OG-00-125
December 20, 2000

WCAP-15603-NP, Rev. 0
Project Number 694

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Subject: Westinghouse Owners Group
Transmittal of WCAP-15603-NP, Rev. 0, (Non-Proprietary), "WOG2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," (MUHP-6074)

This letter transmits twelve (12) copies of the report, WCAP-15603-NP, Rev. 0, (Non-Proprietary) entitled "WOG2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs" dated December 2000.

WCAP-15603-NP 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 seals. The model is based on a Brookhaven National Laboratory seal leakage report that documents the current regulatory model. Several clarifications and modifications were added, based on Westinghouse experience and expert opinion, to produce this WOG2000 seal leakage model.

WCAP-15603-NP, Rev.0, provides the WOG technical documentation necessary to support licensees in risk informed regulatory applications. The WOG is submitting this licensing topical report, WCAP-15603-P, Rev. 0, under the NRC licensing topical report program for review and acceptance for referencing in licensing actions. The objective is that once approved, each WOG member may reference this report in risk informed regulatory applications.

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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

enclosures

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OG-00-125
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WCAP-15603
Revision 0

WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs

Westinghouse Energy Systems

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15603

WOG 2000
Reactor Coolant Pump Seal Leakage Model
for
Westinghouse PWRs

Selim Sancaktar
Reliability and Risk Assessment

December 2000

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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 seals. This model is based on a Brookhaven National Laboratory seal leakage report (Reference 1) that documents the current regulatory model. 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:

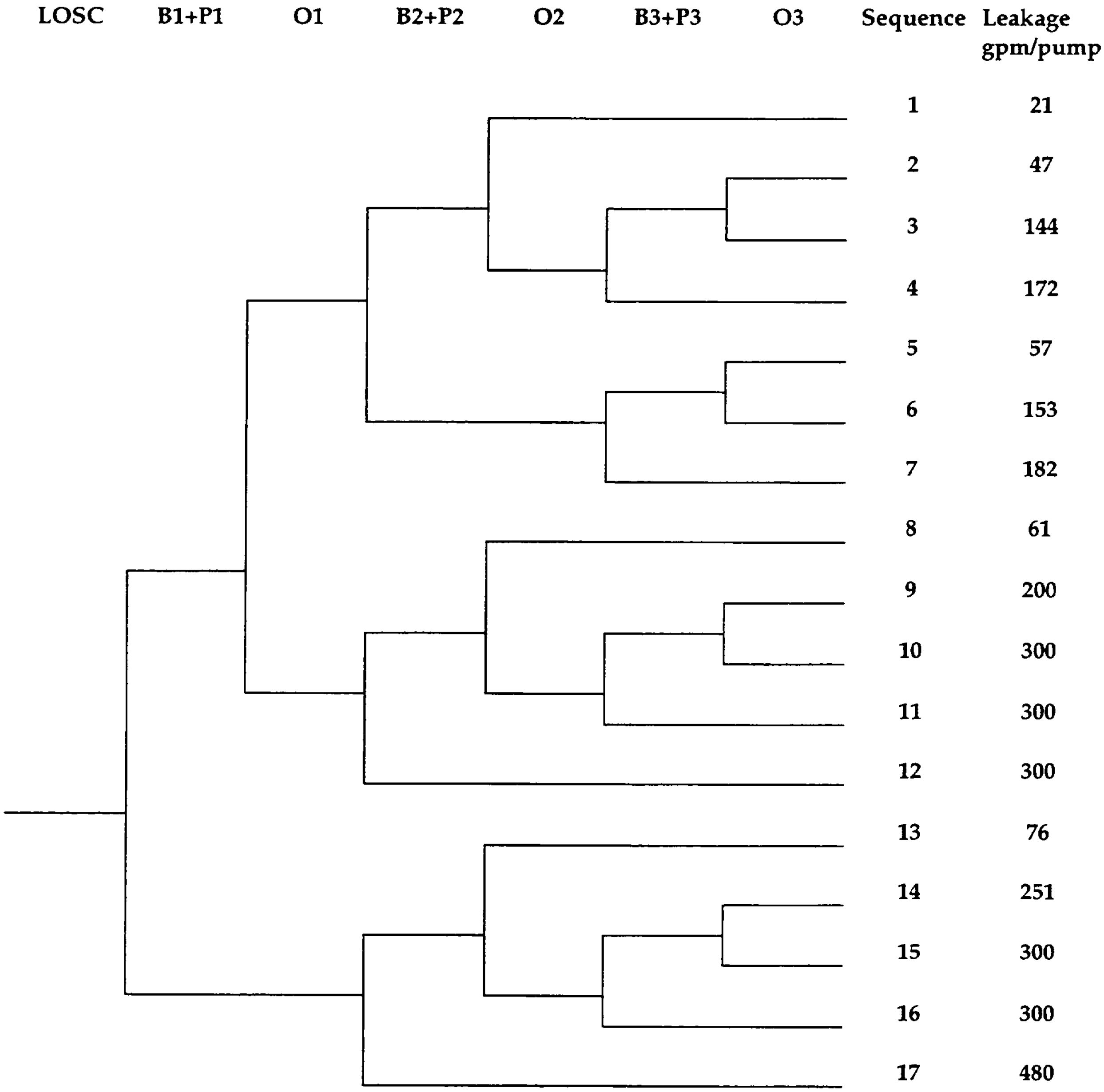
- Popping - opening of the seal faces due to hydraulic instability caused by fluid flashing,
- Binding - binding failure of the seal ring against the housing inserts due to secondary seal extrusion, and
- O-Ring Extrusion - overheating of the secondary sealing elastomers, allowing excessive leakage.

