Westinghouse

Nuclear Safety Advisory Letter

This is a notification of a recently identified potential safety issue pertaining to basic components supplied by Westinghouse. This information is being provided so that you can conduct a review of this issue to determine if any action is required.

1000 Westinghouse Drive, Cranberry Township, PA 16066

Subject: **Impact of Reactor Coolant Pump No. 1 Seal Leakoff Piping on Reactor Coolant Pump Seal Leakage During a Loss of All Seal Cooling**	Number: **NSAL-14-1 Revision 1**
Basic Component: No. 1 Reactor Coolant Pump Seal and Seal Leakoff Piping	Date: 09/08/2014
Substantial Safety Hazard or Failure to Comply Pursuant to 10 CFR 21.21(a)	Yes ☐ No ☒ N/A ☐
Transfer of Information Pursuant to 10 CFR 21.21(b)	Yes ☐
Advisory Information Pursuant to 10 CFR 21.21(d)(2)	Yes ☐

This revision addresses two issues. The first is that Westinghouse became aware of additional plant-specific seal leak-off (SLO) line configuration detail and other input that results in slightly higher calculated seal leak rates than first presented. The second issue pertains to the way that reactor coolant pump (RCP) No. 1 seal leakage has been calculated in the transient modeling of various loss of seal cooling events. The RCP No. 1 seal leakage calculations corresponding to reactor coolant system (RCS) cooldown and depressurization used a simplified orifice break flow correlation approach, versus accounting for the specific pressure and temperature dependent leakage characteristics of the seals. Additionally, this revision augments the prior probabilistic risk assessment discussion with more detailed information.

Revision 0 results are largely unaffected by these changes; however, new information has been added and the recommendations are updated to reflect the use of a more conservative seal leakage methodology, as described in the Attachment. This Nuclear Safety Advisory Letter (NSAL) does not apply to the Combustion Engineering RCP seal design. The information presented has been evaluated and does not lead to a substantial safety hazard (SSH) pursuant to 10 CFR 21.

Changes are identified by revision bars in the margins.

Additional information, if required, may be obtained from George Konopka, (412) 374-5629

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SUMMARY

During plant events resulting in the loss of all seal cooling, RCP seal leakage can be affected by the piping configuration and components of the No. 1 SLO line. The nominal RCP seal leak rate of 21 gallons per minute (gpm) for each RCP, as documented in WCAP-10541, Revision 2 (Reference 1), may not be applicable for all plants with Westinghouse RCPs because of the various thermal-hydraulic conditions set up by plant specific SLO piping designs. WCAP-10541 and this NSAL address the Westinghouse RCP shaft seal package (8 inch nominal pump shaft size) where the No. 1 seal is a controlled-leakage film riding design and the No. 2 and No. 3 seals are rubbing face designs. Plants with Westinghouse style RCP seals other than those described above (e.g., 7 inch nominal pump shaft size seals) may or may not be affected depending on how the Licensee uses WCAP-10541 in their current licensing basis. The plants listed in Table 4 were supplied with Westinghouse seals with the original RCP; however, some plants may have replaced them with another manufacturer's seals. This NSAL presents an evaluation for an estimated No. 1 seal leak rate, consistent with the analysis accuracy performed in WCAP-10541, based on various conservatively modeled categories of SLO piping designs.

WCAP-10541 established the RCP seal performance for events where the No. 1 RCP seal and the SLO lines are subjected to a loss of all seal cooling (i.e., no seal injection, no thermal barrier cooling). These events result in two-phase flow (i.e., water and steam) in the No.1 SLO line. The thermal-hydraulic conditions in the seal and the SLO piping are key factors which determine the nominal steady state leakage of the No. 1 seal. Table 5-4 of WCAP-10541 provides L/D (length/diameter or equivalent length for piping flow resistance) information for a representative Westinghouse 4-loop plant SLO piping system for nominal, upper and lower bound L/D values with the corresponding seal leak rates.

The WCAP leakoff L/D analysis was performed using a representative leakoff line configuration for a typical Westinghouse 4-loop plant. These values were not intended to bound all plant No. 1 SLO line designs. Additional guidance was provided in Technical Bulletin NSD-TB-91-07, Revision 1 (Reference 2) regarding over-pressurization of the RCP SLO line. Technical Bulletin TB-04-22, Revision 1 (Reference 3) addresses loss of all seal cooling and assumes a 21 gpm nominal leak rate resulting from the presence of an orifice or rotameter in the SLO line.

