclear Power Plant
P. O. Box 3
Avila Beach, CA 94177

SUBJECT: DIABLO CANYON NUCLEAR POWER PLANT, UNIT NOS. 1 AND 2 - ISSUANCE OF AMENDMENT RE: ALTERNATE REPAIR CRITERIA FOR AXIAL PRIMARY WATER STRESS CORROSION CRACKING AT DENTED INTERSECTIONS IN STEAM GENERATOR TUBING (TAC NOS. MB3392 AND MB3393)

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PACIFIC GAS AND ELECTRIC COMPANY

DOCKET NO. 50-275

DIABLO CANYON NUCLEAR POWER PLANT, UNIT NO. 1

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 152
License No. DPR-80

1. The Nuclear Regulatory Commission (the Commission) has found that:

   A. The application for amendment by Pacific Gas and Electric Company (the licensee) dated November 13, 2001, as supplemented by letters dated February 26, 2002, March 11, 2002, and April 18, 2002, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's regulations set forth in 10 CFR Chapter I;

   B. The facility will operate in conformity with the application, the provisions of the Act, and the rules and regulations of the Commission;

   C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;

   D. The issuance of this amendment will not be inimical to the common defense and security or to the health and safety of the public; and

   E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment, and paragraph 2.C.(2) of Facility Operating License No. DPR-80 is hereby amended to read as follows:

(2) Technical Specifications

The Technical Specifications contained in Appendix A and the Environmental Protection Plan contained in Appendix B, as revised through Amendment No. 152, are hereby incorporated in the license. Pacific Gas and Electric Company shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan, except where otherwise stated in specific license conditions.

3. This license amendment is effective as of its date of issuance and shall be implemented within 30 days from the date of issuance.

FOR THE NUCLEAR REGULATORY COMMISSION

/RA/

Stephen Dembek, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Attachment: Changes to the Technical Specifications

Date of Issuance: May 2, 2002

PACIFIC GAS AND ELECTRIC COMPANY

DOCKET NO. 50-323

DIABLO CANYON NUCLEAR POWER PLANT, UNIT NO. 2

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 152
License No. DPR-82

1. The Nuclear Regulatory Commission (the Commission) has found that:

   A. The application for amendment by Pacific Gas and Electric Company (the licensee) dated November 13, 2001, as supplemented by letters dated February 26, 2002, March 11, 2002, and April 18, 2002, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's regulations set forth in 10 CFR Chapter I;

   B. The facility will operate in conformity with the application, the provisions of the Act, and the rules and regulations of the Commission;

   C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;

   D. The issuance of this amendment will not be inimical to the common defense and security or to the health and safety of the public; and

   E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment, and paragraph 2.C.(2) of Facility Operating License No. DPR-82 is hereby amended to read as follows:

(2) Technical Specifications

The Technical Specifications contained in Appendix A and the Environmental Protection Plan contained in Appendix B, as revised through Amendment No. 152, are hereby incorporated in the license. Pacific Gas and Electric Company shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan, except where otherwise stated in specific license conditions.

3. This license amendment is effective as of its date of issuance and shall be implemented within 30 days from the date of its issuance.

FOR THE NUCLEAR REGULATORY COMMISSION

/RA/

Stephen Dembek, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Attachment: Changes to the Technical Specifications

Date of Issuance: May 1, 2002

<u>ATTACHMENT TO</u>

<u>LICENSE AMENDMENT NO. 152 TO FACILITY OPERATING LICENSE NO. DPR-80</u>

<u>AND AMENDMENT NO. 152 TO FACILITY OPERATING LICENSE NO. DPR-82</u>

<u>DOCKET NOS. 50-275 AND 50-323</u>

Replace the following pages of the Appendix A Technical Specifications with the attached revised pages. The revised pages are identified by amendment number and contain marginal lines indicating the areas of change.

REMOVE	INSERT
5.0-11	5.0-11
---	5.0-11a
5.0-13	5.0-13
---	5.0-13a
5.0-30	5.0-30
---	5.0-30a

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 152 TO FACILITY OPERATING LICENSE NO. DPR-80

AND AMENDMENT NO. 152 TO FACILITY OPERATING LICENSE NO. DPR-82

PACIFIC GAS AND ELECTRIC COMPANY

DIABLO CANYON POWER PLANT, UNITS 1 AND 2

DOCKET NOS. 50-275 AND 50-323

1.0 INTRODUCTION

By letter dated November 13, 2001, as supplemented by letters dated February 26, 2002, March 11, 2002, and April 18, 2002, Pacific Gas and Electric Company (PG&E) submitted a technical specification (TS) amendment request (application) for the Diablo Canyon Power Plant (DCPP), Units 1 and 2, to incorporate a new alternate repair criteria (ARC) for steam generator (SG) tubes with axial primary water stress corrosion cracking (PWSCC) at dented tube support plate (TSP) intersections. This amendment request would apply to future operating cycles of DCPP Units 1 and 2.

The February 26, March 11, and April 18, 2002, supplemental letters provided additional clarifying information, did not expand the scope of the application as originally noticed, and did not change the staff's original proposed no significant hazards consideration determination published in the *Federal Register* on January 8, 2002 (67 FR 929). The April 18, 2002, supplemental letter also submitted TS pages which clarified, revised, and added additional requirements to the proposed TSs submitted in PG&E's application of November 13, 2001.

Currently, the applicable tube repair criteria for this type of flaw indication are the standard depth-based criteria; namely, tubes with indicated maximum flaw depths greater than or equal to 40 percent of the initial tube wall thickness must be plugged. The proposed ARC consists of an integrated approach to managing axial PWSCC at dented TSP intersections to ensure that tube structural and leakage integrity are maintained. This integrated approach includes an inspection program for detection and sizing of axial PWSCC flaws and methodologies for assessing tube structural and leakage integrity. The ARC itself is not a fixed value; rather, tubes with axial PWSCC indications at dented TSP intersections are accepted for continued service when it can be demonstrated by the assessment methodologies that structural and leakage integrity will be maintained until the next scheduled inspection. In the event that a mixed mode (axial PWSCC and circumferential) indication is detected, the approach includes methods for accounting for the potential effects the circumferential flaw has on the structural and leakage integrity of the axial PWSCC indications left in service.

2.0 BACKGROUND

DCPP Units 1 and 2 are 4-loop Westinghouse plants with Model 51 SGs. Each SG contains about 3400 tubes. The SG tubes are mill annealed Alloy 600 with an outside diameter of 0.875-inches and a wall thickness of 0.050-inches. Each SG contains seven TSPs to provide lateral support to the tubes. The TSPs are carbon steel, 0.75-inches thick, with drilled holes through which the tubes are inserted. There is nominally a 0.013 to 0.018-inch diametral clearance between the tube and TSP at each TSP intersection. At DCPP Units 1 and 2, however, corrosion of the carbon steel TSPs has led to the buildup of hard corrosion product (primarily magnetite) in the annulus between the tube and TSP. This magnetite buildup ultimately leads to radial deformation of the tubes at the vicinity of the intersection. This radial deformation of the tube is referred to as denting. The strain in the tubes at dent locations renders the tubes susceptible to PWSCC. Both denting and PWSCC can be detected during inservice inspections.

3.0 PROPOSED TECHNICAL SPECIFICATION AMENDMENT

PG&E proposes permanent changes to the technical specifications for DCPP Units 1 and 2 to establish an ARC for PWSCC at dented TSP intersections as follows:

- Add a new TS surveillance requirement (SR) (5.5.9.b.5) to require inspection of dented tube support plate intersections to be performed in accordance with Westinghouse Topical Report WCAP-15573, "Depth-Based SG Tube Repair Criteria for Axial PWSCC at Dented TSP Intersections - Alternate Burst Pressure Calculation," Revision 1, dated October 2001. The extent of the required inspection is:

  (a) 100-percent bobbin coil inspection of all TSP intersections.

  (b) +Point coil inspection of all bobbin coil indications at dented TSP intersections.

  (c) +Point coil inspection of all prior PWSCC indications left in service.

  (d) If bobbin coil is relied upon for detection of axial PWSCC in less than or equal to 2 volt dents, then on a SG basis perform +Point coil inspection of all TSP intersections having greater than 2 volt dents up to the highest TSP for which PWSCC has been detected in the prior two inspections or current inspection and 20 percent of greater than 2 volt dents at the next higher TSP. If a circumferential indication is detected in a dent of "x" volts in the prior two inspections or current inspection, +Point inspections will be conducted on 100 percent of dents greater than "x-0.3" volts up to the affected TSP elevation in the affected SG, plus 20 percent of dents greater than "x-0.3" volts at the next higher TSP. The definition of “x” is defined as the lowest dent voltage where a circumferential crack was detected.

(e) If bobbin coil is not relied upon for detection of axial PWSCC in less than or equal to 2 volts dents, then on a SG basis perform + Point coil inspection of all dented TSP intersections (no lower dent voltage threshold) up to the highest TSP for which PWSCC has been detected in the prior two inspections or current inspection and 20 percent of all dents at the next higher TSP.

(f) For any 20 percent dent sample, a minimum of 50 dents at the TSP elevation shall be inspected. If the population of dents is less than 50 at the TSP elevation, then 100 percent of the dents at the TSP elevation shall be inspected.

- Revise the definition of "plugging limit" in SR 5.5.9.d.1.f.3 to state that the 40 percent depth-based limit does not apply to axial PWSCC indications, or portions thereof, which are located within the thickness of dented TSPs which exhibit a maximum depth greater than or equal to 40 percent of the initial tube wall thickness. WCAP-15573, Revision 1 provides repair limits applicable to these intersections.

- Add a new Technical Specification SR (5.6.10.g) that states for implementation of the repair criteria for axial PWSCC at dented TSPs, the NRC shall be notified prior to startup, pursuant to 10 CFR 50.72, of the following conditions that indicate a failure of performance criteria:

  (a) The calculated SG probability of burst for condition monitoring exceeds $1x10^{-2}$, or

  (b) The calculated SG leakage for condition monitoring from all sources (all alternate repair criteria and non-alternate repair criteria indications) exceeds the leakage limit determined from the licensing basis steam line break dose calculation.

- Add a new Technical Specification SR (5.6.10.h) that states for implementing the repair criteria for axial PWSCC at dented TSPs, the results of the condition monitoring and operational assessments will be reported to the NRC within 120 days (henceforth referred to as the 120-day report) following completion of the inspection. The report will include:

  (a) Tabulations of indications found in the inspection, tubes repaired, and tubes left in service under the ARC.

  (b) Growth rate distributions for indications found in the inspection and growth rate distributions used to establish the tube repair limits.

(c) +Point confirmation rates for bobbin detected indications when bobbin is relied upon for detection of axial PWSCC in less than or equal to 2 volt dents.

(d) For condition monitoring, an evaluation of any indications that satisfy burst margin requirements based on Westinghouse burst pressure model, but do not satisfy burst margin requirements based on the combined Argonne National Laboratory (ANL) ligament tearing and through-wall burst pressure model.

(e) Performance evaluation of the operational assessment methodology for predicting flaw distributions as a function of flaw size.

(f) Evaluation that provides the number and size of previously reported versus new PWSCC indications found in the inspection, and the potential need to account for new indications in the operational assessment burst evaluation.

(g) Identification of mixed mode (axial PWSCC and circumferential) indications found in the inspection and an evaluation of the mixed mode indications for potential impact on the axial indication burst pressures or leakage.

(h) Any corrective actions found necessary in the event that condition monitoring requirements are not met. [The condition monitoring requirements are defined in WCAP-15573, Revision 1].

- Add a new Technical Specification SR (5.5.9.d.1.f 4) that states a tube which contains a tube support plate intersection with both an axial outside diameter stress corrosion cracking (ODSCC) indication and an axial PWSCC indication will be removed from service.

4.0 WCAP-15573, REVISION 1, METHODOLOGY OVERVIEW

The scope of the WCAP-15573, Revision 1, methodology includes an inspection program to identify and size axial PWSCC and circumferential PWSCC and ODSCC indications at dented TSP intersections; models for assessing flaw detection and sizing performance, crack growth rate, burst pressure, and accident-induced leakage; and an operational assessment and a condition monitoring methodology. Each axial PWSCC indication found by inspection is dispositioned as acceptable or unacceptable for continued service based on its measured crack profile and the results of an operational assessment.

With the potential for axial PWSCC to occur with either circumferential PWSCC or circumferential ODSCC at the same TSP intersection (i.e., mixed mode indications), any circumferential indication detected during an inspection will also be depth sized (profiled) with a +Point coil. The circumferential indications are sized, even though the tube will be plugged, in order to assess the effects the circumferential indications had on the integrity of the axial PWSCC indications. If the effects of the circumferential indications are significant, the tube structural and leakage integrity evaluations are modified to specifically account for mixed mode indications.

The operational assessment projects the potential growth of the axial PWSCC indication to the next scheduled inspection, allowing for potential error in the measured crack size, and determines the associated burst pressure capability and potential leak rate under postulated accident conditions. The success criteria for burst pressure capability and for accident induced leak rate are consistent with those in NRC Regulatory Guide (RG) 1.121 (Reference 1) and Nuclear Energy Institute (NEI) publication NEI 97-06, Revision 1B, "Steam Generator Program Guidelines" (Reference 2). Tubes with axial PWSCC indications not satisfying the applicable burst pressure and accident leak rate success criteria (see Section 5.4 of this safety evaluation (SE)) are removed from service by plugging. Tubes with axial PWSCC indications satisfying these criteria may be left in service without plugging. Tubes with circumferential indications will be plugged and not left in service. Finally, a condition monitoring assessment is performed on the axial PWSCC indications found at each inspection to confirm that the burst pressure and accident leakage acceptance criteria were in fact met during the preceding operating interval.

