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April 30, 2002
CEOG-02-081

NRC Project 692

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

Subject: Response to Request for Additional Information concerning CEOG Topical Report CE NPSD-1199, "RCP Seal Failure Model"

Reference: Letter, J. Cushing (NRC) to R. Bernier (CEOG), Request for Additional Information – NPSD-1199-P, "Model for Failure of RCP Seals Given Loss of Seal Cooling" (TAC No. MB0337) dated October 16, 2001.

The purpose of this letter is to submit the enclosed responses to staff questions issued in the reference letter. These responses justify the expected RCP seal performance and the seal failure model with its associated failure probabilities based on the available information from industry experience, tests, and manufacturer's data. Revisions made to the fault trees in Section 6 and to the text and tables in Section 9 of the subject report in response to these RAIs are shown in Enclosure 2; these revisions will be incorporated into Rev 01 of CE NPSD-1199. Enclosure 3 provides a non-proprietary version of these responses.

Certain information contained in this response is proprietary to Westinghouse Electric Co. LLC and is requested to be withheld from public disclosure pursuant to 10 CFR 2.790. The reasons for withholding this information are defined on the enclosed affidavit.

Westinghouse and the CEOG utilities are prepared to discuss this response, if needed, in order to facilitate the staff's review of CE NPSD-1199. Please do not hesitate to call me at 623-393-5882 or Gordon Bischoff, CEOG Project Office, at 860-731-6200 if you have any questions.

Sincerely,

Richard A. Bernier

Richard A. Bernier
Chairman, CE Owners Group

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Enclosure 1:
Proprietary Affidavit pursuant to 10 CFR 2.790

Enclosure 2:
Proprietary RAI Responses, pg. 1 – 141, including:

- RAI Responses (pg. 1 –45)
- Attachment A, RAI References (pg. 46, 47)
- Attachment B, Figures for RAI Responses (pg. 48 – 60)
- Attachment C, Typical Revisions to CE NPSD-1199 (pg. 61 – 141)

Enclosure 3:
Non-Proprietary RAI Responses, pg. 1 - 141

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Enclosure 1

Affidavit Requesting Withholding Of Proprietary Information Pursuant to 10 CFR 2.790

I, Ian C. Rickard, depose and say that I am the Licensing Project Manager of Westinghouse Electric Company LLC (WEC), duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and described below. I have personal knowledge of the criteria and procedures utilized by WEC in designating information as a trade secret, privileged, or as confidential commercial or financial information.

This affidavit is submitted in conformance with the provisions of 10 CFR 2.790 of the Commission's regulations for withholding proprietary information. The information for which proprietary treatment is sought, and which document has been appropriately designated as proprietary, is *Enclosure 2 to letter CEOG-02-081, "Response to Request for Additional Information concerning CEOG Topical Report CE NPSD-1199-P, "RCP Seal Failure Model," dated April 30, 2002.* Pursuant to 10 CFR 2.790(b)(4) of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information included in the document listed above should be withheld from public disclosure.

1. The information sought to be withheld from public disclosure is owned and has been held in confidence by WEC. It consists of responses to a staff request for additional information dated October 16, 2001.
2. The information consists of analyses or other similar data concerning a process, method or component, the application of which results in substantial competitive advantage to WEC.
3. The information is of a type customarily held in confidence by WEC and not customarily disclosed to the public.
4. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.
5. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements that provide for maintenance of the information in confidence.
6. Public disclosure of the information is likely to cause substantial harm to the competitive position of WEC because:
   a. A similar product or service is provided by major competitors of Westinghouse.
   b. WEC has invested substantial funds and engineering resources in the development of this information. A competitor would have to undergo similar expense in generating equivalent information.
   c. The information consists of methodology and evaluation results concerning a model developed to predict reactor coolant pump seal failure probabilities at C-E NSSS nuclear power plants, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to design their product or service to better compete with WEC, take marketing or other actions to improve their product's position or impair the position of WEC's product, and avoid developing similar technical analysis in support of their processes, methods or apparatus.
   d. Significant research, development, engineering, analytical, manufacturing, licensing, quality assurance and other costs and expenses must be included in pricing WEC's products and services. The ability of WEC's competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.
   e. Use of the information by competitors in the international marketplace would increase their ability to market comparable products or services by reducing the costs associated with their technology development. In addition, disclosure would have an adverse economic impact on WEC's potential for obtaining or maintaining foreign licenses.

Ian C. Rickard
Licensing Project Manager
Westinghouse Electric Company LLC

Sworn to before me this 30th day of April 2002

Laurie A. White, Notary Public

My commission expires: 8/31/04

Enclosure 3

Non-Proprietary Responses to Request for Additional Information concerning CEOG topical report CE NPSD-1199-P

Contents:

Responses to RAIs Concerning CE NPSD-1199-P, "RCP Seal Failure Model"

RAI 01

Section 3.4 (pg. 3-11 ¶ 2) states that the Kalsi Engineering Tests clearly indicates a high likelihood of high temperature elastomer survivability for periods in excess of eight hours. In addition, Section 5.3.1 (pg. 5-5 ¶ 3) states that "closure of the CBO (controlled bleedoff) line will stop flow through the seal PBDs (pressure breakdown devices) and equalize the seal cavity pressures at the level of the RCS (reactor coolant system) pressure (approximately 1000 - 1200 psia). The RCS temperature ... will be about 500 to 540°F." However, the test failure data points provided in Figure 3.4-1 (pg. 3-12) and discussed in Section 7.3.1 (pg. 7-8 ¶ 5) indicate failures within the first few hours at very high exposure temperatures (i.e. greater than 550°F). Please clarify either how the very high exposure temperature test data points (and if there is any high pressure data) have been used in developing the RCP seal failure model and their associated failure probabilities or justify why these temperatures and/or pressures cannot be reached during any accident scenarios. Also, please provide the basis for the ranges of temperatures and pressures that are considered.

RAI 01 Response

The Kalsi tests subjected static sealing O-rings to high temperatures with a differential pressure of 2250 psig (Reference 1). These seals were prototypical of those seals and seal installation used in the Bingham-Willamette Company's mechanical seal package. They are similar to that used by Byron Jackson in the N-9000 RCP seal design. The intent of these experiments was to determine the extent to which the elastomer seal performance would be affected when exposed to high temperature and pressure. The temperature exposure tests were conducted at 550°F, 600°F and 650°F.

Only two seal failures occurred during the test program. Both seal failures occurred when exposed to a 650°F environment (c.f., Figure 3.4-1). All other seals indicated satisfactory performance for the duration an eight-hour test with no measurable leakage. These points were included in the figure as "open" symbols (that is, no failure).

One of the two data points from the BJ-N-9000 test (Reference 2) was shaded incorrectly. This point represents a non-failure condition. The pressure drop across these seal stages varied during the test dependent upon seal location and status of CBO. Additional data points associated with the ethylene-propylene O-rings used in the BJ/SU have been added to Figure 3.4-1 for completeness. These O-rings successfully operated during conditions typical of a SBO with CBO operational. Elastomers in the lower three stages were exposed to temperatures in excess of 500°F and one stage was exposed to temperatures of about 400°F. Elastomers lasted for more than 40 hours. Pressure drops across these seals varied from about 400 to 1000 psig (Reference 3). An updated Figure 3.4-1 is attached.

One O-ring failure was incorrectly included in Figure 3.4-1. The failure occurred in a small O-ring on the non-rotating face of the upper seal and was due to non-homogeneity in the material resulting from the manufacturing process that has since been refined. The O-ring that failed was constructed from a straight piece of material with the ends bonded together. The bonded region was the O-ring weak point. Current techniques form the O-ring as an integrated unit. This O-ring was identified as the weak point in the N-9000 seal. Other N-9000 elastomers were intact throughout the test and maintained their sealing integrity. (It should also be noted that the failure occurred at a temperature of 500°F, not 350°F as shown in the original figure.) This data point has been removed in the updated Figure 3.4-1.

Not included in the above figures are results of AECL tests for a Bingham Secondary Seal based on a mounting with both 0.009" and 0.018" diametrical clearances (Table 3 of Reference 4). This data included 24-hour high temperature and pressure exposure of the O-rings. Pressure temperature combinations included three tests at 2200 psid and 550°F. Results of these tests also indicated no secondary seal leakage and minimal change in elastomer hardness. Some extrusion was noted, with the length of the extruded material varying from a maximum of 0.02" for the 0.009" tests to 0.1" for the 0.018" clearance test. Typical SBO diametrical gap clearances for the secondary seals for N-9000 and Sulzer seals are about 0.004" and 0.006" respectively. Reference 4 also indicated that BJ static O-rings (such as those used in BJ/SU seals) are expected to function during Station Blackout conditions.

A review of operational loss of seal cooling events supports the conclusions that, with the exception of Nitrile U-cup elastomers utilized in the BJ/SU designs, gasket failures have not contributed to excessive seal leakage. Several instances exist where prolonged RCP seal exposures (six to nine hours) to high temperatures degraded the Nitrile U-cup on the lower seal stage and caused a first stage failure for one event. This conclusion is consistent with Reference 4 which found that the most likely mechanism to cause high leakage through the Byron Jackson BJ/SU seal assembly is hardening of the U-cups.

Late in an SBO event [ ], RCS cold leg temperatures and pressures will be near the saturation temperature for the SG setpoint pressure. This in the range of [ ] (plant specific) for CE designed PWRs. Additional detail on the plant response during an SBO is included in the Response to RAI 2.

Test data and operational experience confirms that the ethylene-propylene elastomers used for secondary seals and static sealing in the BJ/SU, N-9000 and Bingham RCP seals are capable of operating in a station blackout environment. The worst case pressure condition for extrusion for these seals occurs in the vapor stage when CBO is isolated. Under that condition the RCP seal vapor stage (or last stage) is required to hold full RCS pressure. Given early CBO isolation [ ] the vapor seal temperature would be expected to be approximately [ ]. Even if CBO were not isolated, BJ/SU tests indicate that the vapor seal temperature would be approximately [ ]. Thus, when a vapor stage seal arrangement is used, the temperature in that region would be well below [ ] and failure of a vapor stage operating in this temperature regime is unlikely.

The probability of elastomer failure has been re-calculated based on the reassessment of the data as discussed in the responses to RAI 7 and RAI 8. Data used in this calculation include results of the Kalsi experiments and observations from loss of seal cooling events at CE PWRs. The revised Table 9.2-1 is provided in the response to RAI 18. Furthermore, a set of new tables, Tables 9.2-2 through 9.2-10, have been added to identify the elastomer failure probabilities used for each set of RCS conditions.

RAI 02

Section 4.2.3 (pg. 4-16) discusses hydraulic instability (i.e. the pop-open failure mode) and states that the face seal will remain stable if one of two conditions occur; inlet fluid is sufficiently subcooled (i.e. greater than 50°F) or back-pressure acting on the seal is greater than half the saturation pressure at the inlet temperature. This is consistent with NUREG/CR-4821. However, only the subcooling condition is discussed and relied upon throughout the rest of the topical report, which leads to a number of plant-specific questions. These questions are with regard to how plants assure there is adequate subcooling when (1) the majority of plant procedures do not require this amount of subcooling and (2) it is not clear if sufficient subcooling at the seal entrances is achievable under all conditions and is within the control of the operators. The representative post-accident conditions may not be achievable (e.g. pg. 5-6 for Station Blackout (SBO) events and pg. 5-10 for Loss of Component Cooling Water (LOCCW) events). Moreover, it may not even be possible to maintain the RCS 50°F subcooled for either the SBO or the LOCCW conditions. For SBO conditions, it is not possible to maintain coolant level on cooldown because charging is not available and because of coolant shrink and RCS fluid losses. The same is true for LOCCW if the charging pumps depend on Component Cooling Water (CCW). Consequently, pressure control may not be possible, and it may not be possible to maintain 50°F subcooling in the RCS and at the inlet to the first stage RCP seal. Thus, there is a possibility the first seal stage may pop-open, if the backpressure on the first seal stage is less than one-half the stage inlet saturation temperature. The topical report needs to address and reflect in its modeling considerations the potential for sufficient backpressure to exist to maintain the face seal stable.

In addition, the statement made in Section 5.3.1 (pg. 5-5 ¶ 2) that Emergency Operating Procedures (EOPs) instruct operators to maintain the plant in a stable condition with RCS subcooling between 20 and 50°F may be misleading and is inconsistent with the parenthetical statement that procedures only require a minimum of 20°F (pg. 5-8 ¶ 2). Because the RCP seal failure model relies on greater than 50°F subcooling for success, those plants whose EOPs allow RCS subcooling to be less than 50°F must be considered to have a high likelihood of not having adequate subcooling, unless it can be shown that such conditions cannot occur phenomenologically. Per Table 5.3-3 (pg. 5-9) all Combustion Engineering (CE) plants for SBO events have lower subcooling requirements. For these plants and for almost all plants under SBO conditions, the RCP seal failure model could be simplified, if the back-pressure is shown to be inadequate, by assuming inadequate subcooling under these conditions. Otherwise, a justification needs to be provided that demonstrates (1) that the plants will always have 50°F subcooling at the RCP seal inlets even though procedures allow less, or (2) that there is always sufficient back-pressure under conditions in which subcooling cannot be assured.

RAI 02 Response

The response to the question will be divided into three parts. First is a discussion of the use of the 50°F subcooling criterion. Test data will be used to demonstrate the robustness of the seal operation under various high pressure - low subcooling conditions. Secondly, additional information is provided regarding the SBO temperature transient. Finally, the role of the EOPs and operator actions are discussed along with current CEOG intentions to enhance the clarity of the EOPs for operation with complete loss of seal cooling.

Selection of 50°F Subcooling Criterion

The use of the 50°F subcooling criteria alone is conservative. This criterion is sufficient to ensure seal stability. As was noted in the question, when the liquid entering the seal is not subcooled by 50°F, flashing may be significantly abated by increasing the downstream pressure to greater than 50% of the upstream pressure. This feature was not considered when investigating pop-open seal failures for cases where CBO was not isolated. This is conservative as certain opportunistic failures may improve seal stability of downstream seal stages. For example, failure of the second seal stage would increase the pressure on the third stage and hence make it less likely to pop-open. Instead the model assumes that the most likely seal failure would occur first (third stage in the four stage model).

The backpressure issue was included tacitly in the model in the treatment of CBO isolation. CBO isolation will eliminate the pressure breakdown function of the pressure breakdown devices (PBDs) and de-stage the seals. Thus the RCS pressure will be applied to all stages. This in effect removes the seal pressure drop and via the second criteria will consequently stabilize all seals with the exception of the last stage or vapor seal.

The ability of the seal stages to withstand a range of pressures and temperatures without pop-open or significant leakage can be established by investigating the last stage seal performance in the BJ/SU SBO and N-9000 SBO tests. Data from the BJ/SU SBO tests are presented in the attached Figures 1, 2 and 3 (from Reference 3). The test consists of a long duration exposure (40 to 70 hrs) of a BJ/SU seal to SBO conditions. The seal is static and the test facility is pressurized to 2200 psia and maintained at 540°F. CBO is operational throughout this test. Subcooling of the vapor stage can be seen to vary from a low of about 30°F to a high of over 100°F (see Figure 4). The pressure drop across the seal varied from a nominal value of 150 psid to about 650 psid. At no time during the test did seal leakage exceed 0.3 gpm. Thus, for this range of conditions, no pop-open was observed nor was there any significant bistable regime.

The BJ/SU test did note some quasi-static behavior of the third seal stage. This stage appeared to partially open and lost some pressure retention capability. It is estimated that the seal stage face leakage during the interval was about 0.5 gpm and was controlled by the vapor stage. In no instance did the third seal behavior propagate upstream to either the lower or middle seal stages.

