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May 17, 2002

WCAP-15603-NP, Rev. 1
Project Number 694

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

Attention: Chief, Information Management Branch,
Division of Inspection and Support Programs

Subject: Westinghouse Owners Group
Transmittal of WCAP-15603-NP, Rev. 1, (Non-Proprietary), "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs" (MUHP-6074)

Reference: 1) Westinghouse Owners Group Letter, OG-00-125, "Transmittal of WCAP-15603-NP, Rev. 0, (Non-Proprietary), "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," December 20, 2000.

2) NRC Letter, "W3stinghouse Owners Group Transmittal of WCAP-15603-NP, Rev 0, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs, Enclosure: Request for Additional Information" April 5, 2002.

In December 2000 the Westinghouse Owners Group (WOG) submitted WCAP-15603-NP, Rev. 0, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," for approval (Ref. 1). In April 2002, the NRC issued a Request for Additional Information (RAI) (Ref. 2). Please find enclosed WCAP-15603-NP, Rev. 1, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," including the WOG responses to the RAIs in Attachment A of the revised WCAP.

Upon completion of the staff's preliminary review of WCAP-15603-NP, Rev 1, the WOG would welcome the opportunity to meet with the NRC to discuss the content of the document. Additionally the WOG requests that Mr. Jared Wermiel, USNRC, be invited to participate in any NRC/WOG meeting scheduled for review of WCAP-15603-NP, Rev 1. Please contact Mr. Paul Pyle, WOG Project Manager, at 412-374-5673, to discuss the particulars of a WOG/NRC meeting on WCAP-15603-NP, Rev 1.

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If you require further information, feel free to contact Mr. Paul Pyle in the Westinghouse Owners Group Project Office at 412-374-5673.

Very truly yours,

Robert H Bryan

Robert H. Bryan, Chairman
Westinghouse Owners Group

enclosure

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WCAP-15603
Revision 1

WOG 2000
Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15603

Revision 1

WOG 2000
Reactor Coolant Pump Seal Leakage Model
for
Westinghouse PWRs

Selim Sancaktar
Reliability and Risk Assessment

May 2002

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REVISION 1

In this revision of WCAP-15603, contents of Sections 4 and 5 are removed from the document. The WOG-2000 reactor coolant pump seal leakage model for Westinghouse plants is given only for seal packages with high temperature (qualified) o-rings.

WOG responses to the USA NRC RAIs on Revision 0 of this WCAP are also provided as Attachment A to this document.

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1.0 INTRODUCTION

This report defines and documents the technical details of a reactor coolant pump (RCP) seal leakage model (named *WOG2000*) that could be used in PRA studies of Westinghouse pressurized water reactors with the Westinghouse RCP seal packages with high temperature o-rings. This model is based on a Brookhaven National Laboratory seal leakage report (Reference 1). Several clarifications and modifications were added, based on Westinghouse experience and expert opinion, to produce this *WOG2000* seal leakage model.

The Brookhaven best estimate model (Reference 1) is referred to as the Brookhaven Model in this report.

The motivation for this work is the fact that several models for RCP seal leakage following loss of all seal cooling are currently used by different utilities. Also, the same models are used with different assumptions by different utilities. These differences generate a level of inconsistency in results when using PRAs in regulatory applications. A consensus model between the NRC and the utilities regarding an acceptable RCP seal leakage model would facilitate future regulatory initiatives and applications.

The purpose of the report is to document a consensus model acceptable to the NRC that could be used by the licensees in risk-informed regulatory applications. While this model contains assumptions that Westinghouse judges to be conservative (i.e., overstate leakage rates and probabilities), the overall model produces reasonable results.

This report does not discuss the design and operation of the Westinghouse reactor coolant pump seals. Also, the seal failure modes are presented but not described in detail. For a detailed discussion of the RCP seal design, operation and potential failure modes, see Section 2 of Reference 1.

2.0 DEFINITION OF RCP SEAL LEAKAGE MODEL

2.1 SCOPE

The first step in modeling RCP Seal LOCA sequences involves defining leakage scenarios, which has been historically expert opinion driven. Once the leakage scenarios are defined, the next step of a RCP seal LOCA model includes core uncovery times and recovery actions (which are more plant specific) to cope with potential LOCA events. The scope of the *WOG2000* Model is limited to the RCP Seal *Leakage* model.

The RCP Seal Leakage model provides the following event information:

- Combinations of seal failure modes generating a series of leakage scenarios
- A seal leakage rate for each scenario
- Probability of occurrence for each scenario
- Timing of the seal failures (start and progress)
- Conditional probability of multiple RCP pumps undergoing the same combination of failures

Once the leakage scenarios are defined with these characteristics, further parameters are used to produce RCP Seal LOCA core damage event sequences. These parameters, used to calculate the risk from RCP seal leakage, are analytically or actuarially obtainable and may be plant dependent. These include:

- Time to core uncovery given each postulated leakage scenario
- Recovery of systems to cope with the RCS inventory loss defined by the combination of failures
- Impact of depressurization on leak rate

As a result, it is appropriate to address these separately, *outside* the current discussion of the RCP Seal Leakage Model. These parameters can be calculated generically or on a plant-specific basis, but are not included in the scope of the *WOG2000* Model.

2.2 DEFINITION

The RCP Seal Leakage Model is defined for the condition of a sustained total loss of RCP seal cooling with a timely stopping of the reactor coolant pumps. This includes scenarios where both seal injection and thermal barrier cooling are totally lost and where the RCP pumps have been stopped either due to the nature of the initiating event (e.g., loss of offsite power), or by an operator action in the time frame to avoid damaging the seals. This model does not apply to cases where the RCP seal cooling is totally lost and the pump continues to run, damaging the seal material.

When a total loss of RCP seal cooling occurs with the pumps tripped, a combination of seal and o-ring failures can be postulated to occur that define a set of leakage scenarios and corresponding leakage rates. For the *WOG2000* model, this is done in terms of an event tree, as presented by Figure 2.2-1.

The *WOG2000* RCP Seal Leakage Model is based on the model described in Section 3 of BNL Technical Report W6211-08/99 (Reference 1). Figure 2.2-1 presents the RCP seal leakage scenarios directly from the Brookhaven Report. These seal leakage scenarios – combinations of failure modes and resultant leakage rates – are adopted in whole by the *WOG2000* Model. This approach is chosen to eliminate the past confusion and complications stemming from the use and interpretation of various other models, as referenced in (2), (3), (4), and (5).

According to Figure 2.2-1, seventeen leakage scenarios are defined with leakage rates ranging from 21 gpm/pump to 480 gpm/pump. This model allows for generation of scenarios with combinations of failure modes for each of the three stages of hydrostatic seals.

As Figure 2.2-1 shows, three failure modes are hypothesized for each of the three seal stages:

