WESTINGHOUSE OWNERS GROUP
WOG ESTABLISHED-1979

October 6, 2003
WOG-03-510

CE NPSD-1199
Project Number 694

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

Attention: Chief, Information Management Branch,
Division of Program Management

Subject: Westinghouse Owners Group Response to Request for Additional Information on CE NPSD-1199, "Model for Failure of RCP Seals Given Loss of Seal Cooling" (TAC No. MB5803)

Topical report CE NPSD-1199, "Model for Failure of RCP Seals given Loss of Seal Cooling," was submitted for staff review and approval on October 18, 2000. A Request for Additional Information (RAI) was issued on October 16, 2001, with responses to these RAIs transmitted on April 30, 2002 via letter CEOG-02-81. The purpose of this letter is to provide responses to the additional RAIs issued by the staff on July 24, 2003.

These additional RAI responses justify the expected RCP seal performance and the seal failure model with its associated failure probabilities based on information from industry experience, tests, and manufacturer's data. Additional information is provided on the vapor stage performance, the conditional probability of multiple RCPs experiencing failures, and means to assure that adequate subcooling is maintained following a loss-of-component cooling water event. Revisions to the April 30, 2002 RAI responses have also been made to the fault tree logic provided in Section 6 to address potential leakage from the seal vapor stage.

Certain information contained in the attached RAI responses is proprietary to Westinghouse Electric Co. and is requested to be withheld from public disclosure pursuant to 10 CFR 2.790. Enclosure 1, affidavit CAW-03-1707, sets forth the basis on which the information should be withheld from public disclosure.

Enclosure 2 provides the proprietary version of the RAI responses and Enclosure 3 provides the non-proprietary version of the RAI responses. Changes to CE NPSD-1199, as identified in these RAI responses, will be incorporated into the approved version of CE NPSD-1199.

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The Westinghouse Owners Group is prepared to discuss these responses, if needed, in order to facilitate the review of CE NPSD-1199. If you require further information, feel free to contact Mr. Paul Hijeck, Owners Group Project Office at 860-731-6240.

Very truly yours,

Robert H. Bryan, Chairman
Westinghouse Owners Group
Enclosure:

cc: D. G. Holland, USNRC
Management Committee
Risk Management Subcommittee
Project Management Office
H. A. Sepp, Westinghouse
G. A. Brassart, Westinghouse
D. J. Finnicum, Westinghouse

Enclosure 1

Westinghouse Request for Withholding Proprietary Information

CAW-03-1707

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 500
Windsor, Connecticut 06095-0500
USA

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

Direct tel: 860-731-6289
Direct fax: 860-731-6238
e-mail: ian.c.rickard@us.westinghouse.com

Our ref: CAW-03-1707
September 24, 2003

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: **Westinghouse Response to Staff RAIs on CE NPSD-1199-P, "Model for Failure of RCP Seals given Loss of Seal Cooling," (Proprietary), dated September 2003**

Westinghouse hereby transmits responses to a staff request for additional information (RAI) concerning the subject topical report. Portions of these responses contain proprietary information for which withholding from public disclosure is requested. Affidavit CAW-03-1707, signed by Westinghouse Electric Company LLC, the owner of the information, sets forth the basis on which the proprietary information is requested to be withheld from public disclosure by the Commission and addresses the considerations listed in paragraph (b)(4) of 10 CFR 2.790 of the Commission's regulations.

For identification purposes and in conformance with the requirements of 10 CFR 2.790, Westinghouse has enclosed within brackets the proprietary information contained within the subject presentation. The justification for claiming the information designated as proprietary is indicated by means of superscript letters immediately following the brackets. These superscript designators refer to the types of information Westinghouse customarily holds in confidence as identified in Sections (4)(ii)(a) through (4)(ii)(f) of the enclosed affidavit.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-03-1707, and should be addressed to the undersigned.

Very truly yours,

Ian C. Rickard
Licensing Project Manager
Regulatory Compliance and Plant Licensing

Enclosure:

cc: D. G. Holland / NRR

AFFIDAVIT

STATE OF CONNECTICUT)

) ss: WINDSOR, CT

COUNTY OF HARTFORD)

Before me, the undersigned authority, personally appeared Ian C. Rickard, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC ("Westinghouse"), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Ian C. Rickard,
Licensing Project Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 24th day of September 2003.

Notary Public

My commission expires May 31, 2008.