Licensees may have applied the information from the WCAP and Technical Bulletins as an 'acceptance criterion' to show applicability of the nominal case of 21 gpm in regulatory applications including risk-informed applications using probabilistic risk analysis (PRA) methodology.

ISSUE DESCRIPTION

Various plant licensees have inquired about the information provided in WCAP-10541, particularly Table 5-4, "Effect of Leakoff Line L/D on Seal Flowrate." In general, the L/D information in Table 5-4 was used for sensitivity of the No. 1 SLO line performance, given an assumed L/D variation in the No. 1 seal SLO piping design. Licensees may have applied the information from Table 5-4, as well as TB-04-22 information, as an 'acceptance criterion' to show applicability of the nominal 21 gpm performance case in WCAP-10541 (i.e., assuming all seals functioned as expected).

A review of the WCAP-10541 supporting analysis was performed to determine if the basis of the L/D information reported in Table 5-4 could be applied as an acceptance criterion. The RCP loss of all seal cooling event analyzed in the WCAP results in two-phase flow in the No. 1 SLO line. It was determined that an L/D criteria, contained in Table 5-4, could not be used to reliably predict the No. 1 SLO line flow with two-phase flow. It was noted that the WCAP analysis was conservatively performed on a high flow basis; for example, the flow measurement orifice was conservatively ignored and pipe lengths were

varied, but the effect of various pipe diameters was not evaluated. The analyzed plant was chosen as a representative plant for the WCAP-10541 program at that time.

TECHNICAL EVALUATION

Westinghouse first reviewed the different types of SLO piping designs with respect to their flow resistance characteristics with two-phase flow. Analyses were then run to determine the nominal leak rate for various flow restrictors or the equivalent pipe lengths necessary to obtain an estimated No. 1 seal leak rate. The leakage rates obtained by these analyses are based on conservative high-flow piping models assumed by Westinghouse and should only serve as an overall estimated flow consistent with the analysis results provided in WCAP-10541. Licensees that have incorporated the 21 gpm (WCAP-10541) leak rate into their plant specific documentation can compare their specific SLO piping configuration(s) to the configurations addressed in Tables 1 and 2 to determine if the 21 gpm No. 1 seal leak rate remains valid.

SLO Configurations

Westinghouse engineering reviewed a large number of SLO piping configurations of Westinghouse-designed 2, 3 and 4 loop plants. This review identified the various No. 1 SLO piping designs implemented over time. Based on this review, the SLO designs can be grouped into the following general arrangement categories:

1. Early plant designs which used a rotameter for the No. 1 SLO flow measurement. Two models of rotameters were assessed:
   a. Brooks rotameter, which has connections bored to ½" diameter Schedule 160.
   b. Schutte & Koerting rotameter, which has 1" 1500 lb class flanges. The plants with these rotameters were contacted and they have either been replaced or changed to an orifice plate flow meter. The review found one plant replaced this meter with another rotameter with a ¼" minimum clearance.

   These SLO designs used larger bore piping (i.e., greater than ¾" diameter Schedule 160), relative to the latest plant designs. Therefore, the rotameter cases analyzed were ½" diameter Schedule 160 bore and ¼" bore.

Case 1.a: Early plant design ½" Schedule 160 (Brooks rotameter), and
Case 1.b: Early plant design ¼" I.D. bore (replacement rotameter).

   Subsequent to issuing Revision 0 of this NSAL, Westinghouse was informed that several plants have a larger 1" rotameter connection design. To reflect this information, an additional case was added in Table 2a, to supplement Tables 1 and 2.

2. The next generation of plant designs replaced the rotameter with an orifice plate flow meter. The bore size of these orifices is nominally ⅜". These plant designs continued to use larger diameter SLO piping relative to the later designs, consistent with the rotameter designs. Therefore, a ⅜" orifice bore case was analyzed.

Case 2: Orifice plate flow meter with ⅜" bore and > ¾" diameter SLO piping.