5.0 EVALUATION

In Sections 5.1, 5.2, and 5.3, the SG eddy current inspection scope, burst pressure analysis, and accident leakage analysis for axial PWSCC indications are discussed. The effects of a circumferential flaw on the burst pressure and leakage integrity analysis of an axial PWSCC indication are discussed in Section 5.4. The term, "mixed-mode indications," is used to refer to tube support locations where axial PWSCC indications are found in conjunction with circumferential indications.

5.1 SG Eddy Current Inspection Program for Axial PWSCC Indications (WCAP-15573, Revision 1, Section 4)

As part of this ARC, PG&E will apply two SG tube eddy current inspection techniques. The first technique uses a bobbin coil probe, and the second technique uses a rotating probe that provides inspection data from a mid-range +Point and/or a high-frequency (0.080-inch diameter) pancake coil. At TSP intersections where the dents are less than or equal to 2 volts in size, PG&E relies on the bobbin coil technique to quantify the dent size and to optionally detect the presence of PWSCC. If the bobbin inspection detects a flaw-like eddy current signal, PG&E reinspects the intersections using the +Point technique to confirm and size the indication. At TSP intersections where the dents are larger than 2 volts in size, PG&E relies on the +Point technique to both detect and size PWSCC indications. At TSP intersections where the dents are less than 2 volts in size and PG&E elects not to use the bobbin coil for detection of PWSCC indications, PG&E relies on the +Point technique to both detect and size PWSCC indications.

Westinghouse tested and evaluated the eddy current inspection techniques for detecting and sizing axial PWSCC indications following the guidance in Appendix H of the Electric Power Research Institute’s (EPRI) "PWR Steam Generator Examination Guidelines," (Reference 3) and the NRC staff’s Draft Regulatory Guide DG-1074, "Steam Generator Tube Integrity" (Reference 4). From this testing and evaluation, they developed the probabilities of detection (PODs), nondestructive examination (NDE) sizing uncertainties, and a PWSCC indication growth rate methodology to be applied in the operational assessment and condition monitoring. Although the staff reviewed all aspects of the NDE technique development and evaluation, it focused its attention on the data set upon which the technique was developed (including an assessment of noise levels in the performance test database), the results of the POD and NDE sizing uncertainty evaluations, the growth rate methodology, and the steam generator inspection plan. Each of these areas is discussed in more detail below.

5.1.1 Axial PWSCC Database (WCAP-15573, Revision 1, Sections 3 and 4)

The first step in the development of a qualified NDE technique is to assemble a relevant data set. The staff reviewed the data set used by Westinghouse to qualify and validate the two NDE techniques to be applied as part of this ARC. The data set includes five PWSCC flaws obtained from service-degraded tube specimens, one from Sequoyah and four from DCPP. The characteristics of these tubes (i.e., location in the SG, size of the dents, and size of the defects) appear fairly typical and representative of the types of indications to which this ARC is to be applied. Westinghouse supplemented the data set with over 50 additional PWSCC flaws obtained by mechanically denting and chemically attacking 7/8-inch diameter mill annealed Alloy 600 tubing. These flaws varied in length and depth to encompass both very short and very long flaws, very shallow and very deep flaws (lengths of 0.12 inches to 2.6 inches, average depths of 7 percent to 96 percent through-wall, maximum depths of 16 percent to 100 percent through-wall). The flaws were axially oriented PWSCC that initiated within the dented portion of the tube in the minor axis of the dent, consistent with field operating experience. The crack morphology of the laboratory specimens also appears consistent with the pulled tubes. The specimens developed one or two cracks per TSP intersection. The cracks were well aligned axially, some with uncorroded ligaments. The staff visited the Westinghouse test facility for part of the NDE performance testing and found that there was no discernable difference in the eddy current signals obtained from service-induced cracks and laboratory-supplied cracks (Reference 5).

Westinghouse used standard field equipment in the eddy current data acquisition phase. Prior to obtaining the NDE data, they placed carbon steel collars around the specimens to simulate the TSPs and also packed the crevices between the lab specimens and the TSP simulant collars with a magnetite mixture. In this way, the NDE examination of the laboratory specimens included signals from both the TSP and the crevice deposits, as tubes do in the field.

Westinghouse compared the dent morphology and eddy current signals obtained from the laboratory specimens with those typically seen in the field. In general, the laboratory specimens' dent size was typical of that seen in the field, but the dent morphology was not typical. The laboratory specimens had more localized deformation of the tubes than generally seen in the field. Although not prototypical, Westinghouse characterized the laboratory dents as being more difficult to analyze because of the localized distortion and the location of the flaw in relation to that distortion.

The NRC staff finds that the PWSCC data set described in the WCAP meets the industry guidelines for NDE technique qualification as discussed in the EPRI guidelines as well as draft staff guidelines in DG-1074. The data set includes pulled tube specimens supplemented by laboratory specimens that appear representative of field conditions with respect to crack size, crack morphology and the inclusion of denting, TSPs, and TSP crevice deposits. The number of specimens included in the data set is adequate and includes a diverse representation of lengths and depths. The laboratory specimens were fabricated from 7/8-inch mill annealed Alloy 600 tubing, representative of the tubing in the DCPP plants. The staff found that PWSCC associated with very large dent voltages (i.e., greater than 5 volts) was not represented by the PWSCC data set. However, since the +Point probe is a surface riding coil, a flaw signal is less affected by the presence of a dent. As a result, the staff believes the lack of large dents in the PWSCC data set can, in general, be considered acceptable. Nonetheless, to ensure correct probe positioning and movement at dented locations, PG&E has indicated to perform the following with respect to these issues as part of the implementation of the ARC. To ensure correct probe positioning, PG&E will record and observe either pull-out data or axial encoder data to ensure that the correct support plate elevation is being tested. To ensure proper movement of the probe through the dent, PG&E will observe the trigger pulse channel for the rotating probe data from each inspected dented TSP intersection to ensure the rotating probe data is acceptable in terms of evenness around the tube circumference (e.g., no abnormal noise, circumferential scan lines aligned properly, etc.).

To ensure the results from the laboratory-cracked specimens were applicable to the conditions at DCPP, additional evaluations were performed by PG&E. Specifically, noise levels from the laboratory specimens were compared to those from field-dented TSP intersections. This evaluation was performed to support the adequacy of the bobbin and +Point techniques for detecting PWSCC in the field as well as to support the +Point sizing uncertainties. Vertical amplitude noise levels were compared to assess bobbin and +Point detectability and peak-to-peak noise levels were compared to assess +Point sizing.

For the bobbin coil, field noise levels in small dents (less than or equal to 2 volts) are typically higher at the edges of the TSP. For the laboratory specimens, the localized denting and the presence of the set screw (used to create the dent) led to higher noise levels at the center of the TSP rather than at the edge. The noise levels at the center of the laboratory specimens are essentially the same as the levels at the edge of the DCPP support plates. Thus, the detectability of the flaws at the center of the laboratory specimens corresponds to the detectability of flaws at the edge of the field TSPs. Since the laboratory noise levels at the center of the TSP are higher than the noise levels observed at the center of the DCPP SGs (where most of the indications occur), the detectability of flaws at the center of the TSP in the field should be bounded by the test program.

For the +Point coil, field noise levels at the edges of the TSP are not significantly different from the noise levels at the center of the TSP. The +Point noise levels for the laboratory samples at the center of the TSP are about twice that observed in the field (i.e., twice that observed at either the center or the edge of the TSP). Since the noise levels in the laboratory specimens are conservative relative to the noise levels in the field, the test program should result in conservative estimates of the field capabilities.

The above noise comparisons were performed using existing field data. No upper limits are currently established for signal-to-noise ratio values to ensure reliable application of the proposed methods in the future. PG&E has addressed this issue by indicating that the field noise levels are generally bounded by the ARC database noise levels. In addition, since denting is essentially arrested in the DCPP SGs, the noise levels from this study can be expected to be applicable for one or more cycles. Furthermore, if noise levels were masking significant indications, new indications potentially challenging tube integrity limits would eventually be detected when the signals become large enough to detect (in these “high noise level” TSP intersections). Since (1) no new (i.e., not previously detected) indications challenging structural or leakage integrity have been found in the DCPP SGs, (2) WCAP-15573, Revision 1, identifies analysis and reporting requirements in the event that large new indications are found in an inspection, and (3) PG&E has committed as part of the implementation of the ARC to implement industry requirements on signal quality when they are finalized in the Electric Power Research Institute's (EPRI's) "PWR Steam Generator Examination Guidelines," the staff finds this acceptable.

5.1.2 Probability of Detection (WCAP-15573, Revision 1, Section 4)

As discussed above, DCPP will apply two eddy current test techniques during its steam generator tube inspection. DCPP may optionally use the bobbin coil technique to detect the presence of PWSCC at TSP intersections where the dent voltages are less than or equal to 2.0 volts in size. If the bobbin coil technique is not used to detect PWSCC at TSP intersections when the dent voltages are less than or equal to 2.0 volts, the +Point technique will be used. At TSP intersections where the dents are larger than 2.0 volts in size, DCPP will use the +Point technique to both detect and size PWSCC indications.

Westinghouse qualified these two eddy current test techniques for this specific ARC application following the EPRI guidelines. The Appendix H guidelines place a minimum acceptance criterion on the POD of greater than or equal to 80 percent at the 90 percent confidence level. Westinghouse documented a POD of 0.86 at 90 percent confidence for maximum depths greater than 34 percent through-wall for the bobbin coil technique and 0.92 at 90 percent confidence for maximum depths greater than 34 percent through-wall for the +Point technique. These results are documented in ETSS # 96012 for the bobbin coil technique and ETSS # 96703 for the +Point technique. These PODs meet the Appendix H guidelines and therefore, the techniques may be considered qualified for detection of PWSCC at dented TSP intersections.

Westinghouse also validated these NDE techniques following the staff's draft guide DG-1074. The NRC staff focused its attention on the results of this validation effort because this effort provides the most representative assessment of the ability of these NDE techniques. This phase of the NDE technique testing consisted of two or three independent teams performing blind analysis of the PWSCC data set described earlier. From this testing, Westinghouse reassessed the POD performance and quantified the NDE sizing uncertainties. The analysts used these performance tests to quantify the axial PWSCC growth rate.

With respect to the POD, Westinghouse obtained results similar to those obtained for the Appendix H qualification discussed above. The staff agrees that the performance of the +Point coil demonstrated the effectiveness of this specific NDE technique. The POD values easily met the guidelines of Appendix H and the false call rates were very low. However, the POD determined for the bobbin coil technique, although it met Appendix H, also had very high false call rates associated with achieving this POD. The staff is concerned with the high false call rate for the bobbin coil test because it may be masking the true performance of the bobbin coil technique. This in itself is not a concern if analysts continue to overcall in the field. This would be a conservative practice because all bobbin indications receive a reinspection with the +Point probe. However, if the high overcall rate is masking a poor POD, and the analysts relax their standards and do not call as conservatively in the field, this may result in missed PWSCC indications. One way of helping to ensure that analysts continue to call conservatively in the field is to track the +Point confirmation rates. If PG&E continues to have a low +Point confirmation rate (i.e., less than 10 percent), indicating that the analysts are overcalling the bobbin coil results in the field as they did in the performance qualification test, this indicates that analysts are still calling the bobbin coil inspection results conservatively. TS 5.6.10.h.3, requires that this information be provided in the 120-day report.

Missed PWSCC indications may become a structural or leakage integrity concern in two ways. The first way is if the NDE technique is incapable of detecting structurally or leakage significant indications. Westinghouse provided a discussion of the undetected indications in the WCAP and found that the largest indications not detected by either the bobbin coil or +Point probe were neither structurally nor leakage significant. This corroborates the staff's experience to date. The second more likely way missed PWSCC indications can become a problem is due to high growth rates. With high growth rates, a more sensitive NDE technique is required to detect very small indications or a shortened operating cycle is required so that the large growth rates will not impair tube integrity. Based on Diablo's growth rate assessment over the past several cycles, the sensitivity of the NDE techniques to be applied at the upcoming outage are sufficient to provide reasonable assurance that significant PWSCC flaws will be detected and evaluated before such indications become a challenge to structural and/or leakage integrity. The condition monitoring results will assist PG&E and the staff in further assessing this aspect of the ARC.

PG&E uses POD explicitly in its operational assessment of steam generator tube leakage. Because of the concerns discussed above with the validity of the assumed bobbin coil POD, PG&E will use a constant POD value of 0.6, which is required by the WCAP-15573, Revision 1, analyses (response to question 6.1 in the February 26, 2002, submittal). The staff finds this acceptable because operating experience to date using this POD value for the ARC for outside diameter stress corrosion cracking (ODSCC) at the TSPs (i.e., Generic Letter (GL) 95-05 [Reference 6]) indicates its use results in conservative projections of the end of cycle conditions. The use of this same value for PWSCC at the TSPs should provide comparable results because PWSCC is, in general, more easily detected by the bobbin coil compared to ODSCC, as long as the dents are small (i.e., less than 2 volts in size).