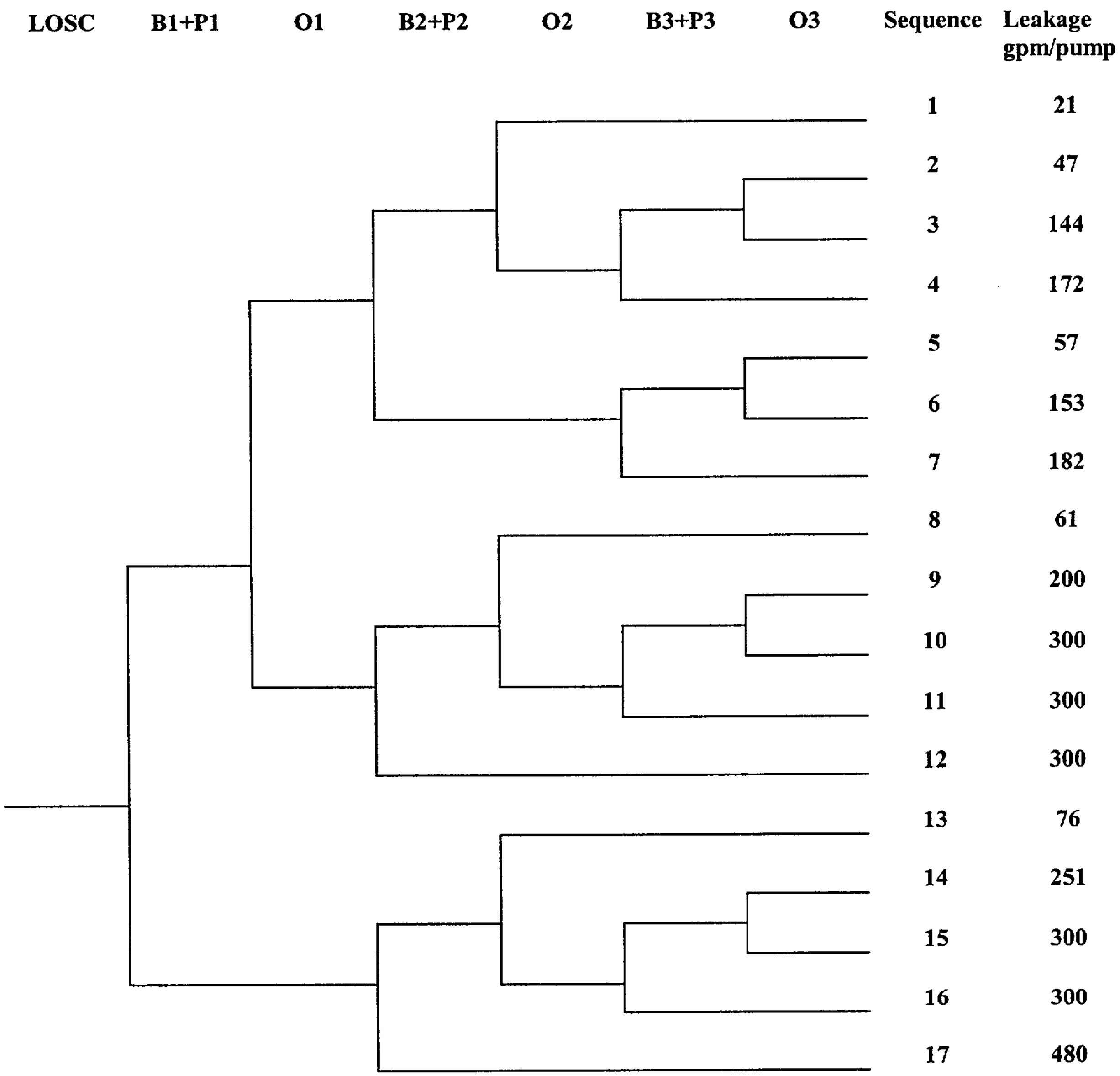
- Popping – opening of the seal faces due to hydraulic instability caused by fluid flashing,
- Binding – binding failure of the seal ring against the housing inserts due to secondary seal extrusion, and
- O-Ring Extrusion – overheating of the secondary sealing elastomers, allowing excessive leakage.

The popping and binding failure modes have been combined in Figure 2.2-1, consistent with the Brookhaven Report, because they are projected to have the same seal leakage consequences.

There have been no events to date in which the seal popping-and-binding failure have occurred. Nonetheless, in order to facilitate progress in the area of risk-informed regulation, the *WOG2000* Model has included this failure mode, with some consideration for the impact of high temperature o-ring material on the likelihood of the binding mechanism (see Section 3.0).

The remaining aspects of the leakage model involve probabilities of the seal and o-ring failures, timing of the scenarios, and the probabilities of multiple pumps undergoing the same failures. These are discussed in Section 3 for pumps containing seal assemblies with high temperature (qualified) o-rings.

Figure 2.2-1 Event Tree for RCP Seal Leakage Scenarios



Note:

LOSC	Loss of Seal Cooling and RCP Pump Stopped
B1 + P1	Binding and Popping Failure Mode for First Stage Seal
O1	O-Ring Extrusion Failure for First Stage Seal
B2 + P2	Binding and Popping Failure Mode for Second Stage Seal
O2	O-Ring Extrusion Failure for Second Stage Seal
B3 + P3	Binding and Popping Failure Mode for Third Stage Seal
O3	O-Ring Extrusion Failure for Third Stage Seal

3.0 RCP SEAL LEAKAGE MODEL FOR PUMPS WITH HIGH TEMPERATURE O-RINGS

Westinghouse has produced a high temperature o-ring material that is designed to function at the temperatures expected in the RCP seal during a loss of seal cooling scenario. These o-rings are not susceptible to extrusion failures, unlike the "old" o-rings, which may extrude excessively upon a loss of RCP seal cooling event. In most Westinghouse RCPs, seal packages with the high temperature o-rings are already installed.

This section presents the *WOG2000* RCP seal leakage model for the RCPs with the seal assemblies containing the high temperature o-rings. The *WOG2000* model adopts the Brookhaven Model, with two modifications:

- The probability of popping-and-binding is reduced by a factor of 2 for seals with high temperature o-rings – see Section 3.1(a).
- The mean starting time of the time-independent seal face failures (popping-and-binding) is postulated to be 30 minutes after the loss of RCP seal cooling – see Section 3.2.

These assumptions are described in more detail in the following subsections, along with a basis for each. These assumptions address conservatisms in the Brookhaven Model but do not alter the failure modes or structure of the model as presented in the Brookhaven Report. They are made to make the model less conservative (i.e., more realistic); conservative modeling in PRA can distort the plant risk profile and mask the "real" risk contributors. Note that these modifications are kept simple to retain the simplicity of the model.

3.1 SEAL FAILURE PROBABILITIES

(a) Popping-and-Binding Failure Mode

The Brookhaven Model gives the following probabilities of opening of the face seals of each stage, due to the "popping-and-binding" failure mode:

$$P(PB1) = 0.025$$

$$P(PB2) = 0.20$$

$$P(PB3) = 0.54$$

where P(PBx) is the probability of popping-and-binding failure (PB) in the x^{th} seal stage.

The Brookhaven Model applies these same probabilities to both the old and the high temperature o-ring seals.

The *WOG2000* Model recognizes the difference between popping failure and binding failure modes. These differences justify reducing the total popping-and-binding probabilities where the high temperature o-rings have been installed. The rationale is as follows:

1. The "binding" failure mode is driven by premature extrusion failure of the o-rings or channel seal elastomers that make up the secondary seals (Section 2.2.1.1 of Reference 1). Since the o-rings are qualified in this case, this failure mechanism is effectively eliminated (based on testing presented in Appendix A of Reference 2).

2. Binding failure dominates the popping-and-binding failure mode for stages 1 and 3 (Section 3.1.1 of Reference 1).

The modification adopted by the *WOG2000* Model is the following:

> Reduce the "popping-and-binding" probabilities for stages 1 and 3, P(PB1) and P(PB3), by a factor of two.

This change reflects the benefit gained by the new material in reducing the "binding" probability. The factor of two decrease is a conservative estimate (i.e., it is likely that a greater reduction could be justified), based on the understanding that binding dominates the popping-and-binding failure mode for stages 1 and 3.

Since the popping-and-binding failure mode is dominated by binding failures, the seal failure probabilities in the *WOG2000* model for popping-and-binding at each stage of the RCP seal become:

$$P(PB1) = 0.0125$$

$$P(PB2) = 0.20$$

$$P(PB3) = 0.27$$

<u>(b) O-Ring Extrusion Failure</u>

The Brookhaven Model uses the following probability distribution for extrusion failure of the qualified o-rings:

$$P(O1) = P(O2) = P(O3) = 0.0$$

where P(Ox) = probability of seal failure at the x^{th} seal stage due to o-ring extrusion (O).

The high temperature o-rings are designed to perform in the high temperature environment expected after loss of seal cooling. Thus, the Brookhaven Model estimates the probability of o-ring failure to be zero. This value is adopted by the *WOG2000* Model.

With these o-ring failure probabilities, the scenario logic given in Figure 2.2-1 reduces to the event tree given in Figure 3.1-1. This reduced event tree for the high temperature o-rings has five scenarios, with leakage rates ranging from 21 gpm to 480 gpm per pump.