The N-9000 test investigated the ability of the advanced BJ seal (without a vapor stage) to withstand a simulated station blackout. The test was conducted for eight hours and consisted of a heatup phase, followed by loss of seal cooling. The CBO was maintained for a period of 30 minutes, allowing the RCP seal chambers to heatup to about 550°F. At 30 minutes, the CBO was isolated the seals de-staged and full system pressure was taken across the last seal stage. Without the CBO flow, the upper stage RCP seal temperatures fell to about 500°F. This resulted in a condition where the last seal stage (upper seal) was exposed to a temperature of 500°F and a stage pressure differential that varied from about 1680 to 2400 psid. This resulted in stage subcooling that varied from 55°F to 130°F. During the test, the upper stage seal operated without any pop-open or bistable behavior. The seal leakage was maintained at 0.04 gpm throughout the event. The test was terminated due to failure of a static O-ring in the upper seal stage; failure was caused by an inhomogeneous O-ring bond, although the elastomer material itself was flexible and showed minimal extrusion. This seal stage connects the upper seal stage with the ambient pressure chamber, thus the leakage pressurized the low pressure region of that stage and leaked through a small hole in the stationary face of the seal to the leakage collection chamber. The hole, intended as a pressure balancing measure to minimize face deflections, limited the outflow to near CBO conditions. The impact of the failure was primarily to re-stage the seals. This seal was predicted to be the weakest link in the component. The seal is no longer made from a bonded strip but is now integral and capable of extended high temperature performance.

The key features of the N-9000 tests were:

1. Pop-open behavior was not observed even though subcooling reached 55°F.
2. Bistable behavior was not noted even though pressure differentials exceeded 2200 psid.
3. Failure of the limiting static O-ring had minimal impact on leakage. However, failure of the uppermost O-ring would re-stage the seals since the pressure-balancing hole provides a leak path to the environment.
4. All elastomer materials performed well during the 8 hour test.

Station Blackout Scenarios

The ability to control subcooling is limited for the SBO event. Analyses of SBO events have been performed for two representative CE PWRs (FCS and a typical 3410 Mwt plant) using the CE Nuclear Transient Simulation Code (Reference 5). CENTS is a code originally developed for use in nuclear plant simulators and is used for both best estimate and design analyses. CENTS analyses provide realistic post SBO plant responses; results of the analyses are presented in Figures 5 through 11. The analyses indicate that, without operator action, the SBO event will maintain the RCS with a > 50°F subcooling for a period of [ ]. The high subcooling is a result of residual hot water in the pressurizer and the approximate 20°F hot leg-cold leg temperature difference that exists during the early natural circulation time period. Such temperature differences have been confirmed through natural circulation testing at SONGS.

In the SBO event considered above, the turbine driven AFW was considered available for the duration of the event. For situations with CBO isolated, the lower seal would lose subcooling first. However, since the seal pressure would be high at all seal stages, pop-open failures would be averted. The last or vapor seal is further protected against pop-open by the lower operational temperatures, ensuring adequate subcooling. It should be noted that since it takes more than three hours for the lowest seal to reach pop-open subcooling levels and since CBO closure removes pressure drops across all seals, save the last one, CBO isolation even late in the scenario would also prevent pop-open failure.

Operator Actions and CEN-152

Loss of CCW events allow control of plant subcooling primarily via use of pressurizer heaters and charging. CE designed plants utilize positive displacement charging pumps without any dependency on CCW, thus, operator actions to control subcooling are readily accomplished. Currently, plant specific procedures for responding to a loss of CCW and CEN-152 (Reference 9) require that a minimum of 20°F subcooling be maintained in the hot leg during the event. Anecdotal evidence suggests that while a minimum subcooling of 20°F is required by procedure, plant operators routinely maintain subcooling margins in excess of 50°F. CEOG plants recognize the significance of higher level of subcooling, therefore such subcooling will be reflected in plant specific analyses.

RAI 03

The topical report makes statements (pg. 4-7 ¶ 1) regarding the potential success or failure of Byron Jackson (BJ) or Bingham Willamette Company (BWC) (now Sulzer) static and secondary seals based on results from tests or calculations made by the contractors to the U.S. Nuclear Regulatory Commission (NRC), which were developed based on limited information, testing, and available materials without the cooperation of either the owners group or the pump manufacturer and should not be taken as definitive results. The topical report must justify the expected performance and failure potentials based on the available information from industry experience, tests, and manufacturer data. Please provide justifications for seal performance assertions based on CEOG and/or RCP seal vendor tests or calculations, including in particular more detail regarding the results of the RCP seal testing and/or analyses that have been performed for BJ and Sulzer seal cartridges (e.g. BJ LOCCW test at St. Lucie and the BJ N-9000 SBO test). Please include a description of how these results are reflected in the model and/or failure data.

Examples of performance claims and conclusions that need further supporting experiential information, analyses, modeling, or test results include:

1. *The statement (pg. 4-6 ¶ 3) that the current BJ and BWC seal designs have superior temperature performance and are consistent with the Brookhaven National Laboratory (BNL) qualified O-rings.*

RAI 03 Response: With the exception of the Nitrile U-cups in the early BJ/SU seal designs, BJ and BW have used ethylene-propylene elastomers in the static secondary seals. Elastomer seals of this type were identified as "qualified" in Reference 6. Tests of prototypical BJ and BW ethylene-propylene seal designs have been performed in References 1, 2 and 3. The Kalsi tests included full pressure (2250 psig) and high temperature 550°F, 600°F and 650°F experiments. The 550°F and 600°F tests indicated no measurable leakage for a period of 8 hours. The tests were terminated at this point. A subsequent seal inspection indicated that seals exposed to 550°F temperatures exhibited no signs of guminess or embrittlement and a small extrusion lip was noticed. The 600°F post-test inspection indicated that the O-rings remained elastic and there was no embrittlement or guminess of the material. During the last four hours of the experiment there was a slight drop in pressure across one of the two seals tested (2300 psig to 2200 psig). The drop was attributed to a small amount of extrusion, which resulted in a small increase in the seal cavity volume. Additional information on seal performance may be inferred from prototype loss of CCW tests conducted with the BJ/SU and N-9000 seals; these tests confirm the robustness of ethylene-propylene seals to successfully operate in a high temperature environment. In the BJ/SU test, the O-rings successfully operated in a 500°F to 520°F environment with pressure drop of between 500 and 1000 psid for a period in excess of 40 hours (Reference 3). Similarly, the N-9000 SBO test indicated successful ethylene-propylene elastomer performance when exposed to high temperature and pressure environments. Since the RCS cold side temperature is limited to a maximum value of 540°F to 565°F (plant specific), these test results support the robustness and low expected failure probability selected for the static ethylene-propylene elastomers.

2. *The statement (pg. 4-7 ¶ 2) that failure of qualified O-rings is unlikely during a Loss of Seal Cooling (LOSC) event, which seems inconsistent with the prior paragraph in the topical report that states one O-ring in each stage of a Sulzer seal assembly is susceptible to significant extrusion failure if subjected to full system pressure during a LOSC event. Note that this statement refers to O-rings that have been tested at specific temperatures, gaps, and pressure differentials expected during a LOSC event. These tests relate to Westinghouse*

RCP seal and O-ring materials. No O-ring material was qualified for "full" system pressure across a single seal stage by these tests.

RAI 03 Response: The secondary seal elastomer tests presented in Appendix A of Reference 4 included experiments on BJ U-cups and Bingham International O-ring arrangements subject to both normal operation (750 psig) and (2200 psig) to pressure loads. Contractors to the U.S. Nuclear Regulatory Commission (NRC) performed these tests, without the cooperation of either the owners group or the pump manufacturer. It was further noted that the test results should not be taken as definitive. However, AECL did indicate that the U-cup test was considered "worst-case" conditions (Reference 4). Findings of U-cup deterioration were similar to that observed in BJ tests and operational events involving the BJ/SU seals. O-ring tests used reasonable (0.009" and 0.018") diametrical gaps and representative materials. While these were not prototypical, the diametrical gaps used bound the BJ seal design. The conclusion that the seals could support high temperature exposure was based on the results of prototype experiments described in response to RAI 01 and the response to RAI 03, item 1.

3. *The conclusion of Section 4.2.3 (pg. 4-17) that the use of improved materials has reduced the potential for significant seal face flaws and thus the potential for a pop-open event.*

RAI 03 Response: The new generation of RCP seals has been designed to improve seal performance for design and off-design conditions. These designs have focused on improving elastomer temperature response, minimizing frictional resistance of gasket seals, and carefully accounting for the effects of thermal expansion. In addition, for N-9000 seals, pressure induced seal face deflections have been eliminated by the inclusion of pressure balancing holes through the face of the seal. The net impact of these changes have been to improve the thermal performance of the seal secondary elastomers by eliminating the use of Nitrile U-cups and by increasing the stability of the seals by minimizing thermal and pressure induced face seal deflections. Finite element analyses of the N-9000 seal design indicate that during a station blackout with the seal in a static condition, the primary sealing surfaces would tend to be divergent, thereby preventing leakage. The designer's concluded that the seal would be "safe in station blackout conditions and not be likely to pop-open" (Reference 8).

4. *The vapor stage temperature for the CBO-not-isolated case (pp. 5-10 and 5-11), which is nearly 100°F below the test results identified in Section 7.1.1 (pg. 7-2, ¶ 4).*

RAI 03 Response: Tables 5.3-4a, 5.3-4b, 5.3-4c, 5.3-5a, 5.3-5b, and 5.3-5c on pages 5-10 and 5-11 of CE NPSD-1199-P are representative of the seal package temperature distributions. The first two columns on each table represent the case when CBO is isolated approximately 10 minutes after loss of seal cooling. Stage temperatures are established based on experimental observations (See attached Figures 2, 3 and 12). CBO isolation imposes a constant pressure across all the seal stages. The low seal temperatures and high seal pressures ensure high subcooling at each seal location.

Columns 5 and 6 on each table represent the case where CBO is not isolated. Under this condition, the seal is staged. That is, the CBO flow creates a near equal pressure drop across each seal stage except the last one. For a four stage seal, each seal stage has a pressure drop of about 700 psid. The last stage is connected to the low pressure Volume Control Tank.

It is assumed that the pressure in the last stage was 70 psia. When the RCS pressure is 2200 psia, the actual pressure drops across each seal stage is about 700 psid. The temperature distribution was based on assuming an "near" adiabatic flow of RCS liquid through the seal stages. As a result of the high pressure on the lower stages the fluid in the two lower most seal cavities would be highly subcooled. The third stage temperature is near saturation with saturation conditions existing in the vapor stage. The presence of a saturated vapor stage has been confirmed in the BJ/SU and N-9000 tests.

Columns 3 and 4 represent a delayed isolation of CBO. The temperature distribution reflects subcooled liquid conditions in all seal cavities at the time the seal package was isolated. The vapor stage temperature is assumed to be ~ 400°F. This is based on observations that equilibrium temperatures during the BJ/SO tests were in the 400°F range. So long as isolation results in seal package pressures in excess of about 250 psi, the liquid would be subcooled and the stage temperature would remain.

Three prototype experiments have been performed for loss of cooling events for cases where CBO is not isolated (References 2, 3 and 7). Reference 2 evaluated the seal conditions for an N-9000 loss of seal cooling event. The test included a prototypical installation. The facility was heated to an inlet temperature of 540°F. The CBO temperature (representative of the vapor seal cavity) remained below 300°F (See Figure 12). BJ/SU tests performed for both a static and dynamic loss of seal coolant events indicate that when the RCS simulated temperature is in the range of 516 to 530°F the temperature of the vapor seal cavity was between 400 and 420°F (see attached Figures 1, 2 and 3.)

5. *The discussion in Section 5.3.2 (pp. 5-11 & 5-12 ¶ 1) that the vapor seal will not pop-open, blowing down to atmospheric pressure.*

RAI 03 Response: When the fluid in the upstream cavity has less than 50°F subcooling and the pressure drop across the seal is greater than one half of the absolute pressure, there exists a potential for the seal to pop-open. These conditions can exist at various seal stages when the CBO is not isolated. Prototypical tests performed on a BJ/SU pump seal demonstrated that the seal stage is capable of maintaining seal integrity for a range of system temperature between 250 and 420°F and system pressures from 150 to 700 psia. Subcooling during this test varied from 30 to 150°F (See RAI 2). Similarly, N-9000 prototype tests indicated that with CBO isolated, vapor seals will not pop-open for pressures up to 2400 psia (subcooling during this test was as low as 55°F). Leakage through the seal during these tests were noted to increase, however, in all cases, the actual leakage vapor was not significant (See Table 1).

Table 1

Test	Description	Vapor Seal Condition	Leakage (gpm)

A review of actual plant LOSC events does indicate that vapor seals have the potential for a small amount of leakage, but at no time was a catastrophic failure of a vapor seal recorded (See responses to RAIs 7 and 8).

6. *The indications that sufficient subcooling is achievable for all potential accident conditions, although essentially none of the plants' procedures require at least 50°F subcooling for all these conditions.*

RAI 03 Response: For SBO conditions, operators will have a limited amount of equipment available for controlling RCS subcooling. However, 50°F subcooling in the cold leg will be maintained for a period of 3 to 4 hours without operator intervention (See response to RAI 02). For non-SBO loss of seal cooling events, operators will have adequate resources available to cool down the plant while controlling RCS subcooling. The 20°F subcooling requirement contained in EOPs is intended to avoid cavitation of the RCP. Plant responses suggest that the plant operators will maintain a comfortable 50°F margin to the required subcooling.

7. *The conclusion that the current generation of RCP seals for the BJ and Sulzer (BJ/SU) RCP designs are not expected to be significantly impacted by binding failure (pg. 4-3 ¶ 5). Note that the preceding text and some of the data points in Figure 3.4-1 (pg. 3-12) seem to refute this assertion. In this section, the cited test indicates a stage failure occurred for a BJ/SU seal exposed to 400°F for more than 70 hours and the cited incident at MP2 indicates a LOCCW event resulted in a stage failure for a BJ/SU seal exposed to 530°F for about four hours. Given that the exposure temperatures for a RCP stage may exceed those of the cited test and incident, it is not clear how the conclusion that binding failure is not expected to occur is supported.*

RAI 03 Response: Nitrile is a low temperature elastomer with a maximum recommended operating temperature of 250°F. Tests of this material performed by Rhodes et. al. indicated that the U-cups will embrittle to a glass-hard state after 8 hours of high temperature exposure. The advanced seal designs have eliminated the use of Nitrile U-cup follower in favor of an ethylene-propylene ring design which has a better temperature endurance. Testing of ethylene-propylene O-rings indicated some extrusion, small changes in hardness and no leakage. Similar conclusions were obtained for prototypical O-rings tested at Kalsi Engineering Laboratories. No operational events have indicated ethylene-propylene elastomer failure as a cause of a BJ or Bingham RCP seal failure.

Following the BJ/SU test, post-test inspections were consistent with the above observation. The inspection indicated hard, brittle U-cups. Flexibility of the O-rings had been retained but the O-rings had taken a compression set. (Reference 3, Section B).

RAI 04

The topical report provides the general model for seal performance, but this model will involve a number of plant-specific considerations. To ensure a consistent implementation of the model, the topical report should identify and provide guidance on how to treat the plant-specific considerations. For example:

1. *Some plants do not isolate CBO for LOCCW and/or station blackout (SBO) events. Please describe how these plant-specific operating conditions impact and should be reflected within the model.*

RAI 04 Response: Plant-specific procedures would be considered by the individual utilities upon model implementation. If CBO is not isolated, the tables that utilize "CBO not isolated" data should be used. If CBO is isolated within 20 minutes, the associated "CBO Isolated" tables should be used and if CBO is isolated sufficiently early to avert significant heatup (within 10 minutes), the associated "CBO Isolated within 10 minutes" tables should be used. Given that the RCPs need to be tripped before isolating the CBO, the tables associated with "CBO Isolated within 10 minutes" would only be used with SBO sequences because the RCPs will automatically be tripped as a result of the initiator.

2. *Section 5.2 (pg. 5-4 ¶ 2) states that about 35,000 gallons of RCS inventory must be lost before incipient core uncovery in the smallest CE plant. As such, for the two-stage failure condition for the System 80 design at the sustained uncompensated leakage rate and the three lower-stage failure condition for the other plants, the identified inventory loss could occur well within the typical 24-hour mission time. If core uncovery could occur within the mission time for failures of less than catastrophic failure of all stages, then these additional accident scenarios would need to be addressed by the plant-specific implementation of the model. This may require that a two-stage failure condition be addressed, at least for a SBO accident scenario in which power is not recovered within the time frame required to avoid core damage. These scenarios do not support the conclusion of this paragraph that the seal is considered functional unless all seal stages have failed. Please describe under what conditions the model is not applicable (e.g., sustained SBO for greater than a specified time period) or how these conditions are to be addressed and/or confirmed in the plant-specific application.*

RAI 04 Response: This issue is plant specific. RCS inventory is proportional to plant power level. Core uncovery typically requires approximately 70% of the RCS inventory be lost. For PVNGS, core uncovery would require the loss of greater than 70,000 gallons of inventory. A seal LOCA for PVNGS will spill RCS liquid at a rate of only 17 gpm per pump when the RCS is at full system pressure. Thus, for a single RCP seal failure, core uncovery would not occur in less than 24 hours. This remains true even if 4 RCP seals fail since the faster depressurization will reduce the break flows. The extended time to core uncovery is a feature of the KSB RCP thermal barrier design. All CE PWRs other than Palo Verde utilize BJ pump designs. CEFLASH-4AS was used to estimate the time to core uncovery following an RCP seal leak with rates. Results are shown below.