3. The latest plant designs used smaller bore piping (i.e., ≤ ¾" diameter Schedule 160) and an orifice plate flow meter with an orifice bore of about ¼". Therefore, a ¼" orifice bore case was analyzed.

Case 3: Orifice plate flow meter with ¼" bore and < ¾" diameter SLO piping

4. For plants that may not fall into the categories listed above, it is recognized that most plants have some amount of ¾" diameter Schedule 160 piping. Therefore, two cases were analyzed in which the

minimum length of ¾" diameter Schedule 160 piping is needed to provide a flow of about 21 gpm or 30 gpm.

Case 4.a:	Plants not in Cases 1, 2 or 3; length of ¾" diameter Schedule 160 piping that provides a flow of 21 gpm, and
Case 4.b:	Plants not in Cases 1, 2 or 3; length of ¾" diameter Schedule 160 piping that provides a flow of 30 gpm.

Unless a plant made a significant SLO line configuration change, Westinghouse anticipates that most configuration changes would fall within the bounds determined by the results of this engineering review (e.g., rotameters that were replaced with orifices would be expected to match the orifice sizes considered above).

No. 1 Seal Faceplate Material

The No. 1 SLO flow performance is related to the No. 1 seal face plate material – either Aluminum Oxide (Al_2O_3) or Silicon Nitride (Si_3N_4). Although most plants would be expected to have upgraded to the lower leakage standard design Si_3N_4 seals, Westinghouse has not confirmed this. Therefore, most of the analyzed cases assumed Al_2O_3 seals because these seals result in higher leakage at nominal RCS operating temperature and pressure following a loss of all seal cooling. Some plants may have installed the 'engineered' Si_3N_4 seal, whose leakage following a loss of all seal cooling is bounded by the standard Si_3N_4 seal performance.

Analysis of SLO Designs

The engineering review identified the categories of SLO piping configurations to consider. Based on the two-phase flow analyses, as indicated in Table 1, the piping designs with flow measuring devices (rotameter or flow orifice) result in choked flow, which occurs at those locations in the system. In the cases analyzed for ¾" diameter Schedule 160 piping, choked flow occurs at the end of the pipe where the pipe length is sufficient to limit the No. 1 seal flow. These are the conservative maximum flows that the system can pass for each configuration, and are independent of the downstream piping effects, such as operator action closing the No.1 seal return containment isolation valve.

Based on the engineering review, the various cases analyzed are summarized in Table 1.

Table 1 – Summary of Cases Analyzed

Case Number	Description	Comments (*Al_2O_3 seals are conservatively assumed, unless noted.)*
1.a.	Early plant design - rotameter case with ½" Schedule 160 bore rotameter connections.	Choked flow occurs across rotameter connections. A Si_3N_4 case is run for this limiting design.
1.b	Early plant design - rotameter case with ¼" bore rotameter connections.	Choked flow occurs across rotameter connections.
2	Orifice plate flow meter with approximately ⅜" orifice plate bore.	Choked flow occurs across the flow element orifice.
3	Orifice plate flow meter with approximately ¼" orifice plate bore.	Choked flow occurs across the flow element orifice.
4.a	Plants not in Cases 1, 2 or 3; determined minimum length of ¾" diameter Schedule 160 piping to limit flow to 21 gpm.	Choked flow occurs at end of pipe. No flow measurement components assumed.
4.b	Plants not in Cases 1, 2 or 3; determined minimum length of ¾" diameter Schedule 160 piping to limit flow to 30 gpm.	Choked flow occurs at end of pipe. No flow measurement components assumed.

Table 2 provides a summary of results for the "21 gpm case" in WCAP-10541, based on the SLO line and seal material assumptions in Table 1. With these results, plants should review their specific SLO piping configuration and use the results as guidance for modeling the plant specific impacts. The results in Table 2 are bounding for the generic SLO piping configurations used in the model when inlet conditions of 2250 psia and 550 Btu/lb (approximately 550°F) are considered. As indicated in Table 2, the ½" diameter Schedule 160 rotameter arrangement provided the highest flows (32 gpm with Al_2O_3 seals). An additional case was run for this design using Si_3N_4 seals, with a resulting flow of 25 gpm. Therefore, for plants with Si_3N_4 seals, the worst case change in performance is from 21 gpm to 25 gpm. Although not specifically analyzed, the same approximate 7 gpm drop in flow could be applied to the ⅜" orifice case for Si_3N_4 seals. That is, 31 gpm predicted for Al_2O_3 seals would equate to about 24 gpm for the Si_3N_4 seals.