5.1.3 NDE Sizing Uncertainties (WCAP-15573, Revision 1, Section 4)

As part of the validation testing, Westinghouse determined the NDE sizing uncertainties to be applied as part of this ARC by comparing NDE data obtained from three independent analyses with destructive examination data for the tube specimens. NDE sizing uncertainties were determined for length, average depth and maximum depth. Westinghouse used the method of least squares regression analysis in examining the relationship between the NDE data and the destructive examination data. The staff found the use of a linear regression acceptable for this application. Westinghouse evaluated the results of various statistical tests (e.g., correlation coefficient, p-value, residual analysis), and these results support the use of this model. DCPP will apply these NDE sizing uncertainties to the crack profiles obtained from the inspection when performing the operational assessment and condition monitoring.

5.1.4 Growth Rates (WCAP-15573, Revision 1, Section 4)

In WCAP-15573, Revision 1, three separate growth rate distributions were presented: one for indication length, one for maximum depth, and one for average depth. These growth rates are based on data from Cycles 8 through 10 at DCPP Units 1 and 2 (for a total of 6 cycles of data, 3 from each unit). There are over 200 axial PWSCC growth data points in the database.

A growth data point is defined only when the indication can be sized in two consecutive cycles. When an indication is found that was not reported in the prior inspection, the prior inspection data is reanalyzed as part of the growth evaluation. If an indication can be identified in the prior inspection data using hindsight (based on knowledge of the flaw location found in the later inspection), it is sized using the same depth profiling techniques used to evaluate the data from the current inspection. There is no reason to believe that this process introduces any bias in the NDE calls. For some indications, the prior cycle reanalysis may indicate that the presence of a flaw is probable even though no sizing can be performed. For some other indications, no flaw may be detectable and the indication would be considered NDD (no detectable degradation). These flaws would not be included in the growth rate database.

In the case where flaws cannot be detected during the "hindsight" re-analysis, the indication at the prior cycle may be present below detectable levels or the indication could have initiated during the cycle. As noted in WCAP-15573, Revision 1, these types of indications (i.e., indications which could not be detected during the hindsight analysis) were not the largest indications found during the inspection. Furthermore, there is no data to suggest that these indications initiated during the cycle and grew at an accelerated rate for the remainder of the cycle while still representing non-structurally significant indications when detected at the end of the cycle. While no absolute statement on initiation time and growth rate can be made, it is clear that indications of this type have their growth rates included in the growth distribution. Given the history (6 cycles of indications) of axial PWSCC at DCPP with no indications found to grow from NDD by reanalysis to large indications, the staff finds PG&E’s approach reasonable.

As discussed above, PG&E determined three separate growth rate distributions for indication length, maximum depth, and average depth. The growth rates are presented as distributions independent of the flaw depth (i.e., the growth rate is treated as independent of flaw depth). In contrast, most laboratory stress corrosion cracking growth tests conducted under constant stress show that the crack growth rate (in the depth direction) increases with increasing crack depth. However, PG&E provided additional information supporting their assumption that the crack growth rate is independent of crack depth. This information supported PG&E's methodology in that not only did the data not show any systematic increase in crack growth rate with increasing depth, it actually showed a slightly negative trend for the deeper cracks suggesting that the crack growth rate on the average for these deeper cracks may be slowing down with increasing depth. This may be due to the relaxation of the residual stress field of the dents, which would very likely provide the primary driving force for the growth of stress corrosion cracks, with increasing crack depth. Thus, by assuming the growth rate distribution to be independent of depth, PG&E is being conservative based on the data discussed above.

With respect to updating the growth rate database, PG&E will add data to the database as it becomes available. Currently, the growth rate database includes data from 3 cycles from both units (for a total of 6 cycles of data) since these many cycles of data are needed to obtain 200 growth data points. As additional cycles of data are added, the data from each cycle are evaluated and if a given cycle of data results in a lower growth rate than other cycles, it can be removed to result in a more conservative growth rate distribution. When a total of 200 data points are obtained over two cycles, then the last two cycles of growth data will be used to develop the growth distributions. The growth distribution used for operational assessments would be the more conservative of the combined data or either of the two cycles. If 200 growth values are obtained over each of the last two cycles, the growth distribution used for operational assessments would be the more conservative of the two cycles of data. In addition, PG&E indicated that when 200 growth values are obtained for each unit, the growth distributions may be separately defined for each unit if any significant differences are found between the units. The staff finds this methodology for updating the growth rate database acceptable.

In determining the tube repair limits (i.e., performing the operational assessment), the growth rate database will not include the data from the most recent operating cycle. The most recent data is not used because of the amount of time and the cost associated with updating the growth rate distribution during the outage. To address the concern that the growth rate distribution may not be conservative since it does not incorporate the last cycle of data, PG&E will determine (as required by WCAP-15573, Revision 1) the growth rates for large indications during the outage and assess the impact on the upper tail of the growth rate distribution. If the new growth rate data causes the growth distribution above 90 percent probability to be more conservative, the new growth rate data will be added to the growth distribution for the operational assessment. This method ensures that the growth distribution is conservative for determining the need for tube repair. In addition, the growth rate distributions for indications found in the inspection and the growth rate distributions used to establish the tube repair limits will be provided in the 120-day report. The staff finds this approach acceptable.

5.1.5 Inspection Scope (WCAP-15573, Revision 1, Section 2)

PG&E will perform a 100 percent bobbin coil inspection of all TSP intersections per proposed TS 5.5.9.5.a. The bobbin coil inspection quantifies the voltage response of dents at each TSP intersection and is the NDE technique to optionally be relied upon to detect PWSCC at TSP intersections with dents not exceeding 2 volts. PG&E will use the +Point coil to confirm all bobbin coil indications and to inspect all prior PWSCC indications left in service.

If the bobbin coil is relied upon for detection of axial PWSCC in dents less than or equal to 2 volts, PG&E will use the +Point probe to inspect all TSP intersections with dents greater than 2 volts up to the highest TSP in each steam generator for which PWSCC has been detected in the current and previous two inspections and 20 percent of such intersections at the next higher TSP. If a circumferential indication is detected in a dent of "x" volts in the current or prior two inspections, +Point inspections will be conducted on 100 percent of dents greater than "x-0.3" volts up to the affected TSP elevation in the affected SG, plus 20 percent of dents greater than "x-0.3" volts at the next higher TSP. The definition of "x" is defined as the lowest dent voltage where a circumferential indication was detected.

If the bobbin coil is not relied upon for detection of PWSCC at dents less than or equal to 2 volts, then on a steam generator basis, PG&E will use a +Plus coil to inspect all dented TSP intersections (no lower dent voltage threshold) up to the highest TSP for which PWSCC has been detected in the current and prior two inspections and 20 percent of all dents at the next higher TSP per proposed TS 5.5.9.5.b. For any 20 percent dent sample, PG&E will inspect a minimum of 50 dents at the TSP elevation per proposed TS 5.5.9.5.f. If the population of dents is less than 50 at the TSP elevation, PG&E will then inspect 100 percent of the dents at the elevation per proposed TS 5.5.9.5.d.

The staff finds the bobbin coil and +Point inspection scope to be comprehensive, appropriately sensitive to inspection findings, and consistent with industry practice.

5.2 Burst Pressure Analysis (WCAP-15573, Revision 1, Section 5)

PG&E documented their approach for performing the burst pressure condition monitoring analyses (for tubes taken out of service) and the operational assessment for PWSCC indications at dented TSPs in Section 5.0 of WCAP-15573, Revision 1. Both analyses use a Monte Carlo simulation approach to evaluate individual crack indications identified by the eddy current inspections. The burst models used in these analyses are discussed below.

5.2.1 Condition Monitoring Model (WCAP-15573, Revision 1, Section 5.2)

PG&E's modeling approach for condition monitoring (discussed in Section 5.7) is based on the "weakest link" concept and considers two lower bound models. The first, a part-through-wall flaw model (PTW model) based on the work of Cochet (References 7 and 8) for flaws that initiate from the tube's outside diameter; and the second, a through-wall flaw model (TW model) from work performed to support limits contained in the American Society of Mechanical Engineers (ASME) Code (Reference 9). To obtain the model predicted burst pressure for a given flaw, the failure pressure is calculated using each model and the larger of the two predictions would be assigned as the model predicted burst pressure. This is an acceptable procedure that is based on the fact that burst of a tube is a two-step process: crack tip ligament rupture followed by unstable burst of the resulting through-wall crack.

Since Cochet's equation for partial through-wall cracks was derived from tests on ODSCC flaws and PWSCC flaws whose flanks were not pressurized, a correction factor to account for pressurization of the crack flanks was developed for partial through-wall PWSCC flaws. This correction factor was applied to the "base" partial through-wall model. Next, PG&E applied the Cochet/ASME model to a large burst pressure database consisting of pulled tubes from many steam generators and laboratory specimens and found the predictions were conservative. They then developed a best-estimate model by linear regression of the model (Cochet/ASME) predicted burst pressures versus the actual test burst pressures.

The staff has concluded that the variables contained in the models for predicting the burst pressure of a given flaw are reasonable. Detailed analyses of available failure data on electric discharged machined (EDM) flaws at ANL have shown that the Cochet/ASME models provide lower bound estimates of burst pressures and the predictions are generally more conservative than those based on the more accurate ANL/EPRI burst model (which is discussed below). Therefore, the staff has concluded that PG&E's burst pressure analysis methodology is acceptable for the condition monitoring of axially oriented, partial through-wall PWSCC indications at dented TSP intersections.

5.2.2 Operational Assessment Model (WCAP-15573, Revision 1, Section 5.3)

Because of NRC concerns that the database for PWSCC flaws may have been affected by the high pressurization rates used in testing some of the specimens, PG&E adopted the ANL ligament rupture model (Reference 10) and the EPRI burst model (Reference 9) for through-wall flaws for use in the operational assessment burst analysis (discussed in Section 5.5). As with the condition monitoring analysis, the higher of the two predicted failure pressures is used as the burst pressure. The equations for these two burst models are given below. The ANL partial through-wall model is described with the following equation:

$$P_B\,(PTW) = P_o/m_p \tag{1}$$

P_o = unflawed burst pressure = $k*(S_y + S_u)*t/R_m$ (2)
S_y = yield strength of the tube
S_u = ultimate strength of the tube
t = tube wall thickness
R_m = mean radius of tube
m_p = factor dependent on tube and crack geometry and fitting parameter β

In Reference 10, k was set equal to 0.55 and β was set to 0.9, based on tests on specimens with part-through-wall and through-wall flaws. In WCAP-15573, Revision 1, k is set equal to 0.595 and β was set equal to 0.85. The k value of 0.595 was determined by Westinghouse by evaluating the burst pressures of a larger database of unflawed Alloy 600 tubes. The staff has verified that both combinations of k and β values predict ligament rupture pressures that are close to each other.

The ANL model was derived from tests on specimens with rectangular EDM notches. It has been applied with moderate success to predict ligament rupture pressures of laboratory generated ODSCC specimens at ANL using the "equivalent crack" approach which is the same as the Westinghouse weakest link model.

The EPRI through-wall model is described with the following equation:

$$P_B\,(TW) = t/R_m*(S_y+S_u)*[b_1+b_2e^{b_3*L*(R_m t)^{-0.5}}] \tag{3}$$

where b_1, b_2, and b_3 are constants, L is the crack length, and the other parameters have been defined previously. The staff has verified that the burst pressures calculated by the EPRI model are very close to those calculated by the Erdogan's formulation for through-wall cracks.

Unlike the database for condition monitoring, the database used for the ANL ligament rupture model and the EPRI burst model did not include any stress corrosion cracks or dented tube data. At the request of the staff, PG&E provided information (in response to question 3.1 in its February 26, and March 11, 2002, submittals) indicating the ANL/EPRI model predicts (using the equivalent rectangular crack method) the burst pressures of the pulled tube burst pressure database more accurately than the Cochet/ASME model, but nonetheless generally conservatively. In the two responses, PG&E argues with good reasons that denting should not affect the burst pressure significantly. The lower 5th percentile predicted burst pressures using the ANL/EPRI model are uniformly conservative. As a result of this demonstration, the staff finds the ANL/EPRI model acceptable for calculating burst pressures of dented SG tubes for the operational assessment.

As indicated above, different burst pressure models are used for the condition monitoring and operational assessment methodologies. Based on WCAP-15573, Revision 1, PG&E will use the Cochet/ASME model for condition monitoring, and the ANL/EPRI model for operational assessment. PG&E requested the NRC approval to use the Cochet/ASME model for performing the operational assessment after the pressurization rate issue is resolved by the industry to the satisfaction of the NRC. The staff finds this acceptable.

5.3 Accident Leakage Analysis (WCAP-15573, Revision 1, Section 6)

PG&E documented their approach for performing the accident-induced leakage analyses for the purposes of operational assessment and condition monitoring for axial PWSCC indications at dented TSPs in Section 6.0 of WCAP-15573, Revision 1 and clarified or amended portions of the approach in the various letters listed in Section 1.0 of this SE. The leakage calculations are performed for all axial PWSCC indications in the entire steam generator using Monte Carlo simulation techniques. This section discusses the leak rate analysis methodology and the development of the leak rate models used in this methodology. The variables used to represent specific quantities in the following discussion may not be identical to those used in Section 6.0 of WCAP-15573, Revision 1.

5.3.1 Determination of Through-Wall Length (WCAP-15573, Revision 1, Sections 5 and 6)

The leakage evaluation starts with the "adjusted" crack depth profile (see Section 5.5.2 of this SE). With the "adjusted" crack depth profile, a crack front search routine is run to determine the ligament tearing pressure, P_T, for every continuous subregion of a flaw. This determination of P_T for each subregion is done using the ANL ligament tearing model. As discussed in Section 5.2.2, the ANL model is constructed around the burst pressure of the undegraded tube (P_o) and a reduction factor (m_p) dependent on the geometry of the tube and the length and depth of the subregion being evaluated. As discussed in Section 5.2.2, the model given in Reference 10 was modified to incorporate different values of the constants k and β.

