UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

R. C. Emrit

November 8, 1999

MEMORANDUM TO: William D. Travers
Executive Director for Operations

FROM: Ashok C. Thadani, Director
Office of Nuclear Regulatory Research

SUBJECT: CLOSEOUT OF GENERIC SAFETY ISSUE 23, "REACTOR COOLANT PUMP SEAL FAILURE"

The purpose of this memorandum is to document the closure of Generic Safety Issue (GSI) 23, "Reactor Coolant Pump (RCP) Seal Failure." The staff activities related to RCPs include (1) those related directly to the scope of GSI-23 and (2) those related to development of RCP models to support future risk-informed activities. Based upon the work performed for GSI-23, the staff concludes that no generic cost-beneficial safety enhancements should be proposed and GSI-23 is closed see Attachment 1 for details. The background information and the basis for this conclusion are presented in the attachments to this memo. In addition to research on seal performance, the staff also reviewed station blackout (SBO) coping analyses using RCP seal leakage rates from their research see Attachment 2. Additionally, a sample of several plants was conducted to examine the potential impact on RCP seal performance for a loss of component cooling water (CCW) and essential service water (ESW) systems. The staff has ongoing activities to acquire additional information and is examining potential actions that would support development of RCP seal models to support future risk-informed decisions. Activities in this area include discussions with licensees.

Background - As a result of RCP seal failures, GSI-23 was identified in 1980. The original scope of GSI-23 also included RCP seal failures caused by SBO. The scope was later expanded to include seal failures caused by loss of the CCW or ESW systems. Initial work to identify a resolution for this GSI included research to identify RCP seal failure mechanisms. The results of this work were contained in various reports (listed in Attachment 3) that were published in the 1980s. (Note: This GSI received a high prioritization classification in 1982, based upon seal performance during normal plant operation as it was understood at that time. If a prioritization were conducted utilizing current information such as plant improvements and improved RCP seal performance during normal plant operation, this issue would no longer have a high priority. This change is based largely on improvements in RCP seal performance during normal operation (See Attachment 1).)

Based on more recent work done in the late 1980s and early 1990s, a draft rule and regulatory guide were developed and presented to the Committee to Review Generic Requirements (CRGR). Based upon CRGR comments, the staff revised the package to contain a discussion

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of the technical issues related to RCP seal performance and published the revised package for public comment in the Federal Register in 1991 (56 FR 16130). The Federal Register Notice stated the staff's current understandings, findings, and potential recommendations regarding GSI-23. Following a review of the comments received, a proposed rule was sent to the Commission (SECY-94-225) in 1994. The Commission disapproved the proposed rule in 1995. In its decision (Attachment 4), the staff requirements memorandum stated that

> The Commission believes that there is insufficient basis for gains in safety and there may be some concerns with seal evaluation models. There is also a wide range of plant-specific considerations for PWRs, some of which would result in expending excessive resources without a commensurate benefit. In some cases, licensees appear to be planning to address the pump seal failure and other plant improvements identified under their IPE program, including use of accident management strategies. The staff should communicate the foregoing decision to reactor licensees.

This decision reflects a conclusion or understanding that the improvements to address RCP seal performance are not generic in nature, but rather are plant-specfic. Licensees were informed of the Commission's decision by Information Notice 95-42 (Attachment 5).

In order to resolve questions related to RCP seal performance, including those in the scope of GSI-23 and related issues such as RCP seal models for non-Westinghouse pumps, the staff has taken a two phase approach. The first phase addresses the issues in the scope of and closure of GSI-23 (Attachment 1). The second phase includes a plant-specific review of the risk significance of RCP seal failure caused by loss of cooling water and interactions with industry related to the development of RCP seal models.

The first phase involves consideration of the Commission's decision, RCP seal performance improvements, plant improvements as a result of meeting SBO requirements of 10 CFR 50.63 and Independent Plant Evaluations (IPE), and a review of SBO coping analyses. The Commission's decision, as noted above, reflects the plant-specific variation and the limited potential improvement in safety associated with imposition of new requirements to address RCP seal performance. In addition to these generic considerations, the staff performed plant-specific reviews of the SBO coping analyses. These SBO reviews were conducted to determine whether further NRC action is necessary as a result of the coping analyses that were part of licensee actions to meet 10 CFR 50.63. This SBO review was conducted by RES with support from NRR. The SBO review included consideration of plant-specific improvements and modifications made as a result of IPEs. The results of this review indicate that, while the 25-gpm leakage assumptions used by licensees may not be correct, the intent of the SBO rule (as given in the statement of considerations and the regulatory analysis of maintaining an industry average core damage frequency from SBO of about 1E-5/yr) is currently being met and licensees should not be required to revise the coping analyses assumptions (Attachment 2). The activities conducted in this phase form the bases for the staff's conclusion that GSI-23 should be resolved without imposing new requirements.