3.2 SCENARIO STARTING TIMES

The Brookhaven Model assumes the following leakage start times for the high temperature o-rings:

- 21 gpm "normal" leakage starts at the beginning of the scenario (t = 0)
- Binding-and-popping failures, if they occur, start at the beginning of the scenario (t = 0)

WOG2000 Model uses the Brookhaven assumption that the "normal" 21 gpm leakage per pump would start at the beginning of the scenario. However, the *WOG2000* model uses the following modification for the starting time of the potential binding-and-popping failures.

The Brookhaven Report (Reference 1, page 24) notes only that the failure is expected sometime during the first hour:

> ".. the processes of binding and popping-open are not time-dependent, and the onset of the probability of opening of the face seals due to either process is assumed *during the first hour* of the LOSC event. For evaluating the probabilistic model, NUREG/CR-4906P does not state the specific time during the first hour of the LOSC event at which the face seals are assumed to fail; we interpret that NUREG/CR-4906P used time = 0, the onset of the LOSC event, as the time of possible failure."

The *WOG2000* model postulates that the binding-and-popping failures would occur at 30 minutes. This is based on analysis of the heatup rate as well as operating experience and expert judgment. There is no physical mechanism for such a failure before 15 minutes following loss of cooling since the seals would not yet experience out-of design basis temperatures.

This is consistent with Reference 2 (Section 10.1.1) which estimates it would take 30 minutes for the #1 seal to become thermally saturated.

Moreover, there is no evidence from operating experience of popping-and-binding failure with loss of seal cooling. Reference 2 (Section 2.4) presents the evidence of 24 RCPs that experienced loss of seal cooling but without popping-and-binding failure. In addition, in the more recent Sizewell loss of RCP seal cooling event (Reference 6), the seal material underwent a total loss of cooling for a 20-minutes period, without a popping-and-binding failure; then underwent further periods of the same conditions until seal cooling was permanently established. At the end of this unplanned "test" with periods of total loss of seal cooling, no binding-and-popping failure was observed.

Using 15 minutes and 60 minutes as the upper and lower bounds respectively, the following approach is used to estimate a reasonable mean time of occurrence of the binding-popping failure mode:

- The time of occurrence is assumed to obey the lognormal distribution (which is a commonly used assumption in PRAs);
- The 5^{th} percentile of the distribution is at 15 minutes

- The 95^{th} percentile of the distribution is at 60 minutes

This results in a mean time of occurrence of 33 minutes.

To see the sensitivity of this mean value to the postulated percentiles, the following scenario is also considered:

- The time of occurrence is again assumed to obey the lognormal distribution
- The 1^{st} percentile of the distribution is at 15 minutes
- The 99^{th} percentile of the distribution is at 60 minutes

This results in a mean time of occurrence of 32 minutes.

Thus, given the physical lower limit of 15 minutes and taking 60 minutes as the upper bound of the expert opinion, the mean time of 30 minutes for the occurrence of these failure modes is reasonable.

3.3 TREATMENT OF MULTIPLE RCPS

The Brookhaven Model postulates that if a leakage scenario occurs, all RCP pumps with the same seal material in a given unit would respond with the same leakage. However, it is not unreasonable to expect some degree of randomness in the failures. Thus, not all RCP seals in a plant would be expected with 100% certainty to undergo the same leakage failure. The current assumption – if one pump has a leakage at a certain rate, then all other pumps have leakages at the same rate – is likely to be conservative (i.e., likely to overstate the expected total leakage). On the other hand, addressing this assumption rigorously would make the model very complicated. In order to maintain the simplicity of the model, this treatment will be recognized as a potential conservatism but will not be addressed quantitatively in the *WOG2000* model.

3.4 LEAKAGE SCENARIOS

Using the above parameters, the RCP seal leakage scenarios can be defined with their probabilities, leakage rates, and times of progression. The results are summarized in Table 3.4-1 for the five scenarios for a single RCP pump. With the simplified treatment of multiple RCP pumps, this result also applies to 2, 3, or 4 pumps in the same unit; however, the total RCS leakage from multiple pumps must be calculated by multiplying the number of pumps with the leakage rate per pump. For example, for a 4-loop plant, the fifth leakage scenario in Table 3.4-1 would have a 1920 gpm (4 * 480) RCS leakage.

The RCP seal leakage scenarios for 2, 3, and 4 loop plants with high temperature o-rings following a total loss of RCP seal cooling with RCP pumps tripped are given in Table 3.4-2.

Table 3.4-1 WOG 2000 Model Scenarios with High Temperature O-Rings		
Leakage Scenarios with High Temperature O-Rings for 1 RCP		
Leakage Rate (gpm/pump)		**Probability**
0 to 30 Minutes*	After 30 Minutes	
21	21	0.7900
21	57	0.1442
21	182	0.0533
21	76	0.0100
21	480	0.0025
Total Probability		1.0000

* Time after loss of all seal cooling with RCP stopped.

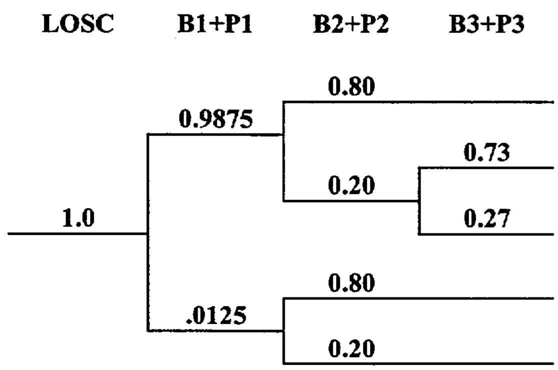
Table 3.4-2 WG2000 Model Scenarios with High Temperature O-Rings for 2, 3 and 4 Loop Plants

2-Loop Plants		
Leakage Scenarios with High Temperature O-Rings		
Leakage Rate (gpm)		***Probability***
0 to 30 Minutes*	After 30 Minutes	
42	42	0.7900
42	114	0.1442
42	364	0.0533
42	152	0.0100
42	960	0.0025
Total Probability		1.0000

3-Loop Plants		
Leakage Scenarios with High Temperature O-Rings		
Leakage Rate (gpm)		***Probability***
0 to 30 Minutes*	After 30 Minutes	
63	63	0.7900
63	171	0.1442
63	546	0.0533
63	228	0.0100
63	1440	0.0025
Total Probability		1.0000

4-Loop Plants		
Leakage Scenarios with High Temperature O-Rings		
Leakage Rate (gpm)		***Probability***
0 to 30 Minutes*	After 30 Minutes	
84	84	0.7900
84	228	0.1442
84	728	0.0533
84	304	0.0100
84	1920	0.0025
Total Probability		1.0000

Figure 3.1-1 WOG2000 Model Event Tree with High Temperature O-Rings



Sequence	Probability	Leakage gpm/pump
1	0.79	21
2	0.1442	57
3	0.0533	182
4	0.01	76
5	0.0025	480

Total Probability = **1.0**

Note:

LOSCLoss of Seal Cooling and RCP Stopped
B1 + P1 Binding and Popping Failure Mode for First Stage Seal
B2 + P2 Binding and Popping Failure Mode for Second Stage Seal
B3 + P3 Binding and Popping Failure Mode for Third Stage Seal

4.0 DELETED

5.0 DELETED

6.0 DISCUSSION OF UNCERTAINTIES

In the past decade, various probability estimates for the failure of face seals and o-rings have been provided by different experts. These estimates provide a range of uncertainty in failure probabilities. A summary of various estimates (by D. B. Rhodes) is provided in Appendix A of Reference 7.

The most important uncertainty issue relates to the probability of the largest size leak (480 gpm/pump). The effect of upper bound failure probability estimates from Reference 7 on the plant CDF will be discussed in terms of Scenario #17 in Figure 2.2-1. In this scenario, both the first and the second seals fail, leading to 480 gpm/pump leakage; furthermore all RCPs are assumed to have this leakage rate. This is the limiting scenario since it is physically the largest possible leakage, leading to core uncovery in 1 to 2 hours if no recovery actions are taken.