Next, the critical pressure is established. The critical pressure (P_{crit}) is the postulated steam line break event pressure modified by the uncertainty associated with the ANL ligament tearing model. The uncertainty in the ANL model is determined by Monte Carlo selection from a histogram of model errors provided in Table 6-6 of WCAP-15573, Revision 1. The ligament tearing pressure for each subregion is then compared to the critical pressure. All continuous subregions for which P_T is less than P_{crit} are identified. If there are no such subregions for a flaw, the flaw is not predicted to "pop-through" the tube wall and, therefore, will not leak under steam line break conditions. If more than one subregion of a flaw exhibits a P_T less than P_{crit}, then the longest such subregion is selected as the principal "pop-through" region, R_1, for the leakage calculation. Finally, the results of the P_{crit} versus P_T comparison are searched again and the next two longest, distinct, subregions that are predicted to "pop-through" (one to either side of the principal breakthrough region) are identified (if any exist). These subregions are noted, R_2 and R_3. The end result of these analyses is the through-wall length(s) of the flaw (or more precisely, the through-wall length of the subregions of the flaw). The through-wall length(s) is then used to determine the leak rate from the flaw, as discussed below. In the case where multiple through-wall subregions are present, all subregions are used to determine the overall leakage from the flaw as the sum of the leakage from R_1, R_2, and R_3 for comparison to total leakage limits. In addition, accident leakage associated with each free span portion of the flaw is summed separately for comparison to other leakage limits. This process is performed for each axial PWSCC flaw at dented TSP intersections in the steam generator.

5.3.2 Calculation of Leak Rate (WCAP-15573, Revision 1, Section 6)

There are two important models used in the prediction of leak rates. First is the leak rate model which is developed on the basis of thermal hydraulic analysis of a constant flow area orifice, and the second is the crack opening area (COA) model which is a function of pressure and crack length. PG&E uses the CRACKFLO code, which has these two models built into it, to calculate leak rates during steam line break accident conditions.

The CRACKFLO code was developed by Westinghouse and has previously been used to calculate the leak rates for free span cracks. The CRACKFLO code is a one-dimensional fluid flow model based on the use of Henry's non-equilibrium equation (References 11 and 12) to account for the effects of finite flashing rates. The governing one-dimensional momentum equation for a homogenous two-phase fluid is given as:

$$(dP/dy) = (1/A_c) * d[G^2 * A_c/\rho]/dy + (f\,G^2)/(2*D*\rho) \quad (4)$$

where: P = the static pressure
y = the flow coordinate
A_c = the crack opening area
G = the mass flux
ρ = the fluid density
D = the flow path hydraulic diameter
f = the friction factor

To calculate COA, CRACKFLO uses the Paris-Tada equation, which gives approximately the same COA as Zahoor's model, a model used by ANL to calculate COAs. To calculate COA for a non-rectangular complex-shaped stress corrosion crack using either of these models, an effective through-wall crack length is needed. An approach based on the concept of an equivalent rectangular crack has been used by PG&E to determine the effective crack length at steam line break pressure differentials from the measured crack depth profiles as determined from NDE (as discussed above).

PG&E has not determined the ability of the equivalent rectangular crack approach to estimate or to conservatively bound the COAs of stress corrosion cracks either by tests or by analyses. Instead, to assess the performance of CRACKFLO, PG&E used the CRACKFLO model to predict the leak rate for six sets of data (three PWSCC data sets, two ODSCC data sets, and one fatigue data set). Destructive examination data (i.e., flaw length and depth) were used as inputs to CRACKFLO. These data sets included data from laboratory specimens and from pulled tubes. Since the laboratory fatigue crack samples were not leak tested under steam line break conditions, the data from this data set were not used in developing the correlations in WCAP-15573, Revision 1.

Material properties, principally the material flow stress which is necessary for calculating the crack opening area, were available for some specimens. In the absence of tube-specific material property data, mean material properties were used. PG&E concluded that this would be acceptable since the model predicted leak rates show only a modest sensitivity to materials property parameters. Lack of knowledge of the tube-specific material properties parameters was also expected to be captured by the scatter of the data around the model regression analysis and thus the uncertainty associated with the use of the model in the Monte Carlo analysis. It was, however, noted that inherent differences in crack morphology (the surface roughness and tortuosity) needed to be accounted for when comparing the leak rate database to the leakage values predicted by the model.

PG&E compared the predicted leak rates from CRACKFLO to the measured leak rates of high temperature tests on tubes with field induced stress corrosion cracks, laboratory generated stress corrosion cracks, and fatigue cracks (i.e., the 6 data sets referenced above). These comparisons were performed using three different input assumptions: (1) mean crack length with "standard" roughness and tortuosity, (2) mean crack length with increased roughness and tortuosity, and (3) through-wall crack length with increased roughness and tortuosity. The crack lengths used in the calculations were from destructive examination data. The material properties used in the calculations were as described above (i.e., mean value or flaw-specific value, if available). The estimates of the surface roughness and tortuosity were based on the type of flaw (PWSCC, ODSCC).

The leak rate predictions by all three assumptions (mean or through-wall crack length with standard or increased roughness/tortuosity) were relatively inaccurate with large scatter. From these comparisons PG&E chose to use the "post-test measured through-wall crack length," rather than the "measured mean length" of the crack, for input into CRACKFLO, even though this particular choice did not produce markedly better predictions of leak rates than the other two assumptions.

To correct for the limitations of CRACKFLO to predict the actual leak rate of a PWSCC flaw, PG&E did a regression fit of the experimental leak rates to the predicted leak rates. That is, a linear regression analysis was performed between the log (base 10) of the actual measured leak rate to the log (base 10) of the CRACKFLO predicted leak rate. Hence, the final form of the linear regression analysis produced a model described by:

$$\log (Q_{actual}) = m * \log (Q_{CRACKFLO}) + b \qquad (5)$$

where:

Q_{actual} = the measured leakage from a specified test in the leak rate database

$Q_{CRACKFLO}$ = the predicted leakage for the flaw based on the CRACKFLO model

and m and b are the fit parameters of the regression analysis. This regression analysis model is then used to predict the leak rate of an axial PWSCC flaw at a dented TSP intersection based on the CRACKFLO predicted leak rate.

Although the use of the through-wall crack length in this analysis instead of the mean crack length was an arbitrary choice, as long as the selected choice is used consistently to characterize both the data in the leak rate database (and thus used in the final regression analysis) and the indications found in-service, the choice should not have an effect on validity of the overall model. Likewise, the precise choice of surface roughness and tortuosity values for each type of flaw should not have an overall effect on the validity of the model provided that the relative differences in roughness and tortuosity (with ODSCC being characterized as rougher and more tortuous) are addressed. Any non-systematic mischaracterization would again be expected to contribute to the scatter of the data around the regression line and the uncertainty in the model predictions.

Nonetheless, to check the overall accuracy of the ARC procedure for predicting leak rate from measured NDE data, PG&E reviewed the PWSCC and ODSCC ARC databases to identify deep, partial through-wall indications that either leaked or did not leak at steam line break conditions. The search produced one PWSCC and two ODSCC flaws which had deep partial through-wall indications that leaked at steam line break conditions. Of these, only the PWSCC flaw had NDE results. For this flaw, flaw profiles were available from three independent analysis of the data since this flaw was part of the NDE performance test database. Since there is no approved method for sizing ODSCC, PG&E used the destructive examination crack depth profiles and added an uncertainty factor for NDE to those profiles. PG&E applied the ARC leakage procedure to these three flaws and showed that the leak rate in each case was predicted conservatively (when NDE uncertainty was added to the destructive examination data for the ODSCC specimens). PG&E also showed that in a number of other tests which did not leak, the ARC procedure was conservative (i.e., it predicted no leakage or predicted some leakage). The ARC procedure for predicting leak rate of PWSCC based on NDE data is essentially validated by only one PWSCC flaw.

5.3.3 Summary of Leak Rate Model (WCAP-15573, Revision 1, Section 6)

The methodology for calculating the leak rate for a specific flaw, therefore, involves the following steps: (1) determining the "adjusted" crack depth profile based on NDE, (2) determining the through-wall length of the flaw using the ANL ligament tearing model, (3) determining the leak rate using CRACKFLO, and (4) converting the CRACKFLO leak rate value to a predicted value using equation 5. In determining the leak rate for a flaw, Monte Carlo methods are used to account for uncertainties in various parameters including the uncertainty associated with the predictions in equation 5 (as a result of the scatter of the leak rate data about the regression line and the uncertainties in the regression slope and intercept values) and the material flow stress.

5.3.4 NRC-Research Experience with Leak Rate Tests

5.3.4.1 Flashing

Many simplified leak rate models assume that because of the large upstream to downstream pressure ratio, flashing occurs in the crack within the tube wall and the flow in the crack is choked. In response to a question from the NRC staff regarding treatment of potential flashing of the pressurized water to steam, PG&E indicated that CRACKFLO does include an internal determination of whether or not flashing is expected to occur within the crack. If the result is positive, then the back pressure that would be associated with flashing is accounted for.

Leak rate tests have been performed by the NRC's Office of Nuclear Regulatory Research. Zahoor's model has been used to calculate the COA as a function of crack length and pressure. Validation of the COA results from Zahoor's model for rectangular EDM notches has been obtained using finite element analysis as well as with tests. For EDM notches, predictions of actual leak rates using single-phase flow (no flashing) orifice discharge equation are reasonable down to leak rates of a few tenths of a gallon per minute. Tests on 1/64-inch diameter circular orifices have not shown any evidence of choking. Although flashing must occur in leak rate tests of stress corrosion cracks in which the leak rates are of the order of a few drops of water per minute, it is not clear whether the same is true when the leak rates are higher.

The presence or absence of flashing and choked flow within the tube wall may have an important bearing on the calculated leak rates. PG&E argues that since the predictions using CRACKFLO were scaled to test data results by the use of the above regression equation (i.e., equation 5), the magnitude of the prediction error standard deviation is likely to increase if no flashing actually occurs. This latter situation had been reported as being the case from recent testing performed by ANL. Since the prediction error standard deviation would be expected to increase if no flashing occurred, leak rate predictions of actual cracks with flashing would likewise be expected to be conservative.

5.3.4.2 Use of the ANL Model to Approximate the Through-Wall Length of a Flaw

Prediction of the measured leak rates of cracks using the equivalent rectangular crack approach (described in Section 5.2.2) has led to mixed results at ANL. Predictions of actual leak rates for stress corrosion cracks, which are accompanied by an abrupt ligament rupture event and subsequent sudden increase of leak rate from essentially zero, are reasonable. However, there are a number of cases where deeper cracks (i.e., cracks with depths greater than or equal to 80 percent average depth) occasionally leak in a gradually increasing manner with increasing pressure starting from pressures that are significantly lower than the predicted ligament rupture pressure. The leak rate predictions in these cases are not as accurate. Most of these tests also showed time-dependent increases in leak rate when held at constant pressure indicating ligament tearing was occurring.

In view of the above, the staff requested PG&E to provide additional details of the leak rate tests conducted to generate the database that was used to validate CRACKFLO, particularly with respect to any ligament tearing that may have been observed. PG&E informed the staff that the data used in the development of the regression equation relating measured leak rate to estimated leak rate using the CRACKFLO code were from several different sources as identified in Table 6-1 of WCAP-15573, Revision 1. Multiple techniques and/or equipment were involved for testing and measuring the leak rate depending on when the tests were performed (techniques are judged to improve with time) and whether or not the tubes were laboratory or pulled tube specimens. In data source set # 2, specimens were fatigue grown cracks and are not susceptible to a time dependent increase in the flow unless material creep were to occur at the tips of the cracks. This would not be expected at the test temperature of interest.

Testing of pulled tube specimens, data source sets #3 and #6, was performed in hot cells at the Westinghouse Science and Technology Center. The procedure duration for measuring the leak rate was a function of the leak rate itself. For large leak rates, the capacity of the system would limit the duration of the test and replicate measurements were made to verify the initial readings. The number of replicates was determined by the test engineer at the time of the test. If the leak rate was low, repeat tests would be made over a period of about twenty to thirty minutes. The water was cooled, condensed, and captured in a graduated cylinder. The accumulated volume of water would be linear over time for a steady-state leak rate. Testing continued until at least two successive measurements were the same. For very slow leaks, the leak rate was measured by counting the number of drops that were condensed over a similar length of time. In all cases, the tests were repeated to verify the leak rate. Thus, a minimum test period of 40 minutes would be typical of data source sets #3 and #6 specimens. A similar procedure would have been used for laboratory generated PWSCC and ODSCC cracks in data source sets #1, #4 and #5 specimens. It is believed that sudden ligament ruptures were not reported for any of the tests listed (data source sets #1 through #6). Some tests showed no leakage at normal operating conditions, but did leak at steam line break differential pressure conditions. Thus, it is likely that some ligament tearing was associated with the increase in pressure.

After reviewing PG&E's procedures, the staff concluded that in the leak rate tests reported in WCAP-15573, Revision 1, the specimens were repeatedly pressurized and held until the leak rate achieved a steady state value at constant (maximum) pressure hold. This ensured that all the ligaments that could be ruptured did rupture before the leak rate readings were recorded and there was no additional ligament tearing during the leak rate measurements.