Table 2 – Summary of Analysis Results

Case Number	Description	Results (1)
1.a.	Early plant design - rotameter case with ½" Schedule 160 bore rotameter connections.	32 gpm (Al_2O_3); 25 gpm (Si_3N_4)
1.b	Early plant design - rotameter case with ¼" bore rotameter connections.	12 gpm (Al_2O_3)
2	Orifice plate flow meter with approximately ⅜" orifice plate bore.	31 gpm (Al_2O_3)
3	Orifice plate flow meter with approximately ¼" orifice plate bore.	16 gpm (Al_2O_3)
4.a	Plants not in Cases 1, 2 or 3; minimum length of ¾" diameter Schedule 160 piping for 21 gpm.	60 ft. of pipe required (Al_2O_3) to limit flow to 21 gpm
4.b	Plants not in Cases 1, 2 or 3; minimum length of ¾" diameter Schedule 160 piping for 30 gpm.	20 ft. of pipe required (Al_2O_3) to limit flow to 30 gpm

Following issuance of Revision 0 of this NSAL, Westinghouse was informed that larger 1" rotameter connections are currently in use. It was also determined that RCS temperatures are capable of exceeding 550°F during some loss of seal cooling events. Both factors increase seal leakage. It was additionally noted that the Si_3Ni_4 seal material is currently the more prevalent design, particularly for plants with 1" rotameter connections. For the purposes of assessing potential impacts to nuclear safety, and to address the aforementioned factors (i.e., the use of 1" rotameter connections, Silicon Nitride (Si_3N_4) seals, consideration of a higher RCS temperature, and the leakage flow peak behavior[(1)]) Table 2a provides a bounding case based on currently known information. It is noted that for the Table 2a case, leakage flow does not choke across the rotameter connections, and the entire SLO line is assumed to remain fully intact under these conditions.

The Si_3Ni_4 seal material performs better than Al_2O_3, resulting in a decrease in seal leakage. Consideration of the more prevalent Si_3Ni_4 seal material offsets the increase in seal leakage flow due to an increased

(1) The results shown in Table 2 correspond to no-load plant conditions (i.e., 2250 psia and 550 Btu/lb enthalpy) and represent the point at which a loss of seal cooling event might initiate. Values given were intended for comparative purposes with the 21 gpm value given in WCAP-10541. As explained in the NSAL Attachment, seal leak rates vary with pressure/temperature conditions, but the leak rate is not directly proportional with decreasing pressure. In particular, an increase in seal leakage occurs as the primary pressure drops to approximately 1500 psia without RCS cooldown. For calculating the time to core uncovery, this relatively short period of higher leakage (i.e., flow peak) should not be ignored as is illustrated in Table 2a and explained in the Attachment.

RCS temperature of 560°F, 572°F, or 582°F. Therefore, Table 2 Cases 1a (Al_2O_3) and 1b through 4b are not revised. The Case 1a result for Si_3Ni_4 seals remains valid at 550°F but slightly increases at 560°F.

Table 2a - Bounding RCP No. 1 Seal Leak-off Flow Rates
(1" Rotameter Connections and Silicon Nitride [Si_3N_4] Seals)

RCS Pressure (psia)	Temperature (°F)	Flow Rate (gpm)/RCP
2250	560	33
1500	560	50[1]
310	415	16[2]
385	435	18[3]

[1] "Flow peak"
[2] Applicable to 3- and 4-loop plants.
[3] Applicable for 2-loop plants.