(1) I, Ian C. Rickard, depose and say that I am the Licensing Project Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC ("Westinghouse"), and as such I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company LLC.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company LLC in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(iii) There are sound policy reasons behind the Westinghouse system for classification of proprietary information, which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iv) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.790, it is to be received in confidence by the Commission.

(v) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(vi) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in the responses to the staff's request for additional information concerning CE NPSD-1199-P, "Model for Failure of RCP Seals given Loss of Seal Cooling," dated September 2003.

This information is part of that which will enable Westinghouse to model the performance of RCP seals under conditions of loss of seal cooling, and in particular to support utilities in the application of such, including:

(a) The identification of important phenomena relevant to the application of risk-informed methodology to RCP seal performance,

(b) An assessment of industry data as applied to RCP seal performance,

(c) The incorporation of RCP seal performance models in plant-specific probabilistic risk applications.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of RCP seal performance.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology that was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar advanced nuclear power plant designs and to provide licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

CAW-03-1707

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence as identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal.

COPYRIGHT NOTICE

The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.790 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

Enclosure 3

Non-Proprietary Response to Request for Additional Information

CE NSPD-1199

CE NPSD-1199-NP, "RCP Seal Failure Model"
Response to Request for Additional Information dated July 24, 2003

RAI 2.1

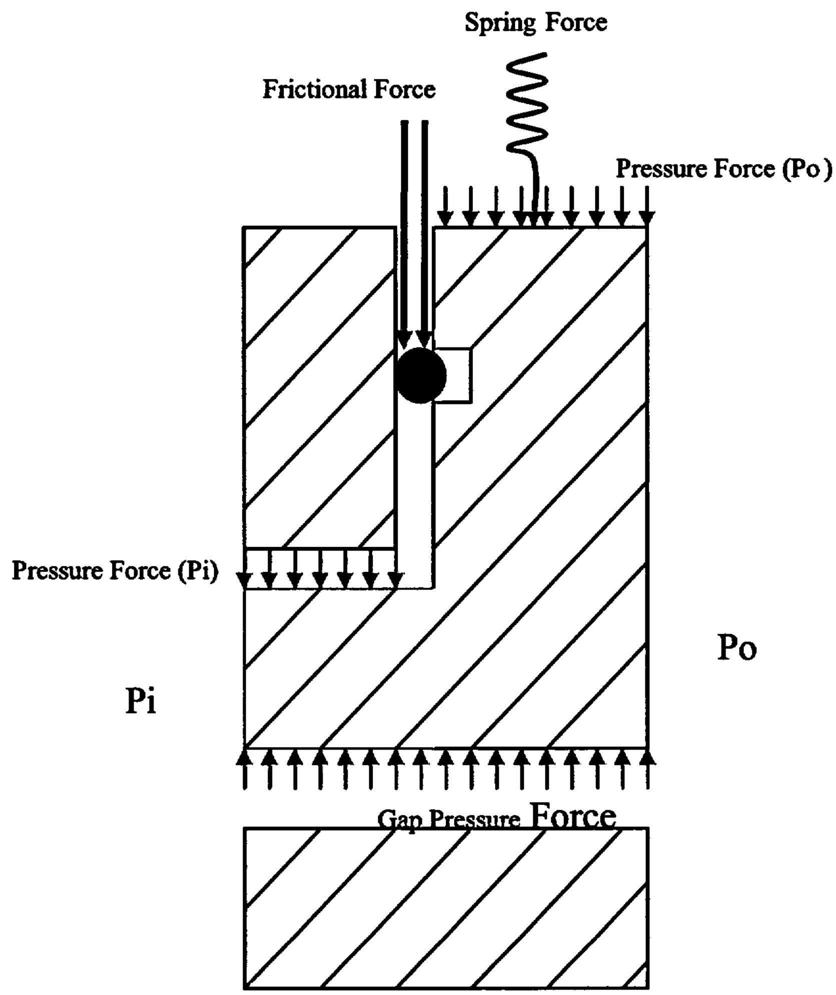
In the response to staffs request for additional information RAI 16 (page 36 of the responses to the RAIs), it is mentioned that when the controlled bleed-off (CBO) is not isolated, the inlet fluid to the vapor seal is not subcooled, but the pressures are not high enough to challenge the vapor seal. However, according to Table 5.3-2a of CE NPSD-1199, the outlet pressure to the vapor seal is less than one-half the inlet pressure to the vapor seal. Thus, neither of the conditions which would ensure the stability of the vapor seal are present and the seal may pop open. Data was discussed in the response to RAI 2 (page 4 of the responses to the RAIs) which indicated that in tests the vapor seal did not pop open. However, there is no subcooling in the case where the CBO is not isolated (fluid is at saturation conditions), so the test results may not be applicable. How then is the probability of failure for the vapor seal, (used, for example, in Table 9.2-15A of the revised Section 9 given in the responses to the RAI) justified?