5.3.5 Conclusions Regarding the Accident Induced Leakage Model

The NRC staff has concluded that PG&E's approach to developing the leak rate regression model is acceptable. Although (1) the leakage model is shown to be dependent on many more parameters than the corresponding burst model, (2) some of these parameters require the use of "nominal" values absent tube-specific or flaw-specific data, and (3) the entire methodology is only validated by one PWSCC test, the regression of the results to established data is expected to compensate for random errors in characterization of the test sample cases. The use of the regression model and its associated uncertainty in the Monte Carlo analysis explicitly addresses these concerns, as addressed by PG&E in its response to question 7 of the April 18, 2002, submittal. However, if during inservice applications of this methodology, the "nominal" settings of some parameters are changed without recalibrating the results to the data, the model would no longer be valid. NRC staff approval would be required prior to the use of any change to these "nominal" parameter values for inservice evaluations, in accordance with TS 5.5.9.d.1.f.3.

With respect to the model only being validated for one PWSCC flaw, the staff notes the following: (1) the model conservatively predicted the leak rate for 9 of the 10 ODSCC flaws when no NDE uncertainties were applied to the destructive examination data (note that 7 of the 9 did not predict leakage), (2) the model conservatively predicted the leak rate for 10 of the 10 ODSCC flaws when NDE uncertainties were applied to the destructive examination results, (3) PG&E will use a POD adjustment of 0.6 in its leakage assessment (discussed in Sections 5.1.2 and 5.6.1), (4) PG&E will evaluate the leakage at a 95/95 confidence level (discussed in Section 5.5), and (5) PG&E has committed to attempt to identify ligament tearing following the steam line break leak test if any tubes are removed either for axial PWSCC or axial ODSCC indications to confirm that the model adequately predicts accident induced leakage (this assessment will be included in the 120-day report). Based on the conference call with the licensee on April 26, 2002, PG&E stated that upon approval of the amendment the commitment in item 5 above with be placed in its Commitment Tracking System, which is based on NEI report “Guidelines for Managing NRC Commitments”, Revision 2, dated December 19, 1995. The staff concludes this is sufficient for the commitment being made. As a result of the above, the staff finds PG&E’s approach acceptable.

5.4 Mixed Mode Indications (WCAP-15573, Revision 1, Sections 4, 5, 6, and 7)

Mixed mode cracking or mixed mode indications are terms used to describe the condition when axial and circumferential flaws occur at the same general location. For this ARC, these terms are used to describe a condition where axial PWSCC flaws/indications occur with either circumferential PWSCC or circumferential ODSCC flaws/indications at the same TSP intersection. Mixed mode indications at TSP intersections can generally be described as being either in a "T-shape" or an "L-shape" configuration. The T-shape configuration can occur when either the axial indication bisects the circumferential indication or when the circumferential indication bisects the axial indication (this latter case can be described as a "T" rotated 90 degrees). The L-shape configuration occurs when the tip of the circumferential indication is near the tip of an axial indication.

The presence of a circumferential flaw near an axial PWSCC flaw can affect its burst pressure and/or the amount the flaw will leak during postulated accidents. Whether a circumferential flaw will affect the integrity of an axial PWSCC flaw depends on many factors including the size (length and depth) of the circumferential flaw, the size (length and depth) of the axial flaw, the orientation of the axial and circumferential flaws ("L"-shaped or "T"-shaped), and the separation distance between the flaws.

Historically, the occurrence of mixed mode cracking at mildly dented TSP locations, as is observed at DCPP, has been limited. In fact, axial and circumferential PWSCC indications have only been found at five TSP intersections in the DC SGs to date. However, as axial PWSCC indications are left in service and the SGs age, the possibility that the frequency and severity of mixed mode cracking will increase cannot be ruled out. To account for mixed mode cracking, PG&E has proposed to assess all mixed mode indications by determining if the presence of the circumferential indication has a significant effect on the structural and/or leakage integrity of the axial PWSCC indication. If it is determined that the presence of a circumferential indication has an effect on the integrity (burst or leakage integrity) of the axial PWSCC indication, PG&E has proposed to change the methodology associated with the axial PWSCC ARC (described in Sections 5.1, 5.2, and 5.3) to specifically account for mixed mode indications.

If "significant" mixed mode cracking is observed (significant in terms of the effects the circumferential indication has on the integrity of the axial PWSCC indication), the burst pressure margin requirements and the leakage from axial PWSCC indications will be increased. These changes are necessary even though tubes with mixed mode cracking will be plugged on detection because there is a possibility that a circumferential indication could "develop" (i.e., either initiate or become detectable) next to an axial PWSCC indication during the course of the next operating interval. The axial PWSCC indication may have been left in service knowingly as a result of this ARC, it may be a new indication, or it may not have been detected because it was below the threshold of detection during the prior inspection.

For mixed mode cracking, the NRC staff has reviewed PG&E's inspection plans and capabilities, their databases for determining the effects of circumferential flaws on the structural and leakage integrity of axial PWSCC flaws, and their proposed changes to their axial PWSCC ARC methodology in the event that circumferential indications begin to have significant effects on the integrity of axial PWSCC indications. These latter changes include (1) increasing the burst margin requirements (e.g., $1.4x\Delta P_{SLB}$) based on the percentage reduction in the burst pressure of the axial PWSCC indication as a result of presence of the circumferential indication, and (2) increasing the leakage from an axial PWSCC indication based on the severity (depth) of the circumferential indications detected. These areas are discussed further below.

5.4.1 SG Eddy Current Inspection Program (WCAP-15573, Revision 1, Sections 4.8 and 4.10)

In addition to the inspection program discussed in Section 5.1, PG&E's inspection program also includes methodologies for evaluating mixed mode indications (axial PWSCC occurring with either circumferential PWSCC or circumferential ODSCC at the same TSP intersection). In particular, two different NDE techniques will be used in these evaluations. One technique is used in determining the separation distance between the axial and circumferential indications, and the second technique is used for sizing the circumferential indication. Sizing of axial PWSCC indications is discussed in Section 5.1.3. Although circumferential indications will not be left in service, sizing of such indications is necessary to determine the need for implementing a more restrictive repair criteria for axial PWSCC indications as discussed in Sections 5.4.2 and 5.4.3.

The two techniques for assessing mixed mode indications are based on the use of eddy current inspection results from rotating probes containing a mid-range pancake coil (0.115-inch diameter), a +Point coil, and/or a high-frequency shielded pancake coil (0.080-inch diameter). Analysis of the high-frequency pancake coil response is performed to determine whether a return to null exists between the axial PWSCC indication and the circumferential indication. If the signal does not display a return to null, the indications are considered to be interacting and could therefore significantly affect the burst pressure and/or the leak rate of the axial PWSCC indication. The basis for the return to null, which indicates the separation distance is less than approximately 0.25-inch, is discussed in Section 5.4.2.2. Analysis of the +Point coil response is performed to profile the depth of the indication along its length. The NDE sizing results on maximum depth, average depth, and angular extent will provide information necessary for determining the effects the circumferential indication has on the structural and leakage integrity of the axial PWSCC indication.

Databases were compiled to assess the ability of determining the separation distance between axial and circumferential indications and for assessing the ability to size circumferential indications (either inside diameter (ID) initiated or outside diameter (OD) initiated circumferential indications). The separation distance evaluation is discussed in Section 5.4.1.1, and the circumferential sizing evaluation is discussed in Section 5.4.1.2.

5.4.1.1 Separation Distance Evaluation (WCAP-15573, Revision 1, Sections 4.8 and 4.10)

To demonstrate that a return to null by the high-frequency pancake coil indicates a separation distance of 0.25 inches between an axial and circumferential flaw, a variety of axial and circumferential EDM notches (T-shaped and L-shaped) were fabricated with separation distances varying from 0.2 inch to 0.3 inch. Ten tube specimens with three or four mixed mode indications per specimen were fabricated for this testing. Only deep notches of 80 percent or 100 percent through-wall depth were included in the test matrix since the presence of shallower circumferential flaws would not result in a significant change to the burst pressure of an axial PWSCC flaw. These tests indicate that if the NDE signal from an 0.080 inch pancake coil (i.e., the high frequency pancake coil) returns to the null point between two through-wall EDM notches, the separation distance is at least 0.25 inch. While cracks with depths less than or equal to 80 percent through-wall may have null points at less than 0.25 inch, the cracks would have negligible mixed mode effects (i.e., negligible effects on the burst pressure or leak rate of the axial PWSCC flaw). Consequently the 80 percent and 100 percent depths in the test matrix are adequate to support the separation requirements.

PG&E also assessed the potential for real cracks to behave differently than EDM notches. That is, they assessed lead-in and lead-out effects and they also assessed the effects of notch width on the null point evaluation technique. The number of null points (i.e., rotational scans with a null point when measuring axial separation) necessary to demonstrate an acceptable separation distance was adjusted to account for these effects.

The method for determining the separation distance between mixed mode indications involves the use of an 0.080 inch (high-frequency) pancake coil operating at 600 kHz. The small coil diameter and high operating frequency of this coil is expected to provide the highest spatial resolution (lowest field spread) among all the coils on a standard 3-coil rotating probe used by the industry to inspect Alloy 600 tubing. The smaller depth of penetration at higher frequencies on the other hand can lead to reduction of coil response to crack segments initiating from the outside diameter of the tube that may be present in mixed mode indications. However, burst tests have shown that mixed mode effects are small even for intersecting axial and circumferential indications when the average circumferential depth is less than approximately 80 percent (i.e., a circumferential crack initiating from the outside diameter of the tube would need to penetrate approximately 80 percent of the wall thickness before it would have a significant effect on the structural and leakage integrity of an axial PWSCC indication). This is in agreement with studies carried out at ANL using EDM notches. With only deep cracks (e.g., greater than 80 percent average depth) potentially contributing to mixed mode effects, the use of the high-frequency pancake coil is considered acceptable for determining the separation distance between axial and circumferential indications.

To ensure the noise levels in the "null point technique" database were representative of (or bounded by) the noise levels in the DCPP eddy current data, eddy current noise was added to the eddy current data for the laboratory specimens. Noise was added to the eddy current data for 8 EDM notch specimens with 5 of those specimens being identified as playing the essential role in establishing the required separation distance (i.e., 0.25 inch) to reach a null point.

The noise levels used in the study were based on a sampling of the SG TSP intersections at DCPP. Intersections where no degradation was identified through the analysis of +Point data were used in this evaluation. Data from all eight DCPP SGs were used. At least 15 intersections per SG for both units were evaluated with a relatively even distribution of dent sizes (less than 2 volts, 2 to 5 volts and greater than 5 volts). Noise evaluations were performed at the highest axial noise levels near the center and edge of the TSP for each of the four 90 degree sectors on the tube. The data indicate that the noise levels in the DCPP SGs are generally low. This noise addition may not represent signal distortion that may occur from wide-range coherent and incoherent sources of noise that are potentially present in the field; however, the plant-specific noise evaluations in WCAP-15573, Revision 1 appear to include typical sources of noise existing at this time. Thus, as stated earlier, with only deep indications contributing to mixed mode effects, the high-frequency pancake coil response is expected to be adequate for performing null point evaluations.

5.4.1.2 NDE Uncertainties for Sizing of Circumferential Cracks (WCAP-15573, Revision 1, Section 4.10)

Although tubes with circumferential indications will not be left in service (i.e., they will be plugged on detection), NDE sizing uncertainties were developed to aid in evaluating the integrity of circumferential indications and their effect on the integrity of axial PWSCC indications (if the circumferential indication is at the same TSP intersection as the axial PWSCC indication). As part of the NDE analysis requirements for condition monitoring assessments, all circumferential indications will be profiled to estimate their maximum depth, average depth, and length (i.e., angular extent). If mixed mode indications are found, the separation distance between the axial and circumferential indications will be determined in accordance with the NDE methodology discussed in Section 5.4.1.1 of this SE.

To develop NDE sizing uncertainties for circumferential flaws (PWSCC and ODSCC) at dented TSP intersections, laboratory and pulled tube data on indications from hardroll and explosive expansion transitions at the top of the tubesheet (TTS) were included in the database to meet the Appendix H requirements on the number and size of indications. That is, data from expansion transitions were used to compensate for the limited amount of destructive examination data for circumferential cracks at dented TSP intersections. The database contained a total of 19 PWSCC specimens with 23 indications and 20 ODSCC specimens with 20 indications. Only data for explosive expansions were included in the ODSCC database. The maximum depth of the cracks in the database varied from approximately 30 percent through-wall to 100 percent through-wall with varying circumferential extents. PG&E justified using the expansion transition indications to develop the NDE uncertainties for circumferential cracks at dented TSP intersections by indicating that the localized dents at TSPs introduce a smaller change in tube diameter (typically less than 0.010 inch) than explosive expansions (approximately 0.015 inch and approximately 3/8-inch long) and smoother transitions than hardroll expansions (approximately 1/4-inch long). The databases did contain data from 2 pulled tubes with circumferential flaws at dented TSPs: one ODSCC flaw and one PWSCC flaw.

Eddy current data analysis guidelines for +Point sizing of circumferential ODSCC and PWSCC are provided in WCAP-15573, Revision 1. The analysis procedure is based, in part, on using the +Point voltage response along the crack. The technique for sizing of circumferential indications differs from that for axial PWSCC indications in that below a cutoff voltage (2.5 volts for PWSCC and 1.5 volts for ODSCC), amplitude response, instead of phase angle, is used to determine the depth. Above the cutoff voltage, the phase angle of the signal is used to estimate the depth. A voltage threshold (7.0 volts) is also selected above which the maximum depth is set to 100-percent through-wall. Due to the limited amount of data on circumferential cracks, engineering judgment was used in selecting both the lower and upper voltage limits.