In Reference 7, the upper bound case for the seal packages with either the high temperature or the old o-rings gives the scenario probability of 0.1 (0.2 * 0.5), whereas the Brookhaven Model gives a scenario probability of 0.005 (0.025 * 0.2), and the *WOG2000* model gives a scenario probability of 0.0025 (0.0125 * 0.2). To put these probabilities in perspective, a simple parametric study is given in Table 6-1 for the potential contribution of this scenario to the plant CDF. The dominant scenario is a station blackout event, where the reactor trip occurs, and the turbine driven auxiliary feedwater pump (or equivalent) functions to provide automatic RCS cooling. The power recovery probability, leading to SI injection to cope with the RCS leakage, is assumed to be 0.5.

From Table 6-1, the upper bound estimate for the contribution of the scenario to the plant CDF is 5 E-05/year for a plant with a SBO frequency of 0.001/year and a recovery failure of 0.5. For plants with lower SBO frequency and/or with a backup AC power source, this upper bound frequency would drop by a factor of 2 to 10. Thus, even this upper bound estimate is well within the range of acceptable CDF.

In Table 6-1, using the WOG2000 model, the same plant with the above mentioned characteristics would have a CDF contribution of 1.3 E-06/year from this scenario; this frequency would drop by a factor of 2 to 10 for plants with lower SBO frequency and/or with a backup AC power source.

Thus, for this example, the difference between the mean value and the conservative upper bound estimate frequencies is a factor of 40, as shown in Table 6-1. Although the conservative upper bound frequency is within the CDF frequency range acceptable for generic plant risk, this factor of 40 is high; it is a indication of the expert opinion driven uncertainty which can influence and skew the plant risk profile, if used indiscriminately.

Table 6-1 A Parametric Study of Effect of Large RCP Seal Leakage Scenario on a Typical Plant CDF

SBO Initiating Event Frequency (per year)	Probability 480 gpm Scenario Occurs	Probability AC Power / SI Not Recovered before Core Uncovery	CDF for the Scenario (per year)	
0.001	0.1	0.5	5.0E-05	Upper-Bound Case
0.0005	0.1	0.5	2.5E-05	Upper-Bound Case
0.0001	0.1	0.5	5.0E-06	Upper-Bound Case
0.001	0.0025	0.5	1.3E-06	WOG2000 Case
0.0005	0.0025	0.5	6.3E-07	WOG2000 Case
0.0001	0.0025	0.5	1.3E-07	WOG2000 Case

7.0 REFERENCES

1. BNL Technical Report W6211-08/99, "Guidance Document for Modeling of RCP Seal Failures," August 1999.

2. WCAP 10541, Revision 2, "Reactor Coolant Pump Seal Performance Following a Loss of All AC Power," November 1986.

3. NUREG/CR-4550, "Analysis of Core Damage Frequency From Internal Events: Expert Judgment Elicitation," Volume 2, April 1989.

4. Reactor Coolant Pump Seal Failure, Appendix A of NUREG/CR-5167, April 1991.

5. Westinghouse/WOG Seal LOCA Model with Popping/Binding, as applied in IPE Studies submitted to the NRC, such as Wolf Creek, Kewaunee, V. C. Summer IPE Studies.

6. WOG Letter OG-99-086 to the US NRC, dated September 17, 1999.

7. Cost/Benefit Analysis for generic Issue 23: Reactor Coolant Pump Seal Failure, R. G. Neve, H. W. Heiselmann, NUREG/CR-5167, April 1991.

ATTACHMENT A

THE USA NRC RAIS ON WCAP-15603, REVISION 0

AND

WOG RESPONSES TO THE RAIS

WESTINGHOUSE OWNERS GROUP
WOG 2000

REACTOR COOLANT PUMP SEAL LEAKAGE MODEL FOR WESTINGHOUSE PWRS

WCAP-15603, REVISION 0

RESPONSES TO THE NRC RAIS

The answers to the 10 RAIs are given below. WCAP-15603 is revised to leave out the RCP seal leakage models for unqualified o-rings to minimize the points of contention. Almost all domestic Westinghouse nuclear power plants have either switched to qualified o-rings, or are scheduled to do so in the near future. Since the RCP seal leakage model for the old o-rings is more involved, we propose not to address it in WCAP-15603 – i.e., to remove reference to old o-rings from WCAP-15603.

NRC REQUEST FOR ADDITIONAL INFORMATION

RAI 1 The Topical Report states in Section 1.0 (page 1-1) that the Brookhaven National Laboratory (BNL) model is the current regulatory model for reactor coolant pump (RCP) seal leakage, and it uses this model as the starting point for the development of the WOG 2000 model. However, the BNL model is not the current regulatory model. The staff committed in resolving Generic Issue 23 to use the Rhodes model until other acceptable reactor coolant pump (RCP) seal models were developed. The original intent of the BNL report was to interpret and clarify the other existing RCP seal models, including the Rhodes model. However, as part of their report, BNL developed their own best-estimate RCP seal model, which differed from the other seal models. In developing the BNL best-estimate model, BNL made assumptions regarding seal failure with which the U.S. Nuclear Regulatory Commission (NRC) staff may not fully agree. For example, the Brookhaven model uses a probability of 0.54 for the popping-and-binding failure mode for the third-stage seal, given that the second stage seal has failed, and the WOG 2000 model reduces this probability to 0.27 for the "new" o-rings. However, the Rhodes model assumed pop-open failure of the third stage seal under these conditions (i.e., probability of one). The Topical Report needs to address and justify the differences between the WOG 2000 model and the Rhodes model.

Response to RAI 1:

The sentence mentioned in the RAI will be modified in WCAP-15603 to describe the BNL Report as the "primary reference" for the WOG2000 model.

The basis for considering the BNL Report as the primary reference is that (a) it contains a best estimate RCP seal Leakage PRA model and (b) it represents the most current effort to provide a reasonable middle ground for this expert-opinion-driven issue. In our opinion, the 'Rhodes Model' represents one opinion, a conservative one at that, which may have been adequate for generically addressing the USI 23 (the purpose of NUREG /CR-4906P and NUREG/CR-5167), but is not appropriate for plant PRA modeling and decision making. Foundational to PRA *philosophy is that the plant risk should not be distorted by conservative assumptions which would mis-focus the component and system importances and PRA insights for risk-informed applications. This position has been supported both by utilities and by NRC. Moreover, it is our opinion that the "Rhodes Model" has not undergone the test of adequate PRA modeling compatible with the current PRA philosophy and practice.*

The whole point of this WCAP is NOT to provide new evidence or analysis to re-evaluate the seal leakage phenomena BUT to agree upon a mutually acceptable PRA model, in a 15-year-old, expert-opinion-driven issue. For this purpose, the WOG2000 model refers to the NRC-sponsored BNL report and uses the best estimate model in that report in the spirit of recent PRA practices and philosophy shared by the NRC and the utilities. The differences between the Brookhaven and WOG2000 leakage models are clearly identified and discussed in WCAP-15603. These differences are introduced to have a realistic representation of the phenomena involved. We have no new analysis or tests to provide.

However, to be responsive to the RAI, we compared the WOG2000 leakage model with the latest discussion we could find of the Rhodes model, namely in Appendix A of NUREG/CR-5167 (April 1991). The discussion in NUREG/CR5167 references to NUREG/CR-4906P (January 1988), but the probabilities and times between the 2 versions differ.

Areas to be compared:

1. *Failure probability for first stage*

   The Rhodes PRA Model in NUREG/CR-5167 gives the failure probability for the first stage as .025. The WOG2000 model gives the failure probability for the first stage as .0125. The rationale for this failure probability is provided in WCAP-15603. The BNL PRA model gives the failure probability for the first stage as .025.

2. *Failure probability for second stage*

   Assumptions are the same across all 3 models.

3. *Failure probability for third stage*

   The Rhodes PRA Model in NUREG/CR-5167 gives the failure probability for the third stage as 1.0. The WOG2000 model gives the failure probability for the first stage as 0.27. The rationale for this failure probability is provided in WCAP-15603. The BNL PRA model gives the failure probability for the first stage as .54.