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 Sections 3 and 4 for pumps containing seal assemblies with either high temperature (qualified) or old (unqualified) o-rings, respectively. The leakage scenario logic given in Figure 2.2-1 applies to both types of seal assemblies.

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 5th percentile of the distribution is at 15 minutes
- The 95th 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 1st percentile of the distribution is at 15 minutes
- The 99th 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.

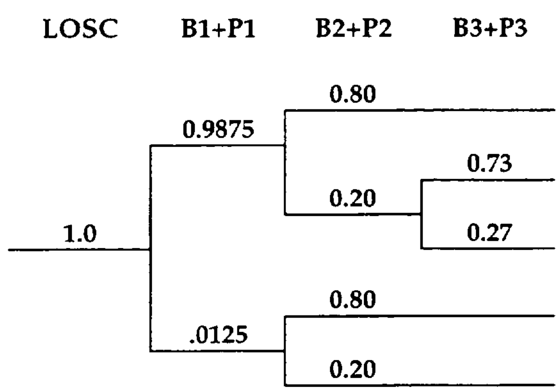
Table 3.4-2 WG2000 Model Scenarios with High Temperature O-Rings for 2, 3 and 4 Loop Plants

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:

LOSC	Loss 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 RCP SEAL LEAKAGE MODEL FOR PUMPS WITH OLD O-RINGS

Although a majority of the Westinghouse plants use the high-temperature o-rings, some Westinghouse plants still have old o-rings. The *WOG2000* RCP seal leakage model adopts the Brookhaven Model for the plants with seal assemblies containing old o-rings. This model, which is deemed to be conservative since it does not assume survival of an o-ring beyond a few hours, is outlined here.

4.1 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 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 uses these probabilities for the old o-rings.

(b) O-Ring Extrusion Failure

The Brookhaven Model gives the following failure probabilities for the old o-ring material:

P(O1) = P(O2) = 1.0 if time ≥ 3 hours
= 0.0 if time < 2 hours - failure occurs during the third hour.

P(O3) = 1.0 if time is ≥ 2 hours after failure of first or second o-ring
= 0.0 for other times

In the Brookhaven Model, the old o-rings are assumed to fail with certainty during the 3 to 5 hour period following loss of cooling, leading to leakage scenarios with 300 gpm/pump. The Westinghouse/WOG position on this failure mode has been a gradual increase of this probability in time, with some residual probability that the 21 gpm per pump scenario will remain. From Reference 2 (page 10-10):

> "However, elastomer extrusion test results... demonstrated that the secondary sealing elastomers have certain performance characteristics and failure probabilities which

depend upon the local conditions in the seal system components, e.g., the temperature, the differential pressure, and the gap between the components."

This is consistent with the seal leakage model documented in NUREG/CR-4550 (Reference 3). To recognize the possibility of the 21gpm scenario remaining, the o-ring failure probability needs to be reduced. A factor of 2 reduction is judged to be an appropriate (conservative) estimate:

reduced probabilities for the old o-ring material:

P(O1) = P(O2) = 0.5 if time ≥ 3 hours
= 0.0 if time < 2 hours - failure occurs during the third hour

P(O3) = 0.5 if time is ≥ 2 hours after failure of first or second o-ring
= 0.0 for other times.

Another factor that would contribute to survival of the old o-rings is the RCS cooldown and depressurization required by WOG Emergency Guideline (ERG) C-0 in events such as station blackout.

When the reduced probabilities are applied to the leakage scenarios (Figure 2.2-1), it is observed that the model got complicated due to generation of a large number of scenarios. For this reason, the *WOG2000* RCP seal leakage model uses the Brookhaven probabilities listed above, instead of the reduced probabilities.

4.2 SCENARIO STARTING TIMES

The scenario starting times are given for o-ring failures in Section 4.1. The starting time for the binding/popping failures of the seals is the same as Section 3.2, since the seal material is not changed. These times are summarized as follows:

- 21 gpm "normal" leakage starts at the beginning of the scenario (t = 0)
- Binding-and-popping failures, if they occur, start at t = 30 minutes
- Old o-ring failures occur at the beginning of the third hour for O1 and O2, and at the beginning of the fifth hour for O3

4.3 TREATMENT OF MULTIPLE RCPS

The treatment of the probability of multiple RCP pumps undergoing RCP seal leakage scenarios is the same as what is discussed in Section 3.3.