Two primary differences exist between the standard voltage-based sizing methods (e.g., EPRI ETSS 96701) and that referred to in the DCPP WCAP report for sizing circumferential flaws. One is that the former procedure uses a linear and the latter an exponential regression fit to construct a voltage versus depth correlation (calibration curve). The second distinction is that the linear voltage-based method does not set any threshold on the maximum voltage above which the depth is assumed to be 100 percent through-wall. Although an exponential trend is expected to more realistically describe the relationship between eddy current amplitude response and the depth of eddy current penetration into a tube wall, particularly at high voltages, its conservatism in estimating the maximum depth cannot be substantiated based on the data provided in WCAP-15573, Revision 1 or in Reference 8-37 of the WCAP (EPRI Report TR-107197-P1). Nonetheless, it is expected that the average depth of significant indications would be estimated conservatively when the NDE uncertainties are included.

PG&E conducted a test on five NDE analysts that perform sizing of circumferential indications in the DCPP SGs. Analyst results were compared against the destructive examination databases. Statistical analyses of the results show relatively large uncertainties at 95 percent confidence for estimating the angular extent of circumferential ODSCC indications. This is associated with the difficulty in detecting the shallow tails of circumferential cracks. Sizing uncertainties at 95 percent confidence for maximum and average depths on the other hand are within the expected range of accuracy of the NDE technique.

To develop NDE sizing uncertainty models for both circumferential ODSCC and circumferential PWSCC, linear, first order regression analyses were performed. These regression analyses were performed to relate the destructive examination results for length, average depth, and maximum depth to the NDE results. For the ODSCC specimens, two analyses were performed resulting in a total of 9 regression models (3 for PWSCC (length, average depth, and maximum depth) and 6 for ODSCC). For the two analyses performed for ODSCC, one involved using the as-measured destructive examination data and the other involved using adjusted destructive examination data in which the shallow tails (defined as less than 30 percent through-wall depth) were eliminated from the profile. For all 9 regression analyses, destructive examination data represents the running average over the coil's approximate field spread (16 degrees to 20 degrees). The values for the standard error of regression and index of determination generally indicate an acceptable correlation between destructive examination and NDE sizing results.

The NDE uncertainties determined from the regression analysis are used to assess circumferential indications regardless of whether they are associated with an axial PWSCC indication or not. For analysis of a circumferential indication without an associated axial PWSCC indication (i.e., a non-mixed mode indication), the uncertainties associated with the length and depth are used in the evaluations of structural and leakage integrity. Both length and depth uncertainties are used since the burst correlation for these indications is based upon the percent degraded area over the circumference of the tube (i.e., 360-degrees). Average depth uncertainties are used for the structural analyses and maximum depth uncertainties are applied for leakage analysis. For mixed mode evaluations, only the uncertainty associated with the depth of the circumferential indication is used in assessing the potential reductions in the axial indication burst pressure or increase in the axial indication leakage.

In applying the uncertainties to mixed mode indications, either deterministic or probabilistic (Monte Carlo) methods can be used. In the deterministic method, the 95^{th} percentile NDE uncertainty value will be added to the NDE results. Sizing uncertainties are included in Tables 4-16 through 4-18 of WCAP-15573, Revision 1. In the probabilistic method, the regression equations and the associated uncertainties will be used to determine the 95th percentile crack size. The regression parameters are listed in Tables 4-19 through 4-21 of WCAP-15573, Revision 1. The deterministic method is a simple analysis that is generally expected to be more conservative than the detailed Monte Carlo analysis.

5.4.2 Mixed Mode Burst Analysis (WCAP-15573, Revision 1, Section 5.5)

5.4.2.1 Burst Pressure Database for Intersecting Axial and Circumferential Flaws (WCAP-15573, Revision 1, Section 5.5)

To determine the effect that a circumferential indication has on the integrity of a nearby axial PWSCC indication, PG&E conducted burst tests on laboratory specimens with EDM notches. In all the tests, the axial flaw was either 0.8 inches long, 72 percent deep or 0.6 inches long, 79 percent deep. The 0.8 inch by 72 percent deep axial flaw size was selected so that the ligament tearing pressure was higher than the burst pressure of a 100 percent through-wall, 0.8 inch long crack (i.e., the specimen would burst unstably immediately after ligament rupture). The 0.6 inch long, 79 percent deep flaw, on the other hand, was expected to have the ligament tearing pressure close to or slightly less than the burst pressure of a through-wall 0.6 inch long flaw.

Each of these axial flaws were combined with circumferential flaws whose lengths were 0.6 inch (approximately 80 degrees). The depths of these circumferential flaws were nominally 60, 70, 80 and 100 percent through-wall. The axial and circumferential flaws in these tests were all intersecting (i.e., no separation distance between the axial and circumferential flaw). In all the sets of the test, except for one, the flaw was L-shaped. The other test was performed with the flaw being T-shaped (with the circumferential flaw intersecting the middle of the axial flaw). Each of the two axial sizes discussed above were also tested as individual axial indications to permit defining the mixed mode effect as the ratio of the mixed mode burst pressure to the axial burst pressure. For each case, a number of tests were run to ensure test repeatability did not mask the results.

The results generally indicated that the mixed mode effect was small for any axial flaw for which the ligament rupture pressure was greater than the burst pressure of the corresponding through-wall axial flaw (i.e., the effect is small when the specimen bursts unstably immediately after ligament rupture). Specifically, the reduction in burst pressure for the 0.8-inch long by 72-percent deep axial flaw was negligible (less than 5-percent) for all except the 100-percent through-wall circumferential flaw for which the burst pressure reduction was only 10-percent.

On the other hand, for the 0.6 inch long, 79 percent deep axial flaw, the mixed mode reduction was only negligible (less than 5 percent) for circumferential flaws with depths less than

70 percent through-wall, while the reduction was 15 percent when the circumferential flaw was 80 percent through-wall, and the reduction was 40 percent when the circumferential flaw was 100 percent through-wall.

For a 0.25-inch long, 100 percent through-wall axial flaw, a 10 percent reduction in the axial flaw's burst pressure was observed when the circumferential flaw's depth was 75 percent through-wall. For a 0.6-inch long, 100 percent through-wall axial flaw, a 35 percent reduction in the axial flaw's burst pressure was observed when the circumferential flaw's depth was 82 percent through-wall. Thus, sizeable mixed mode reductions can occur for short and deep axial flaws for which the ligament rupture pressure is less than the corresponding through-wall burst pressure (i.e., sizeable mixed mode reductions occur when the flaw pops through the tube wall at pressures less than the tube's burst pressure).

The data shows that for circumferential flaws with depths less than or equal to approximately 80 percent through-wall, the maximum possible reduction of burst pressure for 100 percent through-wall axial flaws is 15 percent for 0.24-inch long axial flaws and 30 percent for 0.6-inch long axial flaws. PG&E argues that the vast majority of the axial flaws under the TSP are less than or equal to 0.25-inch long, 100 percent through-wall and when circumferential flaws are present the depth of the circumferential flaw is less than 80 percent through-wall. Based on this observation, PG&E claims that the maximum possible burst pressure reduction due to the mixed mode effect is 15 percent.

Using 15 percent as the maximum burst pressure reduction, PG&E showed that only deep partial through-wall axial cracks with lengths between 0.53 inch and 0.64 inch have the potential to have their burst pressures reduced below the performance criteria of 1.4 times the differential pressure observed during a steam line break ($1.4\Delta P_{SLB}$) as a result of the presence of a circumferential flaw. PG&E calculated that the probability of finding deep axial cracks at TSP intersections within the range of 0.53 and 0.64 inch is very small and the probability of burst is also very small, particularly if denting prevents the TSP from displacing less than 0.001 inch during a steam line break event. The above arguments are contingent on the validity of the assumption that the maximum possible reduction of an axial flaw's burst pressure due to the presence of a circumferential flaw is only 15 percent.

The NRC staff's conclusions regarding the adequacy of this database are discussed in Section 5.4.2.3 of this SE.

5.4.2.2 Burst Pressure Database for Separated Axial and Circumferential Flaws (WCAP-15573, Revision 1, Section 5.6)

PG&E also conducted several mixed mode burst tests with 100 percent through-wall, 0.5-inch long axial and 100 percent through-wall, 120 degree long circumferential EDM notches in a T configuration (axial flaw bisecting the circumferential flaw), but separated by either an axial or a circumferential ligament. These tests showed that for a separation distance of 0.25 inch, the reduction in the axial flaw's burst pressure was only 8 percent. Tests also showed that if there was a degraded region between the axial and circumferential flaws whose depth was approximately 20 percent through-wall, the reduction in burst pressure was 15 percent. From these tests and those described in Section 5.6 of WCAP 15573, Revision 1, PG&E concluded that when both the axial and circumferential flaws are 100 percent through-wall, the potential mix mode effect for a separation distance of 0.25 inch is bounded by 15 percent.

The above conclusion is based on tests with mixed mode flaws in a T-configuration, but they have not been demonstrated for flaws in an L-configuration. For 100 percent through-wall flaws in an L-configuration, the burst pressure may be significantly reduced due to a "peeling" effect at the junction of the two flaws. Results of testing of L-shaped flaws are reported in WCAP-15579, Revision 0, "Burst Pressure Data for Steam Generator Tubes with Combined Axial and Circumferential Cracks," dated September 2000. This effect is limited to flaws which are nearly through-wall. Because of the limited data for L-shaped through-wall axial and circumferential flaws, PG&E has indicated that there may be a need to supplement the burst database if mixed mode indications are detected where the axial and circumferential indications are nearly through-wall. The need for the tests would be based on the available database at the time such indications were identified. The staff considers this acceptable because there is a very low probability of finding a mixed mode indication with both axial and circumferential indications being nearly through-wall based on DCPP's operating experience (and the operating experience of other plants with similar sized dents). Additional staff conclusions are discussed in Section 5.4.2.3 of this SE.

5.4.2.3 Conclusions on Mixed Mode Burst Database

As discussed previously, evaluating the effects that a circumferential flaw has on the burst pressure of an axial PWSCC flaw depends on many factors. These factors include the length and depth of the axial and circumferential flaws, the orientation of the flaws (e.g., T-shaped or L-shaped), and the separation distance between the flaws. The data provided by PG&E provide insights into the expected reduction in the burst pressure of an axial flaw due to the presence of a circumferential flaw; however, the database does not contain all possible flaw sizes, configurations, and separation distances.

Since the effects of a circumferential flaw on an axial PWSCC flaw depends on numerous factors, PG&E will evaluate all mixed mode indications for potential burst and leakage effects and provide the results of the assessment to the NRC in the 120-day report, which is described in Section 3.0. In addition, if the mixed mode database is not adequate to assess the potential reduction in the axial indication burst pressure, additional burst tests may need to be performed to simulate the indication in order to measure the associated reduction in the axial indication burst pressure. The staff finds this acceptable because the burst data provided by PG&E should encompass most of the indications expected to be found during the inspections (based on historical data), the size of the flaws will be adjusted based on the NDE uncertainties discussed in Section 5.4.1.2 to obtain the upper 95^{th} percentile flaw size, and the NRC has the opportunity to review the results of the mixed mode evaluations.

In the event that a circumferential indication is found by the above evaluations to result in (1) a greater than 10 percent reduction in the burst pressure for an axial indication alone (i.e., without the presence of a circumferential indication) and the resultant burst pressure is less than 4000 pounds per square inch (psi), or (2) an axial PWSCC indication not satisfying the burst margin requirements (e.g., $1.4\Delta P_{SLB}$), the burst margin requirements will be increased by the percentage reduction in axial indication's burst pressure. In addition, a trending analysis will be performed to assess the potential for increasing mixed mode effects over time. Since it is expected that the axial cracks will increase in size with time as indications are left in service based upon the ARC, this trending analysis will emphasize tracking of circumferential crack sizes, burst pressure reduction, and increased leak rates occurring at TSP intersections with mixed mode indications. If the trending indicates a need to modify the criteria that cause an increase in the burst margin requirements (i.e., the more than 10-percent reduction and to less than 4000 psi criteria) to ensure that no performance criteria are violated, these criteria will be made more conservative. All mixed mode evaluations and potential corrective actions will be submitted to the NRC in the 120-day report, as required by TS SR 5.6.10.h. The staff finds this approach acceptable.

5.4.3 Mixed Mode Leakage Analysis (WCAP-15573, Revision 1, Sections 5.5.4 and 6.6)

To assess the effects that a circumferential flaw has on the leak rate of an axial flaw, PG&E pressure tested 0.6-inch long, 100 percent through-wall axial flaws with and without intersecting circumferential flaws. The circumferential flaws had a depth of approximately 75-percent through-wall. Following pressurizing these specimens to the differential pressure observed during a steam line break (i.e., ΔP_{SLB}), the crack opening areas were measured by PG&E. The steam line break differential pressure is bounded by 2560 psi at DCPP. The test data indicated that the ratio of the COA for the mixed mode indication to that of a non-mixed-mode axial flaw of similar length is about 1.43. Applying the EPRI PICEP regression equation to a flaw of this size indicated that the ratio of the leak rates (with and without the circumferential indication) is 1.7. That is, the circumferential flaw increased the leak rate for the 0.6-inch long axial flaw by a factor of 1.7.