The second phase was a scoping level review of sample plants to gauge the risk significance of RCP seal failure caused by a failure of component cooling water or emergency service water (CCW/ESW) systems (Attachment 6). This scoping review was conducted using conservative assumptions to identify those plants which would be reviewed in greater detail. The selection of plants chosen for this review were those initially thought to have a relatively high contribution to core damage frequency from sequences involving RCP seal LOCAs, although an effort was also made to include plants from each of the three PWR vendors. For the loss of CCW/ESW sequence, some plants (14) were looked at quantitatively, and other plants (25) were examined qualitatively. The quantitative analysis used RCP seal behavior based on the Rhodes Model (NUREG/CR-5167, Appendix A), but otherwise the assumptions used were those in the plant's IPE, including the initiating event frequencies for losses of ESW and CCW. There are significant uncertainties in the model, especially as related to the probability of a "pop-open" failure mode. The qualitative analysis was conducted if the staff judged the risk of loss of seal cooling was low, because of plant design. For example, plants which have RCP seal injection as a redundant means of RCP seal cooling from a source independent of CCW or ESW will have a lower probability of a RCP seal LOCA, given a loss of CCW or ESW. Twenty-five plants, which were analyzed qualitatively, were identified as having a low risk from RCP seal LOCA sequences initiated by loss of CCW or ESW. For the 14 plants analyzed quantitatively, the core damage frequency for RCP seal LOCA sequences initiated by loss of CCW/ESW ranged from above 1E-3 per year to below 1E-5 per year. Although the calculated core damage frequency values for some plants are high, it is important to consider the analysis was performed with a conservative model that is not applicable all plants. The scoping study was only intended to identify the plants that merited a more in-depth study. As a result of this review, the staff concluded that, except for a few outliers, the majority of plants have a sufficiently low risk from RCP seal LOCA sequences initiated by loss of ESW/CCW that additional action is not appropriate.

Based on this scoping review, the staff has determined that it is appropriate to review all PWRs to determine whether plant-specific backfits are appropriate. With respect to the plant-specific reviews, the staff (NRR and RES) has developed a task action plan to track the completion of this work (Attachment 7). RES will complete these plant-specific reviews to develop scoping estimates of the contribution to the core damage frequency resulting from RCP seal LOCAs induced by the loss of ESW/CCW. The result will be a list of plants that will be examined in additional detail to determine whether plant-specific backfits are appropriate. NRR will provide the necessary plant-specfic information to support these reviews. RES will provide the results to NRR to determine whether any plant-specific licensing actions are appropriate and will provide the technical bases to support NRR in the preparation of plant-specific backfit packages.

The contribution of RCP seal failure to core damage frequency is very plant-specific as shown by the staff's scoping analyses discussed above. As noted in the Commission's decision, there are concerns about the adequacy of RCP seal models. While a model has been developed for Westinghouse RCPs, similar models have not been developed for pumps manufactured by other vendors. There are a number of issues that must be addressed to develop additional RCP seal models that include differences in mechanical design, operating experience, thermal-hydraulic analysis, and seal leak rates. While the staff concludes that GSI-23 can be closed without these additional RCP seal models, the development of these additional models would support future risk-informed licensing decisions. In the interim, the staff will use the Rhodes model in determining the contribution to core damage frequency from RCP induced LOCAs for those plants.

The staff and EPRI are discussing the development of new RCP seal models. The ASME is developing a PRA standard. At this time it is not clear if ASME intends to pursue development of an RCP seal model for this standard. Criteria for the development of an RCP seal model for the standard have been and will continue to be discussed with ASME. Staff resources to support the development of the ASME standard and to conduct limited work with EPRI on development of standard RCP seal models are included in the current budget and operating plan. While the staff will recommend that the ASME develop better standard models, in the interim, the staff will recommend that the Rhodes model be used in the ASME standards. While we recognize that the Rhodes model is conservative, the industry has not provided information for development of a more realistic model. Seal model development is a long term activity and specific research and associated resource requirements for RCP seal model development have not been included in the current RES operating plan or budget.

In summary, as a result of the staff's activities related to GSI-23, the staff concludes that no additional cost beneficial generic requirements should be proposed. This conclusion is based upon the following considerations: (1) the Commission's decision not to proceed with rulemaking, (2) the plant-specific nature of LOCA risk induced by seal failure, (3) industry actions, such as implementation of voluntary corrective actions related to RCP seal failure, including improved O-ring material for Westinghouse seals, (4) implementation of 10 CFR 50.63, the SBO rule, which has reduced the likelihood of RCP seal LOCA in certain plants by the addition of alternate power sources, (5) implementation of 10 CFR 50.65, the maintenance rule, which has reduced the likelihood of a loss of the component cooling water or essential service water systems, and (6) improved RCP seal performance. The staff concludes that closure of GSI-23 is appropriate and that plant-specific backfits based on staff's plant-specific risk analysis of the loss of CCW/ESW systems be pursued as appropriate. The staff will work with industry to develop additional RCP seal models, will continue to use the Rhodes model until a standard is developed, and pursue the need for plant-specfic backfits.