4. *Seal leakage rates for failures*

   Assumptions are the same across all 3 models.

5. *O-ring failure probability as a function of time after start of event*

NUREG/CR-5167 on page A-6 states that (based on Section 8 of WCAP-10541) the plant cooldown is assumed to have little effect on the assumed failure time of the o-rings (which are assumed to fail after 2 hours.) The Rhodes model distinguishes between "Improved" o-rings qualified by Westinghouse and "Qualified" o-rings which would be qualified to withstand 550°F and 2250 psi. However, Section 8 of WCAP-10541 indicates that RCS pressure would be reduced starting almost immediately, either through loss of RCS inventory or through operator action to cool the plant and depressurize.

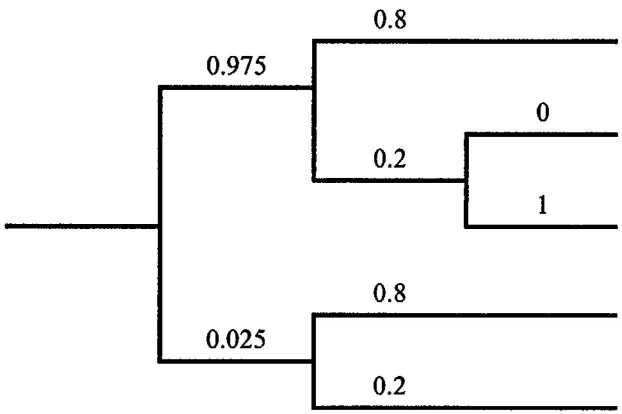
The material presented in WCAP-10541 Section 8, Figure 8-3 indicates that the leakage from the seals results in a slowly decreasing pressure in the RCS for the case of 15 gpm leakage per pump such that RCS pressure is < 2000 psi at 1 hour and ~ 1800 psi when the cooldown is started and < 1600 psi at 2 hours. As noted in the WCAP–10541 text, cooldown was assumed to start (for purposes of these analyses) when pressurizer level decreased to < 10%. For the case with 300 gpm leakage per pump (Figure 8-1) the cooldown started at approximately 15 minutes at an RCS pressure of ~ 1600 psi and reached a pressure of < 1000 psi in approximately 30 minutes. Test and qualification data for high temperature o-rings indicates that all o-ring and gap combinations tested (120 o-rings were tested in the original qualification testing and 188 o-rings have been tested in supplemental batch testing for a total of 308 o-rings tested) did not fail during the 18 or 168 hour test period and the absolute minimum pressurization failure pressure for any combination was 1710 psi. Based on this information, assuming failure at 2 hours (as is stated on page A-6 of NUREG/CR-5167) is overly conservative. Additional information on o-ring testing results is provided in the response to RAI-6.

The comparisons (Rhodes, BNL report, and WOG2000) are provided in Figures A-1 through A-3.

A new data point for seal behavior has been established with the Maanshan SBO event (March 2001), in which the seals were exposed to hot standby RCS pressure and temperatures, which lasted for two hours, with no indications of excessive seal leakage. The seals in one RCP were inspected after the event and were found to be in good condition. Based on this inspection, the seals in the other 2 RCPs were not inspected and were continued in service for the remainder of the operating cycle.

Figure A-1 Our Understanding of the Rhodes Model (Qualified O-Rings Best Estimate)

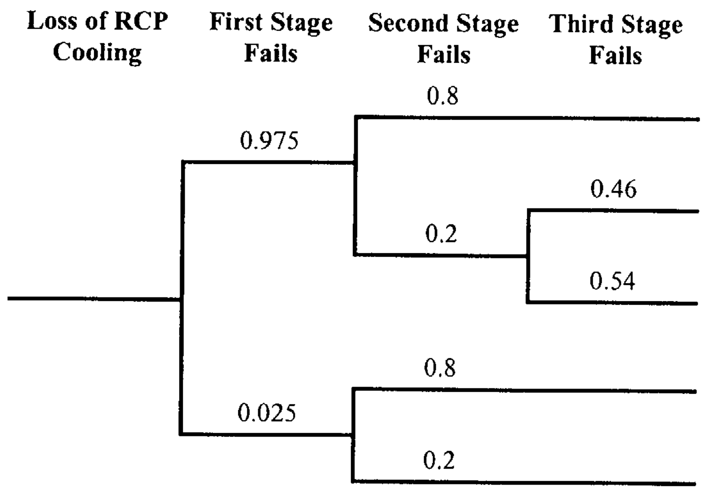
Loss of RCP Cooling	First Stage Fails	Second Stage Fails	Third Stage Fails		Leakage (per pump) (From NUREG/ CR-4906)	Probability	Start of Core Uncovery (hours) With Cooldown	Start of Core Uncovery (hours) Without Cooldown	Comments
				1	21	0.78	20	16	Scenario probabilities and core uncovery times are inferred.
				2	57	0			
				3	182	0.195	5	3.5	
				4	76	0.02	9.5	7	
				5	480	0.005	2	1	2 means that the core uncovery probability is zero from 0 to 120 minutes and jumps up to 0.005 immediately at 120+th minute.
			Sum =			1			



Scenario start time = Not stated. Last paragraph on page A-1 of NUREG/CR-5167 states that the first stage inlet temperature would reach prevailing RCS temperature in 10+3 = 13 minutes, per Westinghouse predictions.

O-ring failure probability = 50% after 2 hours after full system delta P is applied. It is not explained how this is used in the scenarios. It is also not explained what this probability is when the RCS temperature/pressure is reduced first by reactor trip and AFW system operation; next by operator rapid cooldown per ERGs.

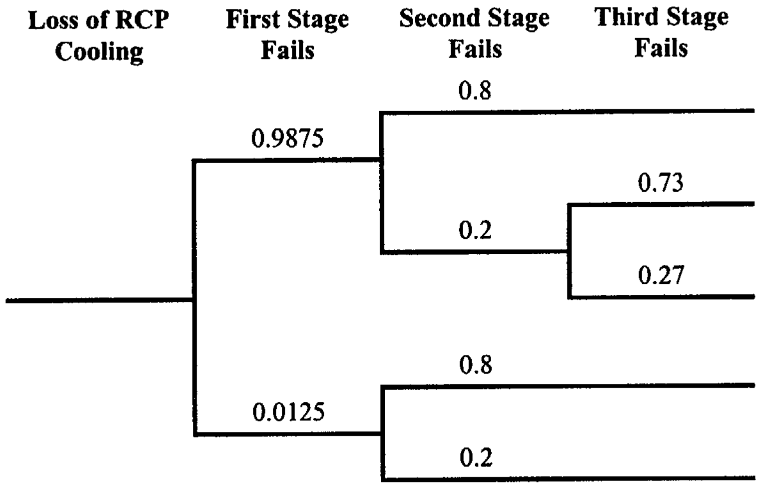
Figure A-2 BNL Best Estimate Model (Qualified O-Rings)



	Leakage (per pump)	Probability	Start of Core Uncovery (hours)	Comment
1	21	0.78	Not in WOG2000 scope.	
2	57	0.0897		
3	182	0.1053		
4	76	0.02		
5	480	0.005		
Sum =		1		

Scenario start time = During the first hour
O-ring failure probability = 0

Figure A-3 WOG2000 Model (Qualified O-Rings)



	Leakage (gpm per pump)	Probability	Start of Core Uncovery (hours)	Comment
1	21	0.79	Not in scope.	
2	57	0.144175	Not in scope.	
3	182	0.053325	Not in scope.	
4	76	0.01	Not in scope.	
5	480	0.0025	Not in scope.	
Sum =		1		

Scenario start time = 5 percentile at 15 minutes; 95 percentile at 60 minutes; log-normal; mean 30 minutes.
O-ring failure probability = 0

RAI 2 The Topical Report defines the RCP seal leakage model for the condition of a sustained total loss of RCP seal cooling with timely stopping of the RCPs. However, the Topical Report does not adequately define or justify the assumption of "timely stopping." The Topical Report implies in Section 2.2 (page 2-1) that, if the RCPs are not stopped within a certain (but unspecified) time period, the RCP seals are assumed to fail catastrophically (i.e., result in a maximum leakage rate). Please state the time in which the RCPs must be stopped for the use of this leakage model and provide a justification for the use of this time. In addition, please state the assumed consequence associated with failing to meet this condition.