To demonstrate that this ratio would bound the leak rate ratio for all axial flaws less than 0.6-inches in length, PG&E indicated that a through-wall axial flaw intersecting a long through-wall circumferential flaw behaves in an analogous fashion to a through-wall edge crack in a rectangular plate. Since the COA ratio of an edge crack and a center crack increases with increasing crack length, the use of the 1.7 factor for flaws less than 0.6 inches in length should be conservative.

PG&E proposes to use a leakage multiplicative factor (L_F) of 1.7 when circumferential indications have average depths (adjusted for NDE uncertainty) greater than 50 percent through-wall and less than or equal to 80 percent through-wall, and PG&E proposes to use a factor of 10 when the average depth (adjusted for NDE uncertainty) of the circumferential indication is greater than 80 percent through-wall. The staff considers this reasonable. Additional information on how these factors will be applied in the condition monitoring and the operational assessments is provided in Sections 5.5 and 5.7.

5.4.4 Conclusions on Mixed Mode Indications

PG&E's approach for addressing mixed mode indications includes (1) plugging all circumferential indications upon detection, (2) assessing the effects of the circumferential indication on the burst pressure and leak rate of an axial PWSCC indication, (3) modifying the burst margin requirements when "significant" (as discussed above and in WCAP-15573, Revision 1) mixed mode indications are detected, (4) modifying the predicted leakage under postulated accident conditions when "significant" (as discussed above and in WCAP-15573, Revision 1) mixed mode indications are detected, (5) trending the effects that circumferential indications have on the integrity of axial indications and modifying their procedures to ensure that no performance criteria are violated, and (6) reporting the results of all mixed mode evaluations to the NRC for review.

The staff considers PG&E's approach for addressing mixed mode indications reasonable, given the limited number and severity of the mixed mode indications detected and PG&E's commitment reflected in PG&E's commitment tracking system for trending mixed mode effects as part of the implementation of the ARC to ensure the criteria remain appropriate.

5.5 ARC Implementation

5.5.1 Inspection and Application (WCAP-15573, Revision 1, Sections 2 and 7)

The proposed PWSCC ARC is applicable to axial PWSCC indications, or portions thereof, that are located within the thickness of dented TSP intersections. In general, PWSCC may extend outside the thickness of the TSP into the free span region. The proposed PWSCC ARC is not applicable to the portions of PWSCC extending into the free span region. These portions of PWSCC cracks will continue to be evaluated against the current 40 percent depth-based repair limit. The ARC is not applicable at certain TSP intersections, namely: (1) intersections near the wedge region because of the potential for yielding of the TSP under certain postulated accident conditions which could lead to the deformation of the tubes, (2) certain intersections at the seventh TSP because of high bending stresses under certain postulated accident conditions, (3) intersections that contain a cracked or missing TSP ligament, (4) intersections with circumferential cracks, and (5) intersections with axial ODSCC indications.

The PWSCC ARC is not a fixed criteria in terms of allowable PWSCC depth or length. Rather, PWSCC indications found by inspection are dispositioned as acceptable or unacceptable for continued service based on their measured size and the results of an operational assessment relative to the applicable acceptance criteria (discussed below) for burst and accident leakage integrity. The operational assessment projects the potential growth of the indication to the next scheduled inspection, allowing for potential error in the measured crack size, and determines the associated burst pressure capability and potential leak rate under postulated accident conditions.

5.5.2 Burst Assessment (WCAP-15573, Revision 1, Sections 5 and 7)

The applicable acceptance criteria for burst pressure are taken from the guidelines of NRC RG 1.121, NRC draft guide DG-1074, and NEI 97-06, Revision 1, and are acceptable to the staff. The criteria include maintaining a factor of at least three against burst under normal operating differential pressure and a factor at least 1.4 against burst during postulated design basis accidents such as a main steam line break. The ARC methodology assumes that the portion of the PWSCC crack within the thickness of the dented TSP is constrained against burst and, therefore, the factor of three criterion is always satisfied for this portion of the crack because the TSP is present during normal operation. Thus, only the free span portions of a given PWSCC crack, if any, are evaluated against the factor of three criterion. For a steam line break, no credit is taken for the constraining effect of the TSP because the TSP is assumed to displace axially as a result of secondary side blowdown effects, potentially exposing the entire PWSCC crack to an unconstrained condition. Thus, the total PWSCC crack (including the portions initially inside and outside the thickness of the TSP) is treated as a free span crack for purposes of evaluation against the 1.4 factor against burst criterion for postulated accidents.

The staff agrees with these assumptions provided that the TSP ligaments between tube holes are free of cracks. Given the level of denting at DCPP is believed by the staff to be “minor” as defined in NUREG-0523 (Reference 13), service-induced cracking would not be considered prevalent. Nonetheless, PG&E will examine the eddy current data for evidence of support plate cracking and exclude affected TSP intersections from application of the ARC. In addition, the ARC will not be applied at locations with missing TSP ligaments.

Input parameters for the operational assessment for burst are as follows:

- the depth profile and length of each PWSCC indication and its location relative to the centerline of the TSP as measured by the +Point coil,

- +Point sizing error distributions for flaw maximum depth, average depth and length (see Section 5.1.3),

- growth rate distributions, adjusted for cycle length and T_{hot}, in terms of maximum depth, average depth, and length (see Section 5.1.4), and

- flow stress distribution.

Monte Carlo simulations are performed to account for the uncertainties/errors in the input parameters and in the predictive model for burst. During a given simulation, the as-measured crack depth profile and length are adjusted by random samples of the sizing error distributions. For burst evaluations, the depth adjustment is taken from the error distribution for average depth. The staff considers this appropriate because burst tends to be a function of average depth over a significant length rather than a localized maximum depth. (For accident leakage evaluations, the depth adjustment is taken from the error distribution for maximum depth.) Depth adjustments are applied to every point along the depth profile. The resulting depth profile and length is then adjusted further by randomly sampling the appropriate growth rate distribution resulting in a projected end-of-cycle (EOC) crack depth profile and length. The projected EOC crack is applied to the burst pressure model described in Section 5.2. The burst model is applied using the weakest link methodology to determine a nominal burst pressure. Additional adjustments are applied to this burst pressure calculation to reflect a random sample of the burst pressure uncertainty and to reflect a random sample of material flow stress variability. This results in the final estimate of the burst pressure capability of the subject indication for a given simulation. Thousands of simulations are performed for each indication resulting in a distribution of burst pressures for each indication. The predicted burst pressure capability for a given indication is the lower 95 percent quantile value of the distribution evaluated at 95 percent confidence. Use of a 95/95 lower bound estimate is consistent with NRC draft guidelines in Reference 4 and is acceptable to the NRC staff. Predicted burst pressure capabilities determined in this fashion conservatively take no credit for the constraint against burst which may be provided by the TSP.

Although the PWSCC ARC applies only to that portion of the crack inside the thickness of the TSP, the above operational assessment methodology is applied to the total length of each

PWSCC indication, even where the indication extends outside the thickness of the TSP into the free span. The applicable acceptance criterion for burst pressure for the total PWSCC crack is the 1.4 criterion as discussed above. The above operational assessment methodology is also conducted for each free span portion of the PWSCC crack. The applicable acceptance criterion for burst pressure for the free span portion is the factor of three criterion. Tubes with PWSCC indications not satisfying the applicable burst pressure success criteria are removed from service by plugging. Tubes with PWSCC indications satisfying these criteria may be left in service without plugging provided the projected accident leakage for the subject indication combined with the leakage contributions from all other indications projected to exist at the time of the next inspection satisfy the applicable acceptance limits as discussed below. In addition, the free span portions of the PWSCC indications must satisfy the 40 percent depth-based limit based on the maximum free span depth measured by the +Point coil.

At each outage, all circumferential indications are to be sized by NDE. The average depths of these circumferential indications are then adjusted by deterministic or Monte Carlo methods to obtain the upper 95th percentile average depth of the circumferential indication. If the circumferential indication occurs at the same TSP intersection as an axial PWSCC indication, a mixed mode evaluation is performed. The mixed mode indication will be evaluated to determine the reduction in the burst pressure of the axial PWSCC indication as a result of the presence of the circumferential indication. If the mixed mode database is not adequate to assess the potential reduction in burst pressure, additional burst tests will be performed to simulate the indications in order to measure the associated reduction in the burst pressure. If the evaluation indicates that the reduction in the axial indication’s burst pressure is more than 10 percent and to less than 4000 psi, or to have caused an indication not to have satisfied burst margin requirements, the burst margin requirements will be increased by the percentage reduction in axial PWSCC indication’s burst pressure. All mixed mode evaluations and potential corrective actions are to be documented in the 120-day report, as required by TS 5.6.10.h. All tubes with circumferential indications will be plugged on detection.

5.5.3 Leakage Assessment (WCAP-15573, Revision 1, Sections 6 and 7)

For accident induced leak rate, the total SG leak rate must be less than or equal to the assumed leak rate in the NRC-approved licensing basis accident analyses. In addition, total SG leak rate from unconfined or free span indications must be less than or equal to 1 gallon per minute (gpm). Therefore, accident leakage associated with each "total" PWSCC indication is summed with all other sources of accident leakage (free span and non free span indications) and evaluated relative to the assumed leak rate in the NRC-approved licensing basis accident analyses. In addition, accident leakage associated with each free span portion is summed with all other sources of free span accident leakage and evaluated relative to the applicable 1 gpm limit. These criteria are consistent with criteria in NEI 97-06, Revision 1B, and are acceptable. If the applicable accident leakage success criteria are not met, tubes with the largest calculated leakage will be removed from service until the revised cumulative leakage for the SG meets the success criteria. Tubes with PWSCC indications satisfying these criteria may be left in service without plugging provided the burst pressures projected to exist at the time of the next inspection satisfy the applicable acceptance limits as discussed above.

Input parameters for the operational assessment for accident leakage are similar to those for the burst evaluation with the exception that the depth parameter of interest in the sizing error and growth rate distributions is the maximum depth rather than the average depth. In the Monte Carlo operational assessment analysis discussed below, PG&E can either perform a single indication leak rate analysis or a total SG Monte Carlo operational assessment. A total SG Monte Carlo operational assessment is only required if the results of the single indication analyses shows leakage for condition monitoring and operational assessments.

The Monte Carlo simulations are performed to account for the uncertainties/errors in the input parameters and in the predictive model accident leak rate. For a given PWSCC indication, the depth profile and the length measured with a +Point coil in the field are adjusted by randomly sampling the applicable sizing error and the growth rate distributions. The results lead to a projected EOC depth profile and length. The projected EOC crack is applied to the accident leakage model discussed in Section 5.3. This projected crack is evaluated by an iterative application of the ANL ligament tearing model to identify the maximum length of through-wall penetrations under the pressure loading associated with the most limiting postulated accident. These through-wall penetrations are applied to the deterministic CRACKFLO model to obtain a nominal leak rate. Additional adjustments are applied to this calculated leak rate to reflect a random sample of the uncertainty distributions for scatter of the leakage data about the regression line, the regression slope parameter, the regression intercept parameter, and material flow stress. This results in the final estimate of the projected EOC accident leak rate for the subject indication for a given simulation. In a similar fashion, projected EOC leak rates are calculated for each PWSCC indication. Summation of the calculated projected EOC leak rates for each PWSCC indication leads to an estimate of total leak rate for a given simulation. Thousands of simulations are performed for the population of PWSCC indications leading to a distribution of potential total accident leak rates. For operational assessments, the predicted total accident leak rate is the upper 95 percent quantile value of the distribution evaluated at the 95 percent confidence level. Use of a 95/95 upper bound estimate is consistent with NRC draft guidelines in Reference 4 and is acceptable to the NRC staff. Predicted leak rates determined in this fashion conservatively take no credit for the constraint against leakage which may be provided by the TSP.

When interacting mixed mode indications (separation distance less than 0.25 inch) are detected and the average depth of the circumferential indication is greater than 50 percent through-wall, the operational assessment total PWSCC steam line break leak rate for each SG will be increased by the leak rate multiplier, M_{Lg}. The generic leak rate multiplier M_{Lg} is defined as follows: $M_{Lg} = 1+(L_F-1)*f*F_1 + (L_F-1)*f*F_2$ where L_F is defined in Section 5.4.3, f is the fraction of detected axial PWSCC indications found to be interacting, F_1 is the fraction of interacting mixed mode indications whose circumferential indications have depths between 50 and 80 percent through-wall, and 80 to 100 percent through-wall, and F_2 is the fraction of interacting mixed mode indications whose circumferential indications have depths greater than 80-percent through-wall.

The generic mixed mode leak rate multiplier was developed under the expected condition that mixed mode indications with predicted leakage would be a small fraction of the population predicted to leak. If the mixed mode indications that leak contribute a significant fraction to total condition monitoring PWSCC ARC leakage, the generic multiplier may not be conservative. In this case, an outage specific multiplier, M_{LOS} is defined as follows: $M_{LOS} = LR_{MM}/LR_{w/o\ MM}$ where

LR_{MM} is the total condition monitoring PWSCC ARC leakage including adjustments for mixed mode indications and $LR_{w/o\ MM}$ is the total condition monitoring PWSCC ARC leakage without any adjustments for mixed mode indications.

The mixed mode leakage multiplier applied for the operational assessment of the next cycle will be the larger of M_{Lg} or M_{LOS}, where M_{LOS} is updated on a cycle-by-cycle basis and M_{Lg} is the generic multiplier with the value of f being the largest value from historical data.