RAI 2.1 Response:

Evaluation of seal events on CE PWRs indicates that the middle seal stages are the more likely to experience "pop-open." While small leakages may be observed through the vapor seal, no catastrophic failure has been noted. While detailed thermal-hydraulic behaviors could not be confirmed for most of these events, it is expected that vapor seal operation was in or near saturation for conditions where CBO was not isolated. Experimental data with CBO operation is limited. However, tests conducted by Byron-Jackson for the loss of component cooling water (Reference 2.1-1) and for station blackout (Reference 2.1-2) seal performance also indicated periods of two-phase and near two phase conditions in a vapor seal while seal leakage remained small (< 0.5 gpm). Specifically in one loss of coolant test the RCP seal cartridge was operated for a period of 30 minutes without seal cooling. The seal cartridge remained operational and the controlled bleedoff (CBO) was not isolated during the test interval. A review of the seal temperature and pressure data indicates a period of ~10 minutes where the vapor cavity was nearly saturated (within ~10°F of saturation) or saturated. Vapor seal leakage measurements conducted at the time indicated seal leakages < 0.26 gpm. No "pop-open" behavior was observed, even though the backpressure to vapor seal cavity pressure ratio was much less than one half. The total upward force (F_{up}) exerted by the fluid in the seal gap was compared to the total downward (restorative) force (F_{tot}) acting on the RCP seal upper face for the N-9000 seal design. This comparison demonstrated that at these lower absolute pressure conditions the upward force generated in the seal by the seal leakage is insufficient to overcome the downward seal force and hence the seal would not "pop-open."

The conceptual seal design is presented in Figure 2.1-1. The downward force is a result of the combined upstream and downstream pressure loads on associated areas, friction and spring load. The upward (or opening) force is based on the fluid pressure in the seal gap. The capability of the seal to remain closed under a pressure differential is based on a balance between the total downward force (F_{tot}) and upward gap pressure force (F_{up}) assuming that the pressure of a two-phase mixture results in a critical flow condition in the seal gap.

Figure 2.1-1: Idealized RCP Seal Stage Force Balance



Results of the evaluation are summarized in Figure 2.1-2. At pressures up to [ ] [a,c] psia (backpressure rates of [ ] [a,c]) the net seal downward load is sufficient to maintain the vapor seal stage integral.

Based on this force comparison, it was concluded that at low upstream RCP seal pressures (at least up to [ ] [a,c] psia), the functional capability of the RCP seal vapor stage is assured despite the fact that the seal back pressure is less than 50% of the upstream pressure (a rule of thumb to estimate seal stability).

Figure 2.1-2: Comparison of F_{tot} and F_{up} for Typical N-9000 Design

a, c

RAI 2.2

On page 117 of the response to the RAIs, it is stated that when CBO is not isolated and the reactor coolant system (RCS) is saturated that stage 4 is relatively subcooled. This is at variance with the statement made in the response to RAI 16, referred to in question 1 above. According to Table 5.3-2a of CE NPSD-1199-P, the inlet conditions to the vapor seal are saturated conditions. There is no subcooling. Please explain this apparent contradiction.

RAI 2.2 Response:

There is no subcooling in stage 4. The reference text (p117 of Reference 2.2-1) should state that when the CBO is not isolated and the reactor coolant system (RCS) is saturated that stage 4 is relatively saturated. This statement will be corrected.

The example below supports this by showing that the stage 4 pressure is low. At these low pressures, the quality of the mixture in the cavity is relatively low, about 0.2.