Time to Core Uncovery Following Onset of RCP Seal Leak			
Plant Category	RCP Seal Leakage (Full Pressure)-gpm	1 RCP Seal Leak (Hrs)	4 RCP Seal Leaks (Hrs)

The model does not integrate the impact of this incremental time in the assessment of core damage. The incremental times identified above may be included in plant specific analyses.

3. *The RCP seal performance during a LOSC event is dependent on operator actions that are plant-specific and non-uniform as indicated in the topical report. Section 5.3.2 (pg. 5-7 .3.2 ¶ 2) notes that, for LOCCW events, it may take 10 minutes for the operator to diagnose the event and trip the RCPs. However, other sections (pg. 6-2) describe the desire to perform other actions within this initial 10-minute time window (e.g., isolating the CBO path) that would tend to occur after the RCP trip action. It is not clear how the operator action to isolate the CBO path could possibly be performed within 10 minutes if it takes that long just to diagnose the event and to trip the RCPs. How are these plant-specific and inter-related operator actions determined to be achievable for all the LOSC accident conditions, and how are the ensuing human error probabilities to be reflected in the model? Please provide a discussion of how the proposed model for RCP seal failure includes the plant-specific operator actions, and please describe the resolution of the apparent inconsistencies regarding operator actions.*

RAI 04 Response: The plant accrues two benefits from isolating CBO. First, early isolation of CBO (within the first 10 minutes of loss of seal cooling) would maintain the RCP seal stages well below the RCS temperature and hence minimize the potential for stage pop-open. Loss of component cooling water test performed by BJ for San Onofre on an operating RCP indicated that fifteen minutes into the loss of seal cooling event the lower, middle and upper seal stages had only achieved a temperature of between 400°F and 425°F. The vapor stage temperature would be closer to 350°F (see Figure 13). Isolation at this time would ensure a high level of seal subcooling during the loss of seal cooling event.

Second, CBO isolation de-stages the seals. That is, it removes the pressure drop across the lower three seal stages and applies the total system pressure drop to the last (or vapor stage). For four stage seal plants, this results in a large pressure drop at the lowest temperature seal. Pop-open of the lower stages would be averted due to the high seal back-pressure (lack of pressure drop); the vapor stage would be subcooled relative to the RCS pressure and would not pop-open. N-9000 tests investigated seal operation during CBO isolated conditions. No pop-open or bistable leakage was observed for a fully pressurized upper seal subjected to a more than 2200 psid pressure drop and an upstream fluid temperature of 500°F.

4. *The topical report contains a parenthetical statement (pg. 5-8 ¶ 3) that the previously stated guidance on not restoring CCW if it has been lost for more than 10 to 30 minutes was based on BJ/SU seal designs and that it is preferable to restore CCW for the CE units with N-9000 seals. What is the impact of implementing or not implementing this guidance at the CE plants with N-9000 seals, and how is this impact reflected in the model?*

RAI 04 Response: Restoration of cooling to the seal is desirable following a LOSC event. Depending on the temperature reached during the event, disassembly and inspection may be warranted before returning the equipment to service. Sulzer recommends that the seal be disassembled and inspected if it was exposed to temperatures higher than 260°F irrespective of time at temperature.

RAI 05

Even if a RCP seal stage does not pop-open (i.e., it is hydrodynamically stable), it may leak substantially (e.g., greater than 200 gpm) (See NUREG/CR-4821, p. iv.). In fact, with the Westinghouse RCP seals, the 182 gpm leak when the second stage seal pops open is caused by the increased leak rate of the first stage seal, although the first stage seal remains hydrodynamically stable. The first stage seal face separation becomes relatively large, but the axially moveable first stage seal face does not move to the limits of its travel, and the relatively large seal face separation is stable with respect to small changes in fluid conditions. If the first stage had also popped open, the leak rate would be even greater, about 480 gpm per pump. The topical report does not consider this possibility.

An example of the relevance of this possibility may be seen by referring to Table 5.3-6 (pg. 5-12). If the third-stage seal fails, and if the second-stage seal inlet conditions are less than 50°F subcooled, the second stage may pop-open. Then, in order to have a large leak, it is not necessary for the first stage seal to pop-open; it is only necessary for conditions to be such that the leakage through the first seal stage be large. The fact that the back-pressure on the first seal stage is low (after the second stage seal pops open) makes this more likely. Finally, the fourth-stage seal may fail after the other three fail, because of the low back-pressure. The failure could be a pop-open failure mode, or it could be a case where the seal faces have a large separation, although the seal remains hydrodynamically stable, as was discussed for the first-stage seal. This type of common cause failure (CCF) mechanism for developing a large leak from a RCP seal package does not appear to be included in the model.

Another example is that, even if the CBO line is isolated early, failure of the vapor seal may result in large leakages. If the vapor seal fails, staging of the pressure across the lower three seal stages, increased flow through these seal stages, and increased heatup of the seal stages will all occur. This condition would have the potential for multiple stages of the pump popping open, and large amounts of leakage through the first seal stage could occur even if it remains hydrodynamically stable. It does not appear that this type of CCF is included in the quantification of the RCP seal failure model presented in Chapter 9 of the topical report.

Please address the above identified considerations and conditions.

RAI 05 Response

The scenarios postulated has not been observed in practice nor are they likely. The BJ type seals have not indicated significant bistable behavior. Each seal stage in the seal package is designed to withstand full system pressure. The closest example of bistable behavior may be inferred from the upper and vapor seal behaviors in the BJ/SU designs from Reference 3. In this instance, seal leakage through the vapor seal was less than 0.27 gpm. Based on that test data the BJ/SU vapor seal stage was able to take a 600 psid pressure drop for more than one day while exposed to 400°F fluid without failure or pop-open. The BJ/SU upper stage seal exhibited some transient behavior where it may have operated in a bistable region. In the 37 to 45 hour portion of this test, the pressure drop across the upper stage reduced to about 150 psid. Since CBO was operating, the flow through the pressure breakdown coils at that time would be 1.0 gpm x (150 psid/750 psid)$^{1/2}$ or 0.45 gpm. Thus, the bistable seal leakage condition would be about 0.55 gpm. At this time, the local subcooling for the upper stage was about 15°F. In another instance, between 45 hours and 55 hours a 500 psid pressure drop was imposed on the upper seal at temperatures of 500°F (~ 44°F subcooling) so that the flow through the pressure breakdown device would be reduced to accommodate a seal leakage flowrate of about 0.2 gpm. Test temperature and pressure traces are presented in the attached Figures 1 through 3.

Even though the upper seal indicated some transient behavior, no direct coupling was noted between the upper seal stage behaviors and the upstream seal stages. Both the middle and lower stage pressure remained relatively unchanged.

The N-9000 test (Reference 2) included conditions where the CBO was operating and when CBO was isolated. The CBO isolated cases indicated the vapor seal held a greater than 2200 psig pressure drop without failure for 8 hours following a loss of seal cooling. Liquid subcooling upstream of the last seal stage was typically greater than 55°F (leakage past the seal face was maintained at 0.04 gpm throughout the test).

Sixteen losses of seal cooling events have occurred at CE-designed PWRs using BJ/SU, N-9000 or Sulzer seals (see revised table 9.2-12, attached and responses to RAIs 7 and 8). Several of these events have resulted in seal conditions that resulted in two-phase flashing across the faces. Pop-open appeared to exist for several tests and was generally limited to stage 3 of the 4 stage seal. In several instances a coupling between stage 2 and stage 3 seals was inferred, however, stage 2 seal failure was not identified. As observed in the experiments, seal stage 4 (vapor stage) remained stable regardless the condition of the upstream seals. Furthermore, of the 38 potential affected stages for pop-open, only six pop-open events were noted within 2 hours of the onset of the loss of cooling event. (Section 9 of CE NPSD-1199-P has been revised extensively in response to these RAIs. The revised section is attached. Table 9.2-12 of the revision summarizes the event data used to quantify the probability of pop-open failures.)

The question postulated that failure of the vapor stage would begin a cascading "unzipping" of the four seal stages. This scenario is modeled but has an extremely low probability of occurrence. Operation of the vapor stage under adverse conditions during test and events has not resulted in a single failure of the vapor seal to maintain pressure. Certain events have resulted in small (~ 1 gpm) increases in seal leakage. Lower seal stages exposed to harsh conditions do not indicate a pop-open event even when the inlet seal temperatures are near saturation conditions. Independent of the downstream conditions, the seal will perform satisfactorily against full RCS pressure (as would any of the four stages), as long as the lowermost seal entry fluid is subcooled by 50°F.

In summary, experimental evidence and operating experience suggests that the cascading nature of the seal failure postulated in the RAI is inconsistent with the observed behaviors of the seal.

1. While coupling is likely between seal stages 2 and 3 due to the low pressure high temperature conditions which results in low subcooling, stage 3 failures have not been associated with equivalent stage 2 pop-open failures.
2. Tests demonstrate that a single stage can withstand full system pressure while operating at elevated temperature. Other tests confirm that even when operating near saturation conditions, seal leakage would be low (less than 1 gpm).
3. While there is an impact in back-pressure on the upstream stage, the stages are intended to perform their function under full system pressure. Thus, the first stage was assumed to be subject to pop-open only when the RCS subcooling is less than 50°F.
4. The last stage operates with atmospheric back-pressure. In no cases did the vapor stage exhibit pop-open, whether or not the CBO was operating. Vapor stage operation under high RCS pressure (CBO isolated) will be subcooled and therefore not subject to pop-open. For

CBO operational conditions the driving pressure in the vapor stage would be much lower. Based on experiments, leakage past the vapor stage would be small.

A review of the issue did uncover one coupling mechanism that was not previously considered. That is, should the vapor seal fail or leak excessively for any reason while CBO is isolated, the failure would re-stage the seal and the lower stages would become subject to pop-open failures as well as thermal effects. Thus, the failure rates for the subsequent stages would be based on CBO operating conditions, not CBO isolated conditions. This feature has been integrated into the model by assuming that all sequences in which the vapor seal fails, the upstream seals would be treated as if CBO were not isolated. The fault tree models in Figures 6.2-1 and 6.2-2 of CE NPSD-1199-P have been revised to include this new coupling mechanism for the CBO Isolated conditions and to include a new failure scenario involving failure of the excess flow check valves and failure of the lower stages for the CBO Not Isolated conditions. The revised fault trees are presented in Figures 6.2-1 through 6.2-4, attached.

RAI 06

The topical report does not address the expected leakage rates for a number of RCP seal stage or related component failure modes. The report should provide these leakage rates. It should also describe how these leakage rates are bounded and/or reflected in the model, including:

1. *The blowout of various O-rings and secondary seals (i.e., complete loss of these type seals).*
2. *The pop-open of a single or multiple seal stages, including the vapor seal with the CBO line isolated.*
3. *The various RCP seal stage failure modes with the CBO line not isolated.*
4. *The failure of the excess flow check valve(s) to limit flow.*

RAI 06 Response

The topical report does not address O-ring failures as these failures would not result in significant changes in seal leakage. Precise calculations are therefore unnecessary. The existing tables (Tables 5.2-1 and 5.2-2) that estimate the impact of individual and multiple seal stage bypass bounds the impact of these elastomer failures. Incomplete seal failures will only marginally decrease the flow resistance between the two adjacent cavities. (As presented in RAI 5, even a seal failure that reduces the seal stage pressure drop from 750 psid to 150 psid will pass only 0.55 gpm.) Thus, the impact would be less than the situation if the seal had catastrophically failed.

Complete loss of all seal elastomers has not been studied. However, the hypothetical loss of all seals would likely render the seal incapable of performing it's function, as flow would likely leak around all seal stages. This degree of failure is considered incredible. Conceptually, the elastomer failure probability considers failures associated with extrusion and binding and general elastomer failure. Thus, this probability, however unlikely, is considered.

The following paragraphs will specifically address some nuances associated with the four points identified.

1. *The blowout of various O-rings and secondary seals (i.e., complete loss of these type seals).*

   As discussed above, these failures are bounded by complete stage failure assessments included in Table 5.2-1 and 5.2-2 of the report.

2. *The pop-open of a single or multiple seal stages, including the vapor seal with the CBO line isolated.*

   Pop-open failure leakage rates based on single and multiple seal stage failures are included in Table 5.2-1 and 5.2-2. Pop-open is assumed to result in a hydraulic bypass path. Note that seal stages are in series. There is no fluid pathway out of the seal without passing through at least three stages of a four stage seal. If CBO is isolated, seal leakage requires the failure of the vapor seal.

3. *The various RCP seal stage failure modes with the CBO line not isolated.*

   Leakage could leave the seal via the CBO line if CBO is not isolated. The excess flow check valves limit this flow path. Leakage will occur if all of the seal lower stages fail and the excess flow check valve fails to stop seal flow. This leakage could be significant; the amount will depend on plant responses to the event (e.g. RCS depressurization). This failure mode has been added to the seal failure model. The fault tree models in Figures 6.2-1 and 6.2-2 of CE NPSD-1199-P have been revised to include a new coupling mechanism for the CBO Isolated conditions, this new failure scenario involving failure of the excess flow check valves, and failure of the lower stages for the CBO Not Isolated conditions. The revised fault trees are presented in Figures 6.2-1 through 6.2-4, attached.

Note that failure of fewer than all of the first three stages plus the vapor stage will not result in significant RCS leakage.

4. *The failure of the excess flow check valve(s) to limit flow.*

Failure of the excess flow check valve to limit flow was not considered. The most likely failure mode for this type of valve is to fail closed. However, should the valve fail to close RCS leakage following failure of all the lower seal stages would be significant. As noted above, this failure mode has been included in the model update.

RAI 07

Some of the operational plant data and RCP seal test data used in the topical report (Table 8-1, pp. 8-2 - 8-6) to quantify the proposed seal failure model has been questioned in the past regarding its accuracy and the actual conditions occurring at the time of the LOSC event (e.g., C. Ruger letter to S. Khalid Shaukat, US NRC, dated June 24, 1994, on the subject of CE Owners Group (CEOG) LOSC events and tests). The Ruger letter states that it appears that many of the LOSC challenges to the seals are not valid challenges that would result in the likelihood of seal failure as determined by generic issue GI-23 research. In addition, note that all of the LOSC challenges were only for BJ/SU or Klein, Schanzlin & Becker (KSB) RCP seal designs. (The Waterford events were listed only as BJ, but could possibly have been for the N-9000 design.) The BJ/SU design is now only used in one plant, and the KSB design is not in any plants. These are very important points because the data is being used to obtain estimates of the seal stage failure probability.

As an example of questionable data, Ruger noted that the St. Lucie Unit 2 event of 12/19/84 is not very clearly described. The description states that seals on pumps 2B1 and 2B2 failed, but then it states that no stage failure was observed. Also, in Table 9.2-4 (pg. 9-14), the event is listed as not applicable. If the pumps were stopped during the event, and if a seal stage failed, it would seem to be applicable. Even if, in an operating event, CCW was lost to the RCP seals, the situation is not the same as a SBO or total LOCCW. The situation is not the same because the charging pumps were likely available and the RCS pressure and the subcooling margin could be better controlled than in a SBO or LOCCW, which would affect the charging pumps.

Please address the deficiencies raised in the June 24, 1994 letter from C. Ruger. Please also clarify the entries in Table 8-1 (pp. 8-2 - 8-6) and related Chapter 9 tables (pp. 9-5, 9-9, and 9-14) to address the numerous event description inconsistencies and failure modeling impacts, including:

1. *Event ANO2-1 is listed as a SBO, but it was only a partial loss of AC power. Also, its short duration of 6 minutes would make it not applicable for most potentially significant failure modes. Even so, it had an increase in vapor seal leakage, though prior text indicates it should not be susceptible for such a short duration event. This leakage through the vapor seal for such a short duration event should be explained.*

RAI 07 Response: Due to the short duration of this event, it was not included in the success or failure counts used to quantify the model. There is no additional information available for this event. Plant staff does not recollect any particular problems with the seal after the event or any prolonged leakage. This event was of such a short duration that the vapor seal would not have seen any adverse conditions associated with a loss of cooling.