The operational assessment steam line break leak rate must also be adjusted if a TSP intersection inspected by +Point coil in the previous (i.e., last) inspection is found to have a circumferential indication with an average depth greater than 80-percent through-wall after accounting for NDE uncertainty (this circumferential indication need not be associated with an axial PWSCC indication). The adjustment factor in this case will be: $M_L = 1+9f$ where f is defined above. This adjustment is also made to the operational assessment leakage for all subsequent operational assessments.

The adjusted axial PWSCC steam line break leak rates (i.e., adjusted for mixed mode indications) are included in the comparisons of predicted total leakage with allowable leakage limits discussed above.

5.6 Use of POD in Operational Assessments and Operational Assessment Methodology Evaluation (WCAP-15573, Revision 1, Sections 5, 6, and 7)

5.6.1 Use of POD in Operational Assessments (WCAP-15573, Revision 1, Sections 5, 6, and 7)

In accordance with NRC GL 95-05, plants with approved voltage-based ARCs for ODSCC at TSPs make a POD adjustment to the conditional probability of burst evaluations and accident leakage evaluations performed as part of the operational assessment. The purpose of this adjustment is to account for flaws which may not be detected during a given inspection in terms of their potential contribution to the total conditional probability of burst and total accident leak rate at the next EOC. The currently approved POD assumption for this purpose is 0.6. The POD adjustment involves taking the as-found distribution of indications as a function of the flaw size parameter (in this case voltage) and increasing the number of indications for each flaw size by dividing by the POD (i.e., 0.6). There is general agreement between the staff and industry that this is a very conservative estimate of actual POD performance in the field for larger flaws which would likely be dominant contributors to the total conditional burst probability and total leak rate.

A similar POD adjustment (i.e., POD = 0.6) will be made for the PWSCC ARC accident leakage evaluation pending resolution of these concerns. The staff believes this to be a conservative assumption for this application.

No POD adjustment will be applied for the PWSCC ARC burst assessment (i.e., POD=1). The burst assessment for this ARC is intended to demonstrate that the most limiting indication in the SGs will satisfy the applicable burst criteria. By assuming a POD of one, it is implicitly assumed in the burst pressure evaluation that the most limiting indication at the next EOC from a burst pressure perspective will come from the population of detected indications which were left in service at the last inspection. This is the appropriate assumption in terms of evaluating whether a given tube with a given indication should or should not be left in service without plugging. However, operational assessments are performed not simply to support implementation of ARCs. Operational assessments are necessary even when implementing the standard 40 percent depth-based limit to ensure that tube integrity will be maintained for the planned operating cycle. This is consistent with the industry's formal position in NEI 97-06, Revision 1B.

Looking at operational assessments from this broader perspective, it is important to monitor the number and size of new indications (i.e., those not detected in the prior inspection) and compare them to the number and size of flaws which were accepted for continued service in previous inspections to ensure that an explicit accounting for such indications when comparing to the factor of 3 and 1.4 criteria is not necessary. To this end, PG&E committed to provide an evaluation of the number and size of previously reported versus new PWSCC indications found during the inspection in the 120-day report. If the burst pressure (evaluated at 95/50 confidence consistent with condition monitoring requirements) for a new indication (i.e., one not detected during the prior inspection) is less than the $1.4\Delta P_{SLB}$ burst margin requirement, a total SG Monte Carlo operational assessment will be performed to determine the burst probability and a POD of 0.6 will be used in this assessment. The Monte Carlo analysis will be performed for all steam generators because new indications are not confined to any one steam generator. Consistent with WCAP-15573, Revision 1, methodology, this burst probability analysis must be completed prior to return to power and the burst probability for axial PWSCC indications must be less than or equal to 1×10^{-2}. To achieve this value, additional indications may need to be repaired prior to return to power.

5.6.2 Operational Assessment Methodology Evaluation (WCAP-15573, Revision 1, Section 7.12)

To assess the overall operational assessment methodology, PG&E has committed as part of the implementation of the ARC to provide an evaluation which compares the projected burst pressures and leak rates for each indication (projected at EOC "x") to the "actual" value obtained for the indication during the next inspection (i.e., at end-of-cycle “x+1"). Tabulations of the projected and subsequent outage burst pressures and leak rates for each indication will be included in the 120-day report. If during this evaluation (1) a single indication burst pressure is less than 5600 psi and more than 500 psi less than the projection obtained using the same burst model; or (2) the single indication leak rate is more than 0.2 gpm larger than the projected steam line break leak rate, additional evaluations will be performed. These additional evaluations include reviewing the growth rate distribution. If the underprediction is due to the growth rate distribution, the 120-day report should provide a corrected growth rate distribution to better predict the next EOC conditions. At the end of the next cycle, the measured growth rate distribution is to be compared with the corrected growth rate distribution that was predicted in the 120-day report. If the 90^{th} percentile measured growth is greater than the 90^{th} percentile predicted growth value, which indicates at least two successive cycles of increasing growth rates, the measured growth rate distribution of the just completed cycle is to be increased by a factor of 1.1 or more and applied in the operational assessment for repair decision to enhance conservatism for the subsequent operating cycle.

5.7 Condition Monitoring Assessment (WCAP-15573, Revision 1, Section 7)

Condition monitoring refers to assessing the "as found" condition of the SG tubes during an inservice inspection relative to the applicable acceptance limits for burst and accident leakage integrity. Satisfaction of these criteria demonstrates that adequate structural and leakage integrity was maintained throughout the most recent operating cycle.

The scope of the condition monitoring assessment for PWSCC at the TSPs includes all indications with greater than or equal to 40 percent maximum depth outside the TSP, indications requiring repair due to not satisfying the burst pressure acceptance criteria under projected EOC conditions, indications detected in the exclusion zones (e.g., wedge region, seventh TSP bending region, etc.), and indications projected by the operational assessment to contribute leakage under accident conditions at the end of the next cycle. The staff finds this scope acceptable. This scope excludes only indications projected by operational assessment to satisfy the applicable burst criteria and to be leak tight under accident conditions at the next EOC. Such indications satisfy the applicable burst criteria and would be predicted to be leak tight under beginning of cycle (BOC) conditions.

Condition monitoring assessments of PWSCC indications are performed using Monte Carlo simulations in a manner similar to that described for operational assessment with the following differences:

- Condition monitoring is an assessment of the "as-found" condition of the tubing. Therefore, the PWSCC depth profiles and length are not adjusted for growth.

- Condition monitoring assessments do not include a POD adjustment (i.e., POD=1). This is based on the premise that flaws resulting in unacceptable burst margins or which may leak would be expected to be detected by bobbin and +Point at that point in time. This premise is consistent with the approach in NRC GL 95-05 for voltage-based repair limits and with the draft guidelines in DG-1074 and is acceptable to the staff.

- Predicted burst pressures for condition monitoring will be the lower 95 percent quantile value of the burst pressure distribution evaluated at a 50 percent confidence level rather than a 95 percent confidence value as is the case for operational assessment. Similarly, predicted accident leak rates will be the upper 95 percent quantile value of the leak rate distribution evaluated at 50 percent confidence. This is consistent with the draft guidelines in DG-1074 and is acceptable to the staff.

- The burst pressure model used in the burst analysis is the Cochet/ASME model (also referred to as the Westinghouse model) rather than the ANL/EPRI model which is used during operational assessments.

- The Monte Carlo accident leakage simulations may initially be performed for individual indications rather than a population of indications as is done for operational assessment. The calculated leakage rate for each indication will be the upper 95 percent quantile, 50 percent confidence value. The 95/50 values for each indication are summed to yield the total SG leakage rate. This "single tube" approach is more conservative than the "population" approach and is therefore acceptable to the staff. However, the "population" approach may be performed as an alternative when evaluating "total crack" leakage consistent with the operational assessment approach. This is also acceptable to the staff.

- If an interacting mixed mode indication is detected (i.e., null point separation requirement of 0.25 inches is not satisfied or both indications are through-wall at any point) and the average depth of the circumferential indication is greater than 50 percent through-wall, the condition monitoring leak rate (95/50 confidence) for the axial indication will be increased by a leakage factor, L_F. L_F is defined in WCAP-15573, Revision 1, Section 6.6. The leakage factor is 1.7 when the circumferential average depth is greater than 50 percent through-wall and less than or equal to 80 percent through-wall, and the leakage factor (L_F) is 10 when the circumferential indication's average depth is greater than 80 percent through-wall. These factors are discussed in Section 5.4.3.

- The burst pressure and accident leakage acceptance limits for condition monitoring are the same as those for operational assessment (see Section 5.5) except as noted in the next bullet for burst pressure. If the acceptance limits for condition monitoring are not met, the results must be reported to the NRC as part of the 120-day report. A corrective action program must be initiated to identify the causative factors. These corrective actions must also be described in the 120-day report.

- As an alternative to demonstrating that the factor of 1.4 against burst criterion is satisfied for each indication at the applicable confidence limits, as allowed by WCAP-15573, Revision 1, methodology, PG&E may calculate the conditional probability that one or more tubes may burst under postulated steam line break conditions. The applicable acceptance limit for this calculated conditional probability is 1.0×10^{-2}. The staff notes that a conditional probability of burst calculation is also performed for plants with voltage-based ARCs for ODSCC at TSPs in accordance with NRC GL 95-05. These calculations are also performed relative to a 1.0×10^{-2} criterion. (This criterion in the context of the voltage-based ARC is actually a reporting threshold rather than an acceptance limit.) Free span portions of PWSCC indications must still be demonstrated to satisfy the deterministic factors of three and 1.4 criteria for burst. This ensures that there are no risk implications associated with the use of the 1.0×10^{-2} criterion as discussed further in Section 5.8 of this SE. The 1.0×10^{-2} criteria is, therefore, consistent with draft guidelines for its use as given in DG-1074. Further, the sum of the criteria for ODSCC and PWSCC (i.e., 2.0×10^{-2}) satisfies the draft guideline criterion in DG-1074 of 2.5×10^{-2} for the total conditional probability of burst associated with known mechanisms. Thus, the staff finds the proposed acceptance criterion for conditional probability of burst to be acceptable. The conditional probability of burst is evaluated using Monte Carlo simulations in a manner similar to that used to calculate the burst pressure of individual tubes. The essential difference is that each Monte Carlo simulation addresses the population of PWSCC indications rather than a single indication. The conditional probability is the number of simulations resulting in one or more tubes with burst pressures less than steam line break pressure divided by the total number of simulations performed and is evaluated at a 95 percent confidence level which is acceptable to the staff.

- If *in situ* pressure testing is performed for free span indications, the results of the burst pressure and accident leak rate tests are used in lieu of the analytical predictions for that indication. *In situ* pressure testing will be performed for any free span portion of a PWSCC indication which cannot be demonstrated analytically to satisfy the applicable 3 times normal operating pressure criterion or which is predicted to leak under accident conditions. The staff agrees that use of *in situ* pressure test results constitutes an acceptable alternative to the use of analytical predictions.

5.8 Operational Leak Rate Limits

The staff has generally requested that licensees submitting requests for ARC and sleeving amendments also change their TS limiting condition for operation (LCO) operational leakage limits to incorporate a 150 gallon per day (gpd) limit. This is a more restrictive limit than the standard technical specification limit of 500 gpd that was in place when the plants were originally licensed. This limit provides added assurance that should leakage develop in service, the plant will be shut down for corrective action before rupture occurs. The DCPP TS already include the 150 gpd operational leakage limit. The staff finds this limit acceptable for purposes of supporting this PWSCC ARC amendment request.

5.9 Risk Considerations (WCAP-15573, Revision 1, Section 7.11)

The current licensing basis in terms of structural margins, allowable leakage during design basis accidents, and tube repair criteria remains unchanged for free span portions of PWSCC indications. The staff believes that any changes to the current licensing basis for cracks in the free span need to be accompanied by a careful assessment of the risk implications of such changes. Available risk analyses (Reference 14) suggest that free span portions of tubing would be substantially challenged during some types of severe accidents.

The confined portions of the PWSCC indications to which the ARC is applicable are not expected to be able to burst or leak substantially since, by virtue of the corrosion product buildup in the annulus between the dented tube and TSP, the TSPs are effectively locked in place and constrain the tubes against radial expansion. Thus, the confined portions of PWSCC indications would not be expected to be severely challenged during severe accidents. The only significant challenge which could potentially be applied to the confined region of the tubes would be a postulated design basis steam line break. The design basis steam line break is accompanied by blowdown of the secondary side resulting in transient pressure differentials across the TSPs. Taking no credit for the TSPs being locked to the tubes, these pressure loads may cause the TSPs to displace axially thus exposing the initially confined indications or a portion of these indications to free span conditions. Catastrophic steam line break accidents resulting in high blowdown loadings on the TSPs are estimated to be extremely infrequent and, thus, this design basis scenario is not believed to be a significant contributor to the realistic estimations of risk attempted by probabilistic risk analyses.

6.0 STATE CONSULTATION

In accordance with the Commission's regulations, the California State official was notified of the proposed issuance of the amendments. The State official had no comments.

7.0 ENVIRONMENTAL CONSIDERATION

These amendments change a requirement with respect to the installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20 and changes surveillance requirements. The NRC staff has determined that the amendments involve no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission has previously issued a proposed finding that the amendments involve no significant hazards consideration and there has been no public comment on such finding (67 FR 929). Accordingly, the amendments meet the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). These amendments also involve changes in recordkeeping, reporting or administrative procedures or requirements. Accordingly, with respect to these items, the amendments meet the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(10). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of these amendments.

8.0 CONCLUSION

The Commission has concluded, based on the considerations discussed above, that (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendments will not be inimical to the common defense and security or to the health and safety of the public.

9.0 REFERENCES

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