May 20, 2003

Mr. Robert H. Bryan, Chairman
Westinghouse Owners Group
Tennessee Valley Authority
Mail Code LP4J-C
6A Lookout Place
1101 Market Street
Chattanooga, TN 37402-2801

SUBJECT: SAFETY EVALUATION OF TOPICAL REPORT WCAP-15603, REVISION 1, "WOG 2000 REACTOR COOLANT PUMP SEAL LEAKAGE MODEL FOR WESTINGHOUSE PWRS" (TAC NO. MB1714)

Dear Mr. Bryan:

On December 20, 2000, the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15603, Revision 0, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs" for NRC staff review and approval. On April 5, 2002, the NRC staff issued a request for additional information (RAI) regarding the TR. The WOG responded to the staff's RAI by letter dated May 17, 2002, with the submittal of Revision 1 to WCAP-15603. The subject TR is a consensus reactor coolant pump (RCP) seal leakage model for pressurized water reactors that utilize the Westinghouse seal packages with high-temperature O-rings.

The staff has found that WCAP-15603, Revision 1, is acceptable for referencing in licensing and other applications to the extent specified and under the limitations delineated in the report and in the associated NRC safety evaluation (SE). The SE defines the basis for acceptance of the report.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of 10 working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

Our acceptance applies only to matters approved in the subject report. We do not intend to repeat our review of the acceptable matters described in the report. When the report appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that the WOG publish an accepted version of this TR within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted version shall include a "-A" (designated accepted) following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusion in this letter, that the TR is acceptable is invalidated, the WOG and/or the applicant referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the TR without revision of the respective documentation.

Sincerely,

/RA/

Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Safety Evaluation

cc w/encl:
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-15603, REVISION 1, "WOG 2000 REACTOR COOLANT PUMP SEAL LEAKAGE MODEL FOR WESTINGHOUSE PWRS"

WESTINGHOUSE OWNERS GROUP

PROJECT NO. 694

1.0 INTRODUCTION

During the closeout of Generic Safety Issue (GSI) 23, "Reactor Coolant Pump (RCP) Seal Failure" (Reference 1), the NRC staff stated that until better models were developed to support future risk-informed licensing decisions, the staff would use the Rhodes model described in Appendix A of NUREG/CR-5167 (Reference 2), for determining contribution to core damage frequency from RCP seal loss-of-coolant accidents (LOCAs). The NRC staff also recommended that the Rhodes model be used in the American Society of Mechanical Engineers (ASME) standards. In practice, however, there currently exist several different models for RCP seal leakage following a loss of all seal cooling that are currently in use by licensees. In some cases, the same models are used with different assumptions by individual licensees. These different assumptions generate modeling inconsistencies in probabilistic risk assessments (PRAs), and raise concerns from the NRC staff when these PRAs are used to support licensee risk-informed regulatory initiatives and applications. The Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15603, Revision 0, in December 2000 for the NRC staff's review. Following a request for additional information (RAI) from the NRC staff on April 5, 2002, the submittal was subsequently revised and resubmitted as Revision 1 (Reference 3) on May 17, 2002, presenting a consensus RCP seal leakage model for plants that use the Westinghouse seal packages with high-temperature (also referred to as high-temperature qualified) O-rings.

2.0 BACKGROUND

In Appendix A of NUREG/CR-5167, three categories of O-rings are defined: unqualified, improved, and qualified. Unqualified O-rings are those made from the Westinghouse standard reference compound (or similar compound), which has been shown to soften and extrude when subjected to conditions comparable to those that are expected during a station blackout. These unqualified O-rings are also referred to as "old" O-rings. The improved O-rings are those made from material much less susceptible to extrusion failure in hot water. The qualified O-rings are those that will not fail for 20 hours when subjected to 2250 pounds per square inch (psi) pressure differential at 550°F, with extrusion gaps predicted at these conditions. The high-temperature O-rings fit into the improved O-ring category, since they are not qualified for the full system pressure conditions, but they are tested as part of an O-ring qualification program for combinations of O-rings and gaps that the WOG states as bounding the limiting conditions for the RCP seals. The test and qualification data for high-temperature O-rings indicate that all combinations of O-rings and gaps tested did not fail during the 18-hour or 168-hour test period. Since no high-temperature O-ring failed at the specified test conditions for the test intervals of either 18 hours or 168 hours, the test pressure was increased in increments of 50 to 250 psi at 5-minute intervals to determine a failure pressure for the O-rings. If the O-rings did not fail during these pressure increases, the highest test pressure was reported as the O-ring pressure capability. The absolute minimum pressurization failure pressure for any combination of O-rings and gaps in these tests was 1710 psi. This value is used in this safety evaluation (SE) to establish the minimum pressure capability of the high-temperature O-rings.

2.1 Scope and Summary of Proposed Approach

The WOG developed the WOG 2000 model, described in WCAP-15603, Revision 1, to address RCP seal leakage following a loss of all seal cooling for those plants that use high-temperature O-rings. The WOG 2000 model only addresses the seal leakage scenarios, including the probabilities, leakage rates, and timing associated with these scenarios. It does not address other factors associated with PRA-related modeling considerations of RCP seal LOCA scenarios. For example, the WOG 2000 model assumes the RCPs are stopped in a timely fashion to avoid seal damage, and does not address the core uncovery times and recovery actions related to an RCP seal LOCA. Therefore, these modeling aspects and their supporting analyses and bases must be developed and documented in the licensee-controlled plant-specific PRA documentation. Furthermore, the WOG 2000 model does not address the Westinghouse seal packages that use the "old" O-rings. The NRC staff's expectation is that the Rhodes model will be used to model the Westinghouse seal packages that use "old" O-rings.