Subsequent to a loss of all seal cooling event, the plant operators will take actions to cool down and depressurize the plant to conserve reactor coolant inventory. Decay heat removal will be provided by the steam generators with possibly very low reactor coolant sub-cooling levels. With respect to the Table 2a values, the end point of these actions is assumed to be above the residual heat removal system cut-in conditions of about 310 psia, 391 Btu/lb enthalpy, 415°F and 5.4°F sub-cooling for a three or four loop plant. The limiting 1" diameter Schedule 160 rotameter case was analyzed for these 'end of cooldown' conditions with a flow of 16 gpm, which applies to Si_3N_4 seals. The applicable end of cooldown conditions for a two loop plant are 385 psia, 413 Btu/lb enthalpy, 435°F, and 5.9°F sub-cooling, resulting in a flow rate of 18 gpm. Table 2a results are significantly different than the leakage assumed for the RCP seals at reduced pressure in WCAP-10541, Figure 5-5 and conditions that are predicted by plant response computer code analyses which use an orifice break flow model for seal leakage during cooldown and depressurization.

Orifice Plate Evaluation

Since these analyses credit the high velocity choked flow conditions (note, the Reference 1 analysis ignored the orifice), the limiting component flow measurement orifices were evaluated for integrity in order to supplement the piping integrity recommendations and assumptions in References 2 and 3. Based on evaluating the ¼" and ⅜" bore, ⅛" thick flat plate orifices, the results were:

- Negligible erosion after 16 hours of the worst case conditions in Table 2; and
- Minimal deflection of the orifice plate.

Therefore, the flow performance assumptions remain valid. However, if a loss of all seal cooling event occurs, replacement of the orifice plate is recommended prior to returning the orifice plate to normal flow measurement service.

SAFETY SIGNIFICANCE

Westinghouse performed a 10 CFR 21 evaluation (Part 21 evaluation) for this NSAL revision. The Part 21 evaluation addressed the bounding configuration and conditions presented in Table 2a. The conclusion remains unchanged in that this issue will not lead to a substantial safety hazard (SSH).

Westinghouse determined that when modeling the SLO line for plants with certain types of SLO piping configurations, and those that use the Si_3N_4 No. 1 seal faceplate material, the SLO flow peak could be as

high as 50 gpm at 1500 psia and normal operating temperature. Most plants are not expected to be in this category. The Al_2O_3 faceplate material is expected to produce even higher SLO flowrates during a loss of all seal cooling event, as compared to the standard faceplates made from Si_3N_4. Westinghouse is not aware of any plant that is presently using the 1" sized rotameter in addition to having Al_2O_3 seals installed. Although the flow peak estimate of 50 gpm (33 gpm at 2250 psia and normal operating temperature and 16 or 18 gpm at end of cool down) is applicable to only some of the current Westinghouse plants, it was conservatively assumed for the Part 21 evaluation. It was concluded with respect to the events and evaluations associated with a loss of all seal cooling, that an increase in the as-calculated RCP seal leakage rate to a peak of 50 gpm during a loss of all seal cooling event will not create an SSH. The calculated increase in seal leak rate during such conditions was evaluated as discussed below.

RCS Loop Operability in Modes 1, 2, 3, and 4

RCS loop operability in Modes 1, 2, 3, and 4, which is required to provide forced reactor coolant circulation, is not impacted. This issue does not affect RCS integrity nor loop flow through the RCP. The issue only affects the small flow through the RCP seal package following a loss of all RCP seal cooling; the RCP seal package performance during normal operation of the RCPs is not impacted. Any loss of all RCP seal cooling event would result in a trip or shutdown of the RCPs, when they are no longer required to provide forced reactor coolant circulation.

10 CFR 50.63 Station Blackout (SBO)

In previous SBO analyses, the time to core uncovery following a loss of seal cooling was originally evaluated using the WFLASH, TREAT and the LOFTRAN codes. The Westinghouse nuclear steam supply system (NSSS) designs are licensed with an SBO coping time based on NUMARC 87-00, Revision 1 (Reference 4) and typically fall into the 4-8 hour range for a.c. power recovery. Previous analyses have shown that with the operators performing a plant cooldown and assuming an initial 21 gpm leakage rate per RCP, the time to core uncovery far exceeds an 8 hour coping time. If initial seal leakage increases to 33 gpm at 2250 psia, peaks at 50 gpm at approximately 1500 psia, and seal leakage after plant cooldown is assumed to be 16 or 18 gpm depending on number of loops, the time to core uncovery, based on a reference plant analysis, is estimated to be approximately 12.5 hours, which does not adversely impact the coping time. Therefore, it is concluded that the time to core uncovery following an SBO event will occur beyond the plant licensing basis coping time, even with an increased seal leakage rate as a result of bounding seal and seal leakoff line design parameters.