Attachments: As stated

cc: F. Miraglia, EDO
C. Paperiello, DEDMRS
K. Cyr, OGC
S. Collins, NRR

CONTACT: J. Jackson, RES
415-6656

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failure as a result of plant specific changes such as installation of alternate power sources, (5) implementation of 10 CFR 50.65, the maintenance rule, which has reduced the likelihood of a loss of the component cooling water or essential service water systems, and (6) improved RCP seal performance during the past decade.

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Attachment 1

Resolution of GSI-23, "Reactor Coolant Pump Seal Failure"

BACKGROUND

Reactor coolant pump (RCP) seal failure refers to degradation of the RCP seals that leads to a loss of reactor coolant which can not be isolated. One potential cause of seal failure is a lack of seal cooling water as a result of station blackout (SBO), a loss of component cooling water (CCW), or a loss of service water (SW). However, the reactor coolant pump seal issue was originally prioritized based on the frequency of RCP seal failures that occurred during normal operation. The high rate of seal failures experienced during normal operation from the mid 1970s to the early 1980s led to the seal failure problem being categorized as a high priority issue. The actual normal-operation seal failure frequency exceeded the small break LOCA frequency assumed in the WASH-1400 study by an order of magnitude. The normal operation seal failure rate has since been significantly reduced through industry improvements, so that if the issue were prioritized now based on normal operation failure alone, the issue would no longer be a high priority issue.

As described in NUREG-0933, "A Prioritization of Generic Safety Issues," the scope of GSI-23 originally included RCP seal failures caused by SBO. The scope was expanded to include consideration of GSI-65, "Probability of Core-Melt Due to Component Cooling Water System Failures," and GSI-153, "Loss of Essential Service Water in LWRs." These additions expanded the scope of GSI-23 to include the loss of all seal cooling from SBO, loss of CCW, or loss of SW. The scope of GSI-23 does not include BWRs because operating experience and analyses indicate that BWRs have smaller seal leak rates resulting from seal failures than PWRs. In BWRs, the potential problem of seal failure is mitigated by the smaller leak rates, recirculation loop isolation valves, and the larger makeup capability of the reactor core isolation cooling systems, high-pressure coolant injection systems, and feedwater system. A few older isolation condenser BWRs do not have the independently powered emergency makeup systems. Of these, only two are still in operation; Nine Mile Point I and Oyster Creek. Nine Mile Point I has successfully tested their recirculating pump seals under SBO conditions [see docketed letter from licensee on "Completion of SBO Rule Commitments," dated December 9, 1992]. Oyster Creek also uses the same type of recirculating pump seals. Due to the above considerations, the staff considers the risk from BWR recirculation pump seal failure to be low, therefore GSI-23 only deals with PWRs.

The staff produced a large body of work leading up to a proposed resolution and rule in 1994, as shown in the references in Attachment 3. This research program addressed the degradation of polymer seals, conditions under which polymer seals would experience extrusion, and the effects of loss of cooling conditions on the primary hydraulic seals. Additionally, this research addressed the conditions in which hydraulic seals are likely to become unstable.

RES sponsored the development of a document related to the RCP seal failure model, "Guidance Document for Modeling of RCP Seal Failures," BNL Technical Report W6211-08/99, January 1999. This document was prepared to assist the staff in performing reviews of licensees' submittal and PRAs on a plant-specific basis.

In SECY-94-225, dated August 26, 1994, a draft rule was proposed to resolve GSI-23. On March 31, 1995, the Commission disapproved issuance of the proposed rule stating that

> The Commission believed that there was insufficient basis for gains in safety and there may be some concerns with seal evaluation models. Furthermore, there was a wide range of plant-specific considerations for PWRs, some of which would result in expending excessive resources without a commensurate benefit in safety. In some cases, licensees appear to be planning to address the pump seal failure and other plant improvements identified under their IPE program including use of accident management strategies.

The industry and the public were informed of the Commission's decision when the staff issued Information Notice 95-42, on September 22, 1995. This information notice also reminded licensees that RCP seal leak rates that are substantially higher than those assumed in the coping analyses required by the SBO rule (10 CFR 50.63) could affect licensees' analyses and actions addressing conformance to the SBO rule. The GSI-23 studies showed that substantially higher leak rates than those assumed in the coping analyses could occur. These higher leak rates are described in NUREG/CR-4948, "Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure" (March 1989). Following the Commission's decision, additional studies and reviews were conducted to determine whether generic cost beneficial safety enhancements were appropriate. The results of this work are discussed below.

BASIS FOR RESOLUTION OF GSI-23

The following factors provide a basis for concluding that GSI-23 is resolved.

Station Blackout Considerations

The staff's generic analysis indicates that plants that are required to cope with a 4-hour SBO will still be able to do so, even considering RCP seal failures. Plants that are required to cope with an 8-hour SBO have estimated contributions to core damage frequencies resulting from RCP seal LOCA due to SBO that are near 1E-5/yr. Thus, the intent of the SBO rule, as given in the statement of considerations and the SBO regulatory analysis of maintaining an industry average core damage frequency near 1E-5/yr, is currently being met without any additional action. The supporting analysis for these conclusions is given in Attachment 2.