Example calculation of mixture density for h_o = 490 Btu/lbm, P_{sat} = 70 psia

Initial conditions: h_o = 490 Btu/lbm
h_f = 272.7 Btu/lbm from steam tables (Reference 2.2-2)
h_{fg} = 907.8 Btu/lbm (References 2.2-2)
υ_g = 6.2 ft^3/lbm (Reference 2.2-2)
υ_f = 0.0175 ft^3/lbm (Reference 2.2-2)

Quality is found:

$$X = \frac{h_o - h_f}{h_{fg}} = 0.239$$

RAI 2.3

Table 5.3-2a of CE NPSD-1199-P, for post-accident conditions following a station blackout (SBO) event, gives the pressures and temperatures at the inlets to the various seal stages. Consider the case where the CBO is not isolated. Here, the pressure is assumed to drop uniformly across the first three seal stages. The pressures given in Table 5.3-2a of CE NPSD-1199-P are based on the assumption of a uniform pressure drop across the first 3 stages. This is a reasonable assumption for normal operation. However, as several stages will experience two phase conditions, the pressure drops in the pressure breakdown devices will be influenced by flashing. This is particularly significant for those seal stages that appear to indicate the presence of a superheated condition. Under these conditions the pressure drop across the various seal stages will not be uniform. Likely, the flow resistance will be greater where saturated and supersaturated conditions occur. The flow model has to take into account the flashing of the water in the pressure breakdown devices and controlled bleed-off line. Once the pressures are recalculated, the probability of seal failure may change, and the applicability of loss of seal cooling events may be affected. Please analyze.

RAI 2.3 Response:

The pressure distributions presented in Table 5.3-2a as with the other related tables indicated "representative" seal stage pressures and subcooling. Regardless of the displayed subcooling, setting the "pop-open" failure probability for the internal seal stages (seal stages 2 and 3) was assumed that both internal stages were saturated and subject to "pop open."

To demonstrate the impact of two-phase flow through the seal pressure breakdown devices (PBDs) and controlled bleedoff (CBO) line, a limited scope analysis was performed. The intent of the calculation was to predict the impact of the emergence of two-phase conditions on the RCP seal stage pressure distribution and the pressure drop in the CBO line. The calculation assumes the CBO line is not isolated and the enthalpy losses of the liquid in the seal are negligible. The CE NSSS RCP seal design is such that the seal stage pressure drops are controlled by the PBD flow. The pressure drop through the PBD are calculated using the Martinelli-Nelson two-phase flow multiplier (Reference 2.3-1, Two-phase multiplier charts are reproduced below, see Figure 2.3-1). This correlation provides the two-phase multiplier ($F_{2\varphi}$) as a function of pressure and mixture quality.

a, c

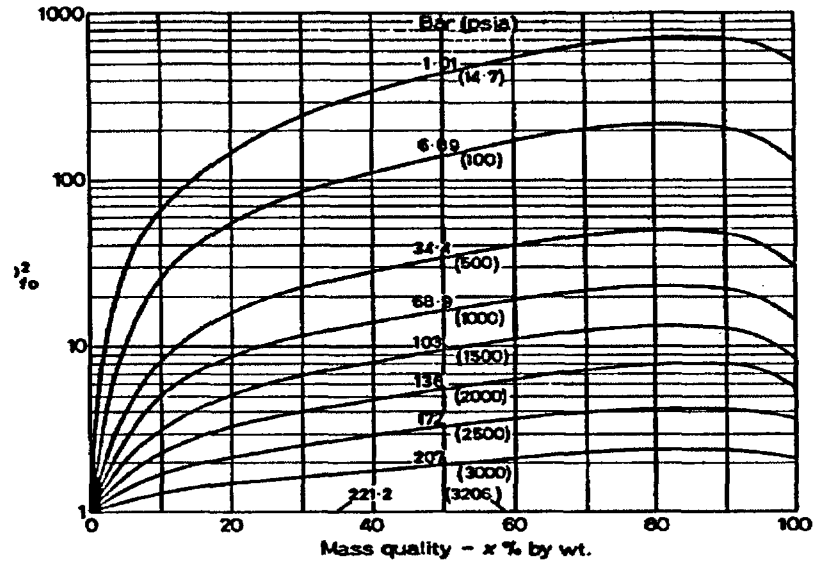


Fig. 2.3-1: Value of F_{fo}^2 as a Function of Pressure and Mass Quality (Martinelli-Nelson)

Using this methodology, revised pressure drops were calculated for the various seal stages. Since the RCS and downstream CBO discharge pressure at the volume control tank are relatively fixed, increasing the PBD resistance across saturated and nearly saturated stages will both (1) reduce the CBO flow and (2) skew the pressure distribution such that the larger pressure losses will be taken across the third stage (last PBD). A comparison of the linear single-phase distribution and the alternative distribution accounting for two-phase flow phenomena is presented in Table 2.3-1. Note that the effect of the increased resistance is to reduce the pressure drop across seal stages 1 and 2, further stabilizing both.