Extended Loss of AC Power (ELAP)

Plant specific FLEX (Diverse and Flexible Coping Strategies) analyses evaluate timelines necessary to implement operator actions, including RCS makeup capabilities to maintain core cooling. In these ELAP analyses, the time to initiation of reflux cooling and to core uncovery will be shortened by an increase in RCP seal leakage and may result in additional requirements for makeup capability or resources to complete the required manual actions to maintain core cooling. RCP seal leakage as high as 33 gpm at 2250 psia, 50 gpm at approximately 1500 psia, and 16 or 18 gpm after plant cooldown to RHR cut-in conditions may affect those timelines and capabilities using accepted compliance methodologies. This would include the potential impacts on the evaluations performed in WCAP-17601-P, Revision 1 (Reference 5).

10 CFR 50.48, Fire Protection and 10 CFR 50, Appendix R, Fire Protection Program

10 CFR 50.48(a) and (b) / 10 CFR 50, Appendix R, specifies the requirements for an acceptable fire protection program. 10 CFR 50 Appendix R (III)(L)(2)(b) states, “The reactor coolant makeup function shall be capable of maintaining the reactor coolant level above the top of the core for BWRs and be within the level indication in the pressurizer for PWRs.” Some fire scenarios result in a loss of RCP seal

cooling and a loss of all high pressure RCS make-up capability. The Appendix R fire protection coping analyses evaluate timelines necessary to restore some means of high pressure make-up to maintain the pressurizer water level on-span. RCP seal leakage as high as 33 gpm at 2250 psia with a peak as high as 50 gpm at approximately 1500 psia will challenge those timelines and may not allow compliance with the "pressurizer water level on-span criterion." However, there will be sufficient mass remaining in the RCS to prevent core uncovery up to the make-up restoration timeline, should a fire result in a loss of seal cooling.

Risk-Informed Applications and Methods, and Use of the PRA Model

WCAP-15603 (Reference 9) provides the current PRA methodology for modeling seal leakage from RCPs with Westinghouse seal packages following loss of all seal cooling. This approach, which has been reviewed and approved by the NRC, is called the WOG2000 model. As summarized in Table 3, the WOG2000 model includes probabilities for a range of possible leak rates considering functionality of the first and second seal stages.

Table 3
WOG2000 PRA Model for RCP Seal Behavior following Loss of all Seal Cooling

Probability[1]	Leak Rate (gpm/pump)	No. 1 Seal Status	No. 2 Seal Status
0.79	21	Normal[2]	Normal
0.01	76	Failed	Normal
0.1975	182	Normal	Failed
0.0025	480	Failed	Failed

[1] Probability given a loss of all seal cooling event.
[2] "Normal" refers to expected behavior for a loss of seal cooling event

The WOG2000 model has been implemented in numerous PRAs of Westinghouse plants. It is used to evaluate the various scenarios that can lead to loss of seal cooling, including station blackout, loss of component cooling water, and loss of service water. It is also used for fire-initiated events that involve loss of RCP seal cooling as a result of loss of power or spurious valve operation.

In support of this NSAL, Westinghouse assessed the increase in seal leakage above 21 gpm due to variations in the SLO line configuration as well as the higher than expected leakage during cooldown and depressurization following a loss of seal cooling with respect to the possibility that these conditions could pose an SSH as defined by 10 CFR Part 21. The conclusion of the assessment is that there is no SSH posed by these results. This conclusion is based on the following:

1. PRA is not used alone to make decisions. All risk-informed applications are required by Regulatory Guide 1.174 (Reference 10) to satisfy five integrated decision-making principles, including regulation, defense-in-depth, safety margin, monitoring, and risk assessment.
2. The increased leakage would not place the plant in an unrecoverable condition. Plant design includes systems that can prevent core damage if the increased leakage were to occur. Furthermore, the increased leakage does not compromise containment integrity, which would be available to prevent significant fission product release to the public in the unlikely event of fuel damage.

Reportability

While the issues addressed herein could adversely impact license basis evaluations, they would not significantly degrade plant safety as discussed in NUREG-1022, Revision 3, "Event Report Guidelines 10 CFR 50.72 and 50.73" (Reference 8).