Loss of CCW/ESW Considerations

For the plants reviewed to date, there is a wide variation of core damage frequencies from RCP seal LOCA sequences initiated by loss of CCW or loss of ESW. The core damage frequencies for these sequences ranged from over 1E-3 per year to less than 1E-5 per year when the Rhodes model for RCP seal failure was used. The Rhodes model is likely a conservative model, particularly when applied to non-Westinghouse RCP seals. The selection of plants chosen for analyses were those which were initially thought to have relatively high contributions to the core damage frequency from sequences involving RCP seal LOCAs. They are not a random sample of plants and cannot be used to estimate an average industry risk from seal LOCAs caused by a loss of ESW or CCW.

Several Westinghouse plants have already implemented changes to reduce the core damage frequency from loss of ESW and CCW. Most commonly, these plants have implemented an alternative means of cooling the charging pumps from fire water or another water source. This results in maintaining RCP seal injection and avoiding the RCP seal LOCA. In addition, many Westinghouse plants have installed high temperature O-rings. When this information was known for a plant, it was used in evaluating the core damage frequency from the ESW/CCW sequences involving RCP seal LOCAs, or in assessing whether these sequences were risk significant at a given plant.

The results obtained used consistent models of RCP seal behavior for the different plants. However, there are large epistemic uncertainties in the probability of the pop-open mode of seal failure. Although the models of RCP seal behavior were consistent across the plants, other modeling assumptions were taken from the IPE and may reflect differences in modeling assumptions as well as differences in the plants. External events were not considered.

Many plants already have an acceptable or low risk from RCP seal LOCAs. For plants with a vulnerability, or if it is believed there are cost effective risk reduction measures possible, the best solution should be determined on a plant-specific basis. However, for plants with non-Westinghouse RCPs, the uncertainty in the RCP seal models is such that it would be prudent to obtain models with less state of knowledge uncertainty before attempting to determine the need for plant-specific fixes. With the current state of knowledge, it would be inappropriate to impose a backfit based on a potentially highly conservative analysis, especially for plants with non-Westinghouse RCPs. For plants with Westinghouse RCPs, depending on the initiating event frequencies for loss of CCW/ESW and other factors, it may be possible to justify requiring the use of the improved O-rings, since there is considerable experimental evidence to show their improved high temperature behavior.

CONCLUSIONS

Based on the plant reviews of risk related to RCP seal failure, the staff concludes that a cost effective generic solution is not justified to address this issue. GSI-23 is considered closed for all the PWRs based upon (1) the Commission's decision not to proceed with rulemaking, (2) seal failure induced LOCA risk is very plant-specific in nature and therefore a generic solution is not justifiable, (3) some licensees' voluntary corrective actions related to RCP seal failure, including improved O-ring material for Westinghouse seals, (4) SBO rule has reduced the likelihood that seal cooling would be lost because of SBO, (5) maintenance rule has reduced the likelihood of a loss of CCW or SW, and (6) improved seal performance.

RES has evaluated the core damage frequency from SBO-induced RCP seal LOCAs, and concludes that the risk from SBO-induced RCP seal LOCAs is consistent with the intent of the SBO rule. Preliminary estimates of the core damage frequency from loss of CCW or loss of ESW induced RCP seal LOCAs have been performed and show that this risk is plant-specific in nature. RES will investigate the feasibility of using improved RCP seal models, will refine the analyses of the plants already studied, and perform reviews for the remainder of PWRs. The staff (NRR and RES) is developing a task action plan for the individual plant reviews. NRR will provide the necessary plant-specific information to support the reviews.

Attachment 2

STATION BLACKOUT COPING ANALYSIS CONSIDERATIONS

The station blackout rule, 10 CFR 50.63, requires that each light-water-cooled nuclear power plant licensed to operate be able to cope with a station blackout (SBO) for a specified duration. Since the RCP seal leak rate was one of the factors considered in the plant-specfic coping analyses, compliance with 10 CFR 50.63 was identified as a potential item to be reviewed following resolution of GSI 23. Based upon the NEI guidance document approved by the staff, many licensees completed their station blackout coping analysis based upon the assumption that the leakage from the reactor coolant pump (RCP) seals would be limited to 25 gpm per pump. As a result of the initial research activities, the staff developed a seal failure model for Westinghouse RCPs. The results of this model indicate that the leak rate for RCPs may be greater than the 25 gpm assumed in coping analyses. To evaluate the effect of this additional leakage, the staff reviewed factors affecting the coping capability of PWRs to determine if these plants could cope with a station blackout of either 4 or 8 hour duration.