Table RAI 2.3-1: Typical seal stage pressure distributions

Seal Stage	RCS Pressure (psia)			

a, c

In summary, consideration of two-phase conditions in the RCP seal indicates that while the seal pressure distribution is not linear, the two-phase behavior serves to stabilize the upstream seal stages by reducing the pressure drop of the upstream seals. Furthermore, as the risk model for both intermediate seals considered these seal stages to be subject to two-phase induced "pop-open", the details of the pressure variation does not impact the risk model.

RAI 2.4

The response to RAI 12 gives estimates of the common cause failure (CCF) Gamma factor. As the staff understands, this factor is used to address the potential that all RCPs experience a seal failure, given that one RCP experiences a seal failure. In this sense, the Gamma factor used by the Combustion Engineering Owners Group (now known as the Westinghouse Owners Group - WOG) represents a conditional probability of failure.

The WOG has identified only a few historical events that have involved multiple RCPs, of which none resulted in seal failure and only two events involved stage failures on multiple RCPs. The derivation of the Gamma factor is based on this limited data and engineering judgment with the judgment that the potential for CCF is relatively low early in the event, but will increase as the exposure time increases. The staff agrees with the basic rationale for the engineering judgment, but does not believe the resulting distribution generated by the WOG properly reflects the limited information and large uncertainties with these events. The staff believes the information presented can be used as indicators of the potential for CCF of seals by considering the information on CCF potential at the stage level (i.e., use the stage-related information as an indicator of the RCP seal CCF potential).

The staff notes that of the events involving multiple RCPs, a number of events did not experience any stage failures and reported no increased leakage. These events cannot be considered in deriving the conditional probability of multiple RCPs experiencing failures since the conditional event (failure of one RCP stage) did not occur. Of the remaining events, one event lasted only 0.1 minutes and should not be considered since its exposure time is so brief as to not expose the RCP seal stages to any significant conditions. Of the remaining events, there was either increased seal leakage or a reported stage failure. From these remaining events are the two events that involved stage failures on multiple RCPs and appear to have affected the same stage on these RCPs by the same failure mode, which is indicative of a CCF condition at the stage level. In both events, the staff understands that the affected RCPs were the only RCPs that were exposed throughout the entire event (i.e., other RCPs may have initially lost seal cooling, but cooling was restored to the other RCPs early in the event). One of these two events lasted only one-half hour and the other event lasted about 4.5 hours. The latter event is also the only event involving multiple RCPs that lasted longer than 1.5 hours. The precise timing of when increased leakage was detected, which would be indicative of when the stage failure actually occurred, is not presented. The other remaining events indicate very small leakage and/or state that only one RCP had a stage failure. Based on this limited information (i.e., a few events that exposed multiple RCPs that also involved some change in seal performance by either increased leakage or stage failure to at least one RCP, of which there are only two events that impacted the seal performance on multiple RCPs) and making a number of assumptions of when the failures occurred, the staff believes a distribution could be developed that would be technically defensible.

Please provide additional justification for the Gamma factors proposed to be used by the WOG in the RCP seal loss-of-coolant accident (LOCA) model.

RAI 2.4 Response:

Westinghouse reconsidered the information on CCF potential at the stage level (i.e., use the stage-related information as an indicator of the RCP seal CCF potential). It has been noted that of the 9 events involving multiple RCPs, at least 3 events did not experience any stage failures and reported no increased leakage. These 3 events cannot be considered in deriving the conditional probability of multiple RCPs experiencing failures since the conditional event (failure of 1 RCP stage) did not occur. Of the remaining 6 events, 1 event lasted only 0.1 minutes (ANO2-1) and should not be considered since its exposure time is so brief as to not expose the RCP seal stages to any significant conditions. Of the remaining 5 events, there was either increased seal leakage or a reported stage failure. Two of these five events involved stage failures on multiple RCPs and appear to have affected the same stage on these RCPs by the same failure mode, which is indicative of a CCF condition at the stage level.

In both events, only the affected RCP seals were exposed throughout the entire event (i.e., other RCPs initially lost seal cooling, but cooling was restored to the other RCPs early in the event). For SL2-2 the event lasted only one-half hour and for SL2-3 the event lasted about 4.5 hours. The SL2-3 event is also the only event involving multiple RCPs that lasted longer than 1.5 hours. The precise timing of when increased leakage was detected, which would be indicative of when the stage failure actually occurred, is not presented. The other 3 events indicate very small leakage (< 3 gpm) and/or state that only 1 RCP had a stage failure.

