October 16, 2001

Mr. Richard Bernier, Chairman
CE Owners Group
Mail Stop 7868
Arizona Public Service Company
Palo Verde Nuclear Generating Station
P.O. Box 52034
Phoenix, Arizona 85072-2034

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION (RAI) - NPSD-1199-P, "MODEL FOR FAILURE OF RCP SEALS GIVEN LOSS OF SEAL COOLING" (TAC NO. MB0337)

Dear Mr. Bernier:

By letter dated July 7, 2000, the Combustion Engineering Owners Group (CEOG) submitted for NRC staff review CE NPSD-1199-P, "Model for Failure of RCP Seals Given Loss of Seal Cooling." As a result of the review, the NRC staff has determined that additional information is needed to complete the review. The information needed is detailed in the enclosure.

The enclosed request was discussed with Mr. Paggen of your staff on September 17, 2001. A mutually agreeable target date of April 30, 2002, was established for responding to the RAI. As requested by Mr. Paggen, TAC No. MB0037 is closed. No further review of the subject topical report will be done until the staff has received your response to this RAI at which time the staff will recommence its review. If circumstances result in the need to revise the target date, please call me at your earliest opportunity at (301) 415-1424.

Sincerely,

/RA/

Jack Cushing, Project Manager, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 692

Enclosure: Request for Additional Information

cc w/encl: See next page

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REQUEST FOR ADDITIONAL INFORMATION

COMBUSTION ENGINEERING OWNERS GROUP

NPSD-1199-P, "MODEL FOR FAILURE OF RCP SEALS GIVEN LOSS OF SEAL COOLING"

PROJECT NO. 692

1. Section 3.4 (page 3-11, paragraph 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 (page 5-5, paragraph 3) states that "closure of the CBO [controlled bleed off] 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 (page 3-12) and discussed in Section 7.3.1 (page 7-8) indicate failures within the first few hours at very high exposure temperatures. 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 reactor coolant pump (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.

2. Section 4.2.3 (page 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., page 5-6 for station blackout [SBO] events and page 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 back-pressure 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 back-pressure to exist to

maintain the face seal stable.

In addition, the statement made in Section 5.3.1 (page 5-5, paragraph 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 (page 5-8, paragraph 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 (page 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, or (2) that there is always sufficient back-pressure under conditions in which subcooling cannot be assured.

3. The topical report makes statements (page 4-7, paragraph 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 experimental information, analyses, modeling, or test results include:

   a. The statement (page 4-6, paragraph 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.

   b. The statement (page 4-7, paragraph 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.

c. The conclusion of Section 4.2.3 (page 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.

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

e. The discussion in Section 5.3.2 (pages 5-11 and 5-12, paragraph 1) that the vapor seal will not pop-open, blowing down to atmospheric pressure.

f. 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.

g. 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 (page 4-3, paragraph 5). Note that the preceding text and some of the data points in Figure 3.4-1 (page 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 Millstone Nuclear Station (MNS) Unit 2 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.

4. 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:

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

b. Section 5.2 (page 5-4, paragraph 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.

c. 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 (page 5-7, section 5.3.2, paragraph 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 (page 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.

d. The topical report contains a parenthetical statement (page 5-8, paragraph 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?

5. 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, page 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 (page 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.

6. 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:

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

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

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

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

7. Some of the operational plant data and RCP seal test data used in the topical report (Table 8-1, pages 8-2 through 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, USNRC, 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 safety issue (GSI) 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 used 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 December 19, 1984, 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 (page 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 (pages 8-2 through 8-6) and related Chapter 9 tables (pages 9-5, 9-9, and 9-14) to address the numerous event description inconsistencies and failure modeling impacts, including:

a. Arkansas Nuclear One Unit 2 (ANO-2) 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.

b. 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.

c. Fort Calhoun Station (FCS) event 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?

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

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

f. MNS event MNS 2-1 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.

g. MNS 2-2 occurred while the plant was in hot standby. Were the conditions applicable to full power operations?

h. Palo Verde Nuclear Generating Station (PV) event PV 2-1 and PV 2-2 occurred before commercial operations. Were these conditions applicable to full power operations? Further, PV 2-2 appears to be related to PV 2-1 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.

i. PV3-1 illustrates an event - addition of hot RCS water without interstage 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.

j. The report states that St. Lucie (SL) SL 2-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?

k. The report states that no stage failures were observed for SL 2-2, 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?

l. SL 2-3 indicates that the third stage was degraded and possibly failed on two RCPs, but this is not reflected in Table 9.1-1 (page 9-5). How were these potential failures addressed?

m. San Onofre Nuclear Generating Station (SONGS) event SOS 2-T indicates cracked vapor seal rotating ring and deterioration of elastomers. How were these potential failure precursors factored into the data of Chapter 9?

n. Item 4 in Section 9.1.1 (page 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.

o. Waterford Steam Electric Station Unit 3 (WSES) event WSES 3-1B 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 (page 9-5) attributes 6 stages to one RCP. Please correct the number of stages exposed in the table.

p. 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 (page 9-7, paragraph 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.

q. The number of failures identified in Table 9.2-4 (page 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 (pages 9-16 and 9-17).