AFFECTED PLANTS

Any plant that has used or applied the WCAP-10541 RCP SLO line leak rate of 21 gpm for licensing basis purposes is potentially affected by the NSAL. This NSAL, and the cases specifically evaluated above, address the Westinghouse-supplied RCP shaft seal package design, where the No. 1 seal is a controlled-leakage film riding seal and the No. 2 and No. 3 seals are both rubbing face designs. Some plants may employ RCP seals of a similar design but may have been supplied by a manufacturer other than Westinghouse. If this is the case, there is a possibility that the SLO line backpressure issue could apply to these plants and this possibility should be evaluated on an as-needed basis.

The plants listed in Table 4 are units where Westinghouse originally supplied the RCP shaft seal package as part of the Westinghouse NSSS or in a few cases, to non-Westinghouse plants. Plants that are no longer operating are not listed. In some cases the current RCP seals may have been supplied by a manufacturer other than Westinghouse.

Table 4 - RCP Seals Originally Supplied by Westinghouse Electric Company

A.W. Vogtle 1 & 2	Diablo Canyon 1 & 2	Millstone 3	Shikoku Ikata 1
Almaraz 1 & 2	Doel 1, 2 & 4	North Anna 1 & 2	Sizewell B
Angra Dos Reis 1	Genkai 1	Oconee 1	South Texas 1 & 2
Asco 1 & 2	H.B. Robinson 2	Ohi 1 & 2	Surry 1 & 2
Beaver Valley 1 & 2	Indian Point 2 & 3	Point Beach 1 & 2	Takahama 1 & 2
Beznau 1 & 2	J.M. Farley 1 & 2	Prairie Island 1 & 2	Three Mile Island 1
Braidwood 1 & 2	Kori 1, 2, 5 & 6	R.E. Ginna	Turkey Point 3 & 4
Byron 1 & 2	Krsko	Ringhals 2, 3 & 4	V.C. Summer
Callaway	Lemoniz 1 & 2	Salem 1 & 2	Vandellos 2
Catawba 1 & 2	Maanshan 1 & 2	Seabrook 1	Watts Bar 1 & 2
Comanche Peak 1 & 2	McGuire 1 & 2	Sequoyah 1 & 2	Wolf Creek
D.C. Cook 1 & 2	Mihama 1, 2 & 3	Shearon Harris	Yonggwang 1 & 2

NRC AWARENESS

This issue is not reportable in accordance with 10 CFR 21. Therefore, the NRC has not been notified by Westinghouse.

RECOMMENDED ACTIONS

The recommended actions from Revision 0 of this NSAL were appropriate for determining the impact of SLO line configuration on the RCP No. 1 seal leakage rate. In response to the flow peak information included in the Attachment, the following actions are recommended:

1. Review the information presented in the Attachment. It is recommended that affected plants re-evaluate their plant-specific seal leakage analyses to account for the actual SLO line configuration and the RCP seal leakage behavior that occurs at approximately 1500 psia and normal operating

temperature[(2)]. Including the flow peak behavior in these flowrate evaluations increases the integrated inventory loss, which may impact the current licensing basis (CLB) even if the seal leak rate is less than the nominal 21 gpm value (Reference 1).

2. Evaluate the impact to the plant's CLB and other in-process programs.
    a. With respect to 10 CFR 50.63, SBO; confirm that the updated time to core uncovery (coping time) remains greater than the plant specific coping time
    b. For FLEX mitigating strategies; confirm that the timelines and capabilities remain within the plant specific analyses
    c. For 10 CFR 50.48(a) and (b)/Appendix R Fire Protection Program; review the impact of the issue against the Fire Protection Program licensing basis
    d. For risk-informed applications, including NFPA-805, and other applications of the PRA model; assess the impact of increased leakage on the PRA model and risk-informed applications that utilized the PRA model