RCP Seal Model for Station Blackout Coping Analysis

The model used for this review is given in Appendix A to NUREG/CR-5167, "Cost Benefit Analysis for GSI-23: Reactor Coolant Pump Seal Failure." This Appendix to NUREG/CR-5167 was written by David Rhodes, and the model is referred to as the "Rhodes model." The Rhodes model is for Westinghouse RCPs. RES sponsored research conducted at AECL identified two basic failure modes for RCP seals. The first is failure of the elastomers, the second is "pop-open" or lifting of the mechanical seals.

The first failure mode involves elastomers (O-rings, channels seals, and U-cups) that can fail to perform their sealing function as a result of being exposed to temperatures above their design limit. There are several considerations related to this potential failure mode that is caused by a loss of cooling to the RCP seals and the resulting leakage. Tests simulating SBO conditions on the older unqualified or low temperature O-rings show that the probability of failure is low for the first 2 hours. This allows time for seal cooling to be restored. Westinghouse redesigned the O-rings to a newer, qualified design/material composition. While the new, high temperature O-rings have been installed in many plants, the staff is working to determine which, if any, plants have not installed these O-rings in Westinghouse RCPs.

According to the Rhodes model, the unqualified O-rings will fail at about 2 hours after loss of RCP seal cooling, leading to a leak rate of 300 gpm per pump. (High temperature O-rings do not fail during loss of cooling unless one of the stages of the RCP fails resulting in an increased differential pressure.) Based upon tests results contained in NUREG/CR-4821, the staff assumed in this review that the RCP seals installed in plants with RCPs manufactured by the other RCP vendors, Byron-Jackson, KSB and Bingham, will not fail during SBO conditions as a result of elastomer failure.

The second failure mode involves movement of the mechanical seal faces, which can separate (pop open) caused by an increase in the seal opening forces as a result of the two-phase flow associated with a loss of seal cooling (hydraulic instability). For these pumps, the model gives a 20% chance that the RCP seals will "pop open" at ten minutes after a loss of RCP seal cooling (because of a change in the balance of forces on the movable seal faces when there is two-phase flow between the seal faces), leading to a leak rate of 182 gpm per pump. The 20% probability represents state-of-knowledge uncertainty. There is a 20% degree of belief that the RCP seals will pop open, and if the seals in one RCP pop open, the seals in the other RCPs will also pop open. More precisely, the second stage seal pops open, and this is assumed to lead to a probability of one that the third stage seal will pop open leading to the 182-gpm leak. There is a low probability of about 2.5% that the first stage seal will pop open. If this is the only failure, the leak rate is only 76 gpm per pump. The probability that both the first and second stages pop open is .025*.2, or 5E-3. The leak rate here is 480 gpm per pump, but the probability is quite low. In either case, the effects on the results are quite small, and are neglected.

The time to core uncovery, for a leak of a given size, depends on whether operator action is taken to cool the plant down. The staff assumed that such operator action is taken, according to procedures. Table 2 of the Rhodes memo shows that there is a 20% chance of core uncovery at 5 hours after onset of the SBO if qualified O-rings are used. This means that if the pop-open mode occurs, the core will uncover in about 5 hours. From looking at Table 1 of the Rhodes memorandum, there is a 100% chance of core uncovery (given the Rhodes model) in 4 to 5 hours if unqualified O-rings are used. There are, of course, two possibilities for unqualified O-rings: (1) either the seals pop open at 10 minutes leading to a 182 gpm leak per RCP, and then this leak increases to 300 gpm at 2 hours because the O-rings fail, or (2) the seals do not pop open at 10 minutes but a leak of 300 gpm starts at 2 hours. Core uncovery should occur at different times for the two cases, but Table 1 of the Rhodes memorandum does not distinguish these two cases. For the analyses given below, the staff assumed that core uncovery occurs at 4 hours for both of these cases. Note that Table 1 of the Rhodes memorandum shows that the core will uncover in less than 5 hours even if the pop-open mode of RCP seal failure does not occur, but the O-rings fail.

For certain plants, the primary concern or cause of loss of RCP seal cooling is hurricane-induced loss of offsite power. The procedures at these plants require that the plants be shut down when a hurricane warning is received. When the plant is in this mode and there is a loss of RCP seal cooling, the effects of subsequent RCP seal failure are less significant. While the pop-open failure mode is possible, elastomer failure is less likely because of the decreased temperature and pressure in the reactor coolant system. Additionally, if there were a pop-open failure the leak rates would be less due to decreased system pressure. This would significantly increase the time to core uncovery. Although the increased time to core uncovery may reduce the core damage frequency, no credit was given in this analysis for shutting the plant down on a hurricane warning.

The above estimates, based on the Rhodes model, are for Westinghouse RCPs. Detailed information for RCPs manufactured by other vendors (Byron Jackson, Bingham International, KSB) is not currently available. From the design information that is available, the staff concludes that the pop-open mode of RCP seal failure, occurring at 10 minutes, with a leak rate of 182 gpm per pump and a 20% probability of occurrence, is a conservative estimate of the behavior of these non-Westinghouse pumps. Additionally, based on tests and operating experience, the staff concludes that these RCPs are not vulnerable to secondary seal (such as O-ring) failure caused by a loss of cooling to the RCP seals. The staff's estimate is that the core uncovery times are about the same as for a Westinghouse reactor, if the leak rates are the same.