The WOG 2000 model is defined for conditions of a sustained total loss of RCP seal cooling following the timely stopping of the RCPs. This includes scenarios where both seal injection and thermal barrier cooling are completely lost, and where the RCPs have been stopped either due to the nature of the initiating event (e.g., loss of offsite power) or by operator action within an established timeframe to avoid damaging the seals. The WOG 2000 model addresses the combination of RCP seal component failures that could occur and the resultant leakage rates. This is accomplished using an event tree logic that contains five sequences which result in leakage rates that range from 21 gpm/RCP to 480 gpm/RCP. The three specific RCP seal component failure modes addressed in WCAP-15603, Revision 1, are:

- Popping-open - opening of the seal faces due to hydraulic instability caused by fluid flashing.

- Binding - binding failure of the seal ring against the housing inserts due to secondary seal extrusion.

- O-ring extrusion - overheating of the secondary sealing elastomers, allowing excessive leakage.

Consistent with previous RCP seal leakage models, the binding and popping-open failure modes are combined in the WOG 2000 model since they are postulated to have the same seal leakage consequences and because there are large uncertainties associated with the potential for these failure modes.

3.0 REGULATORY EVALUATION

The NRC's policy statement on the use of PRA methods in nuclear regulatory activities (Reference 4) encourages greater use of this analysis technique to improve safety decisionmaking and improve regulatory efficiency. Examples of where elements of risk-informed decisionmaking are currently used include: the reactor oversight process, the significance determination process, the implementation of the maintenance rule, backfit and generic safety issue analyses, and modifying an individual plant's licensing basis. The NRC's policy statement also states that the PRAs used in support of regulatory decisions should be as realistic as practicable. Further, as part of the closeout of GSI-23, the NRC staff stated that, until better models were developed to support future risk-informed licensing decisions, the NRC staff would use the "Rhodes model" in determining the contribution to the core damage factor from RCP seal LOCAs. For those plants that use the Westinghouse seal packages with high-temperature O-rings, the Rhodes model would produce results that are very conservative, especially for accident sequences that are not terminated within two hours. With the issuance of WCAP-15603, Revision 1, as modified by the NRC staff conditions identified in this SE, an alternative RCP seal leakage model will be recognized by the NRC staff for those plants that use the Westinghouse seal packages with high-temperature O-rings.

The NRC staff reviewed the WOG 2000 RCP seal leakage model presented in WCAP-15603, Revision 1, and compared it with the Rhodes model described in NUREG/CR-5167. The staff also considered other related information, such as the Brookhaven National Laboratory (BNL) guidance document for modeling RCP seal failures (Reference 5) and the Atomic Energy of Canada Limited (AECL) review of WOG TR WCAP-10541, Revision 2, "Reactor Coolant Pump Seal Performance Following a Loss of All AC Power" (Reference 6), which was also documented in NUREG/CR-4906P (Reference 7).

4.0 TECHNICAL EVALUATION

Sections 4.1 through 4.4 of this SE address topics covered under Sections 3.1 through 3.4 in WCAP-15603, Revision 1. Section 4.5 addresses the uncertainties discussed in Section 6.0 of WCAP-15603, Revision 1. Section 4.6 addresses other considerations and factors that are outside the specific scope of WCAP-15603, Revision 1, but are related to this topic (e.g., Westinghouse plants with the "old" O-rings). Section 4.7 addresses aspects of model documentation.

4.1 Seal Failure Probabilities

In Section 3.1 of WCAP-15603, Revision 1, each of the RCP seal component failure modes identified above are addressed. The staff's evaluation of the treatment of these failure modes and their associated failure probabilities in the WOG 2000 model is provided in this section.

a. Binding/Popping-Open Failure Mode

Section 3.1 of WCAP-15603, Revision 1 states that the binding failure mechanism is effectively eliminated by the use of high-temperature O-rings. It further states that the binding failure mode is the dominant failure mode for the first and third seal stages. The probability of the binding/popping-open failure mode was originally derived for O-rings in WCAP-10541, Revision 2, which was cited in the BNL guidance document. The failure probability for the first seal stage was based on no indications of failure being observed during loss of seal cooling events involving 24 pumps and assuming a 50 percent chance that the next event would involve such a failure. This results in a failure probability of 0.02 (0.5/25), which is then assumed to be the median value of a lognormal distribution with an error factor of 3. Based on this approach, the mean probability value is calculated as approximately 0.025. For the third seal stage (i.e., the vapor seal), the probability of the binding/popping-open failure mode is given as 0.54, which is based on engineering judgement as no additional justification is provided for this value in WCAP-10541, Revision 2. In WCAP-15603, Revision 1, the failure probabilities for the first and third seal stages are reduced by a factor of two to reflect the expected improved performance of the high-temperature O-ring seals. Thus, the first seal stage is given a failure probability of 0.0125 for binding/popping-open and, assuming the second seal stage has failed, the third seal stage is given a failure probability of 0.27.

The failure probabilities derived in WCAP-10541, Revision 2, for the binding/popping-open failure mode for the first and third seal stages have been disputed by the NRC and were questioned by AECL in NUREG/CR-4906P. For the first seal stage, however, despite disagreement regarding the experiential information used to derive the probability of binding/popping-open, the calculated mean value of 0.025 has been accepted and is used in most current RCP seal leakage models for the first seal stage. The rationale for such a relatively low value for the first seal stage is given in NUREG/CR-5167, which states that the first seal stage is inherently stable and resistant to axial seal friction because of its large coning angle and wide face. Because the high-temperature O-rings are expected to have essentially eliminated the dominant failure mode associated with the first seal stage (i.e., binding), the staff accepts that there is a reduction in this failure probability for the first seal stage high-temperature O-rings. Therefore, based on its inherent stability, resistance to axial seal friction, and the significant reduction (if not elimination) of the binding failure mode for the first seal stage, the staff accepts a failure probability of 0.0125 for the binding/popping-open failure mode for the first seal stage in plants that use high-temperature O-rings.