Based on this limited information (i.e., 5 events that exposed multiple RCPs that also involved some change in seal performance by either increased leakage or stage failure to at least 1 RCP, of which there are only 2 events that impacted the seal performance on multiple RCPs) and making a number of assumption of when the failures occurred leads to the following:

a, c

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:

( ) a,c

These parameters were estimated based on the following considerations:

1. Common cause failure is possible but not assured.
2. The likelihood of common cause failure increases with the exposure time.
3. A Γ of [ ] a,c is a reasonable estimate for the 0 to 1 hour time frame because all events involving loss of seal cooling to multiple RCPs in Table 8-1 had exposure times greater than 0.1 hours and none resulted in a common cause failure of the affected seals."

RAI 2.5

The response to RAI 2 indicates that while a minimum subcooling of 20 °F is required by emergency operating procedures, plant operators routinely maintain subcooling margins in excess of 50 °F. Please describe the modified plant-specific operating procedures and the operator training program that will assure the operator actions to maintain subcooling margins in excess of 50 °F following a loss-of-component cooling water (CCW) event. Also, is the failure probability of maintaining this required operation factored into the RCP seal failure model?

RAI 2.5 Response:

Four cases that determine the RCP seal failure fault tree basic event probabilities have been examined:

(1) CBO isolated / maintain subcooling > 50 °F
(2) CBO isolated / subcooling not maintained > 50 °F
(3) CBO not isolated / maintain subcooling > 50 °F
(4) CBO not isolated / subcooling not maintained > 50 °F

These cases cover all of the plant and transient possibilities. Individual plants will need to choose the applicable cases for the plant specific PRA model. This can vary from plant to plant and transient to transient and needs to be handled appropriately.

Table RAI 2.5-1 lists where the results can be found in Reference 2.2-1 and in RAI 2.7 (due to fault tree changes). These tables include elastomer failure probability, stage pop-open failure probability and random RCP seal stage failure probability. Also included are pre-existing RCP failure, check valve failure and seal restaging due to excessive vapor stage leakage.

Table RAI 2.5-1: RCP Seal Failure Fault Tree Basic Event Probabilities

RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Isolated and RCS Cold Leg Subcooling > 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	Within 20 Minutes	RAI 2.7	RAI 2.7-1
BJ/SU	Within 10 Minutes	RAI 2.7	RAI 2.7-3
N-9000 / Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-5
N-9000 / Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-7
Three Stage Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-9
Three Stage Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-11
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Isolated and RCS Cold Leg Subcooling < 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	Within 20 Minutes	RAI 2.7	RAI 2.7-2
BJ/SU	Within 10 Minutes	RAI 2.7	RAI 2.7-4
N-9000 / Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-6
N-9000 / Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-8
Three Stage Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-10
Three Stage Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-12
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Not Isolated and RCS Cold Leg Subcooling > 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	N/A	2.2-1	9.3-1C
N-9000 / Sulzer Balanced Stator	N/A	2.2-1	9.3-2C
Three Stage Sulzer Balanced Stator	N/A	2.2-1	9.3-3C
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Not Isolated and RCS Cold Leg Subcooling < 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	N/A	2.2-1	9.3-1D
N-9000 / Sulzer Balanced Stator	N/A	2.2-1	9.3-2D
Three Stage Sulzer Balanced Stator	N/A	2.2-1	9.3-3D

RAI 2.6

The response to RAI 2 indicates that the WOG analysis indicates that, without operator action, the SBO event will maintain the RCS with more than 50 °F subcooling for a period of time. Please provide more discussion on the temperature transient during this event. Is a temperature transient curve available for the staff review?

RAI 2.6 Response:

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. 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 the figures below. The analyses indicate that, without operator action, the SBO event will maintain the RCS with a > 50 °F subcooling for [ ] a,c. The duration of 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 (3410 MWt).

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.

Figure RAI 2.6-1 shows the vapor stage subcooling during the BJ/SU SBO Test. This includes subcooling versus time with 50 °F subcooling as a reference point.

Figure RAI 2.6-2 shows the BJ/SU SBO Test Vapor Stage Seal Leakage versus time.

Figure RAI 2.6-3 shows the pressurizer pressure versus time for the Fort Calhoun Station SBO with no operator action.

Figure RAI 2.6-4 shows the hot leg temperature versus time for Fort Calhoun Station SBO with no operator action.

Figure RAI 2.6-5 shows the subcooling for the hot and cold legs versus time for Fort Calhoun Station SBO with no operator action.

Figure RAI 2.6-6 shows the RCS pressure versus time for a typical 3410 MWt plant with no operator action.