Response to RAI 2:

The time window for the operator action of timely stopping of the RCP pumps after a loss of seal cooling event applies to "abnormal" events such as total loss of CCW, etc, but does not apply to LOSP and SBO events in which the pumps are stopped by the nature of the initiating event. WCAP-15603 is silent on the time window by design; this is left to plant-specific operator action analyses, which will consider the abnormal operating procedures and manufacturer's recommendations. The intent of including this scenario in WCAP-15603 is to assure that it is addressed by each utilities' PRAs for completeness and consistency.

Plants have been provided with plant specific RCP Instruction Manuals and operating guidelines which have been used to develop operating procedures for abnormal and emergency events. The general form of these procedures is to instruct the operators to monitor the RCP operating limits, particularly the bearing and seal temperatures. The operator should attempt to restore seal cooling (either seal injection or CCW) to the RCP if these operating limits have not been exceeded, and the RCP has not been stopped. Once the RCP has reached one or more of the operating limits, the operator should stop the RCP in accordance with the RCP Instruction Manual. The RCPs are tripped prior to exceeding the applicable RCP Instruction Manual limits (i.e., 235°F seal leak off, 225°F pump bearing). The time at which the RCP is tripped depends on the nature of the event and the plant conditions that existed before the complete loss of seal cooling. An example of the time to reach these temperatures is provided by the Sizewell test data which indicate that the seal leakoff temperature and pump bearing temperature limits were reached at 12-14 minutes after complete loss of seal cooling.

This time window for stopping of the RCP has been modeled at the order of 10-15 minutes in PRA models. Such a time window will be included in the implementation guide as a default model. Also, if this operator action fails, it is postulated that all seals that lost cooling will undergo the 480 gpm/pump leakage scenario. This is a conservative consequence assumption but the frequency of this sequence is generally low. Thus, this assumption should not distort the risk profile.

RAI 3 The leakage model does not address the potential for operations with pre-existing stage failures and/or random failures (e.g., associated with manufacturing defects or installation errors/damage). Please justify not explicitly including these specific failure contributions in the model or address them in the model.

Response to RAI 3:

Random failures of seals ARE included in every PRA implicitly in the small LOCA (or very small LOCA) frequency. In the current PRA studies, these types of events are observed not to contribute significantly to small LOCA risk. Most of such events observed in the past are in the leakage category, in which the normal CVCS makeup is sufficient to deal with the leakage, while the plant may be brought to an orderly safe shutdown state, without a reactor trip. The reason that RCP seal LOCAs are modeled separately from small LOCAs is the DEPENDENCY between the initiator and failure of mitigation.

In addition, the RCP seal leakage is routinely monitored on an individual pump basis. In the case of an abnormal seal leakage, or even a change in the "normal" seal leakage associated with a specific pump, the situation is immediately subjected to engineering and risk evaluations to determine if the plant should be shutdown for repair. Westinghouse engineers cognizant in RCP pumps and others in PRA have first-hand experience in participating in evaluations with the plant engineers, where a change as small as from 3.5 to 4.0 gpm (which is still in the normal range of operational leak rates) for a pump seal leak off, is evaluated for potential remedial action. With such practices, namely, careful and routine monitoring of the leakage, and shutting down the plant if a narrowly defined normal leakage rate is not maintained, it is extremely unlikely that a consequential hidden defect mentioned in the RAI will be allowed to reach a point of causing an automatic reactor trip. Thus, such events are not explicitly modeled in PRAs.

RAI 4 The Topical Report states in Section 3.1 (pages 3-1 and 3-2) that the binding failure mechanism is effectively eliminated by the use of qualified o-rings. Based on this assertion, it reduces the combined probability of popping open or binding failure by a factor of two. RCP seal hydraulic instability (i.e., pop-open) and seal binding are two separate phenomena that occur as a result of different physical conditions. Popping open can occur whenever net positive RCP seal face closing forces are lost due to a change in the thermodynamic fluid conditions. Popping open will occur at the time the conditions are favorable for the phenomenon and is therefore not time-dependent. Binding can occur after the extrusion of the secondary seal (i.e., o-ring or channel seal). This usually occurs only after some time at elevated temperature and is therefore somewhat time-dependent. In the Rhodes and BNL models, the probabilities of these failure modes were combined because of the state of knowledge at that time. For example, the Rhodes and the BNL models both use a combined popping and binding probability of 0.025 for the first-stage seal. This assumption is made for seal assemblies using “old” o-rings and those using “new” and “improved” o-rings that are qualified for high temperature and the expected pressure differential without seal stage failure. The Rhodes model, as shown in Appendix A of NUREG/CR-5167, and the NUREG-1150 model both use a failure probability of 1.0 for the third-stage seal (i.e., the vapor seal) because it is not designed to withstand full system pressure. The NUREG-1150 model was also constructed with expert opinion input from Westinghouse. Therefore, reducing the combined probability of popping and binding by a factor of two does not appear to be justified based on the present state of knowledge. Please provide additional justification, including any supporting test results, analyses, and operational events, for eliminating the binding failure mechanism due to premature extrusion failures of the o-rings or channel seal elastomers and for reducing the combined probability of popping open or binding failure.

Response to RAI 4:

As noted in WCAP-10541 Revision 2, there have been a number of occurrences of loss of seal cooling and none of those has resulted in excessive leakage that can be attributed to “popping.” Since no cases of excessive leakage due to popping have occurred, there were no cases of popping or binding resulting in popping of seals.

Since the publication of WCAP-10541 Revision 2, there have been 2 cases that resulted in loss of all seal cooling. The first is the Sizewell RCP Seal test in 1991. This case was described in a meeting with NRC staff on June 7, 1993 and was also described in letter OG-99-086 dated September 17, 1999. In the Sizewell test, seal cooling was lost and regained several times over a period of approximately 45 minutes. The second case was the complete loss of AC power for 2 hours at the Maanshan plant in Taiwan on March 18, 2001. We have been able to obtain only limited information on the event, but have confirmed that RCP leakage was not excessive and that the RCP seals functioned normally after power and seal cooling were restored.

In WCAP-15603, there is no intention to reduce the popping failure probability. To avoid a misunderstanding, we explained the rationale on page 3-2 as follows:

> *As stated in items 1 and 2 on page 3-2 (taken from the BNL report Sections 2.2.1.1 and 3.1.1), binding failure is driven by premature extrusion failure of the o-rings, and dominates the popping-and-binding probability, P(PB) for stages 1 and 3. Thus, if*
>
> $$P(PB) = p(P) + p(B) = \varepsilon + p(B),$$
>
> *where ε represents the small probability for the popping mode relative to binding, then reduction of the binding probability by a factor of two results in*
>
> $$\varepsilon + p(B)/2 \sim P(PB)/2.$$
>
> *We consider this reduction as a conservative representation of one of the benefits of using the qualified o-rings. It is included to give proper credit for reduction in plant risk when plants switch from old to qualified o-rings.*

RAI 5 The Topical Report assumes in Section 3.2 (pages 3-3 and 3-4) and Section 4.2 (page 4-2) that the onset of seal leakage occurs 30 minutes after the loss of RCP seal cooling. The correct time for onset of 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-stage seal reaches full reactor coolant temperature. This is estimated in WCAP-10541 to be approximately 10 to 13 minutes after loss of RCP seal cooling in the Westinghouse RCP seal design. Popping open of the second-stage seal, if it occurs, will most likely occur at this time. Please provide additional justification, including any supporting test results, analyses, and operational events, for the delay in this timing to 30 minutes, instead of using a time of 10 to 15 minutes.