For the third seal stage, the BNL guidance and NUREG/CR-4906P state that no justification is provided for the failure probability cited. Furthermore, per the Rhodes model, if the second seal stage fails, the third seal stage is assumed to fail, because it is not designed to withstand a pressure differential greater than normal operating pressure differential. Therefore, the staff requires that, for the use of the WOG 2000 model, the value used for the failure probability of the binding/popping-open failure mode for the third seal stage be set to unity, considering that it will be subjected to a pressure differential greater than the normal operating pressure differential following failure of the second seal stage. With the assumed failure of the third seal stage if the second seal stage has failed, the seventeen sequence event tree provided as Figure 2.2-1 of WCAP-15603, Revision 1, is reduced to nine sequences (see the Rhodes RCP seal leakage event tree model that is provided in the attachment to this SE).

If a licensee can demonstrate that the third seal stage can survive actual thermal conditions, including the effects of failure of the second seal stage, then that analysis, resulting probability estimation, and related bases must be documented in the licensee-controlled PRA documentation. In addition, a summary discussion of such analysis, failure probability estimate, and bases must be included in any risk-informed license applications submitted to the NRC for review and approval.

Based on the results of a number of the references (References 2, 3, 5, and 7), the dominant failure mechanism for the second seal stage is expected to be popping-open. A failure probability value of 0.2 is consistently used for various RCP seal leakage models based on expert judgement. The BNL guidance states that this relatively high value was chosen to account for uncertainties with the processes related to the popping-open failure mechanism. As this value is not changed for WCAP-15603, Revision 1, the staff accepts the use of a value of 0.2 for the failure probability of the binding/popping-open failure mode.

b. O-ring Extrusion Failure

Section 3.1(b) of WCAP-15603, Revision 1 uses an O-ring extrusion failure probability of 0.0 for high-temperature O-rings. It also states that these are designed to perform in the high-temperature environment expected after a loss of seal cooling. The use of a zero probability of O-ring extrusion failure effectively reduces the WOG 2000 model event tree from seventeen sequences to five sequences. In addition, an assumed failure of the third seal stage upon failure of the second stage, as described above, would further reduce the event tree to four sequences.

In the Rhodes model, the extrusion failure of the high-temperature O-rings (referred to in NUREG/CR-5167 as the "improved" O-rings) has a probability of 0.5 after 2 hours of being subjected to full system conditions with no back pressure. In response to the staff's April 5, 2002, RAI, the WOG referred to Section 8, Figure 8-3 of WCAP-10541, Revision 2, to indicate that leakage from the seals results in a gradually decreasing pressure in the reactor coolant system (RCS). For a 15 gpm/RCP leakage rate, RCS pressure is less than 2000 psi at 1 hour, at about 1800 psi when plant cooldown starts, and less than 1600 psi at the 2 hours point. The WOG further stated that the test and qualification data for high-temperature O-rings indicate that all O-ring and gap combinations tested did not fail during the 18-hour or 168-hour test period. Since no high-temperature O-ring failed at the specified test conditions for the test intervals of either 18 hours or 168 hours, the test pressure was increased in increments of 50 to 250 psi at 5-minute intervals to determine a failure pressure for the O-rings. If the O-rings did not fail from the pressure increases, the highest test pressure is reported as the O-ring pressure capability. The absolute minimum pressurization failure for any O-ring and gap combination was 1710 psi.

Based on the above justification, the NRC staff accepts the use of a zero failure probability for O-ring extrusion failure of high-temperature O-rings as long as the licensee documents the justification and supporting analyses and bases in the licensee-controlled PRA documentation. Such documentation should show that the plant's cooldown will result in a RCS pressure of less than 1710 psi within 2 hours. If a licensee cannot demonstrate by analyses and/or by procedure that the plant's cooldown will result in a RCS pressure less than 1710 psi within 2 hours, the licensee must assume a probability of 0.5 for extrusion failure of the O-rings after 2 hours. This will also require the licensee to expand the WOG 2000 model logic back to the seventeen sequence event tree provided as Figure 2.2-1 in WCAP-15603, Revision 1, (or nine sequence event tree resulting from assuming the failure of the third seal stage upon failure of the second seal stage) to incorporate these potential failure modes.

4.2 Scenario Starting Times

Section 3.2 of WCAP-15603, Revision 1, assumes that the 21 gpm "normal" leakage will start at the beginning of the scenario, and postulates that the binding/popping-open failures, if they occur, will happen after 30 minutes into the scenario, resulting in higher leakage rates. The derivation of the 30 minutes to binding/popping-open failure is based on limited experiential evidence (i.e., no failures for 24 RCPs that experienced loss of seal cooling events and no failure during a recent loss of RCP seal cooling event at Sizewell) and a statistical analysis in which the timing is assumed to be lognormally distributed with an assumed 5^{th} percentile value of 15 minutes and an assumed 95^{th} percentile value of 60 minutes.