Figure RAI 2.6-7 shows the hot leg temperature versus time for a typical 3410 MWt plant.

Figure RAI 2.6-8 shows the subcooling in the hot and cold legs for typical 3410 MWt plant.

Figure RAI 2.6-1: Vapor Stage Subcooling during BJ/SU SBO Test

a, c

Figure RAI 2.6-2: BJ/SU SBO Test: Vapor Stage Seal Leakage

a, c

Figure RAI 2.6-3: FCS Station Blackout: No Operator Action

a, c

Figure RAI 2.6-4: FCS Station Blackout: No Operator Action

a, c

Figure RAI 2.6-5: FCS Station Blackout, No Operator Action

a, c

Figure RAI 2.6-6: Station Blackout : RCS Pressure: 3410 Mwt

a, c

Figure RAI 2.6-7: Station Blackout: Hot Leg Temperature: 3410 Mwt

a, c

Figure RAI 2.6-8: Station Blackout: Subcooling in Hot and Cold Leg: 3410 Mwt

a, c

RAI 2.7

In Figures 6.2-1, 6.2-2, 6.2-3, and 6.2-4 (of the fault trees presented in the RAI response dated April 29, 2002), there appears to be some erroneous logic, especially for cases where the vapor stage leaks enough to cause a restaging of the lower stages. Also, there is no difference in specific stage failures regardless of the CBO being isolated or not. Please confirm that the fault trees are correct or modify them to appropriately reflect the specific conditions being evaluated.

RAI 2.7 Response:

The vapor stage leakage condition is similar to the condition when the CBO is not isolated. This similarity is due to the leakage rates and temperatures being roughly the same for both the CBO not isolated case and the vapor stage leakage case. Because of this similarity, the CBO isolation case must be able to not only account for when the vapor stage does not leak, but also when the vapor stage leaks.

For the case where the CBO is isolated, the lower seal stages will, early on, be at or well below the expected equilibrium temperature (based on timing of isolation) of ~300 °F. The temperatures of the lower seals will gradually increase due to conduction. Over time, the stage cavity will no longer be in saturated equilibrium, which will cause the vapor stage to reach temperatures of about 400 °F. Therefore, following isolation all stages will see temperatures in the 400 °F to 525 °F range. See Reference 2.2-1, page 106, for more detail.

For the case of when the vapor seal leaks, which is similar to the CBO not isolated case, the lower seal stages will approach their equilibrium temperature in about 30 minutes with stage temperatures in the range of 525 °F for the first stage down to about 500 °F for the third stage. The vapor stage cavity will contain a two-phase mixture. Therefore the temperature of the fourth stage will be the saturation temperature (about 300 °F) for the anticipated stage pressure of about 70 to 100 psia. See Reference 2.2-1, page 105, for more detail.

Given that the vapor stage leaks, the probability of elastomer failure will be lower due to lower temperature conditions on the vapor seal (as compared to CBO isolation case).

The fault tree model provided in Reference 2.2-1 (pages 67-88) did not correctly account for the CBO isolation with the vapor stage leaking case. A new basic event has been added for when the vapor stage leaks using the elastomer failure probabilities for when the CBO is not isolated. This is a valid assumption because the expected vapor stage leakage flowrate and temperature are roughly the same as the flowrate and temperature as the case when the CBO is not isolated.

Changes have been made to the fault tree model (changes provided in Figures RAI 2.7-1 and RAI 2.7-2) to account for the impact on the lower temperature (as compared to the CBO isolation case) that the vapor stage is exposed to when the vapor stage leaks. The existing basic event that represents elastomer failure of the vapor stage was replaced with a basic event that reflects the difference in expected temperature of the vapor stage. The associated probabilities for elastomer failure are shown in Tables RAI 2.7-1 to RAI 2.7-12. The quantified results show a small increase (in comparison to the model results presented in Reference RAI 2.2-1) for the overall seal failure probability.

Note that the difference for the specific stage failures is in the form of the basic event probabilities changing based on CBO isolation, RCS Cold Leg Subcooling and the thermal exposure time. Each plant must choose the model that applies to the specific plant conditions (based on CBO isolated/not isolated and RCS subcooling temperatures).