2. *ANO2-2 was not a LOCCW, but a degraded CCW flow. The applicability of this event is questionable because some CCW flow may have existed.*

RAI 07 Response: No additional information on this event was available from the plant. Given that the event descriptions indicated only "degraded" CCW flow without specifying how much or how little CCW flow was available, Westinghouse concurs that this event might not have involved a total loss of CCW flow and this event has been deleted from Tables 8-1, 9.1-1, 9.2-1 and 9.2-4 in CE NPSD-1199-P. The revised tables are included in the revision of Section 9 of the report attached to these RAI responses. Note that due to other changes, the former Table 9.2-4 has been renumbered as Table 9.2-12. (Note that this question implies that any CCW flow to the seal is sufficient to preclude seal failure.)

3. *FCS-2 indicates one failed stage on one pump, but the seals on all pumps were replaced. What were their conditions? Were they degraded or leaking substantially, but not failed?*

RAI 07 Response: During this event, there were no indications of seal stage failures. However, the seals exceeded the manufacturers recommended operating conditions. Therefore, as a precautionary measure, Fort Calhoun replaced all seals in accordance with the manufacturer's recommendations.

4. *FCS-5 is a short-duration exposure during startup. Were the conditions applicable to full-power operations?*

RAI 07 Response: Events with duration of 0.1 hours or less were not used to quantify the model. They were included in the lists for reference only. To avoid future confusion, the calculation for the interval 0 to 0.1 hours has been removed from Tables 9.2-1 and 9.2-4. The revised tables are included in the revision of Section 9.

5. *FCS-6 is listed as the same event as FCS-5, but it is listed separately and counted separately in Table 9.2-1 (pg. 9-9). This double-counting appears to artificially and inappropriately lower the failure probability*

RAI 07 Response: The original information used in CE NPSD-755 indicated that two similar events had occurred in July 1992. Fort Calhoun has the available operating information and can find only the event on July 1. Therefore, FCS-6 has been deleted from Tables 8-1, 9.2-1 and 9.2-4. The revised tables are included in the revision of Section 9.

6. *MNS2-1 indicates that lower seal temperature increased (275-330°F), but this is not at the exposure temperature level expected to cause some of the failures for which it is counted in Chapter 9.*

RAI 07 Response: For Event MNS2-1, the event data indicates that the temperature in the lower seal stage was beyond the strip-chart range of 355°F for 3 hours and 45 minutes. Since the plant was in hot standby with an RCS temperature of about 530°F and CBO was operating, it is expected that the temperature in the lower stage would be about the same.

7. *MNS2-2 occurred while the plant was in hot standby. Were the conditions applicable to full power operations?*

RAI 07 Response: At the time that event MNS2-2 occurred, Millstone 2 was in hot standby with the RCS temperature at 530°F with the system at about 2200 psia. The stage failure on this seal manifested itself on RCP restart shortly after cooling was restored.

8. *PV2-1 and PV2-2 occurred before commercial operations. Were these conditions applicable to full power operations? Further, PV2-2 appears to be related to PV2-1 in that the earlier event is what led to the degraded seals and the latter leakage events. Therefore, it appears that these events should not be treated as separate events.*

RAI 07 Response: At the time that event PV2-1 occurred, Palo Verde Unit 2 was operating in hot standby with the RCS pressure and temperature at normal operating values. Hot standby conditions are covered by Technical Specifications and are the same for both commercial and pre-commercial operation. Event PV2-2 describes a stage failure that occurred during power operation about 3 months after event PV2-1. It is believed that this stage failure related to the affects of the conditions experienced during event PV2-1 and was originally included in Table 8-1 for completeness. This event has been deleted to avoid confusion since it was not used for failure or success counts (see revised Table 8-1). Note that the PVNGS data in general was only used for quantification of elastomer survivability as the PVNGS units had KSB seals. The elastomers used in the KSB seals are equivalent to the elastomers used in the other seal designs used by CE plants.

9. *PV3-1 illustrates an event - addition of hot RCS water without inter-stage cooling - that is not addressed by the model. Further, the temperatures are below 500°F. Thus, there is a question about the applicability of this event to specific failure phenomena. A stage failed, but it is not clear how it was counted.*

RAI 07 Response: The mechanism that lead to the failure described in event PV3-1 was unique to the KSB seal design and could not occur on the Byron-Jackson SU seals, the Flowserve N-9000 seals or the Sulzer Balanced stator seals. This event was used for evaluating the ethylene-propylene elastomer failure potential because the elastomers are equivalent but it was not used for evaluating the potential for pop-open failure. Palo Verde was the only plant to use KSB seals; these were replaced with Sulzer Balanced Stator three stage seals in 1996.

10. *The report states that SL2-T shows that seals can withstand extended SBO events, but it also shows cracking, deformation, and hardening that would suggest potential for failure. What temperatures were reached in the test? Are these applicable to full-power operational events?*

RAI 07 Response: The test lasted 70 hours. Nitrile U-cups were severely degraded and some O-ring deformation was noted. No stage failures resulted. The test was conducted at approximately 520°F with seal temperature/pressure exposure typical of post-accident CBO operation. Note that RCS cooling during an actual event would reduce RCS temperature and pressure exposure and further mitigate the seal failure threat.

11. *The report states that no stage failures were observed for SL2-2, but it also states that two seals failed. The Nuclear Plant Reliability Data System (NPRDS) indicates that one RCP seal was leaking excessively and suffered significant seal damage. How was this discrepancy resolved and why is it appropriate to consider this as "no failures" in Chapter 9?*

RAI 07 Response: There is limited additional information available for this event. Discussions with the plant personnel indicated that their typical practice was to call a stage failed if the pressure breakdown across the stage was < 100 psi and to call the seal failed if the operating environment exceeded the conditions recommended by the manufacturer for more than 10 minutes, especially if there was any increase in leakage above the nominal limit. Plant personnel advise that catastrophic seal failure did not occur. However, based on similar information for other events, it is possible that the third stage on the two affected RCPs "popped-open." Therefore, two additional stage failures have been included in the revised Tables 8-1, 9.1-1 and 9.2-4.

12. *SL2-3 indicates that the third stage was degraded and possibly failed on two RCPs, but this is not reflected in Table 9.1-1 (pg. 9-5). How were these potential failures addressed?*

RAI 07 Response: As indicated in Table 8-1, it appears that the third stage on two of the pumps might have failed. These two stage failures were treated as pop-open type failures as shown in the revised Table 9.1-1 and 9.2-4 for event SL2-3A.

13. *SOS2-T indicates cracked vapor seal rotating ring and deterioration of elastomers. How were these potential failure precursors factored into the data of Chapter 9?*

RAI 07 Response: The pump was operating with a loss of CCW (i. e., without seal cooling). None the less, all stages maintained their sealing capability during the test and throughout the following cooldown. This test demonstrated the ability of seals to remain intact following a delayed RCP shutdown. Similar demonstrations of this capability have been performed on BJ seals and have occurred in the field. This information was used to estimate that, while damage may occur to the seal, it will serve its safety function for a minimum of approximately one hour. Field experience has resulted in more than 30 minutes of operation without cooling with limited damage. It was extrapolated that seals would maintain their integrity following operation without cooling for periods of up to 1 hour. This has been revised downward to 20 minutes to stay within the data and to simplify the modeling with respect to CBO Isolation timing as shown in the revisions to Section 6.

14. *Item 4 in Section 9.1.1 (Pg. 9-4) states that events of UNKNOWN duration were attributed to the "less than one-hour exposure" class. However, if these events were under 10 minutes, it could be argued that they should not even be counted as a challenge. If these events resulted in a degraded or failed stage that is counted in the data, then it is probably appropriate to place them in the "less than one-hour" class. However, if no failures are indicated, they should not be included at all. Please adjust the data accordingly or provide a justification for including extremely short-duration events that probably were not of sufficient duration to challenge the RCP seal stages.*

RAI 07 Response: All of the events with duration of less than 0.1 hour were included in the report for reference. These events were not used to determine success counts or failure counts.

15. *WSES3-1B shows that for pop-open it is not the duration of the event that is important, but the time to the proper conditions, which occurred at 40 minutes. For this event, Table 9.1-1 (pg. 9-5) attributes 6 stages to one RCP. Please correct the number of stages exposed in the table.*

RAI 07 Response: Table 9.1-1 has been corrected.

16. *The stage elastomer failure probabilities were established using the experience data by observing the number of stages exposed to a high-temperature environment, which is parenthetically identified as 500°F (pg. 9-7 ¶ 3). Most of the experience either does not identify the temperature of the individual stages or indicates that they were less than 500°F. However, Table 9.2-1 uses many of these events to determine the above failure mode probability, even though these events may not have reached this temperature. Please explain how the events used to establish the failure probabilities were determined to have reached a high temperature.*

RAI 07 Response: Temperatures were from the plant conditions and results of loss of seal cooling tests on similar seals. For example, seal tests indicated that after ~ 0.5 hour, the three lower seal stages reach an equilibrium condition of slightly below the inlet/test stand temperature. The vapor stage is seen to be at a considerably lower temperature. It was assumed that for loss of seal cooling events with CBO operating and RCS temperatures at hot standby or at power, seal stage temperatures in the vicinity of seal stages 2 and 3 would be slightly lower than the RCS temperature and the temperature in the lower seal stage would be close to RCS temperature. The vapor stage seal would see a much lower temperature due to the presence of saturation conditions and heat losses to the ambient.

17. *The number of failures identified in Table 9.2-4 (pg. 9-14) may be incorrectly calculated in that they do not recognize previous stage failures. The failure count may need to be cumulative, depending on how the model uses the information. Thus, failures that occurred in the first hour may need to also be counted as failures through the second hour and beyond because these stages did not make it through the interval in question. In other words, it is a given that these stages have already failed and will not survive the next interval. This will result in an increase in calculated failure probabilities. This also impacts Tables 9.2-5a through 9.2-5f (pp. 9-16 and 9-17).*

Response: All pop-open failures will be taken to occur in the 0.5 to 1 hour time interval. This is consistent with the onset of limiting thermal hydraulic conditions as indicated by loss of seal cooling experiments. Elastomer failures were associated with Nitrile U-cup deterioration. Experimental data on ethylene-propylene elastomer installations indicates excellent performance through 8 hours. Only one seal stage failure was noted to be caused by Nitrile elastomer degradation. The event involved isolation of CCW to the seal for more than 4 hours while the plant was in hot standby with the pump shutdown. The failure was placed in the > 4 hour interval because the stage failure after seal cooling was restored and the pump restarted.

RAI 08

Please justify the applicability of the events identified in Chapter 8 to their use in deriving the failure probabilities in Chapter 9. Include a discussion of the validity of these operational and test data, specifically addressing:

Did a complete LOSC occur during full-power plant operations?

Were individual stages actually challenged, and did conditions for hydraulic instability, binding, etc. exist for each stage?

Did the tests actually model the potential stage conditions and challenges?

RAI 08 Response:

The response to RAI 7 provides additional information for a number of the events covered in Table 8-1. As a result of the re-evaluation of the events discussed in RAI 7, several of the events were removed from consideration. In addition, the event PV1-1 was also removed from consideration. Additional information provided by Arizona Public Service indicated that while both seal cooling and seal injection were lost during this event, there was a limited time period during which seal injection and seal cooling were unavailable at the same time. The remaining events represent occurrences in which seal cooling was lost during normal operation or the seal was subjected to plant conditions equivalent to normal power operation in terms of RCS temperatures and pressures. These events are summarized in the revised Table 8-1.

All the events considered are subject to prototypical system pressures and temperatures following a total loss of seal cooling. To ensure local seal conditions were sufficiently high to challenge the seal stage for elastomer integrity or pop-open, only events whose duration was at least 0.5 hour was considered. Tests show that by one-half hour into a loss of seal cooling event with CBO operational, seal stage temperatures in the lower three seals (for a four stage seal) would reach equilibrium temperatures (> 500°F) (See Reference 7). For events in which CBO is not isolated, subcooling for the third stage will be less than 50°F within about 0.5 hours; other seal stages will remain subcooled. Should the third stage pop-open, the subcooling in the second stage will be slightly less than 50°F. Therefore, events lasting ~ 0.5 hours or more are used for evaluating pop-open failure probabilities. For each such event, one challenge (for the third stage) is counted for each pump. If a pop-open occurs, one additional challenge is counted for the second stage that would then be less than 50°F subcooled. Thus, in the treatment of pop-open, the third stage was the only stage considered initially subjected to the phenomenon. If a third-stage pop-open occurred, the second stage was considered to be subject to pop-open conditions with the potential for a pop-open failure. Note that this logic is revised from that presented in the original report; where pop-open failure of stages 2 and 3 were treated simultaneously. The data review also indicated that most pop-open events may have occurred early and hence are not time dependent. This logic was also used when re-assessing the data.

All seal stages subjected to temperatures in excess of 500°F (typically three stages in a four stage seal) were considered in the calculation of elastomer integrity. Elastomer pressures varied from nominal 750 psid per stage to 2400 psid for selected stages.

All events involving a loss of seal cooling lasting less than 0.1 hour have been excluded because the seals would not be expected to experience elastomer failure or pop-open within such short exposure time. The temperatures in the lower three stages for a four stage seal (lower two stages for a three stage seal) would reach equilibrium temperatures within about 0.5 hours of loss of seal cooling given that CBO flow is not isolated. Therefore, only events involving a loss of seal cooling for 0.5 hours or more were used to evaluate the potential for elastomer failure. Tables 9.1-1, 9.2-1 and 9.2-4 of CE NPSD-1199-P have been revised to reflect these selection criteria.

RAI 09

The topical report presents a formula (pg. 9-7) for estimating the failure probability, Q, from data when zero failures were observed in a number of challenges, N, as:

$$Q=0.455/(2*N)$$

The origin of the expression is the median of a Bayesian posterior distribution for the probability, Q, when a non-informative prior of $1/\sqrt{Q}$ *is used, and a Poisson approximation to the binomial is used for the likelihood function. The numerator is the median value of the chi-square distribution with one degree of freedom. However, it would be more appropriate to use the mean value of the posterior distribution for Q. The posterior mean for zero failures is 1/(2*N), when the non-informative prior given above is used. The expressions for the posterior probability density function, the posterior mean, and the posterior median are given in NUREG/CR-2300, on p. 5-50. The quantity "T" in this reference is to be identified with "N," and the quantity "λ" in this reference is to be identified with "Q." If the mean probabilities are used instead of the median, the estimates are multiplied by a factor of 2.2 (i.e., 1/0.455).*

For the case of zero failures, the upper confidence limit on Q, for a confidence level α, is $Q_{upper} = -ln(1-\alpha)/N$*. By solving this equation for α, one finds that the Bayesian median value of Q corresponds to a confidence level of 20%. The Bayesian mean value of Q corresponds to a confidence level of 40%. The 50% confidence level of Q is -ln(0.5)/N, or 0.69/N = 1.39/(2*N).*

All of the above presupposes a non-informative prior of $1/\sqrt{Q}$ *is used, which has not been justified. Since a probability is bounded by 0 and 1, a non-informative prior that is uniform between 0 and 1 could be used. With this prior, the posterior probability density function is proportional to the likelihood. For the case of zero failures, the (normalized) posterior density function for Q is N*exp(-NQ) and the Bayesian mean value of Q is 1/N, or 2/(2*N), which is an even higher estimate than the 50% upper confidence limit on Q. Summarizing these estimates:*

Estimate Type	*Point estimate of Q*
Bayesian Median (prior $1/\sqrt{Q}$*)*	*0.455/(2*N)*
Bayesian Mean (prior $1/\sqrt{Q}$*)*	*1.0/(2*N)*
50% upper confidence limit (prior $1/\sqrt{Q}$*)*	*1.39/(2*N)*
Bayesian Mean (flat prior)	*2.0/(2*N)*

Because point estimates of probabilities should be mean values, and not median values, the Bayesian median estimate should not be used. However, it is clear that the choice of prior has substantial influence on the results. If a flat prior is used, the Bayesian posterior mean is a factor of two greater than if a $1/\sqrt{Q}$ *prior is used.*

Please provide the justification for the formula used to calculate the failure probability, Q, from data when zero failures are observed in a number of challenges, N. Without an adequate justification for using the $1/\sqrt{Q}$ *prior, the Bayesian mean with a flat (uniform) non-informative prior should be used (i.e., Q=1/N).*

RAI 09 Response:

The $1/\sqrt{Q}$ prior is equivalent to the Jeffreys non-informative prior. Use of the $1/\sqrt{Q}$ prior is consistent with the data analysis approaches presented in NUREG/CR-2300. Furthermore, as discussed by Atwood in EGG-RAAM-11041 (Reference 10), work performed by Box and Tiao (Reference 11) indicates that there are fundamental reasons for preferring the Jefferys non-informative prior to the uniform prior. Westinghouse does concur that use of the Bayesian Mean would be more appropriate than use of the Bayesian Median.