Effect of the Rhodes Model on SBO Coping Analysis for Plants Which Must Cope for 8 Hours

The pop-open mode of failure of the RCP seals for these plants has a 20% chance of occurring at about 10 minutes after loss of RCP seal cooling. Therefore, if a plant cannot restore RCP seal cooling within 10 minutes, there is a probability of 20% of a small break loss of cooling accident (LOCA). If the alternate AC system is brought on line in 10 minutes or less and RCP seal cooling is restored, then the RCP seal leak will not occur. While all of the 8-hour coping plants have alternate AC, some require up to 1 hour to restore AC power. The alternate AC systems are not required to be able to power a high pressure injection pump, but only to supply normal charging and makeup. If the RCP seals pop open, the reactor core will uncover in about 5 hours, if the emergency core cooling systems are not restored by that time. The estimates of the contribution (C) to the core damage frequency from SBO-induced RCP seal failures are based on the following Boolean expression:

C=SBO*S*NR(4)

where SBO is the event of station blackout, S is the event of RCP seal failure, and NR(4) is the event of non-recovery of AC power in 4 hours. This expression is slightly conservative in that if the alternate AC fails, and AC power is not recovered in 4 hours, core damage may occur even if the RCP seals do not fail. If the auxiliary feedwater system fails, the time to core uncovery may be affected by whether or not the RCP seals pop open, but this effect is entirely negligible.

Of the plants which must cope with an 8 hour SBO, only Turkey Point Units 3 and 4 can bring the alternate AC system online in 10 minutes. None of the 8 hour plants state that they can power an HPI pump with their alternate AC sources. There are only seven units which must cope with an 8 hour SBO; because of individual differences in the plants, it is best to look at each case separately.

Turkey Point Units 3 and 4

These units have committed to bring the alternate AC online in 10 minutes. This is sufficient to restore component cooling water flow to the thermal barrier in sufficient time to prevent an RCP seal LOCA from the pop-open mode. (The 10-minute time for pop open is conservative by a few minutes.) Also, O-ring failure will not occur because the RCP seal cooling has been re-established. The loads for the alternate AC do not include a high pressure injection system pump, but if no LOCA occurs, it would not be necessary. Also, there are 5 black start diesel generators, in addition to the emergency AC generators, onsite. (These may not be available in severe weather; they were not available in hurricane Andrew.) From a deterministic standpoint, the Turkey Point units can cope with an 8-hour SBO. To estimate the core damage frequency from SBO-induced RCP seal LOCAs we assume that there is a 20% chance that the alternate AC will not be restored before there is two-phase flow between the seal faces, and that, given the two phase flow there is a 20% probability of pop open. Therefore the probability of pop open is 0.04. The probability of a severe weather loss of offsite power at Turkey Point is 0.0305 per year according to NUREG/CR-5496 (Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980-1996). The probability that a severe weather related loss of offsite power is not recovered in 4 hours is 0.585 (from the lognormal distribution in NUREG/CR-5496, for nonrecovery in 4 hours.) The frequency of severe weather-related losses of offsite power exceeding 4 hours is then 0.018 per year. The frequency of plant-centered losses of offsite power lasting more than four hours is estimated from the data in NUREG/CR-5496 as 0.003 per year, and the estimated frequency of losses of offsite power from all causes which lasts longer than four hours is then 0.021 per year. Each Turkey Point unit has two diesel generators in its emergency AC system, and the alternate AC system is from a diesel generator at the other unit. The failure probability of the emergency AC system is 0.003, using the alpha model for common cause failure with α=0.03, from NUREG/CR-5497 (Common Cause Failure Parameter Estimations), with a failure probability of 0.025 for a diesel generator to start and run for one half hour, and with a test and maintenance unavailability of 0.03. Then the core damage frequency is given by the frequency of losses of offsite power exceeding 4 hours (0.021/yr), times the probability the onsite emergency AC fails (0.003), times the probability of 0.04 that the seals pop open as calculated above. The result is 2.5E-6 per year, for the contribution of SBO-induced RCP seal LOCA to the core damage frequency.

Indian Point Unit 2

This unit takes one hour to bring alternate AC online. A high pressure injection (HPI) pump is not one of the Alternate AC loads. Because the alternate AC can be brought online in an hour, it is sufficient to preclude O-ring failure by restoring RCP seal injection.