Table RAI 2.7-13 lists the locations, for the RCP seal failure fault tree basic event probabilities, within Reference 2.2-1. This is broken down into categories based on whether or not the CBO is isolated and if the RCS cold leg has subcooling above or below 50 °F. Also note that some of these tables have been modified in Tables RAI 2.7-1 through RAI 2.7-12 due to the fault tree modification (Figures RAI 2.7-1 and RAI 2.7-2). These changes will be incorporated in Reference 2.2-1 and in CEOG Topical Report CE NPSD-1199-P.

Figure RAI 2.7-1: RCP Seal LOCA Given Loss of Seal Cooling – 3 Stage, CBO Isolated (Page 1)

a, c

Figure RAI 2.7-1: RCP Seal LOCA Given Loss of Seal Cooling – 3 Stage, CBO Isolated (Page 2)

a, c

Figure RAI 2.7-1: RCP Seal LOCA Given Loss of Seal Cooling – 3 Stage, CBO Isolated (Page 3)

[ ] a, c

Figure RAI 2.7-1: RCP Seal LOCA Given Loss of Seal Cooling – 3 Stage, CBO Isolated (Page 4)

[ ]a, c

Figure RAI 2.7-1: RCP Seal LOCA Given Loss of Seal Cooling – 3 Stage, CBO Isolated (Page 5)

a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 1)

a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 2)

[ ]a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 3)

a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 4)

[ ] a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 5)

a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 6)

a, c

Figure RAI 2.7-2: RCP Seal LOCA Given Loss of Seal Cooling – 4 Stage, CBO Isolated (Page 7)

[ ] a, c

Table RAI 2.7-1: Modified Fault Tree Basic Event Probabilities

a, c

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 RAI 2.7-2: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-3: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-4: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-5: Modified Fault Tree Basic Event Probabilities

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	

a, c

Table RAI 2.7-6: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-7: Modified Fault Tree Basic Event Probabilities

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**	

a,c

Table RAI 2.7-8: Modified Fault Tree Basic Event Probabilities

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 ≤ 1	**0.1< T ≤ 2**	**0.1< T ≤ 4**	**0.1< T ≤ 8**	**0.1< T ≤ 24**	

a, c

Table RAI 2.7-9: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-10: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-11: Modified Fault Tree Basic Event Probabilities

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	

a, c

Table RAI 2.7-12: Modified Fault Tree Basic Event Probabilities

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**	

a, c

Table RAI 2.7-13

RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Isolated and RCS Cold Leg Subcooling > 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	Within 20 Minutes	RAI 2.7	RAI 2.7-1
BJ/SU	Within 10 Minutes	RAI 2.7	RAI 2.7-3
N-9000 / Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-5
N-9000 / Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-7
Three Stage Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-9
Three Stage Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-11
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Isolated and RCS Cold Leg Subcooling < 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	Within 20 Minutes	RAI 2.7	RAI 2.7-2
BJ/SU	Within 10 Minutes	RAI 2.7	RAI 2.7-4
N-9000 / Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-6
N-9000 / Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-8
Three Stage Sulzer Balanced Stator	Within 20 Minutes	RAI 2.7	RAI 2.7-10
Three Stage Sulzer Balanced Stator	Within 10 Minutes	RAI 2.7	RAI 2.7-12
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Not Isolated and RCS Cold Leg Subcooling > 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	N/A	2.2-1	9.3-1C
N-9000 / Sulzer Balanced Stator	N/A	2.2-1	9.3-2C
Three Stage Sulzer Balanced Stator	N/A	2.2-1	9.3-3C
RCP Seal Failure Fault Tree Basic Event Probabilities For CBO Not Isolated and RCS Cold Leg Subcooling < 50 °F			
Seal Design	CBO Isolated	Reference	Table
BJ/SU	N/A	2.2-1	9.3-1D
N-9000 / Sulzer Balanced Stator	N/A	2.2-1	9.3-2D
Three Stage Sulzer Balanced Stator	N/A	2.2-1	9.3-3D

References

2.1-1 Byron Jackson Report GS-1520, "Report on Loss of Component Cooling Water Test on Nuclear Reactor Coolant Pump," April 1979.

2.1-2 Byron Jackson Report GS-1543, "Loss of Component Cooling Water to the Reactor Coolant Pump Seal Cartridge on Hot Standby," November 1980.

2.2-1 CEOG-02-081, "Response to Request for Additional Information Concerning CEOG Topical Report CE NPSD-1199, 'RCP Seal Failure Model,' " April 30, 2002.

2.2-2 Steam Tables, Properties of Saturated Steam, American Society of Mechanical Engineers, 1967.

2.3-1 Collier, J.G., " Convective Boiling and Condensation," McGraw Hill, 1972, London.