8. 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:

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

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

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

9. The topical report presents a formula (page 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 page 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-α)/N. By solving this equation for α, one finds that the Bayesian median value of Q corresponds to a confidence level of 20 percent. The Bayesian mean value of Q corresponds to a confidence level of 40 percent. The 50 percent 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 percent 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 percent 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).

10. The topical report states in Section 9.2.3 (page 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 GSI-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), <u>either</u> elastomer binding (in conjunction with RCP shaft movement) <u>or</u> 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 (page 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.

11. The time dependence for the probability of the pop-open failure of the RCP seal stages (page 9-12, paragraph 2 and page 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.

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 (page 6-6, paragraph 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.

13. The topical report concludes in Section 4.2 (page 4-2, paragraph 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 (page 5-12, paragraphs 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.

14. A footnote to Table 9.2-4 (page 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 (pages 9-16 and 9-17).

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).

a. The RCP1HR top event (page 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 (page 5-7, section 5.3.2, paragraph , page 5-13, section 5.5, paragraph 1, and page 7-3, section 7.1.2, paragraph 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.

b. As implied by the text for CBO isolation (page 6-2), why will the seal assembly not heatup during the top event RCP1HR? Since the seal assembly should heatup 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.

c. The topical report states (page 4-6, paragraph 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 (page 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 (page 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.

d. The topical report states in Section 3.2.1 (page 3-5, paragraph 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.

e. It appears from the information presented (pages 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).

f. 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, page 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?

g. 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.

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).

a. The fault logic model in Chapter 6 (pages 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 (page 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 (pages 9-16 and 9-17).

b. The "Impact of Failure Mechanism on Stage" column (pages 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 (page 9-12), which applies to the specific condition of the CBO being isolated and the RCS being saturated. Please explain this inconsistency.

c. It is stated in Section 6.2.2 (page 6-5, paragraph 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?

d. 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.

e. The discussion in Section 9.1 (page 9-2, paragraph 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.

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 probabilistic risk assessment (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.

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.

Attachment: Editorial and Clarification Comments

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.
Page 3-4, paragraph 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 (page 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 (page 2-1). Please clarify these apparent inconsistencies.
Page 3-5, section 3.2.1	The topical report states 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.
Page 3-9	The Table 3.3-1 flow capacity entry for Arkansas 2 is not provided.
Page 3-10	Figure 3.3-1 misidentifies the third RCP as RCP 4; it should be RCP 3.
Page 4-1, section 4.1, paragraph 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.
Pages 4-4 and 4-5, 4-8 through 4-15, and 4-18 and 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.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Pages 4-6, paragraph 2 and 4-16, paragraph 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.
Page 4-7, paragraph 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)?
Pages 5-2 and 5-3	Table 5.2-1 refers to plant-specific Table 5.2-3 (page 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.
Page 5-6	What is the source of information for Tables 5.3-1 and 5.3-2a?
Page 5-9	What is the meaning of the last line of Table 5.3-3, "RCS Pressure for RCP to Reseat?"
Pages 5-10 and 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?
Page 5-11	The CBO isolation early temperature entry for Seal Cavity 1 is not provided in Table 5.3-5a.
Pages 5-13 and 5-14, section 5.6, paragraph 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.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Page 6-3, section 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)?
Page 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.
Page 6-5, section 6.2.1, paragraph 2, page 9-11, section 9.2.2, paragraph 1, and page 9-20, section 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.
Pages 6-7 and 6-8	The "RCP Stage 2 Fails" gate should be SF003, not SF002.
Page 9-2, section 9.1, paragraph 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.
Page 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.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Page 9-11, section 9.2.2, paragraph 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
Page 9-11, section 9.2.2, paragraph 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
Page 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.
Page 9-12, paragraph 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.
Page 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 (page 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.
Page 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 (page 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.

RAI-18 EDITORIAL AND CLARIFICATION COMMENTS

Reference	Comment
Page 9-19	Table 9.2-7c third-stage entries are stated earlier in the topical report (page 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.
Page 9-20, section 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.
Page 9-25	Table 9.3-4 should include end state RCPF17 so that the sum of the end states equals one.