The text and calculations in Section 9 have been revised to reflect these changes.

RAI 10

The topical report states in Section 9.2.3 (pg. 9-11) that a pop-open seal stage failure requires the coincidence of three conditions: (1) elastomer binding, (2) movement of the RCP shaft due to depressurization of the RCS or differential thermal expansion of the RCP shaft, and (3) thermal-hydraulic conditions in the vicinity of the seal stage faces that are amenable to pop-open due to hydraulic instability. This statement is not in agreement with the results of the work done for generic issue GI-23. As noted in Section 2.2.1 of the BNL guidance document (G. Martinez-Guridi et al, "Guidance Document for Modeling of RCP Seal Failures", BNL Technical Report W6211-08/99, August 1999), either elastomer binding (in conjunction with RCP shaft movement) or thermal-hydraulic conditions leading to popping open is sufficient for RCP seal stage failure. An intermittent popping open mode does not occur if there is hydrodynamic instability. Unless cooling is restored, the seals remain "popped-open." Binding is a second way of having the seal faces separate, but it is not required for popping-open of the seal faces. Binding and hydrodynamic instability are two separate failure modes. Later in Section 9.2.3 (pg. 9-13), in the discussion of the pop-open mode of failure, the topical report states that, for short-duration events, there is insufficient time for the seal to be sufficiently deformed to prevent return of the stage to its seated position. But pop-open is just a question of hydrodynamic instability; it does not require deformation of the seal. NUREG/CR-4821 discusses the hydrodynamic instability mode of failure of a seal stage. Please correct these aspects of the topical report, including any changes in the modeling and data to properly reflect the conditions and differences in the pop-open and binding failure modes, or explain how the conditions are appropriate for the RCP seals for CEOG plants.

RAI 10 Response

Data obtained from tests on BJ designed seals and experiential data obtained from loss of seal cooling events indicates a low propensity of seal stages to pop open when subjected to low subcooling conditions and a similarly low potential for significant bistable operating behavior. Furthermore, stage failures subjected to subcooled inlet flow conditions showed a dependence on time. This transient behavior was noted in the third seal stage of BJ/SU seal SBO test (See attached Figure 3).

Based on that behavior, the likely scenario is that a small seal leak due to a minor pop-open could be exacerbated over time by degraded seal elastomers. This is also consistent with some seal stage failures. However, it was believed that such seal leakage would be associated with the BJ/SU Nitrile U-cup seal design, which degrades at high temperature. No such behavior was noted in the N-9000 seal design. The only impact this approach has on the analysis was in the binning of the pop-open failure data. The data has been reviewed and seal pop-open failures were re-binned to reflect the earlier potential onset of the "failure." Based on expected seal heatup, the stage local pressure and expected stage subcooling only the third stage was considered to be initially susceptible to pop-open for this binning. Thirty-eight (38) seal stages have been identified as having the potential for pop-open during loss of seal cooling events. This is based on events in which the seals were exposed to a LOSC event for at least 30 minutes and CBO was not isolated. For these events, six (6) stage failures were classed as pop-open failures. The pop-open failure rate was computed as 6/38 or 0.16. Pop-open failures were not seen to propagate upstream. As previously discussed, a pop-open failure of stage 3 would result in a reduction of subcooling for stage 2. Therefore, the above data was used to estimate the conditional probability of stage 2 experiencing a pop-open failure given that stage 3 had popped open. There were 6 events in which a stage 3 pop-open failure appears to have occurred and no evidence of any stage 2 pop-open failures. Based on the response to RAI 8, the failure probability is estimated as:

Q(0) = 1.0/(2*N) = 1.0/(2*6) = 0.08. However, the correlation between a pop-open failure of stage 3 and a pop-open failure of stage 2 is the fact that a stage 3 failure would expose stage 2 to pop-open conditions. Therefore, the same pop-open failure probability was used for both stage 3 and stage 2 for LOSC events where CBO was not isolated.

The present pop-open model is driven local conditions. The only time dependence included is that associated with the delayed onset of first stage pop-open conditions (see RAI 2). Section 9 of CE NPSD-1199-P has been revised to reflect the revised treatment of pop-open failures.

RAI 11

The time dependence for the probability of the pop-open failure of the RCP seal stages (pg. 9-12 ¶ 2 and pg. 9-13 Figure 9.2-2) does not appear to be valid. If the seal stage is subject to pop-open, pop-open will occur as soon as the appropriate thermal-hydraulic conditions are present (i.e., it is a demand failure, not a time-dependent failure). Unless a probability-versus-time curve can be developed for these thermal-hydraulic conditions, there is no justification for assuming a time dependence for the pop-open failure mode. For the quantification of the event trees and fault trees, the pop-open mode of failure should be assumed to occur (if it occurs at all) as soon as the thermal-hydraulic conditions are favorable for its occurrence. Please either (1) provide the analysis that supports the time dependence of the development of the thermal-hydraulic conditions that result in the pop-open failure mode, or (2) revise the resulting failure probabilities to reflect the fact that pop-open occurs (if it is going to occur) when the conditions are present and that it is not a time-dependent failure. Note that for the Rhodes model for Westinghouse RCPs, this time to the conditions for the second stage seal was assumed to be about 10 minutes.

RAI 11 Response

The time dependence arose as a result of observations of BJ/SU experiments and events. As discussed in the response to RAI 2, experiments did not exhibit the pop-open phenomena. A re-assessment of the data suggests that seals were more likely subject to a bistable condition that would produce only minor leakage (0 to 3 gpm). No event indicated the total inability of a seal stage to hold pressure. There was some evidence (see for example stage 3 and vapor stage in BJ/SU hot standby test) that a seal allowed a small amount of leakage (0.2 to 0.5 gpm). These behaviors were observed to be quasi-steady; the seal failures were classified as pop-open failures based on this behavior.

RAI 12

The CCF of RCP seal stages in different pumps exposed to the same conditions is not explicitly addressed in the topical report. The statement in Section 6.3.1 (pg. 6-6 ¶ 3) that multiple RCP seals will be exposed to the same environmental conditions is a strong argument for CCF consideration, but this paragraph concludes that the model treats the RCPs independently. The condition of the seal faces may be important. If the seal faces in one pump are worn, it is likely that the seal faces in the other pumps will also be worn. Please modify the model to address this CCF consideration or provide additional justification for not addressing these CCFs.

RAI 12 Response

As stated in Section 6.3.1, the model for failure of an RCP seal given loss of cooling presented in CE NPSD-1199-P is for the seal for a single RCP. An SBO initiator will affect all four RCP seals while a Loss of CCW will affect one or more RCPs depending upon the specifics of the initiator. All RCP seals that lose cooling as a result of the initiator will see equivalent environmental conditional and thus are potentially subject to common cause failure. The third paragraph of Section 6.3.1 of CE NPSD-1199-P will be revised as follows:

Existing:
"When all seals are exposed to the same environmental conditions, the probability of multiple RCP seal cartridge failures is established assuming the RCP failure response in each seal are independent of one another (See Section 9)."

Will be changed to:
"When multiple RCP seals are exposed to the same environmental conditions, the probability of multiple RCP seal cartridge failures should include a common cause factor to address the potential impact of common conditions. There is insufficient data available to calculate specific common cause factors such as β, γ, and δ. Therefore, engineering judgement is used in conjunction with the available operating experience data to estimate a common cause factor, Γ, which represents the probability that all affected RCP seals fail given that one of the affected RCP seals fails.

Table 8-1 presents the operating events involving loss of seal cooling to one or more RCPs. As shown on this table, there have been only nine events involving loss of cooling to multiple RCPs. Seven of these events involved loss of cooling to all 4 RCPs (ANO2-1, ANO2-1, FCS-1, FCS-3, PV3-1, SL1-2, and SL2-3), one event involved loss of cooling to 3 RCPs (WSES3-1) and one event involving loss of cooling to 2 RCPs (SL2-2). For one of the events (SL2-3) in which cooling was initially lost to all four RCPs, cooling was restored for two of the four RCPs after about 14 minutes. The time frames for which RCP seal cooling was lost in these events ranged from 0.1 hours up to 4.5 hours. None of the events resulted in a seal failure and only two of these events involved stage failures on multiple pumps. In both events involving stage failures on multiple RCPs, the information on the stage failures is limited, but they were most likely pop-open failures for stage 3.

This data is insufficient to calculate the common cause failure factors for multiple RCP seal failures given the failure of one RCP seal, but it does provide solid evidence that failure of all seals exposed to loss of seal cooling is not guaranteed given that one fails. However, as stated above, there is a potential for common cause failure of all seals exposed to a loss of seal cooling. Because of the time dependent thermal aspects of the seal failure mechanisms, the potential for common cause failure of the seals is judged to be relatively low early in the event but will increase as the exposure time increases. Using engineering judgement in conjunction with the operating experience data in Table 8-1, the following Γ factors will be used to estimate the potential for common cause failure of all RCP seals affected by a loss of cooling event given that one seal fails:

These parameters were estimated based on the following considerations:

RAI 13

The topical report concludes in Section 4.2 (pg. 4-2 ¶ 2) that each stage of an RCP must be individually evaluated because the failure mechanisms affect each individual stage differently. This conclusion may be correct, but it would then require RCP modeling to be extremely detailed and to consider or bound every possible condition that might occur for an individual stage as a result of the conditions and failures associated with the other stages, individually and in combination. Thus, the potential for cascading failures would also have to be explicitly modeled and the order of stage failures definitively described or bounded by the model. The need for this modeling is supported by the text in Section 5.3.3 (pg. 5-12 ¶ 2 and ¶ 4). However, the model does not provide this level of detail. Please clarify the intent of the stage modeling as described in Section 4.2 and explicitly address in the model and/or failure data the increased potential for stage failures, given that other stages are already failed, or justify why the topical report does not need to address this potential.

RAI 13 Response

The initial model considered a high probability potential pop-open relationship between stages 3 and 2. The lowermost and vapor stages are treated independently, i.e., failures in the middle seals are not propagated to either the lower or vapor seal. This feature is supported by observations of the BJ/SU and N-9000 SBO tests. By not crediting the benefit of backpressure, the model assumes pop-open potential whenever the upstream subcooling is adverse. A 50°F target is used even though experiments indicate that pop-open is not likely at that level, and if pop-open would occur at all it would occur much closer to saturated conditions. This treatment adequately models the seal failure probability for the condition when CBO is operational. The pop-open failure probability of each stage was considered the same for all stages.

For the CBO isolated condition, a constant pressure is applied to all seal stages. This results in a condition where the lower seal stages carry no load. The only seal load is felt across the vapor stage. The vapor stage will be highly subcooled as the local fluid will be at RCS pressure while the fluid temperature (depending upon the time of isolation) will be between 200 and 400°F. Thus, pop-open failure of the vapor stage is remote. So long as the vapor stage is intact, the probability of pop-open of the lower seal stages is negligible. If lower stages fail, the seal conditions are largely unchanged. If the vapor stage fails, a condition arises that was not modeled in the original report. While pop-open failures are remote, other failure possibilities exist such as failures due to existing defects or elastomer failures that would result in vapor stage bypass leakage (such as failure of the stationary face O-ring). While this does not imply a seal failure, the failure will restage the seals. Thus, the lower stages that previously were not subject to pop-open, again should be treated as if they were staged. The fault tree models in Section 6 of CE NPSD-1199-P have been revised to incorporate this failure scenario. The revised fault tree models are attached to these RAI responses.

RAI 14

A footnote to Table 9.2-4 (pg. 9-14) states that, for the seals other than the BJ/SU seals, the probability of pop-open was reduced by a factor of 10 from the estimates given for BJ/SU seals because of improved design features. The justification for this reduction is not supported by any analyses. Only one N-9000 seal has been exposed to pop-open conditions (i.e., the N-9000 test). This is insufficient data upon which to support the factor of 10 reduction in value shown in the last row of the table. Were the newer seals specifically designed to have low leakages under conditions when they were not cooled? Without additional data or experience, a value much less than the existing BJ/SU seal values does not appear warranted. Please provide additional justification for this reduction factor or for a more justifiable value for the "improved" seals. This comment also impacts Tables 9.2-5a through 9.2-5f (pp. 9-16 and 9-17).

RAI 14 Response

Elastomer seal failures were largely attributed to deterioration of the Nitrile U-cups of the BJ/SU seals. Similar failures were not observed for ethylene-propylene sealing materials used in the RCP seals. Since no seal stage failures were attributed to these alternate materials/designs, a factor of 10 reduction was placed on the elastomer failure model. This factor is consistent with the differences in the Nitrile and ethylene-propylene survivability curves (see RAI 1). These curves shows that for instances where a Nitrile seal will fail, an equivalent ethylene-propylene design will require much longer to fail (see Figure 3.4-1 of CE NPSD-1199-P). Newer seals are also designed to ensure small at-temperature gaps that reduce the possibility for extrusion. The operating experience has been used to estimate an elastomer failure rate for seals with Nitrile U-cups (see the revised Table 9.2-1 of CE NPSD-1199-P). Based on the information shown in Figure 3.4-1, the failure rates for seals that used only ethylene-propylene elastomers were estimated by shifting the Nitrile U-cup failure rates presented on Table 9.2-1 one time step to the right. Section 9.2.1 has been revised accordingly.

The likelihood of pop-open stage failure is also considered lower for the N-9000 seal than for it's BJ/SU predecessor. Whereas the BJ/SU test indicated small leakage during the SBO test (< 0.3 gpm), N-9000 leakage was controlled to about 0.04 gpm. Furthermore, the N-9000 seal has been designed such that when the seal is static the seal faces would be divergent, thus minimizing the potential for seal leakage (Reference 8). Based on this, the probability of pop-open failures for the N-9000 and Sulzer Balanced Stator seals is assumed to be a factor of two lower than for the BJ/SU seals as is shown in revised Section 9.2.2.

RAI 15

Please address the following comments and questions regarding the success criteria and conditions addressed in the environmental conditions event tree presented in Section 6.1 and the associated quantification information (Chapter 9).

1. The RCP1HR top event (pg. 6-2) uses one hour to define success. However, this success criterion is not consistent with the text presented elsewhere in the topical report that indicates the RCP seals are designed to remain intact when the pumps are operated for only about 30 minutes (pg. 5-7 § 5.3.2 ¶ 2, pg. 5-13 § 5.5 ¶ 1, and pg. 7-3 § 7.1.2 ¶ 5). What evidence is there that the seals will not fail when allowed to run this long? Please justify the success criterion for the RCPs being shutdown within one hour or use a shorter time that is supported by tests and operational experience, such as within 30 minutes. Use of a shorter time would also have to be reflected in the quantification data collection.

RAI 15 Response: The top event has been clarified. The definition of this event was an attempt to simplify the modeling. The selection of one hour as the time available to trip the RCP was based on tests and operating events that indicated that seals could be operated successfully for up to 40 minutes or more. As data for RCP seal operation without seal cooling for one hour is not available, this event will be redefined to require tripping the RCP within 20 minutes. This is conservative for this top event because the tests and operating events have demonstrated that an RCP can operate without seal cooling for 30 to 40 minutes without failing any seal stage.

2. As implied by the text for CBO Isolation (pg. 6-2), why will the seal assembly not heat up during the top event RCP1HR? Since the seal assembly should heat up with the RCP operating for up to 1 hour, the statement regarding isolation of CBO within 10 minutes becomes moot. This event assumes that the RCPs must have already been tripped, but there is a disconnect between the timing involved in the top events. This problem demonstrates the inter-relationship between the top events of the event tree that have not been completely considered in the model. Please provide a justification as to the appropriateness of the environmental conditions individually represented by the event tree top events or revise the event tree to reflect the inter-relationship of these top events. For example, the timing could be set for both top events, RCP tripping and CBO isolation, at a time (such as 20 minutes) that supports both top events through tests and operational experience.