There are three diesel generators at Indian Point Unit 2. The operation of any of these three diesels will provide adequate power to prevent RCP seal failure. The dependency of one of the three diesel generators on the other two, through the HVAC system, has been fixed. The dominant mode of failure of the three diesel generators will be common cause failure. If an alpha factor of 0.0166 is used, from NUREG/CR-5497 (Common Cause Failure Parameter Estimations), and a probability of failure to start and run for the first half hour of 0.025, for the diesel generator, then the probability of failure of the onsite diesel generator system is 0.0166*0.025=4.2E-4 per demand. According to NUREG/CR-5496 (Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980-1996), the frequency of losses of offsite power caused by severe weather at the Indian Point site is 0.005 per year, and the frequency of severe weather losses of offsite power which last longer than 4 hours is 0.0029 per year. Plant-centered losses of offsite power contribute about 0.0029 per year also.

Also, there is no contribution from grid-related offsite power events. NUREG/CR-5496 notes that grid-related losses of offsite power have become increasingly rare events and none have occurred in the 1990s. Thus the frequency of a SBO which lasts for 4 hours is about 2.4 E-6 per year. Since Indian Point Unit 2 uses high temperature O-rings, the only failure mode of concern is the pop-open mode at 10 minutes. Since there is a 20% chance of the pop-open mode, one obtains 5E-7 per year as an estimate of the core damage frequency due to SBO-induced RCP seal LOCAs at Indian Point Unit 2.

Indian Point Unit 3

Indian Point Unit 3 uses an Appendix R diesel generator, rated at 2500 kW, for Alternate AC. HPI is not one of the Alternate AC loads. Only the loads required to maintain the plant in hot standby, given no LOCA, are powered by the Alternate AC. Also, the time for the Alternate AC to be brought online is one hour. Indian Point Unit 3 is like Unit 2 in that there are 3 diesel generators and only one is required to maintain hot standby. (Containment building fan recirculation coolers may have to be manually isolated from the essential service water header to permit a 1 out of 3 diesel generator success criterion.) Indian Point Unit 3 also uses the high temperature O-rings.

An estimate of the core damage frequency due to SBO-induced RCP seal LOCAs is the same as for Indian Point Unit 2, since the loss of offsite power frequency and recovery is the same, and both units have 3 diesel generators with one out of 3 required. Therefore, the core damage frequency from SBO-induced RCP seal LOCA is about 5E-7 per year.

Millstone Unit 2

Millstone Unit 2 uses the 800 kW excess capacity of the Millstone Unit 1 diesel generator for Alternate AC power. This is insufficient to power an HPI pump in addition to the other required loads. The time to bring the Alternate AC online is one hour. The unit is a Combustion Engineering unit with Byron-Jackson RCPs. Hence, the only mode of seal failure of concern is the pop-open mode. Failure of the elastomer secondary seals is not of concern. Unit 2 has two diesel generators in its emergency AC system.

There may be difficulties in the use of the Alternate AC source at Millstone Unit 2. The manual actions required to bring Alternate AC to Unit 2 from Unit 1 include manipulations at an outside panel which is exposed to severe weather, and should not be considered reliable for weather-induced SBO events. But these are the events of most concern. This affects the coping analysis for Millstone Unit 2 in general, but is of lesser importance as far as the RCP seal LOCA is concerned.

The core damage frequency from SBO-induced seal LOCAs giving no credit for the Alternate AC is calculated using the alpha model for common cause failure and using α=0.03, from NUREG/CR-5497, with a failure probability of 0.025 for a diesel generator to start and run for one half hour, test and maintenance unavailability as 0.03, the severe weather related loss of offsite power frequency as 0.035 per year (from NUREG/CR-5496), the non-recovery probability for a severe weather related loss of offsite power as 0.585 (from the lognormal distribution in NUREG/CR-5496, for nonrecovery in 4 hours), a frequency of plant-centered losses of offsite power for greater than 4 hours of 0.003 per year, and the probability of 0.2 that the RCP seals pop open at 10 minutes. The result of this calculation is a contribution to core damage frequency of 1.4 E-5 per year from SBO-induced RCP seal LOCAs at Millstone Unit 2.

Millstone Unit 3

Millstone Unit 3 has two diesel generators in its emergency AC system. The alternate AC source is a third station blackout diesel generator, with a 2000kW capacity. The time to bring the alternate AC source online is one hour. Unit 3 is a Westinghouse unit which uses high temperature O-rings; therefore O-ring failure is not a concern. For the pop-open failure mode the calculation is the same as that discussed above for Unit 2, 1.4 E-5 per year for the contribution to the core damage frequency from SBO-induced RCP seal LOCAs.

Robinson Unit 2

Robinson Unit 2 is a Westinghouse plant; it has two diesel generators as part of its emergency AC system. The alternate AC source is an Appendix R diesel generator which can be brought online within one hour. The old, unqualified O-rings are used at Robinson Unit 2. However, the emergency procedures have instructions to restore RCP seal cooling once the AAC is brought online. Therefore, O-ring failure need not be considered. The loads on the alternate AC source do not include a high pressure injection pump, but do include the hot standby loads. Using a frequency of severe weather related offsite power of 5.2E-3 per year from NUREG/CR-5496, a probability of nonrecovery of a severe weather related offsite power event in 4 hours of 0.585, a frequency of plant-centered losses of offsite power lasting more than 4 hours of 0.003 per year, and a probability of failure of the onsite emergency AC of 0.003 (using the same diesel generator data as given for Millstone unit 2 above), the frequency of station blackouts that exceed 4 hours is 1.8E-5 per year. Since there is a 20% probability the RCP seals will pop open, the core damage frequency from SBO-induced RCP seal LOCAs is estimated as 4E-6 per year.