The assumption that the 21 gpm "normal" leakage will start at the beginning of the scenario is a conservative simplification and thus, the NRC staff accepts this modeling assumption for the WOG 2000 model. However, the WOG has not provided in WCAP-15603, Revision 1, a satisfactory justification or any thermal hydraulic analysis that supports a determination of the time to binding/popping-open failure. For example, of the 24 RCPs that have experienced a loss of seal cooling cited in WCAP-15603, Revision 1, it was noted in NUREG/CR-4906P that only 6 of these RCPs lost seal cooling for longer than 10 minutes. Thus, the vast majority of these events did not last long enough for the seals to be exposed to the thermal conditions that might cause increased seal leakage and/or failure.

The correct time for the onset of increased RCP seal leakage in the model should be at the end of the thermal transient leading from the fully-cooled condition at the first stage of the seal assembly to the time when the fluid temperature at the entrance to the first seal stage reaches full reactor coolant temperature. If popping-open of the second seal stage, judged in a number of the references to be the dominant failure mode for this stage, is going to occur, it will most likely occur when the above thermal conditions are reached. In accordance with WCAP-10541, Revision 2, the timing to these thermal conditions is estimated to be approximately 13 minutes after the loss of RCP seal cooling. Therefore, notwithstanding any other analyses of these potential thermal conditions, the NRC staff requires that when using the WOG 2000 model, the timing to the binding/popping-open failure of the second seal stage, if it occurs, and the resulting increased leakage, be assumed to occur no later than 13 minutes after the loss of RCP seal cooling.

If, on a plant-specific basis, it is shown by thermal hydraulic analyses that the thermal conditions described above are not reached until some later time, and that this later time is used in a plant-specific application of the WOG 2000 model, the analysis and related bases for such time must be documented in the licensee-controlled PRA documentation. In addition, a summary discussion of this plant-specific analysis and bases must be included in any risk-informed license applications submitted to the NRC for review and approval.

4.3 Treatment of Multiple Reactor Coolant Pumps

For modeling simplicity, Section 3.3 of WCAP-15603, Revision 1, assumes that all RCPs for the affected unit experience the same leakage scenario. It states that this modeling approach is likely conservative, but that to rigorously address multiple RCP leakage scenarios would make the model very complicated.

The staff concurs with the assessment that to address the RCPs individually would involve a greater level of complexity, including the need to address the potential common cause conditions (e.g., RCP seal inlet temperatures) and common cause failure modes between RCPs. The WOG 2000 model approach is consistent with the currently accepted RCP seal leakage model approach and is considered to be conservative. Thus, the staff agrees with and accepts this simplification approach in the plants that use RCP seal packages with only high-temperature O-rings.

However, this simplified approach limits the WOG 2000 model's usability for plants that have a mixed arrangement of RCP seal packages (i.e., some RCPs use "old" O-rings and some use high-temperature O-rings). Based on the acceptance of the simplified approach, the staff finds that the WOG 2000 model is not appropriate for plants that operate with a mixture of types of RCP seal packages and thus, the WOG 2000 model cannot be used at these plants until the licensee replaces all "old" O-rings with high-temperature O-rings. The staff expects that the Rhodes model will continue to be used to model all RCPs (conservatively assuming that all RCPs use the "old" O-rings) at the plant until all "old" O-rings are replaced with the high-temperature O-rings.

If, on a plant-specific basis, a licensee uses the WOG 2000 model, but addresses RCP seal leakage scenarios on an individual RCP basis, or still uses "old" O-rings in its plant, then the complete RCP seal LOCA model and its related bases and supporting analyses, including the increased complexity associated with addressing common cause contributions and the combinations of individual RCP seal leakage scenarios, must be documented in the licensee-controlled PRA documentation. In addition, a summary discussion of this more complex model and its related bases and analyses must be included in any risk-informed license applications submitted to the NRC for review and approval.

4.4 Leakage Scenarios

In Section 3.4 of WCAP-15603, Revision 1, the leakage scenarios are developed for a single RCP and then tabulated for various Westinghouse designs, depending on the number of RCPs in each design (i.e., 2-loop, 3-loop, or 4-loop plants). The staff agrees with and accepts this tabulation approach, as long as the timing and probability aspects of the tabulations are revised to reflect the conditions, limitations, and modifications identified throughout Section 4 of this SE.

4.5 Uncertainties

In Section 6.0 of WCAP-15603, Revision 1, a sensitivity calculation is presented of the largest size leak scenario as part of its discussion of uncertainties. However, the WOG does not directly address the uncertainties in the RCP seal leakage model and the failure mode probabilities. The potentially large uncertainties associated with the plant-specific RCP seal leakage model will need to be addressed and documented in the licensee-controlled PRA documentation. This evaluation of uncertainties can be done qualitatively and/or quantitatively and may involve parametric sensitivity studies and/or direct application of uncertainty parameters. An acceptable approach to addressing uncertainties in risk-informed license applications is described in Regulatory Guide 1.174 (Reference 8).

In particular, in WCAP-10541, Revision 2, an error factor of 3 was assumed for the binding/popping-open failure mode for the first seal stage. This assumed error factor is judged by the NRC staff to be too small, given the limited number of tests and operational experiences that lasted long enough to cause significant heating of the seal assembly to generate seal failures. In Section 6.6 of the Appendix to NUREG/CR-4906P, upper and lower bound parameter values are provided. These bounds cover a very large range such that at the lower bound, RCP seal LOCAs essentially do not occur (i.e., all failure modes have a probability of zero) beyond the expected increased leakage rate of 21 gpm/RCP, while at the upper bound all failure modes have a probability at or greater than 0.2, which also includes the failure of the O-rings due to extrusion failure. Due to the large uncertainties associated with these models and the various RCP seal component failure modes and failure probabilities (and resulting leakage scenarios), the staff expects that the associated error factors used in any quantitative uncertainty analysis will typically be very large (i.e., typically not less than an error factor of 10).