RAI 15 Response: The intent was that when quantified, CBO Isolated early implies that both the RCP is tripped and CBO isolated by t = 20 minutes. At the end of the interval, vapor stage temperatures could reach 370°F and the other stage temperatures could be about 450 to 470°F. Tripping the RCP by this time would significantly limit seal degradation and avert pop-open as stage 3 subcooling at the Main Steam Safety Valve setpoint (~ 1000 psia would be > 50°F as T_{Sat} is about 540°F).

3. The topical report states (pg. 4-6 ¶ 4) that there is potential for cascading failures as the stages heat up; with the lower stage potentially failing first due to its initially higher temperature exposure. Then, over time, the upper stages may also fail as they reach the higher temperatures. The affect of CBO isolation appears to be a slowing of the heatup rate, and thus it takes more time to reach high temperatures in the upper seals. However, based on the text, the upper seals will still reach high temperatures eventually if the accident scenario is not terminated. Assumption 2 of Section 9.2.1 (pg. 9-7) implies that the upper stages are not affected at all if CBO is isolated within 20 minutes. This assumption is also not consistent with the discussion in the last sentence under CBO Isolation in Chapter 6 (pg. 6-2), which uses a one-hour duration for *isolating the CBO to define success. In the preceding paragraph of the Chapter 6 discussion, the topical; report states that isolation within 10 minutes will ensure temperatures of the upper seal component are sufficiently controlled. It adds that experience has shown that failure to isolate CBO within 20 minutes will result in a significant heatup rate of all seal stages. It seems from these statements that a conservative time would be about 10 to 20 minutes for the upper stages and even less for the lower stages, but clearly not as long as one hour. By counting events greater than 20 minutes in the data, the overall number of stages exposed is increased, which in effect lowers the failure probability for each interval. Please change the criterion to reflect the above experience or provide justification for use of a one-hour duration, as opposed to a shorter time. Also, please ensure that the success criterion in Chapter 6 matches the failure data development in Chapter 9. Further, it should be explicitly stated that, for those plants that do not require the CBO isolation, this branch of the event tree should be assumed failed.*

RAI 15 Response: The event tree model has been revised to reflect: (1) RCP operation for > 20 minutes without seal cooling will conservatively be assumed to result in a failure of the seal package, and (2) if the RCP is turned off and CBO isolated within 20 minutes, seal failure will be based on failure of seal stages exposed to subcooled conditions with seal stage temperatures which reflect isolation at 20 minutes. For loss of offsite power events where the RCPs are automatically tripped, isolation of the CBO can occur rapidly, so for this scenario, the fault tree models have also been quantified based on failure of seal stages exposed to subcooled conditions with seal stage temperatures which reflect isolation at 10 minutes. The HEP for this CBO Isolation timing would reflect the shorter time and plant-specific AOPs/EOPs. The revised event tree and fault tree models are attached.

4. The topical report states in Section 3.2.1 (pg. 3-5 ¶ 2) that the early CE BJ RCPs are likely to experience significant heat losses in the upper two stages, while more recent (i.e., System 80) RCP stages are well insulated. It further states that the impact of this heat loss arrangement is significant during RCP seal accident scenarios. However, it is not clear that this consideration has been taken into account in the modeling. Please clarify how this difference in specific RCP designs, including Sulzer RCPs, is addressed by the RCP seal failure model and failure data.

RAI 15 Response: The referenced System 80 RCP seals were the KSB RCP seal design; this seal design is no longer used in the United States. The three stage seal currently used at Palo Verde is expected to exhibit temperature behaviors typical of the N-9000 test, which used a three stage pump seal. The lower temperatures noted in this test included the effect of heat losses but were primarily the result of the saturated conditions that result from flashing of the high enthalpy fluid as it enters the cavity of the last seal stage.

5. It appears from the information presented (pp. 5-10 and 5-11) that, for the vapor stage, the temperature is actually higher if the CBO is isolated late as opposed to not being isolated at all. Please explain what is meant by "late" (i.e., how much time after the LOCCW makes its isolation late). Also, please explain how this condition is reflected in the model since the model only addresses isolation within one hour or not. (In other words, it does not differentiate between late isolation and no isolation though there is a difference in conditions apparent for the vapor stage).

RAI 15 Response: See responses to RAI 3 and to item 4 above.

6. End states RCPF-9 through RCPF-16 reflect the condition in which CBO isolation does not occur within the first hour. As such, these end states should have a more rapid heatup of the upper seal stages then the other end states (i.e., RCPF-1 through RCPF-8), leading to earlier and more likely failure of the upper stages. However, Chapter 9 (e.g., Table 9.3-1, pg. 9-22) does not *show any differences in some of these probabilities for similar scenarios (e.g., RCPF-13 and RCPF-5). How is this conditional difference reflected in the model and the quantification?*

RAI 15 Response: The elastomer failure probabilities presented in Table 9.3-1 were based on the operating experience data presented in Table 9.2-1. CBO was not isolated for all but one event presented in Table 9.2-1; the event where CBO was isolated was the Palo Verde test and lasted only 0.6 hours. Thus, the elastomer failure probabilities used in Table 9.3-1 are representative of the "CBO Not Isolated" condition and as such the quantification for endpoints RCPF-1 through RCPF-8 is conservative. Section 9 been revised to clarify the quantification of the model (see also the responses to RAI 18.) The revised Section 9.2.2 explicitly defines each value used in the quantification of the model for each seal design. Tables 9.3-1, 9.3-2 and 9.3-3 have been restructured to make the quantification easier to see and to provide explicit pointers to Section 9.2.2 for each value used.

7. The conditions reflected by the end states are very specific to the top events and will differ considerably based on the assumptions in the model. As an example, RCPF-1 reflects the condition in which the RCP may have operated for up to one hour after the event, the CBO may have been left unisolated for up to one hour after the event, the RCS may have been just 50°F subcooled, and the seals may have had a thermal exposure of up to one hour. It does not appear that these worst-case conditions are used to establish the conditions experienced by the RCP seal stages. Are these conditions used to determine the probabilities of survivability of the seal stages for this end state or was a less severe condition assumed? If the latter, please ensure the event tree success criteria are consistent with the event tree modeled conditions and resulting end states.

RAI 15 Response: As noted above, the model has been revised to change the timing for tripping the RCP and isolating CBO. Furthermore, the definition of the endpoints has been revised to facilitate implementation of the updated pop-open model as shown by the revised event tree, attached. Also, as noted in the response to item 6 of this RAI, Section 9 has been revised to clarify the quantification of the model. The revised Section 9.2.2 explicitly defines each value used in the quantification of the model for each seal design. Tables 9.3-1, 9.3-2 and 9.3-3 have been restructured to make the quantification easier to see and to provide explicit pointers to Section 9.2.2 for each value used.

RAI 16

Please address the following comments and questions regarding the modeling and conditions addressed in the RCP seal failure/leak model presented in Section 6.2 and the associated quantification information (Chapter 9).

1. The fault logic model in Chapter 6 (pp. 6-8 and 6-11) contains the potential conditional pop-open failure of stage 2 due to the failure of stage 3, but it does not include the potential for stage 2 to independently pop-open. Likewise, Table 9.2-3 (pg. 9-12) does not address the potential for an independent failure of the second stage (P02) in addition to it being coupled with the third stage (P03). Both potential events (i.e., coupled failure and independent failure of P02) need to be addressed in the model and reflected in the data because both events could occur. This comment also impacts Tables 9.2-5a through 9.2-5f (pp. 9-16 and 9-17).

RAI 16 Response: Given a loss of seal cooling with CBO not isolated, the first stage seal will have more than 100°F subcooling, the second stage seal will have just over 50°F subcooling and the third stage seal will have just under 50°F subcooling. The vapor stage is not subcooled but the pressures are not high enough to challenge the seal as shown by operating events. Thus, operating events demonstrate that the third stage is the stage most likely to pop-open or fail. Given failure of stage 3, the subcooling for stage 2 will be reduced thereby increasing the likelihood that stage 2 will pop-open, as represented in the model. The independent pop-open failure for stage 2 is about two orders of magnitude lower and would still require a failure of the third stage before a seal failure could occur. The failure of stage 3 does impact the subcooling for the first stage or the vapor stage so there is no coupling between a failure of the third stage and failure of the first stage.

Failure of the first stage due to pop-open or any other mechanism would increase the subcooling for both the second and third stage and thus reduce their potential for pop-open failures. This beneficial coupling was not modeled.

Likewise, a failure of stage two for any reason would increase the inlet pressure to and hence the subcooling for the third stage. Again, this beneficial coupling was not modeled. With CBO not isolated, failure of the vapor stage would not affect the subcooling of the lower stages so there would be no coupling to the failure potential of the lower stages.

2. The "Impact of Failure Mechanism on Stage" column (pp. 4-18 and 4-19) indicates that, for every stage except the vapor stage, there should be no cause for pop-open if the CBO is isolated. However, this does not seem consistent with the model and Condition 2 of Section 9.2.3 (pg. 9-12), which applies to the specific condition of the CBO being isolated and the RCS being saturated. Please explain this inconsistency.

RAI 16 Response: When CBO is isolated, there is no flow through the seal stages. The entire pressure drop is taken across the vapor stage so there is no pressure drop across the first, second or third stages. Given that the pressure is the same on both sides of the first, second and third stages, there is no potential for a pop-open of these stages. However, should the fourth stage fail, flow through the lower stages will be re-established and they will re-stage. These stages will then be subject to pop open as represented in the model. In essence, the model assumes that stage four fails first.

3. It is stated in Section 6.2.2 (pg. 6-5 ¶ 1) that there is an increased potential for the second-stage seals to pop-open in the 3-stage model as compared to the 4-stage model, but this does not *seem to be reflected in the numbers presented in Chapter 9 (pp. 9-22 through 9-24). How is this increased potential for pop-open failure reflected in the model?*

RAI 16 Response: For a loss of seal cooling event with CBO not isolated, the subcooling of the first stage is governed by the subcooling of the RCS cold leg and is not affected by the condition of the stages above it. The second stage in the three stage seal design has less subcooling than the second stage in the four stage seal, but it is still slightly greater than 50°F. Failure of the second stage would not affect the first stage and would increase the subcooling of the third stage. If the third stage fails, the subcooling in the second stage will become slightly less than 50°F and thus would become subject to pop-open. In the revised model, the second stage in the three stage seal design is modeled like the third stage seal in the four stage seal design. Sections 6 and 9 of CE NPSD-1199-P have been revised extensively in response to these RAIs. The revised sections are attached. Table 9.2-12 of the revision summarizes the event data used to quantify the probability of pop-open failures.

4. The potential for conditional pop-open failure of a stage is only applied to stage 2, which is dependent upon stage 3 failure. Why are the other stages not likewise dependent? For example, if stage 2 fails, why doesn't this cause the potential for increasing the failure likelihood of stage 1, or stage 4 failure causing the failure of stage 3? In particular, there seems to be an inconsistency between the 3-stage model and the 4-stage model in this regard.

RAI 16 Response: See response to item 1 above.

5. The discussion in Section 9.1 (pg. 9-2 ¶ 2) on the coupling of stages 2 and 3 is tied to the CBO not being isolated. Please justify why this coupling cannot occur when CBO is isolated. Absent such justification, please explain the impact of the possible condition on modeling and failure data development.

RAI 16 Response: When CBO is isolated, there is no flow through the seal stages. The entire pressure drop is taken across the vapor stage so there is no pressure drop across the first, second or third stages. Given that the pressure is the same on both sides of both the second and third stage, there is no potential for a pop open and thus no coupling of the potential for pop-open failure between stages 2 and 3 when CBO is isolated.

RAI 17

Chapter 10 of the topical report provides two sample cases. However, these cases are very narrowly focused and contain a number of simplifying assumptions. These cases do not demonstrate the utility and complexity of the CEOG RCP seal model, and they raise questions regarding the assumptions used in the sample. For example, why is it assumed that the operators trip the RCPs instead of using a human error probability estimate for this branch probability? Why is recovery limited to four hours instead of over the whole mission time, which may vary? Why is the RCS assumed subcooled? What is the impact if there is a common cause CCW dependency? These unanswered questions lead to the conclusion that the full and proper use of the CEOG RCP seal model is not clearly presented. A complete sample application that shows its use in a plant's PRA, with step-by-step results, should be provided to better demonstrate the utility and complexity of the model, use of the data, and integration into a PRA.

RAI 17 Response

The first paragraph of Section 10.0 states that the calculations are illustrative only; they were not intended to represent any plant or group of plants, nor their PRA models. The model presented in Section 6.2 is for failure of a single RCP seal given loss of cooling to that seal. This model is intended to be inserted into a given utility's PRA model to cover the potential for RCP seal failure for sequences that would result in loss of cooling to one or more RCPs. As illustrated by the event tree model presented in Figure 6.1-1, the potential for failure of an RCP seal given loss of seal cooling is influenced by plant conditions and actions associated with the sequences of interest. The exact status of plant conditions, their associated probabilities and the potential for human actions are highly dependent on the sequence of interest and are plant specific. As with all other aspects of the overall PRA, it is the responsibility of the utility to determine all sequences where this model is required and to properly identify the associated plant status at the time of occurrence for each specific sequence and for properly determining the appropriate human actions and HEPs. The sample calculations are illustrative only and were deliberately kept at a high level to avoid the appearance that they represented a complete calculation.

RAI 18

The following attachment provides typographical, editorial, consistency, clarification, and calculational comments on the topical report. Please address these items in the revision to the topical report. A formal response to them as part of the response to the RAI is not required or desired, except for those with which the CEOG may disagree.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
General	*The topical report uses the word "stage" as a subcomponent of a RCP "seal." However, there are numerous places throughout the topical report where "seal" is used when "stage" is intended. To a lesser degree there are places where "stage" is used when "seal" is intended. These inconsistent uses of these words need to be corrected so that the proper meaning is conveyed.*
Response	Text was revised as appropriate throughout report.
pg. 3-4 ¶ 3	*The topical report states that the CBO water flows at a rate of 0.6 to 1.5 gpm during normal operations, but Table 3.2-1 (pg. 3-3) shows a design flow rate of 1.0 to 3.0 gpm for various plants (1.0 to 1.5 gpm without CE System 80 RCPs), with low and high flow rate alarms ranging from 0.75 to 6.0 gpm (0.75 to 2.25 gpm without CE System 80 RCPs), respectively. Also, these values differ from those presented in the CBO definition (pg. 2-1). Please clarify these apparent inconsistencies.*
Response	The text was revised to be consistent with Table 3.2-1.
pg. 3-5 § 3.2.1	*The topical report states in that all RCP seal stages are designed to seal at 2500 psig with the pump stationary. However, it is possible that the seal stages are designed to seal at 2500 psig when the seal stages are cooled and that they may not be designed to seal at 2500 psig when the seal stages are not cooled. Please clarify the conditions under which the pumps are designed to seal at 2500 psig.*
Response:	The seals are designed for 2500 psig and [ ]. Elastomers have been demonstrated to survive at a pressure of 2500 psig and [ ]. (See RAIs 1, 2 and 3) The N-9000 test demonstrated the integrity of the vapor stage under SBO conditions at a pressure of 2500 psig.
pg. 3-9	*The Table 3.3-1 flow capacity entry for Arkansas 2 is not provided.*
Response	The CBO Isolation Line Relief valve flow rate is 22 gpm. This value was inadvertently omitted from Table 3.3-1. The corrected version of this table is provided with the responses to these RAIs.
pg. 3-10	*Figure 3.3-1 misidentifies the third RCP as RCP 4; it should be RCP 3.*
Response	Figure 3.3-1 was corrected. The corrected version of this figure is provided with the responses to these RAIs.
pg. 4-1 § 4.1 ¶ 1	*This section divides RCP seal failures into three categories. Please clarify how each of these failure categories is reflected in the RCP seal failure model in Chapter 6. If a category is not reflected, please provide a justification for why this category of failures does not need to be considered in the RCP seal failure model.*
Response	Section 4.1 provides a discussion of operating failures encountered during the early years of plant operation to indicate the type of problems that lead to concerns about RCP seal reliability. The model presented in this report is for RCP seal failure given loss of seal cooling. The other operational failure mechanisms are addressed only implicitly in the