REFERENCES

1. WCAP-10541, Revision 2, "Westinghouse Owners Group Report, Reactor Coolant Pump Seal Performance Following a Loss of All AC Power," November 1986.
2. Westinghouse Technical Bulletin NSD-TB-91-07, Revision 1, "Overpressurization of RCP #1 Seal Leakoff Line," June 18, 1992.
3. Westinghouse Technical Bulletin TB-04-22, Revision 1, "Reactor Coolant Pump Seal Performance – Appendix R Compliance and Loss of All Seal Cooling," August 9, 2005.
4. NUMARC 87-00, Revision 1, "Guidelines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at Light Water Reactors," August 1991.
5. WCAP-17601-P, Revision 1, "Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcock & Wilcox NSSS Designs," January 2013.
6. WCAP-15603, Revision 1-A "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," June 2003.
7. NFPA-805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," 2010 Edition.
8. NUREG-1022, Revision 3, "Event Report Guidelines 10 CFR 50.72 and 50.73," January 2013.
9. WCAP-15603, Revision 1-A, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs," June 2003.
10. Regulatory Guide 1.174, Revision 2, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis."

(2) Note that Table 2a presents a limiting case.

ATTACHMENT

Subsequent to the first issuance of this NSAL, the Pressurized Water Reactor Owners Group (PWROG) RCP Working Group initiated a program to perform additional seal leakage analysis work. The Owners Group program analyzed multiple No. 1 SLO line configurations and seal leakage rates were calculated for a range of RCS pressure and temperature conditions that occur during the plant depressurization and cooldown conditions following the loss of seal cooling event. As discussed in the main body of this document, the recent work indicated that with certain No. 1 SLO arrangements, a much higher leak rate could occur with constant RCS temperatures but lower RCS pressures. This highlighted the fact that a potentially non-conservative treatment of seal leakage could exist in RCS transient modeling for certain RCP seal responses to a loss of seal cooling. Because the RCS thermal-hydraulic codes were not designed to handle the complex response of the RCP seal leakage due to higher temperatures, in some cases, the leakage had been determined via a simple orifice break flow correlation (i.e., proportional to pressure.) As explained below, the orifice break flow model does not account for the RCP seal response that is predicted by the PWROG analysis.

The PWROG work indicates that the maximum seal leakage flow rate does not occur at normal operating pressure and temperature (i.e., 2250 psia and normal operating temperature). Instead, the leakoff flow increases as the plant initially depressurizes without cooldown, reaching a flow peak at approximately 1500 psia. The flow then decreases as the plant simultaneously depressurizes and cools down after that point because the postulated loss of seal cooling events are assumed to include an RCS temperature reduction early into the event to reduce seal leakage and/or maintain RCS sub-cooling margin.

The seal has two behaviors that control seal leakage and yield the flow peak. The first is that the seal moves axially along the shaft and this can open or close the seal face clearance based on the balance of pressure upstream and downstream of the seal. The second is the tendency of the seal face deflection angles to increase as the differential temperature across the seal face increases, which also effectively opens the seal face clearance. The combination of these two behaviors is responsible for the peak seal leakage flow at approximately 1500 psia without RCS cooldown. The duration of this flow peak is anticipated to be short in response to a loss of seal cooling event, since operators are expected to take action to depressurize and cool down the plant to conserve reactor coolant inventory. However, with significant leak-rate increases noted in some leak-off system configurations, as well the time of initiation of RCS cooldown having some variability, this transient behavior cannot be ignored.

The peak flow behavior from the PWROG work was also apparent in Table 5-2 of Reference 1. This table shows an increase in flow of 1.6 gpm as the pressure decreases from 2250 psia to 1500 psia while the temperature remains constant. It is apparent from the PWROG results that for seal leak-off line configurations which have high flow rates at 2250 psia, the transient flow peak at 1500 psia is more significant than for plants with lower flow rates. Note that although the peak flow is observed from both the Reference 1 and the PWROG calculations, some of the available test data and other analytic work, while limited, does not exhibit this trend. Therefore, it is conservative to include the transient flow peak in seal leakage analyses.

Although the aforementioned behavior was understood at the time Reference 1 was issued, it was assumed that the small increase in flow would have a negligible impact on the time to core uncovery. Thus, for simplification purposes, seal leakage was calculated using an orifice break flow correlation to determine the change in flow rate for depressurization and cooldown in subsequent plant response analyses. Based on the recent PWROG program results, it has been determined that use of the orifice

break flow methodology can be non-conservative. This does not present a condition adverse to nuclear safety, as is explained in the main body of this NSAL.

REFERENCE

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