Response to RAI 5:

WCAP 10541 estimates the time to purge the seal inlet volume to be 10-13 minutes (WCAP-10541 page 3-7). This estimate does not fully consider the effects of cooling of the RCS fluid by the thermal barrier heat exchanger and the pump parts. Therefore, the initial effects of the hotter water will begin after approximately 15 minutes.

WCAP-10541 Revision 2 Supplement 2 provides a transient behavior analysis of the number 2 seal during loss of all seal cooling. This analysis shows that the number 2 seal reaches a large, stable and increasingly divergent combined face condition well before the onset of 2 phase flow conditions in the number 1 seal leakoff cavity (number 2 seal inlet). Consequently, the number 2 seal would be expected to become firmly closed and the postulated hydraulic instability failure ("popping open") cannot occur.

Data from the Sizewell Loss of Seal injection test has been reviewed to obtain additional insight for application to the WOG2000 model. This test experienced a loss of CCW approximately 2 hours after the start of the scheduled loss of seal injection acceptance test for the pump. This resulted in a complete loss of seal cooling. Review of the data indicates the following:

The Sizewell test was simulating a loss of seal injection to show that the thermal barrier heat exchanger was capable of providing sufficient cooling for the seal package without seal injection. During that simulation, the seal injection flow was secured. Approximately 2 hours after seal injection was secured, the test facility experienced a loss of power to the pump simulating the Component Cooling Water (CCW) flow to the thermal barrier heat exchanger. During the Sizewell test, with the existing loss of seal injection and cooling only with CCW (prior to the loss of power to the CCW pump), the bearing temperature, seal leak off temperature and seal housing temperatures indicated 194°F as the starting point temperature from which the complete loss of seal cooling proceeded. For purposes of this discussion, the start of the loss of CCW flow is taken as 0 minutes. At 16 minutes, seal bearing temperature was 264°F, Seal leakoff temperature was 277°F, Seal housing temperature was 401°F (top of scale), Seal Leakoff Flow was 6.7 gpm, and Number 1 Seal leakoff pressure was 108 psi. At 20 minutes, seal bearing temperature was 401°F (top of scale), Seal leakoff temperature was 293°F, Seal housing temperature was 401°F (top of scale), Seal Leakoff Flow was 12.2 gpm, and Number 1 Seal leakoff pressure was 108 psi. Even though the seal was subject to elevated temperatures for

20 minutes, the seal leakoff flows did not exceed 14 gpm, thus indicating that the seals did not pop open and did not exhibit large leakage.

On March 18, 2001, the Maanshan plant in Taiwan (a 3 loop Westinghouse PWR with Westinghouse RCPs and seals) experienced a complete loss of all AC power event while the plant was shutdown at hot standby conditions in the RCS. During the loss of all AC event at Maanshan in Taiwan, there were no reports of excessive seal leakage in the presence of a loss of all seal cooling. Detailed information on the seal temperatures, pressures and flows is not available. The Atomic Energy Council of Taiwan report of the event states, "When the incident happened, both reactors have already been shutdown for 21 hours. They were in hot shutdown conditions with reactor pressure at 157 kg/cm^2 (2235 psi) and temperature at 291°C (555°F). During the event, the turbine driving auxiliary feedwater pump functioned normally as designed, and with the proper operation of SGs PORV, the core temperature and pressure continued to reduce throughout the event. According to the level variation of coolant drain tank and containment floor sump, there was no sign of RCP seal leakage." This last statement indicates that the number 2 and number 3 seals did not exhibit any significant leakage during the event since the number 2 seal leak off flows to the coolant drain tank and the number 3 seal leak off drains to the containment sump. This indicates that the seals did not pop open and did not exhibit large leakage.

The discussion on the determination of the time of 30-minutes as the expected time of occurrence of potential popping or binding failures is given on page 3-3 of WCAP-15603. The expert opinion documented in the BNL Report (Page 24) states that if such a failure occurs, it can occur in the first 60 minutes. In fact, it can not occur before the seals experience full RCS temperature after the cooler water in the cavity around the seal is replaced with RCS water through normal leakage. The expected value of 30 minutes is calculated as described in WCAP-15603 on pages 3-3 and 3-4, where 15 and 60 minutes are used as the lower and upper bounds of this uncertain time interval and the mean of the postulated log-normal distribution is approximately 30 minutes.

RAI 6 The Topical Report assumes in Section 3.1 (page 3-2) a failure probability of 0.0 for "new" or "improved" o-rings that have been qualified for the conditions expected under a loss of RCP seal cooling, assuming that no seal stage failures have occurred. That is, these new or improved o-rings have been qualified for full reactor coolant temperature, gap differentials at the expected seal stage temperature, and the pressure differential that each o-ring would experience without any seal stage failure. Fully qualified o-rings could withstand full reactor temperature and pressure at the expected gaps. However, no information has been presented to support that any fully qualified o-rings exist and are in use in commercial nuclear power plants. Therefore, using a probability of 0.0 for failure of the "new" o-rings is only justified for those cases in which no seal stage failures occur. Further, the BNL model also recognized the potential for failure of the improved o-rings after 2 hours and stated that "... this assumption (i.e., failure after 2 hours) is more justifiable than the one made in the best-estimate model (i.e., the BNL model that assumed o-rings would not fail) because there is not clear proof that the new o-ring material would survive full system pressure. If the difference in risk between these two cases is judged significant, then further elastomer qualification testing would be necessary to resolve this issue." Please provide additional justification, including additional test results, for using a zero probability of elastomer failure for the "new" o-rings, or provide the rationale (and comparison to the Rhodes model) for use of a non-zero probability.

Response to RAI 6:

The RCP Seal o-rings are fully qualified for the conditions that are predicted to occur during a loss of all seal cooling. The o-ring qualification is discussed below.

The o-ring qualification program for high temperature o-rings is documented in WCAP-10541 Revision 2 Supplement 1 which was submitted to NRC via OG-88-018, May 12, 1988. The qualification program determined the pressure differential for the seal locations, o-ring sizes and gaps based on the thermal-hydraulic analyses of seal conditions. The combinations of o-rings and gaps tested were selected to bound the limiting conditions in the RCP seal. The gaps were selected based on conservative analyses of the seal thermal hydraulic conditions to determine the maximum total diametral gaps. The pressure differential was selected from the expected pressure differential across the entire seal stage without regard to the number of o-rings that would have to fail to develop the pressure differential across the subject o-rings. The locations of the o-rings are depicted in Figures 6-1, 6-2, and 6-3 of WCAP-10541 and the o-ring diameters and gaps are listed in Table 6-1 of WCAP-10541. Examination of the figures and the table yields the limiting locations and combinations of o-ring size and diametral clearance.

In addition to the initial qualification testing, each batch of o-ring material is also tested to confirm that the o-rings will provide the same capability as was demonstrated during the initial qualification testing. Information regarding supplemental testing is available in Westinghouse files.

The qualification and supplemental tests for RCP Seal o-rings were performed to demonstrate that the o-rings would perform their function during postulated loss of all seal cooling conditions. The test process uses 2 full cross-section o-rings with full size gaps in each scaled (reduced diameter) fixture. The o-rings are pressurized to the specified test pressure and heated to the specified test temperature. The test fixture is held at pressure for the duration of the test, *including the heatup time. Since no high temperature o-ring has ever failed at the specified test conditions for the test intervals of either 18 hours or 168 hours, the test pressure is increased to determine a failure pressure for the o-rings. At the end of the test time, the pressure is increased in increments of 50-250 psi at 5 minute intervals until one of the two o-rings fails. The failure pressure is reported for both o-rings in the test fixture. If the o-rings do not fail from the pressure increases, the highest test pressure is reported as the o-ring pressure capability.*

HOWEVER, the concern elaborated in this RAI (namely, the o-rings not surviving full system pressure, and having a failure probability after 2 hours) is seen to be of no consequence in PRA event sequences, as discussed below.