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
	model to the extent that they could contribute to the potential for a pre-existing stage failure or a random stage failure.
pp. 4-4 & 4-5, 4-8 - 4-15, and 4-18 & 4-19	*These tables provide qualitative information regarding the impacts of various conditions and failure mechanisms on the stages, but it is not clear how this information is reflected in the RCP seal failure model. It does not appear that the model explicitly addresses all the potential impacts and conditions identified in these tables. Please explain how the information presented in these tables was used in developing the RCP seal failure model. If some impacts are not reflected, please provide the justification for ignoring these potential impacts. Further, it would be helpful in understanding the impacts better if some quantitative information (e.g., resulting leakage flowrate) was also included in these tables.*
Response:	The information presented in these tables is a qualitative evaluation performed prior to the development of the model and provides supplementary background information. This information is not used directly in the model. The model reflects the key failure mechanisms described in the BNL Report (BNL Technical Report W6211-08/99, "Guidance Document for Modeling of RCP Seal Failures," Martinez-Guridi, G., et. al., August 1999.). The RCP seal stage model lumps binding and elastomer failure together. Failure probability is based on test data and event observations. Leakage information is contained in Tables 5.2-1 and 5.2-2.
pp. 4-6 ¶ 2 and 4-16 ¶ 2	*These paragraphs identify the potential inter-relationships between different failure mechanisms of RCP seal stages, which do not appear to have been reflected in the follow-on tables, the RCP seal failure model in Chapter 6, or the quantification in Chapter 9. Please explain how the model reflects how one failure mechanism on one stage may directly lead to or contribute to a different failure mechanism in another stage. If these failure mechanisms are treated as independent events, please justify this treatment, especially in light of its apparent inconsistency with these paragraphs.*
Response:	With regard to page 4-6, ¶ 2, the impact between binding and pop-open was considered appropriately by treating pop-open as an unrecoverable process. That is, if all seal stages fail, a LOCA is initiated and restoration of CCW was not considered as a mechanism for terminating the LOCA. Recovery of power/CCW following the initiation of a LOCA is considered as a recovery mechanism to the extent that recovery of CCW and power permits mitigation of the LOCA. Recovery of power/CCW prior to failure of all seal stages is considered to preclude the LOCA because the intact stages will remain intact.
Pg. 4-7 ¶ 2	*The concluding sentence of this paragraph is ambiguous. Are there any BJ or Sulzer seals in use that do not utilize "qualified seals constructed of ethylene propylene" (i.e., potentially containing Nitrile compounds)?*
Response	At the time the original report was prepared, Fort Calhoun had the original BJ/SU seals with Nitrile cups. However, Fort Calhoun will install Flowserve N-9000 seal packages on all RCPs during their May 2002 outage.
pp. 5-2 & 5-3	*Table 5.2-1 refers to plant-specific Table 5.2-3 (pg. 5-3) for two conditions, but Table 5.2-3 only addresses the catastrophic failure of all RCP seal stages. Do these leakage rates also apply to the conditions when the vapor seal is intact, but the other stages are failed catastrophically? If not, please provide the additional leakage rates for this condition directly in Table 5.2-1 or explain how it is addressed in the model, or, if it is plant-specific, provide another table to present this information.*
Response	The fourth entry in Table 5.2-1 is somewhat misleading. If all three lower PBDs failed catastrophically and the vapor stage is intact, the CBO flow would be limited by one of 3 factors. If CBO is fully isolated, the leakage flow would be limited by the leakage through

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
	the intact vapor stage seal, which would be small. If CBO is not isolated, then the CBO flow rate would be limited by the flow limiting check valves which, depending on the plant, will limit flow to between 10 and 15 gpm. If CBO flow is not isolated and the excess flow check valve fails, the values in Table 5.2-3 would bound the absolute maximum possible leakage rates because these values represent the maximum possible flow through the RCP thermal barriers and into the seals. Table 5.2-1 has been accordingly.
Pg. 5-6	*What is the source of information for Table 5.3-1 and 5.3-2a?*
Response	The information contained in the tables is a composite based on observations from BJ/SU SBO and LOCCW tests (References 1 and 2 respectively) and seal stage hydrodynamic characteristics. That is, the BJ/SU SONGS LOCCW tests indicated seal heatup such that 10 minutes after the onset of the event, the seal stage temperatures vary from 250°F for the vapor stage and 300 – 350°F for the lower stages. For SBO conditions (RCP off), a somewhat slower heatup would be expected. It was assumed that when CBO is isolated early, the temperature distribution in the seal would be relatively low and well below saturation conditions. The 1000 psia system pressure is based on the steam generator set-point pressure (Tsat ≈ 540°F). When CBO is isolated, this pressure is applied to all stages. The CBO isolated late case is based on both BJ/SU tests. Extended heatup would allow temperatures to reach a near equilibrium condition with the lower stages at 515°F to 525°F and the vapor stage around 400°F (see attached Figures 1, 2 and 3). Late isolation does not avert heatup of the stages. However, with late CBO isolation, the seal de-stages due to the loss of flow through the PDBs and all stages see the same pressure. Under these conditions, the vapor stage provides the final seal. Under the temperature and pressure conditions associated with the late CBO isolation, the vapor stage has sufficient subcooling to preclude the potential for seal stage pop-open failures. The CBO not isolated case is based on observations in the FPL BJ/SU SBO test. Variations in the vapor stage pressure were observed during that test. The point used in the vapor stage assessment was assumed to be slightly above the typical VCT pressure of ~ 50 psig and the stage was assumed to be saturated. In the 70 hour test, conditions in this region varied from 50 to almost 700 psi and temperatures from 250°F to 400°F.
pg. 5-9	*What is the meaning of the last line of Table 5.3-3, "RCS Pressure for RCP to Reseat"?*
Response	The RCP has upper and lower stops to limit shaft motion. When the plant is shutdown, the RCPs sit on the lower stop. At the plant starts up and increases pressure, there is a point at which the system pressure offsets the weight of the RCP motor, so that as the pressure increases, the pump shaft moves upward towards the upper stop. During normal operation at normal system pressure (~ 2250 psia) the pump operates with the shaft at or near the upper stop. As the plant shuts down, the reverse process occurs so that when the system pressure drops below the point at which it just matches the downward force due to gravity acting on the pump motor, the whole assembly will reseat on the lower stop and there will be no further downward motion.
pp. 5-10 & 5-11	*What is the source of information for Tables 5.3-4a, 5.3-4b, 5.3-4c, 5.3-5a, 5.3-5b, and 5.3-5c?*
Response:	See response to question about Tables 5.3-1 and 5.3-2A, above. Temperature data is extrapolated from BJ/SU SBO/LOCCW tests (References 1 & 2 respectively). Also note that for the CBO not isolated cases, stage pressures are based on fully operational PBDs and nominal CBO flows. In the 4 stage seals, the PBDs produce equal stage pressure drops.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
pg. 5-11	*The CBO Isolation Early Temperature entry for Seal Cavity 1 is not provided in Table 5.3-5a.*
Response	The temperature should be 300°F. The "3" was inadvertently omitted. Table 5.3-3a, attached, has been revised.
pg. 5-13 & 5-14 § 5.6 ¶ 1	*How is this information on RCP motor performance utilized in the RCP seal failure modeling? It appears from the text that some utilities have postulated or assumed that the RCP motors fail on a LOCCW, thus eliminating the potential for a RCP to operate during these events. However, as this section indicates, that assumption is not supported by the events and experimentation. The assumption essentially is taking credit for an assumed beneficial failure to avoid a worse situation. As presented, this assumption is not appropriate and should be corrected in existing models that use it to avoid having to address the continued operation of RCPs during a LOCCW.*
Response	The information in § 5.6 ¶ 1 is not directly used in the RCP seal failure model. Section 6.2 presents the model for failure of an RCP seal given loss of seal cooling and Section 6.1 presents an event tree which delineates the environment conditions which impact the quantification of the seal failure model. As can be seen from Figure 6.1-1 and the associated discussions, one of the key factors that influences the failure likelihood of the seal is whether or not the RCP has been tripped. When a utility incorporates the seal failure model at the appropriate places in their PRA, they are responsible for determining the appropriate environmental conditions and for establishing the appropriate split fractions for each of the key environment conditions discussed in Section 6.1. With respect to tripping the RCP, the split fraction would be 1.0 for loss of offsite power while the split fraction for a loss of CCW event would typically be based on the probability that the operators would trip the RCPs in time given the loss of CCW. Failure of the RCP motor itself as a direct result of the loss of CCW had also been postulated as a way in which the pumps might be stopped. (Note that this would be considered a consequential failure, not a "beneficial" failure.) Section 5.6 discusses this mechanism and provides evidence that the pump motor would most likely not fail within the time frame of interest. While it is still the utility's responsibility to select values appropriate for their plant, the following sentence has been added to the end of the first paragraph in Section 5.6, as revised: "Given this information, utilities should not credit failure of the RCP motor as a means of stopping the RCP given loss of CCW unless they have documentation that loss of cooling to the pump motors will result failure of the motors within the time frame of interest for their RCPs."
pg. 6-3 *§ T-EXP*	*This breakdown of exposure times seems very detailed, without any apparent corresponding benefit. It seems the model could be greatly simplified if the thermal exposure categories were reduced to two (e.g., thermal exposures less than 1 hour and exposures greater than 1 hour)?*
Response:	The breakdown of exposure times is based on typical battery depletion times and offsite power recovery times used in most SBO PRA models. These exposure times are needed to support the recovery analyses.
Pg. 6-4	*For the last column, T-EXP (Thermal Exposure Time), the event tree branches leading to the identified end states all only represent the failure branch for the individually identified time exposure intervals. Each branch under T-EXP should also reflect a success branch, or this top event could be expanded to reflect the progressive success and failure paths. For example, the event tree could include top event T-EXP1 (success or failure of stage within first hour of exposure), then top event T-EXP2 (success or failure of stage during second hour of exposure if it survived the first hour) and so on.*

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Pg. 6-5 § 6.2.1 ¶ 2, pg. 9-11 § 9.2.2 ¶ 1, and pg. 9-20 § 9.2.5	*It is not clear why the pre-existing seal stage failures are limited to one RCP or why there could not be more than one stage failure in a given year. It seems that plants could operate with a degraded or failed stage on multiple RCPs or that multiple failures could occur throughout a year, especially if considering the potential for design/manufacturing errors. Either the potential for multiple pre-existing failures, including manufactured defects, should be included in the model, or a justification for why this condition cannot occur should be presented. Further, the text in Section 9.2.5 should clearly indicate the rationale for assuming that there cannot be a pre-existing failure at the startup of the plant to support its calculation at the end of this section that uses a 0.5 multiple with the year.*
Response:	As discussed in Section 9.2.2 of the report, the assertion that an operating plant could expect to experience one operating RCP seal stage failure per year on average was based on a brief review of recent plant operating experience. This information indicated that CE plants see one or fewer stage failures in any given year. The model, therefore, assumed that there would be one stage failure event per year per plant. The likelihood that a given stage would be the stage that failed is 1/16 except for Palo Verde which would be 1/12. Given that a specific stage does fail, that failure can occur anywhere in time, from T = 0 to T = 1 year, with equal likelihood. Thus, the plant could run with a failed stage for anywhere from a full year to essentially no time. The potential challenge (the loss of seal cooling) also occurs randomly in time so, on the average, the probability that the stage failure occurs before the challenge is 0.5. The pre-existing stage failures on a given pump are treated as mutually exclusive because a plant will shutdown should a second stage fail on a given pump. Thus, the window of exposure for multiple pre-existing stage failures on a given pump would be extremely small. As previously discussed, the seal failure model presented in CE NPSD-1199-P is for a single seal package only. When this model is incorporated in the plant PRAs, the plant must account for the fact that the output of this model is the probability that a specific seal will fail and that the overall probability must reflect that this failure could occur on any one (or more) of four RCPs. This is done by multiplying the base probability by four to account for all of the RCPs. The text in Section 9.2.5 points to Section 8.1.2. This section does not exist. The text has been modified to point to Section 9.2.2.
Pp. 6-7 & 6-8	*The "RCP Stage 2 Fails" gate should be SF003, not SF002.*
Response:	Figure 6.2-1, attached, has been modified to address this issue as well as the issue discussed in the next item.
Pg. 9-2 § 9.1 ¶ 1	*The equation's nomenclature is not consistent with the fault tree nomenclature (pp. 6-7 – 6-11). To avoid confusion, the nomenclature should be made consistent.*
Response:	The equation on page 9-2 has been revised to read as follows: $$\text{Probability of RCP Seal Failure} = \prod_{N=1}^{N = \text{total stages}} (\text{SFOON})$$ Figure 6.2-1 has been also been revised so that the gate names reflect the appropriate seal stage consistent with the equation on page 9-2. (See response to previous item.)
pg. 9-9	*The entry for event FCS-2 for the duration between 1 and 2 hours should be blank, not 12, and the ensuing calculations in this column should reflect this change.*
Response:	Table 9.2-1, attached, has been revised.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Pg. 9-11 § 9.2.2 ¶ 1	*The parenthetical calculated λ does not include the apparent consideration of the number of stages at a plant. The equation is also incorrectly shown. Based on the presented information, the random stage failure rate should be:* *λ = (1 stage failure/16 total stages) / (1 year * 8760 hours/year * 0.75)* *= 9.5E-6 failures/hour*
Response:	Section 9.2.2 and Table 9.2-2, attached, have been revised. Note that the time interval 0 < T < 24 hrs was also added to provide coverage for longer time intervals.
Pg. 9-11 § 9.2.2 ¶ 2	*The estimated random seal degradation value for PVNGS does not include the 0.75 plant availability factor as used for the other plants. This would increase the degradation rate to:* *λ = (2 stages degraded/36 stages) / (6 years * 8760 hours/year * 0.75)* *= 1.4E-6 degraded/hour*
Response:	Section 9.2.2 and Table 9.2-2, attached, have been revised.
Pg. 9-11	*The last column in Table 9.2-2 is not based on a 24-hour mission time, but rather, uses a calculation time of 10 hours. This column should either use a 24-hour mission time or justify the use of a shorter time. In either case, the text should state that the plant-specific implementation needs to assess the appropriateness of the mission time used in this column and to adjust the failure rates accordingly.*
Response:	The time interval 0 < T < 24 has been added to Table 9.2-2. A copy of the revised table is attached.
pg. 9-12 ¶ 2	*The concluding paragraph ends with the statement that only events where CBO was not isolated were assumed to contribute to the failure mode of pop-open, but then the conditions identified below this paragraph involve the condition when the CBO is isolated. This apparent discrepancy needs to be clarified.*
Response:	The sentence refers to the selection of data used to quantify pop-open failures. Even though pop-open is not considered credible given a high degree of subcooling, a failure probability of 0.001 was applied. Section 9.2.3, attached, has been modified to discuss pop-open failures.
Pg. 9-18	*In Table 9.2-6a, the probability of failure for the third stage is supposed to be the same as for the prior Table 9.2-5c per the preceding text (pg. 9-18), but the "less than one hour" entry is an order of magnitude lower. Likewise, the third stage entries in Table 9.2-6b are not consistent with those of Table 9.2-5d, and the third stage entries in Table 9.2-6c are not consistent with those of Table 9.2-5f. Please correct these inconsistencies.*
Response:	These tables have been restructured based on a re-review of the data.
Pg. 9-19	*The text indicates that saturation conditions are assumed to exist at all stages and that this is conservative for the fourth-stage vapor seal, but then the fourth-stage entries in Tables 9.2-7a through 9.2-7c (pg. 9-19) use the values derive for subcooled conditions instead of the values derived from the data, which are supposedly associated with saturation conditions. Please correct the inconsistency between the text and the resulting tables.*
Response:	Vapor stage performance is unique. During LOCCW or SBO events, vapor stages, when CBO is not isolated, operate under low pressure saturated conditions. BJ/SU seals have been operated 50 – 70 hours under CBO not isolated conditions without experiencing pop-open. Also, in the events and tests where the vapor stage was exposed to SBO conditions, no pop-open event has occurred. Based on the positive past performance and the less

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
	adverse operating conditions, vapor stage pop-open was treated as a low probability failure. In the case of the N-9000 seals, this is further supported by their observation based on structural analyses which indicates that under "static" SBO conditions, the seal stage faces would be divergent and not subject to pop-open.
Pg. 9-19	*Table 9.2-7c third-stage entries are stated earlier in the topical report (pg. 9-17) to be one-half the improved seal stage value for this stage. However, this entry is only one-third the value. Please correct or explain this inconsistency.*
Response:	These tables have been restructured based on a re-review of the data.
pg. 9-20 § 9.2.5	*It is not clear why credit is taken for plant availability in the calculation in Section 9.2.5, as it is not contingent on the operation of the plant to determine the time to failure. Please remove the availability factor from the equation and revise the calculation.*
Response:	The calculation has been revised as shown in Section 9.2.5, attached.
pg. 9-25	*Table 9.3-4 should include end state RCPF17 so that the sum of the end states equals one.*
Response:	The event tree and fault tree models in Section 6 of the topical have been revised in response to these RAIs. Endpoint RCPF17 has been renamed as RCPF21. RCPF21 represents guaranteed failure of the RCP seal given that the RCP is not tripped within 1 hour. The probability of this endpoint would be calculated using plant specific HEPs for the top event "RCPs Secured within 20 Minutes." The conditional seal failure probability given failure to secure the RCPs is 1.0. This is equivalent to the other conditional seal failure probabilities presented in Table 9.3-4. The other top events in the event tree also require plant-specific failure probabilities which are not within the scope of this report.