4.6 Other Considerations

There are a number of considerations that are related to the modeling of the potential for creating a RCP seal LOCA that are not addressed or are implicitly assumed in the WOG 2000 RCP seal leakage model. These considerations would need to be addressed and documented in the licensee-controlled PRA documentation, regardless of the specific model employed by the licensee. This section addresses these other considerations.

In WCAP-15603, Revision 1, the WOG 2000 model is defined for the condition of a sustained total loss of RCP seal cooling with "timely stopping" of the RCPs. In addition, it assumes that if the RCPs are not stopped in a timely manner, the RCP seals are assumed to fail catastrophically (i.e., result in the maximum leakage rate). However, "timely stopping" is not quantitatively defined. In response to the staff’s RAI, the WOG stated that the time window for the operator action of timely stopping of the RCPs after a loss of seal cooling event applies to abnormal events, such as a total loss of component cooling water (CCW), but did not apply to loss of offsite power and station blackout events in which the RCPs are stopped by the nature of the initiating event. The WOG further stated that WCAP-15603, Revision 1, was silent on the time window by design since this is left to plant-specific operator action analyses that consider the abnormal operating procedures and manufacturer’s recommendations. Therefore, the licensee must establish and justify on a plant-specific basis the time(s) in which the RCPs can be stopped by the operators to avoid the assumed catastrophic failure of the RCP seals for those initiating events that do not cause the RCPs to stop by the nature of the event. Furthermore, this time window or a bounding (i.e., shorter) time window, properly reduced for detection and execution times, must be used in the development of the human error probability associated with this operator action. Finally, if this operator action fails, the RCP seals must be assumed to catastrophically fail at the maximum leakage rate (i.e., 480 gpm/RCP).

The WOG 2000 model is implicitly based on plants operating in a manner consistent with the WOG Emergency Response Guidelines (ERGs) and the RCP vendor manuals. In particular, Guideline ECA-0.0, "Loss of All AC Power," provides a significant amount of direction for protecting the RCP seals, including an assessment that determines the most appropriate method of restoring seal cooling following an extended loss of all AC power event, which would also be applicable for any extended loss of RCP seal cooling event. This guidance specifically cautions that restoring CCW to the thermal barrier heat exchanger could jeopardize the integrity of the CCW system and takes the position that the integrity of the CCW system should not be jeopardized in order to restore seal cooling. The guidance also does not recommend that the plant reestablish seal injection after the seals have been heated, due to the potential damage to the RCP seal package and shaft. The timing to these conditions was previously determined in WCAP-10541, Revision 2, to be reached at 13 minutes after the loss of all seal cooling. Rather than either of the above approaches, the guidance takes the position that RCP seal cooling by seal injection and CCW should not be restored until the RCP seal package is first cooled by reducing the primary system temperature (i.e., controlled RCS cooldown), which will reduce the temperature of the water flowing through the RCP seals. If a licensee uses a RCP seal leakage model for Westinghouse RCP seal packages but does not follow these guidelines, then the applicability of the model and its inherent assumptions, must be evaluated and documented in the licensee-controlled PRA documentation. Furthermore, under these atypical conditions, the model used by the licensee would have to be expanded to specifically address the potential that the restoration actions proposed could, with a high probability, create or exacerbate RCP seal leakage instead of terminating it or could cause catastrophic failure of the RCP seals. Further, depending on the specific actions that the licensee may direct by procedures and/or operator training, the PRA event tree model may also need to be expanded and additional analyses may be required to address the potential for failing the CCW system due to creating a water hammer event during the restoration action. In conclusion, if a licensee uses the model in which there are plant-specific conditions and/or procedures that are different than typically assumed for Westinghouse plants, based on Westinghouse ERGs ECA-0.0, Revision 1C (e.g., if restoration of seal injection or thermal barrier cooling is allowed after 13 minutes of a loss of all seal cooling without first performing RCS cooldown), then the licensee must provide a justification for that model, including its supporting analyses and related bases, in their licensee-controlled PRA documentation. In addition, a summary discussion of these differences in the plant-specific operations and model used by the licensee must be included in any risk-informed license applications submitted to the NRC for review and approval.

The WOG 2000 model does not address the core uncovery times and recovery actions related to an RCP seal LOCA. Since these aspects of RCP seal LOCA sequence modeling are not addressed, any modeling aspects and their supporting analyses and bases must be developed and documented on a plant-specific basis by the licensee in their licensee-controlled PRA documentation.

WCAP-15603, Revision 1, was published to provide a consensus RCP seal leakage model for those plants that utilize the Westinghouse seal packages with high-temperature O-rings. The WOG 2000 model does not address the Westinghouse seal packages utilizing "old" O-rings. The staff expectation is that the Rhodes model will be used to model the Westinghouse seal packages that use "old" O-rings. The staff cautions in the use of other RCP seal leakage models that have been developed in the past, since some have subsequently been shown to contain errors. For example, the NUREG-1150 (and NUREG/CR-4550) model makes an assumption that precludes seal leakage for the first hour and one-half following a loss of seal cooling. This assumption is incorrect, as increased seal leakage has been determined to possibly occur as soon as 13 minutes after the loss of all seal cooling. If a licensee with "old" O-rings in its plant uses a model other than the Rhodes model to address the potential for RCP seal leakage, that licensee must provide a justification for the model, including any additional supporting analyses and related bases that are necessary to verify the appropriateness of the model used in their licensee-controlled PRA documentation. In addition, a summary discussion of these differences in the plant-specific model used by the licensee must be included in any risk-informed license applications submitted to the NRC for review and approval.