Effect of the Rhodes Model on SBO Coping Analysis for Plants that Must Cope for 4 Hours

The results of the staff's evaluation for plants in this category show that with an assumed pop-open mode of RCP seal failure, and the failure of the O-rings at two hours, the core will not uncover before 4 hours using best-estimate values. Using the Rhodes model, Westinghouse plants without alternate AC and with unqualified O-rings have an 100% chance of core uncovery in 4 to 5 hours following the RCP seal LOCA, if power is not recovered before core uncovery. With qualified O-rings, there is a 20% probability of core uncovery in 4 to 5 hours. Therefore, plants which must cope with a 4-hour station blackout will still be able to do so, even considering the RCP seal LOCAs induced by the station blackout.

The core damage frequency due to SBO-induced RCP seal LOCAs may be estimated as follows. In general, for the 4-hour plants, the frequency of losses of offsite power which exceed 4 hours in duration would not be much larger than that for Robinson. If the plant had only two diesel generators in its emergency AC system, then the frequency of station blackout exceeding 4 hours would be about the same as for Robinson, or about 1.8E-5 per year. If the plant were a Westinghouse plant with unqualified O-rings, then the frequency of core damage due to the RCP seal LOCA sequences would be about 2E-5 per year. This is a conservative estimate, since even if the RCP seal LOCA were not to occur at about 4 hours, battery depletion may occur before AC power is restored. (For example, battery depletion may occur at 6 hours. Then, using the same data as above, the core damage frequency from battery depletion even if the RCP seal LOCA did not occur is 1.2E-5 per year, and the contribution of the RCP seal LOCA sequences to core damage is 6E-6 per year. This assumes that there is no alternate AC in the 4-hour plant; otherwise battery depletion would not occur if the alternate AC functions.) If the plant uses other than Westinghouse RCPs, or uses Westinghouse pumps with high temperature O-rings, there is a 20% chance of core uncovery if offsite power is not restored in 5 hours, and the core damage frequency from SBO-induced RCP seal LOCAs is about 3E-6 per year. (Consideraton of battery depletion at 6 hours would reduce this to about 1E-6 per year.) About 75% of Westinghouse pumps currently use the high temperature O-rings, so most 4-hour plants will have about a 3E-6 per year core damage frequency from SBO-induced RCP seal LOCAs, not including the overlap with battery depletion sequences.

Summary of Results

Plants that are required to cope with a station blackout of 4 hours will still be able to do so based upon calculations using the Rhodes model of RCP seal LOCA, since core uncovery times from the RCP seal LOCAs exceed 4 hours.

Plants with non-Westinghouse pumps are assumed not to be vulnerable to O-ring failure, but the RCP seals can pop open with 20% probability. Also, plants with Westinghouse pumps and high temperature O-rings are not vulnerable to O-ring failure unless the RCP seals have popped open. However, in our simplified model, the core uncovers in 4 hours when the RCP seals have popped open, independent of whether the O-rings fail or not.

Of the 8-hour plants, only Turkey Point units 3 and 4 bring the alternate AC online and can restore RCP seal cooling in ten minutes. For these units, given successful restoration of RCP seal cooling in ten minutes, the RCP seal LOCA will not occur.

The core damage frequency from RCP seal LOCA sequences on station blackout were estimated, for the plants which are required to cope with a station blackout of 8 hours. These values are given in Table 1.

Table 1. CDF FROM SBO-INDUCED RCP LOCA, FOR PLANTS THAT MUST COPE WITH AN 8 HOUR SBO

Plant	AAC time	EAC success criteria	P(EAC)	F(sw-losp)	CDF from RCP seal LOCA, on SBO
Turkey Pt 3 and 4	10 minutes	1 out of 2	0.003	0.0305 /yr	3E-6 /yr
Indian Pt Unit 2	1 hour	1 out of 3	4E-4	0.005 /yr	5E-7 /yr
Indian Pt Unit 3	1 hour	1 out of 3	4E-4	0.005 /yr	5E-7 /yr
Millstone Unit 2	1 hour	1 out of 2	3E-3	0.035 /yr	1E-5 /yr
Millstone Unit 3	1 hour	1 out of 2	3E-3	0.035 /yr	1E-5 /yr
Robinson Unit 2	1 hour	1 out of 2	3E-3	0.005 /yr	4E-6 /yr

Key:

AAC= Alternate AC source
EAC= Emergency AC source
P(EAC)=Probability EAC is failed
LOSP= Loss of Offsite Power
F(sw-losp)=frequency of severe weather LOSP
CDF=core damage frequency
SBO=station blackout

Attachment 3

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