ATTACHMENT A

REFERENCES FOR RAI RESPONSES

RAI REFERENCES:

1. "O Ring Static Seal Performance Evaluation Under Loss of Component cooling Water to Reactor Coolant Pump at SONGS Units 2 and 3," Kalsi Engineering, Inc., March 1986

2. TR-ESE-754, "Test Report for the Performance Test of a Byron Jackson Pump Seal Cartridge under Simulated Plant Loss of Cooling Conditions," Combustion Engineering, Inc., June 1988.

3. GS-1543, "Loss of Component Cooling Water to the Reactor Coolant Pump Seal Cartridge on Hot Standby," Byron Jackson Pump Division, November 1980

4. NUREG/CR-4821, EGG-2492, AECL-9342, "Reactor Coolant Shaft Stability During Station Blackout," Rhodes, D. B. et. Al., EG&G Idaho, Inc., May 1987 (page 7)

5. CENPD-282-P-A, Technical Manual for CENTS (Combustion Engineering Nuclear Transient Simulation) Computer Code, February, 1991

6. BNL-TR W6211-08/99, "Guidance Document for Modeling of RCP Seal Failures," Ruger, C. et al, BNL, August, 1999

7. GS-1520," Loss of Component Cooling Water to the Reactor Coolant Test on Nuclear Reactor Coolant Pump," Byron Jackson Pump Division, May 1979.

8. "Station Blackout Test on a Reactor Coolant Pump Mechanical Seal", Marsi, J. A., Fifth International Workshop on Main Coolant Pumps, April 21-24, 1992, Orlando, Florida

9. CEN-152, Revision 5.0, Combustion Engineering Emergency Procedures Guidelines, Prepared for the CE Owners Group by Combustion Engineering, December, 1999

10. Atwood, Corwin. L.; *Hits per Trial: Basic Analysis of Binomial Date*; EGG-RAAM-11041, Prepared by Idaho National Engineering Laboratory for the Reliability and Risk Analysis Branch, Safety Programs Division, Office for Analysis and Evaluation of Operational Data, U.S. Nuclear Regulatory Commission; September, 1994

11. Box, George E. P., and Tiao, George C.; 1973, *Bayesian Inference in Statistical Analysis,* Reading, MA; Addison-Wesley

ATTACHMENT B

FIGURES FOR RAI RESPONSES

ATTACHMENT C

TYPICAL REVISIONS TO BE INCORPORATED INTO CE NPSD-1199-NP, Rev 01

Table 3.3-1
CBO Relief Valve Set Pressures and Flow Capacities

Table 5.3-5a
3-Stage Seal Design
Representative Post-Accident Conditions following a LOCCW Event
Plant Placed In Hot Standby (RCS Pressure assumed = 1800 psia)

5.6 Failure of RCP Motor

Loss of CCW may also result in loss of cooling to the RCP motor. The ability of the pump motor to survive an extended loss of cooling is not well understood. Some utilities have postulated that, given a loss of component cooling water, failure of the RCP motor may occur prior to RCP seal cartridge failure. However, loss of CCW to RCPs has been tested for the System 80 RCP motors and they were able to survive a thirty-minute interval with no cooling. RCP motor performance tests were also included in the SONGS BJ SU seal experimental test program[27]. These tests confirmed acceptable motor performance for a greater than 20 minute duration. Fort Calhoun operated their RCPs for a period of 45 minutes without CCW and did not experience a motor failure. Given this information, utilities should not credit failure of the RCP motor as a means of stopping the RCP given loss of CCW unless they have definitive documentation that this failure will occur within the time frame of interest for their RCPs.

8.0 LOSS OF SEAL COOLING EVENTS AT OPERATING PLANTS

Operating events at nuclear plants has provided additional evidence for the robustness of the multistage RCP seal used by CE PWRs. Over the past twenty five years, twenty one total Loss of RCP Seal Cooling events have occurred at CE PWRs. Most of these events occurred in the early years of plant operation. The Loss of Seal Cooling events varied in duration from very short (under 10 minutes) to greater than four hours. Several events included extended RCP operation. However, no LOSC event that occurred at a CE plant has resulted in failure of a single seal cartridge. This section assembles and summarizes the significant LOSC events at CE plants since 1974. The event data is presented in Table 8-1 and is arranged first by plant, and then chronologically. The information contained in Table 8-1 includes:

Plant Name/Event ID:	A unique event identifier to allow event to be readily referenced in Section 9, and consistent with earlier versions of CEOG RCP Seal reports
Date of the event	
Type of RCP seal:	To date, LOSC challenges have occurred only for BJ/SU and KSB RCP seal designs
Event category:	SBO, LOCCW or LOCCW/Loss of Safety Injection
Duration of event	The duration of concern is the time interval from the initial loss of seal cooling to seal cooling restoration.
Description of the event	Information was extracted from several sources including event LERs, staff interviews, utility internal reports and other related information notices.
Status of Controlled Bleedoff (CBO)	Established based on direct reports, procedural expectations or review of cavity pressure data.

Table 8-1
CE Plant Operating Events Leading to Loss of RCP Seal Cooling

Plant Name	Date of Event	Event No.	RCP Seal Type	Event Category	Duration (hrs)	CBO Isolated ?	Stage Fails	Event Description

Table 8-1
CE Plant Operating Events Leading to Loss of RCP Seal Cooling

Plant Name	Date of Event	Event No.	RCP Seal Type	Event Category	Duration (hrs)	CBO Isolated ?	Stage Fails	Event Description

Table 8-1
CE Plant Operating Events Leading to Loss of RCP Seal Cooling

Plant Name	Date of Event	Event No.	RCP Seal Type	Event Category	Duration (hrs)	CBO Isolated ?	Stage Fails	Event Description

Table 8-1 CE Plant Operating Events Leading to Loss of RCP Seal Cooling								
Plant Name	Date of Event	Event No.	RCP Seal Type	Event Category	Duration (hrs)	CBO Isolated ?	Stage Fails	Event Description

Table 8-1
CE Plant Operating Events Leading to Loss of RCP Seal Cooling

Plant Name	Date of Event	Event No.	RCP Seal Type	Event Category	Duration (hrs)	CBO Isolated ?	Stage Fails	Event Description

9.0 QUANTIFICATION OF THE RCP SEAL FAILURE MODEL

This section provides the basis for quantification of the CEOG seal failure models presented in Section 6.0. Specifically, the model parameters discussed are those directly associated with the mechanistic RCP seal failure modes associated with a LOSC including consideration of the time varying influence of the local seal stage environments. Model parameters are, to some extent, seal design specific. The current quantification does not address the selection of plant operational parameters associated with the onset of LOSC events and associated post-accident actions. These parameters are plant specific. The impact of these parameters may be significant as they affect the relative probability of experiencing various post-accident seal environments. This present quantification also does not consider recovery actions that may be implemented following the onset of an RCP seal LOCA.

9.1 General Approach To Model Quantification

9.1.1 Summary of Loss of Seal Cooling Test Data and Operational Occurrences

Table 9.1-1
Summary of Loss of RCP Seal Cooling Events and Experiments

Plant	Date	Event No.	No. of RCPs affected	Duration of Loss (hrs)	Pump Operating Y or N?	CBO isolated? Y or N?	Nitrile U-cups? (BJSU pumps)	Used to quantify Elastomer failure? (a)	# Stages Exposed to High Temperature	Elastomer Failure Y or N?	Used to quantify Pop-Open (b)	# Stages subject to Pop-Open	# Stages failed due to Pop-Open	Reference(s)	Comment

NOTES for Table 9.1-1

9.2 Quantification of Seal Failure Parameters

[ ]

9.2.1 RCP Stage Failure due to Elastomer Degradation [ ]

[ ]

Table 9.2-1 Elastomer Failure Probability Calculation								
Event ID	**Date**	**Duration**	**Number of Pumps**	**Stages Exposed To Thermal Transient During Interval (Vapor Stage Not Counted)**				
				0.1 < D ≤ 1 Hr	**1 < D ≤ 2 Hr**	**2 < D ≤ 4 Hr**	**4 < D ≤ 8 Hr**	**8 < D ≤ 24 Hr**

Table 9.2-2 **Elastomer Failure Probability Given CBO not Isolated**					
BJ/SU Seals with Nitrile U-cups					
Basic Event	**Time Frame**				
	0.1 < D ≤ 1 Hr	**1 < D ≤ 2 Hr**	**2 < D ≤ 4 Hr**	**4 < D ≤ 8 Hr**	**8 < D ≤ 24 Hr**

Table 9.2-3 Elastomer Failure Probability Given CBO not Isolated					
N-9000 and Sulzer Balanced Stator Four Stage Seals with Ethylene-Propylene Elastomers					
Basic Event	**Time Frame**				
	0.1 < D ≤ 1 Hr	**1 < D ≤ 2 Hr**	**2 < D ≤ 4 Hr**	**4 < D ≤ 8 Hr**	**8 < D ≤ 24 Hr**

Table 9.2-4 Elastomer Failure Probability Given CBO not Isolated					
Sulzer Balanced Stator Three Stage Seals with Ethylene-Propylene Elastomers					
Basic Event	**Time Frame**				
	0.1 < D ≤ 1 Hr	**1 < D ≤ 2 Hr**	**2 < D ≤ 4 Hr**	**4 < D ≤ 8 Hr**	**8 < D ≤ 24 Hr**

Table 9.2-5 Elastomer Failure Probability Given CBO Isolated Within 20 Minutes					
BJ/SU Seals with Nitrile U-cups					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

Table 9.2-6 Elastomer Failure Probability Given CBO Isolated Within 20 Minutes					
N-9000 and Sulzer Balanced Stator Seals					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

Table 9.2-7 Elastomer Failure Probability Given CBO Isolated Within 20 Minutes					
Sulzer Balanced Stator Three Stage Seals with Ethylene-Propylene Elastomers					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

Table 9.2-8 Elastomer Failure Probability Given CBO Isolated Within 10 Minutes (SBO only)					
BJ/SU Seals with Nitrile U-cups					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

Table 9.2-9 Elastomer Failure Probability Given CBO Isolated Within 10 Minutes (SBO only)					
N-9000 and Sulzer Balanced Stator Seals					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

Table 9.2-10 Elastomer Failure Probability Given CBO Isolated Within 10 Minutes (SBO only)					
Sulzer Balanced Stator Three Stage Seals with Ethylene-Propylene Elastomers					
Basic Event	Time Frame				
	0.1 < D ≤ 1 Hr	1 < D ≤ 2 Hr	2 < D ≤ 4 Hr	4 < D ≤ 8 Hr	8 < D ≤ 24 Hr

9.2.2 Random Failure Probability [ ]

Table 9.2-11 Random RCP Seal Stage Failure Probability					
Exposure Time	< 1 hr	0 hr < T < 2 hrs	0 hrs < T < 4 hrs	0 <T < 8 hrs	0 < T < 24 hrs

9.2.3 Hydraulic Instability/Pop-Open and Stage Failure [ ]

Table 9.2-12
RCP Seal POP-OPEN Failure Probability Calculation

			Stages Exposed To Thermal Transient (Vapor Stage Not Counted)				
Event ID	Date	Duration	Number of Pumps	Stages Initially Subject to < 50°F Subcooling	Associated Stage Failures	Stages Subsequently Subject to < 50°F Subcooling	Associated Stage Failures

Table 9.2-13A Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Isolated		
BJ/SU Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-13B Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Isolated		
N-9000 and Sulzer Balanced Stator Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-13C Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Isolated		
Three Stage Sulzer Balanced Stator Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-14A Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Isolated		
BJ/SU Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-14B Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Isolated		
N-9000 and Sulzer Balanced Stator Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-14C Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Isolated		
Sulzer Balanced Stator Three Stage Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-15A Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Not Isolated		
BJ/SU Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-15B Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Not Isolated		
N-9000 and Sulzer Balanced Stator Four Stage Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-15C Stage Pop-Open Failure Probability When RCS is Subcooled and CBO is Not Isolated		
Sulzer Balanced Stator Three Stage Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-16A Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Not Isolated		
BJ/SU Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-16B Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Not Isolated		
N-9000 and Sulzer Balanced Stator Four Stage Seals		
Basic Event	Probability of Failure	Reference

Table 9.2-16C Stage Pop-Open Failure Probability When RCS Subcooling < 50°F and CBO is Not Isolated		
Sulzer Balanced Stator Three Stage Seals		
Basic Event	Probability of Failure	Reference

9.2.4 Common Cause Relationships

9.2.5 Pre-Existing Failure [ ]

9.2.6 Excess Flow Check Valve Fails to Limit Flow (4FCV4)

9.2.7 Vapor Stage Leaks Enough to Restage Seal (sVSLeak)

9.3 Quantification of the Event Tree and Fault Tree Models

Table 9.3-1A RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design						
CBO Isolated within 20 minutes and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-1B
RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design

CBO Isolated within 20 minutes and RCS Cold Leg Subcooling < 50°F

Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-1C RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design						
CBO Not Isolated and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-1D RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design						
CBO Not Isolated and RCS Cold Leg Subcooling < 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-1E RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design						
CBO Isolated within 10 minutes and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-1F RCP Seal Failure Fault Tree Basic Event Probabilities for the BJ/SU Seal Design						
CBO Isolated within 10 minutes and RCS Cold Leg Subcooling < 50°F						
Basic Event	**Time Frame (Hours)**					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2A
RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design

CBO Isolated within 20 minutes and RCS Cold Leg Subcooling > 50°F

Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2B RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design						
CBO Isolated within 20 minutes and RCS Cold Leg Subcooling < 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2C RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design						
CBO Not Isolated and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2D RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design						
CBO Not Isolated and RCS Cold Leg Subcooling < 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2E
RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design

CBO Isolated within 10 minutes and RCS Cold Leg Subcooling > 50°F

Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-2F
RCP Seal Failure Fault Tree Basic Event Probabilities for the N-9000 and Sulzer Balanced Stator Seal Design

CBO Isolated within 10 minutes and RCS Cold Leg Subcooling < 50°F

Basic Event	Time Frame (Hours)					Reference
	$0.1 < T \le 1$	$0.1 < T \le 2$	$0.1 < T \le 4$	$0.1 < T \le 8$	$0.1 < T \le 24$	

Table 9.3-3A RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design						
CBO Isolated within 20 minutes and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-3B
RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design

CBO Isolated within 20 minutes and RCS Cold Leg Subcooling < 50°F

Basic Event	**Time Frame (Hours)**					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-3C
RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design

CBO Not Isolated and RCS Cold Leg Subcooling > 50°F

Basic Event	Time Frame (Hours)					Reference
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-3D
RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design

CBO Not Isolated and RCS Cold Leg Subcooling < 50°F

Basic Event	Time Frame (Hours)					Reference
	0.1< T ≤ 1	0.1< T ≤ 2	0.1< T ≤ 4	0.1< T ≤ 8	0.1< T ≤ 24	

Table 9.3-3E RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design						
CBO Isolated Within 10 Minutes and RCS Cold Leg Subcooling > 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

Table 9.3-3F RCP Seal Failure Fault Tree Basic Event Probabilities for the Three Stage Sulzer Balanced Stator Seal Design						
CBO Isolated Within 10 Minutes and RCS Cold Leg Subcooling < 50°F						
Basic Event	Time Frame (Hours)					**Reference**
	0.1< T ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	