4.7 Documentation Requirements

The RCP seal leakage model, including any related bases and analyses, used by the licensee must be documented in the licensee-controlled PRA documentation. This documentation must include the licensee’s evaluation of and determination that the plant-specific procedures and conditions support the applicability of the model used.

If, on a plant-specific basis, the WOG 2000 model is used in a manner different than described in WCAP-15603, Revision 1, as modified by the conditions, limitations, and modifications imposed by this SE, or if it is used for plant-specific conditions and procedures that are different than typically assumed for Westinghouse plants, based on Westinghouse ERGs ECA-0.0, Revision 1C (e.g., if restoration of seal injection or thermal barrier cooling is allowed after 13 minutes of a loss of all seal cooling without first performing RCS cooldown), then the licensee must provide a justification for that model, including its supporting analyses and related bases, in their licensee-controlled PRA documentation. In addition, a summary discussion of these differences in the plant-specific model used by the licensee must be included in any risk-informed license applications submitted to the NRC for review and approval.

5.0 CONCLUSION

The staff has found that the WOG 2000 model presented in TR WCAP-15603, Revision 1, is acceptable for use in plant-specific PRAs and in support of risk-informed applications, provided it is supplemented and used in accordance with the following limitations, conditions, and modifications:

1. The failure probability of the third seal stage, given failure of the second seal stage, is unity since the third seal stage is not designed to handle more than the normal operating pressure differential of a few psid.

2. The failure probability for O-ring extrusion is zero, if it can be justified that the plant’s cooldown will result in an RCS pressure of less than 1710 psi within 2 hours; otherwise extrusion failure of the O-rings must be assumed to have a probability of 0.5 at 2 hours after the loss of all seal cooling.

3. The time for the onset of increased RCP seal leakage (i.e., above the "normal" expected leakage of 21 gpm) is when the fluid temperature at the entrance to the first seal stage reaches full RCS temperature, which has been determined to be about 13 minutes.

4. In quantitative uncertainty analyses, the error factors associated with the modeled failure mode probabilities are expected to be very large.

5. The licensee must justify on a plant-specific basis the time(s) in which the RCPs can be stopped by the operators to avoid the assumed catastrophic failure of the RCP seals (resulting in maximum leakage rate of 480 gpm/RCP) and use this (or a shorter bounding) time in developing the human error probability for this operator action.

6. The licensee must ensure that the use of the WOG 2000 model is applicable to their plant, including that their RCP seal-related operations, procedures, and recovery actions are consistent with the WOG ERGs and RCP vendor manuals, or, if the plant operations are not consistent with these guides, the licensee must evaluate and document the justification for the use of their model, including any necessary additional PRA modeling considerations and/or analyses to address the plant-specific conditions potentially created by their operations and actions.

7. Core uncovery times and recovery actions related to an RCP seal LOCA must be developed and documented on a plant-specific basis.

8. The WOG 2000 model cannot be used for RCPs that utilize "old" O-rings, for which the staff expects to be modeled using the Rhodes model.

9. For plants that have a mixed arrangement of RCP seal packages (i.e., some RCPs using the "old" O-rings and some RCPs using the high-temperature O-rings), the WOG 2000 model cannot be used for the plant until the licensee replaces all the "old" O-rings with the high-temperature O-rings. The staff expects that the Rhodes model will continue to be used to model all RCPs at the plant (conservatively assuming all RCPs use the "old" O-rings).

10. The RCP seal leakage model, including any related bases and analyses, used by the licensee must be documented in the licensee-controlled PRA documentation.

11. If, on a plant-specific basis, the WOG 2000 model is used in a manner different than described in WCAP-15603, Revision 1 (as modified to address the above items), then the licensee must provide a justification for that model and/or the specific parameters that are different, including its supporting analyses and related bases, in their licensee-controlled PRA documentation and a summary discussion of these differences in the plant-specific model used by the licensee must be included in any risk-informed license applications submitted to the NRC for review and approval.

The WOG 2000 RCP seal leakage model, with the modifications imposed by this SE, is presented in the attachment to this SE. In addition, the Rhodes RCP seal leakage model, which is expected to be used by plants that utilize the "old" O-rings, is also presented in the attachment to this SE, as well as a table that compares the different leakage rates for each model at different times after the loss of all seal cooling.

6.0 REFERENCES

1. Letter from Ashok C. Thadani, Director Office of Nuclear Regulatory Research, to William D. Travers, Executive Director of Operations, *Closeout of Generic Safety Issue 23, "Reactor Coolant Pump Seal Failure,"* November 8, 1999.

2. Scientech, Inc., *Cost/Benefit Analysis for Generic Issue 23: Reactor Coolant Pump Seal Failure*, NUREG/CR-5167, April 1991.

3. Westinghouse Electric Company, LLC, *WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs*, WCAP-15603, Revision 1, May 2002.

4. U.S. Nuclear Regulatory Commission, *Use of Probabilistic Risk Assessment Methods in Nuclear Activities: Final Policy Statement*, *Federal Register*, Volume 60, page 42622 (60 FR 42622), August 16, 1995.

5. Brookhaven National Laboratory, *Guidance Document for Modeling of RCP Seal Failures*, W9611-08/99, August 1999.

6. Westinghouse Electric Company, *Westinghouse Owners Group Report - Reactor Coolant Pump Seal Performance Following a Loss of All AC Power*, WCAP-10541, Revision 2, November 1986.