4.4 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 4.4-1 for the seven 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 seventh leakage scenario in Table 4.4-1 would have a 1920 gpm (4 * 480) RCS leakage.

Note that all scenarios, except the 7th one, converge to a 300-gpm per pump leakage by the fifth hour. No credit is given for survival of any old o-rings after the fourth hour.

The RCS seal leakage scenarios for 2, 3, and 4 loop plants with old o-rings following a total loss of RCP seal cooling and stopping of RCP pumps are given in Table 4.4-2.

Table 4.4-1 RCP Seal Leakage Scenarios with Old O-Rings – *WOG2000* Model					
Leakage Scenarios with Old O-Rings For One RCP					
Leakage Rate (gpm/pump)					***Probability***
0 to 30 Minutes	**30 Minutes to 2 Hours**	**3rd Hour**	**4th Hour**	**5Th and Following Hours**	
21	21	200	200	300	0.3588
21	21	300	300	300	0.4212
21	57	300	300	300	0.0897
21	182	300	300	300	0.1053
21	76	251	251	300	0.0092
21	76	300	300	300	0.0108
21	480	480	480	480	0.0050
Total Probability					1.0

Table 4.4-2 WOG2000 Model Scenarios for Various Plants with Old O-Rings

Leakage Scenarios with Old O-Rings For 2-Loop Plants				
Leakage Rate (gpm/pump)				*Probability*
0 to 30 Minutes	**30 Minutes to 2 Hours**	**3rd and 4th Hours**	**5Th and Following Hours**	
42	42	400	600	0.3588
42	42	600	600	0.4212
42	114	600	600	0.0897
42	364	600	600	0.1053
42	152	502	600	0.0092
42	152	600	600	0.0108
42	960	960	960	0.0050
Total Probability				1.0

Leakage Scenarios with Old O-Rings For 3-Loop Plants				
Leakage Rate (gpm/pump)				*Probability*
0 to 30 Minutes	**30 Minutes to 2 Hours**	**3rd and 4th Hours**	**5Th and Following Hours**	
63	63	600	900	0.3588
63	63	900	900	0.4212
63	171	900	900	0.0897
63	546	900	900	0.1053
63	228	753	900	0.0092
63	228	900	900	0.0108
63	1440	1440	1440	0.0050
Total Probability				1.0

Leakage Scenarios with Old O-Rings For 4-Loop Plants				
Leakage Rate (gpm/pump)				*Probability*
0 to 30 Minutes	**30 Minutes to 2 Hours**	**3rd and 4th Hours**	**5Th and Following Hours**	
84	84	800	1200	0.3588
84	84	1200	1200	0.4212
84	228	1200	1200	0.0897
84	728	1200	1200	0.1053
84	304	1004	1200	0.0092
84	304	1200	1200	0.0108
84	1920	1920	1920	0.0050
Total Probability				1.0

5.0 *WOG2000* RCP SEAL LEAKAGE MODEL SUMMARY

The *WOG2000* Model is summarized in Table 3.4-1 for RCP seal assemblies with high temperature o-rings and Table 4.4-1 for RCP seal assemblies with old o-rings for a single RCP pump. The model scenarios for 2, 3, and 4-loop plants are summarized in Tables 3.4-2, and 4.4-2 for RCP seal assemblies with high temperature and old o-rings, respectively.

5.1 SIMPLIFIED MODELS

When the *WOG2000* Model is implemented in a PRA model, scenarios may be binned to reduce the number of cases to evaluate. This binning could be performed in such a way to have minimal effects on the results. As an illustration, the five RCP seal leakage scenarios for high temperature o-rings can be reduced to four scenarios, by keeping the first, second and the fifth scenarios as is and reducing the 3rd, and 4th scenarios into a single one as follows:

Leakage Scenarios with High Temperature O-Rings for 1 RCP Pump – Simplified Model		
Leakage Rate (gpm/pump)		***Probability***
0 to 30 Minutes	After 30 Minutes	
21	21	0.7900
21	57	0.1442
21	182	0.0633
21	480	0.0025
Total Probability		1.0

Similarly, for the old o-rings, the number of scenarios can be reduced to 4 as follows:

Leakage Scenarios with Old O-Rings for 1 RCP Pump – Simplified Model			
Leakage Rate (gpm/pump)			**Probability**
0 to 30 Minutes	30 minutes to 2 hours	After 2 Hours	
21	21	300	0.780
21	57	300	0.090
21	182	300	0.125
21	480	480	0.005
Total Probability			1.0

This report recommends that the simplified models given in this section be used in PRA models for RCP seal leakage scenarios.

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.