The WOG Emergency Response Guidelines (ERGs) provide operator guidance for coping with and mitigating postulated accidents. Guideline E-0, Reactor Trip or Safety Injection provides symptom-based diagnosis of plant conditions and directs the operator to the proper Optimal Recovery Guideline based on the symptoms of the event. If the event sequence is due to a loss of all AC power, Guideline E-0 Step 3 will direct the operators to Guideline ECA-0.0 Loss of All AC Power which will direct the operator to maintain plant conditions for optimal recovery by isolating the RCS leakage paths and using the TDAFW pump to feed, cool, and depressurize the intact SGs (thereby reducing RCS pressure and temperature via a natural circulation cooldown.) If the event sequence is due to loss of CCW or loss of SW, the increasing RCP seal temperatures and RCP lube oil temperatures will require the operators to trip the plant and the RCPs, thereby leading to Guideline E-0. In E-0, Step 3 checks for AC power available, Step 4 checks SI status. If SI is not required, then the operator enters Guideline ES-0.1 Reactor Trip Response. In ES-0.1, RCS temperatures, level and pressure are maintained and SG cooling is checked. Since seal cooling is lost on loss of CCW/SW and an RCP would not be restarted, then RCS natural circulation cooling and depressurization is established in accordance with Guideline ES-0.2 Natural Circulation Cooldown. Since the operator cooldown action is initiated during the first hour, the RCS pressure will be significantly reduced below the initial RCS pressure, rapidly approaching the secondary side pressure around 1100 psia. This reduces the pressure on the o-rings to below the pressure differentials for which the o-rings were qualified.

Thus, there are NO loss of RCP seal cooling event sequences in PRA models where (a) the RCS maintains full system pressure and (b) credit is taken for the RCP seals to hold full RCS system pressure for an extended period of time. In the sequences modeled for different initiating events, the RCS pressure will drop significantly due to AFW/SG cooling. Also, pressure will drop further if actions for rapid depressurization of the RCS are implemented. Thus, for these sequences, the concern does not exist.

If the AFW fails, the RCS pressure will remain high. The timing of this event is driven by loss of inventory out the pressurizer PORV; the size and timing of the seal LOCA is not very significant to the outcome (i.e., to the time to core uncovery). For these sequences, the PRA models require recovery of AC power within a two-hour period for the SBO event, after which the RCS will be depressurized and the sequence is treated as a LOCA. Thus, in this case, the non-zero failure after 2 hours is not a concern, since the sequence is already assigned a core damage end state after two hours if the AC power is not recovered. The same argument applies to the total loss of CCW or SWS events, in which some means of decay heat removal is required in a short time period, such as 2 hours.

RAI 7 The Topical Report assumes in Section 4.1 (page 4-2) that "old" o-rings for the first and second seal stages have a failure probability for extrusion failure of 0.5 for times greater than three hours and that the "old" o-ring for the third seal stage has a probability of extrusion failure of 0.5 for times greater than two hours after failure of the first or second o-ring. The "old" o-ring material was tested, per NUREG/CR-4077, at temperatures, gaps, and pressure differentials predicted by Westinghouse for a loss of RCP seal cooling event. Most o-rings tested failed in two hours or less when subjected to these conditions. Therefore, the use of a failure probability of 0.5 for old o-rings for times greater than three hours is not consistent with these results, and neither is the BNL model estimate of a probability of 1.0 of failure of all stages of o-rings in the third to fifth hours. Because of the modeling complexity created by the proposed change in failure probabilities from those in the BNL model, the Topical Report model reverts to the BNL model failure probabilities. Given that the ultimate result is no change as compared to the BNL model, either eliminate this discussion or provide additional justification to support the statements that the failure probability could be reduced from the BNL probabilities for the elastomer failure of "old" o-rings after two hours of exposure. Also, please justify the modeling and associated failure probabilities that are used in the WOG 2000 model for extrusion failure of the "old" o-rings (including any based on the BNL model) against the modeling conditions and failure probabilities established by the Rhodes model.

Response to RAI 7:

All domestic Westinghouse nuclear power plants have either switched to qualified o-rings, or are scheduled to do so in the near future. Since the old o-rings are no longer used, we have removed reference to old o-rings from WCAP-15603. For any plants with old o-rings, this will be handled on a case-by-case basis.

RAI 8 The Chapter 4 discussion and results are not fully consistent with the RCP seal leakage event tree model presented in Figure 2.2-1. To be consistent with the Chapter 4 tables, there should be branch points in Figure 2.2-1 under the B3+P3 for each scenario path. Specifically, Scenarios 1 and 13 should be split to represent success or failure of the B3+P3 branch. This condition is reflected in the WOG 2000 model tables for the period, t, greater than or equal to 0.5 hours, but less than 2 hours. Likewise, Scenario 12 should be split to reflect "t" greater than or equal to 2 hours, but less than 4 hours. For "t" greater than or equal to 4 hours, Scenario 12 should be split further, for the B3 + P3 success branch previously split, under the O3 branch. Further, the associated scenario leakage rates need to be established for each of these additional scenarios. The leakage rates for Scenarios 1b and 13b (failure of B3 +P3) need to be established or justified as remaining at the rate for the success path. Likewise, the leakage rates for Scenarios 12a (success of B3 + P3) and 12b (failure of B3 + P3) need to be established or justified. This justification is needed because these branches come from Scenarios 5 and 7, respectively, which have different leakage rates of 57 gpm and 182 gpm, respectively. Finally, the leakage rate for Scenario 12aa (success of B3 + P3 and O3) needs to be established. Should the rate be 251 gpm (similar to Scenario 14 conditions) or 300 gpm?

Response to RAI 8:

Chapter 4 of WCAP-15603 deals exclusively with old o-rings. All domestic Westinghouse nuclear power plants have either switched to qualified o-rings, or are scheduled to do so in the near future. Since the old o-rings are no longer used, we have removed reference to old o-rings from WCAP-15603. For any plants with old o-rings, this will be handled on a case-by-case basis.

RAI 9 Extrusion failure of "old" o-rings is assumed to occur during the third to fifth hour period. The third hour starts at time, t, equal to 2 hours. Thus, the probabilities related to this time for the first two stages should be stated as ≤ 2 hours (not 3 hours). For the third stage, which is assumed to fail two hours after the failure of either of the first two stages, it should be stated as ≤ 4 hours (not 5 hours). Please correct the information in Chapter 4 to be consistent with this condition.

Response to RAI 9:

All domestic Westinghouse nuclear power plants have either switched to qualified o-rings, or are scheduled to do so in the near future. Since the old o-rings are no longer used, we have removed reference to old o-rings from WCAP-15603. For any plants with old o-rings, this will be handled on a case-by-case basis.

RAI 10 Chapter 5 of the Topical Report recommends using a simplified model. However, the basis for the simplification is not provided. In particular, for the "new" O-rings, the simplification only eliminates one scenario. Because the WOG 2000 model provides scenarios of different leakages, binning should be related to the leakage rates. Thus, for the "new" O-rings, the five scenarios should not be reduced in number unless plant-specific success criteria result in no difference in the leakage rates among selected scenarios. For example, after 2 hours, Scenario 2 has a per-pump leakage rate of about 57 gpm (228 gpm for a four-loop plant), and Scenario 4 shows a rate of 76 gpm (304 gpm for four-loop plant). If the plant-specific analysis indicates that these rates do not result in any differences in system success criteria, these scenarios could be combined. However, this is a condition of the plant-specific analysis and is not appropriate for the generic-type WOG 2000 model to address. Likewise, the "old" O-ring model should only be reduced generically to five scenarios to reflect the five different leakage rates identified in Chapter 4 (assuming the changes identified in Item 8 above do not affect the resulting simplifications), with the scenario combinations based on the leakage rate (i.e., from Chapter 4 Table 4.4-1 combining Scenarios 1 and 2 and combining Scenarios 5 and 6). Please revise the Chapter 5 discussion accordingly or provide additional justification for the proposed combination simplifications.

Response to RAI 10:

The simplified model was presented as an optional implementation of the WOG2000 model. While there are arguments that would support the accuracy of the proposed simplification, for the purposes of moving forward with the WOG2000 model review, we have removed this section from WCAP-15603.