7. Atomic Energy of Canada Limited, *Review of the Westinghouse Owners Group Report WCAP-10541, Revision 2, "Reactor Coolant Pump Seal Performance Following a Loss of All AC Power,"* NUREG/CR-4906P, January 1988.

8. U.S. Nuclear Regulatory Commission, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*, Regulatory Guide 1.174, Revision 1, November 2002.

Attachment: Seal Leakage Models
w/Comparison Table

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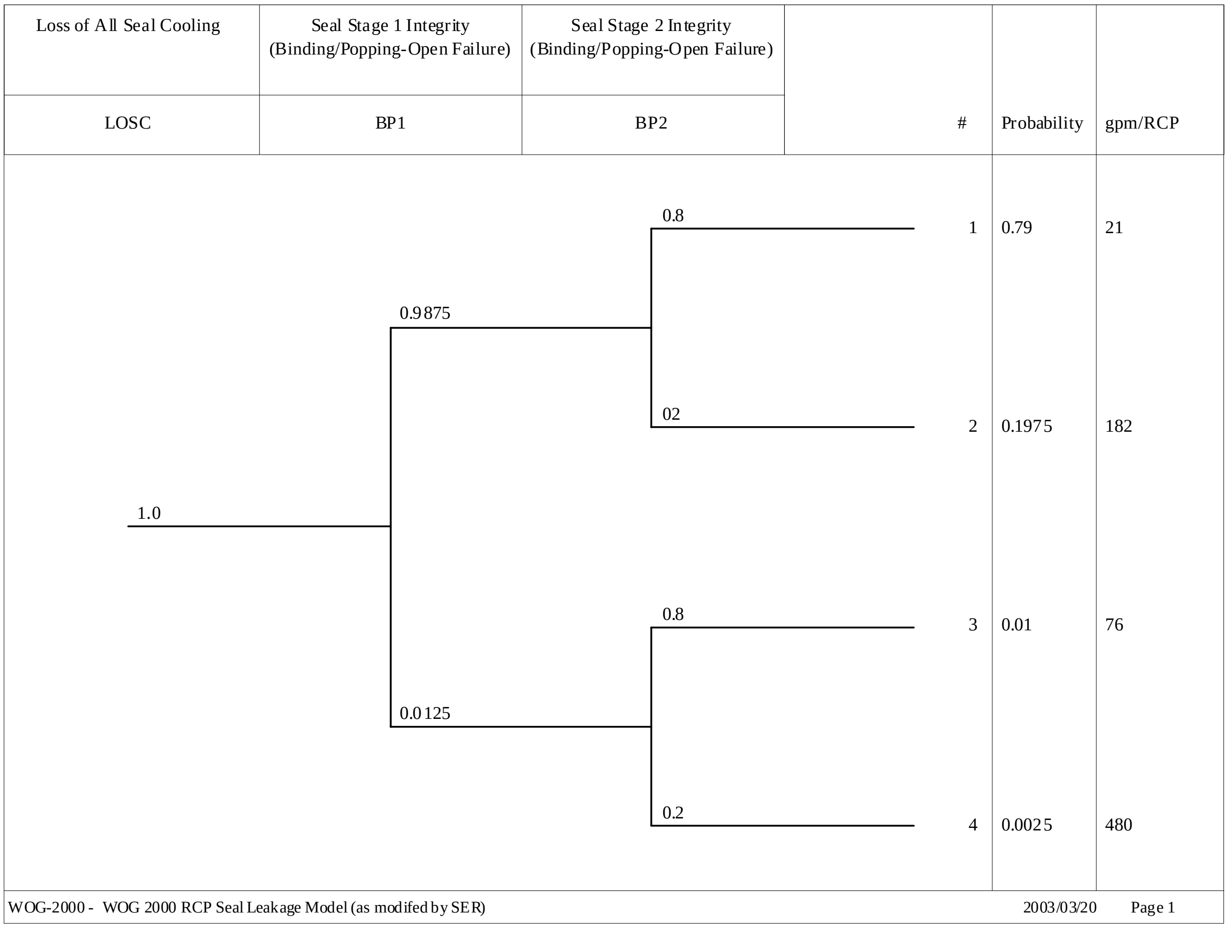
Date: May 20, 2003

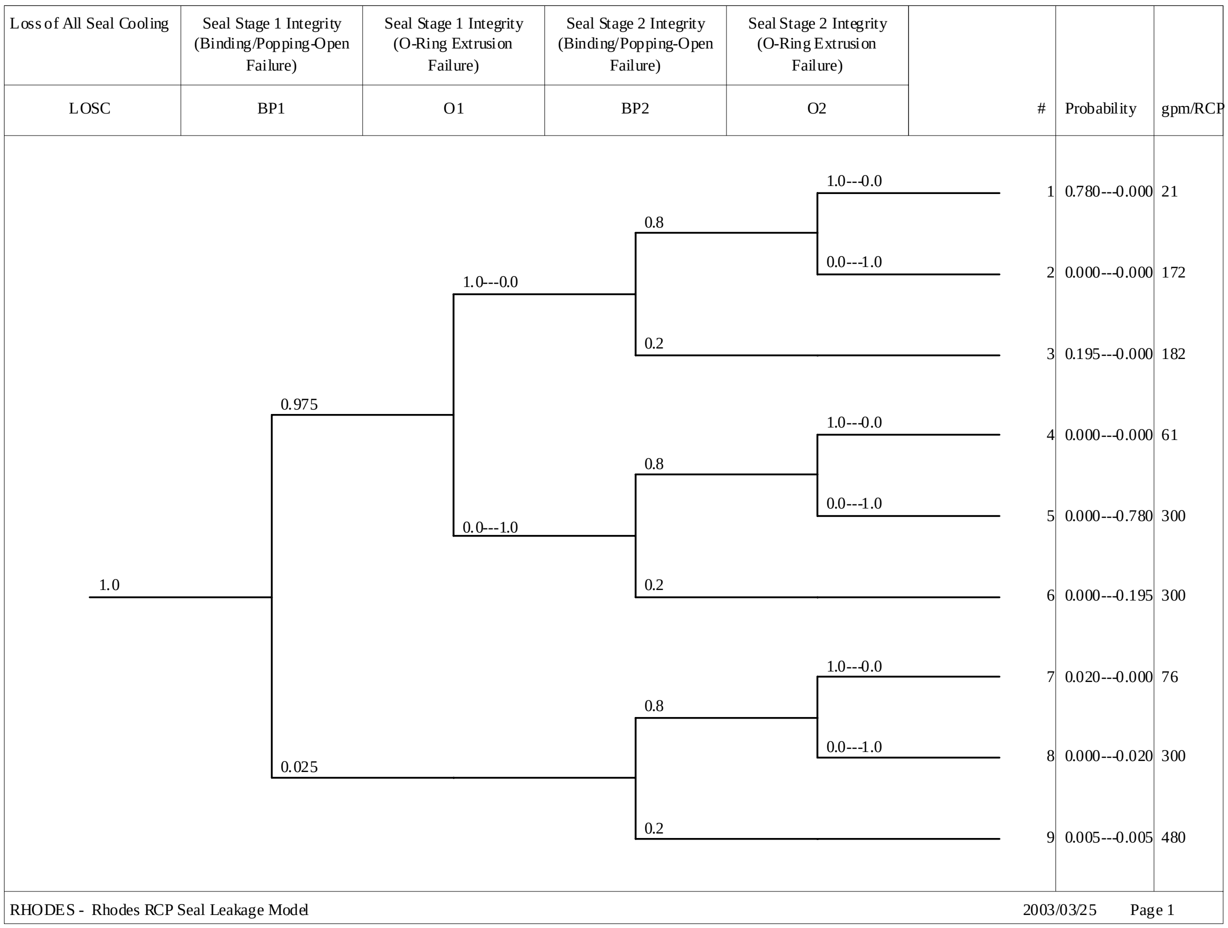
WOG 2000 REACTOR COOLANT PUMP SEAL LEAKAGE MODEL
FOR HIGH-TEMPERATURE O-ringS
(AS MODIFIED BY THE STAFF SAFETY EVALUATION)



The failure of the third seal stage is not shown since it is assumed to fail (i.e., has a failure probability of unity) if the second seal stage fails and is assumed irrelevant if the second seal stage does not fail. This effectively reduces the WOG 2000 model from five sequences to four sequences.

For the first 13 minutes after the loss of all seal cooling, the leakage rate is 21 gpm (i.e., Sequence 1 with a probability of unity). The probability of O-ring extrusion failure is zero for the high-temperature O-rings, as long as the plant cooldown will result in a RCS pressure less than 1710 psi within 2 hours. Thus, under these conditions after the first 13 minutes, the leakage rate is as provided in the figure above with the associated sequence probabilities. If the plant cooldown will not result in an RCS pressure less than 1710 psi within 2 hours, then extrusion failure of the O-rings must be addressed with a failure probability of 0.5 for the high-temperature O-rings.

RHODES REACTOR COOLANT PUMP SEAL LEAKAGE MODEL FOR "OLD" O-ringS (BASED ON NUREG/CR-4906P AND NUREG/CR-5167)



The failure of the third seal stage is not shown since it is assumed to fail (i.e., has a failure probability of unity) if the second seal stage fails and is assumed irrelevant if the second seal stage does not fail. This effectively reduces the Rhodes model from seventeen sequences to nine sequences.

For the first 13 minutes after the loss of all seal cooling, the leakage rate is 21 gpm/RCP (i.e., Sequence 1 with a probability of unity). The probability of O-ring extrusion failure is zero for the first two hours, but is unity after the first two hours. Therefore, after the first 13 minutes and up to 2 hours, the leakage rate is as provided in the figure above with the first probability value given in the figure. After 2 hours, the leakage rate is as provided in the figure above with the second probability value given in the figure.

COMPARISON OF RCP SEAL LEAKAGE RATES FOR THE "OLD" O-ring SEALS VERSUS THE HIGH-TEMPERATURE O-ring SEALS (AS MODIFIED BY THE STAFF SAFETY EVALUATION REPORT)

TIMING AFTER LOSS OF ALL RCP SEAL COOLING					
0 - 13 minutes		13 minutes - 2 hours		> 2 hours	
"old" O-rings (RHODES)	high-temperature O-rings (WOG 2000)	"old" O-rings (RHODES)	high-temperature O-rings (WOG 2000)	"old" O-rings (RHODES)	high-temperature O-rings (WOG 2000)
gpm/RCP (probability)	gpm/RCP (probability)	gpm/RCP (probability)	gpm/RCP (probability)	gpm/RCP (probability)	gpm/RCP (probability)
21 (1.0)	21 (1.0)	21 (0.78)	21 (0.79)		21 (0.79)
		76 (0.02)	76 (0.01)		76 (0.01)
		182 (0.195)	182 (0.1975)		182 (0.1975)
				300 (0.995)	
		480 (0.005)	480 (0.0025)	480 (0.005)	480 (0.0025)

*Sequences with the same resulting leakage rate have been combined in the above table.

Attachment