May 1, 2001

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FROM: Patrick W. Baranowsky, Chief
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SUBJECT: IMPLICATIONS OF USING RHODES RCP SEAL LOCA MODEL IN RISK ASSESSMENTS

REFERENCES:

1) MEMO FROM ASHOK C. THADANI TO WILLIAM D. TRAVERS, “CLOSEOUT OF GENERIC SAFETY ISSUE 23: REACTOR COOLANT PUMP SEAL FAILURE,” NOVEMBER 8, 1999.

2) COMBUSTION ENGINEERING OWNERS GROUP REPORT NO. CE NPSD-1199-NP, “MODEL FOR FAILURE OF RCP SEALS GIVEN LOSS OF SEAL COOLING,” JULY 2000.

3) WESTINGHOUSE OWNERS GROUP REPORT NO. WCAP-15603, “WOG2000 REACTOR COOLANT PUMP SEAL LEAKAGE MODEL FOR WESTINGHOUSE PWRS,” DECEMBER 2000.

The purpose of this memorandum is to inform the Standardized Plant Analysis Risk (SPAR) model users and other agency risk analysts about the implications of using the “Rhodes Model” to model reactor coolant pump (RCP) seal loss-of-coolant accidents (LOCAs). The SPAR models are used in analyses that support regulatory activities, such as: (1) the Significance Determination Process (SDP) in the Reactor Oversight Process, (2) enforcement actions which are based on risk significance, (3) risk-informed reviews of license amendments, and (4) the Accident Sequence Precursor (ASP) Program. We are providing this information because the Rhodes Model is different from the RCP seal LOCA model incorporated in the SPAR models at the present time. For Westinghouse RCP seal assemblies, the SPAR models use RCP seal LOCA models developed to support NUREG-1150 “Severe Accident Risks: An Assessment for Five U.S. Nuclear Plants.” For non-Westinghouse RCP seal assemblies, the SPAR models use a model developed in the ASP Program (NUREG/CR-4674, Vol. 21, Appendix H) using operating experience. Under some circumstances, using the Rhodes Model will yield significant differences in the probabilistic risk assessment results.

BACKGROUND

The Thadani to Travers memorandum (Ref. 1, ADAMS accession No. ML993370509) closed out Generic Safety Issue (GSI) 23, “Reactor Coolant Pump (RCP) Seal Failure.” This memo stated that, until additional RCP seal LOCA models are developed, the staff will use the Rhodes Model to determine the contribution to core damage frequency (CDF) from RCP seal LOCA induced sequences.

Rhodes Model

Appendix A to NUREG/CR-5167 “Cost/Benefit Analysis for Generic Safety Issue 23: Reactor Coolant Pump Seal Failure,” describes the Rhodes Model. The Rhodes Model assumes that ten minutes after a loss of RCP seal cooling, there is a 20% chance that Westinghouse RCP seal assemblies with unqualified (old) or improved O-rings will “pop open.” If RCP seal cooling remains unavailable for two hours, it is assumed that the unqualified O-rings will fail with a probability of 1.0. For the Westinghouse RCP seal assemblies with improved O-rings, the likelihood of O-ring failure as a result of elastomer failure due to long-term loss of RCP cooling is assumed to be negligible.

The Rhodes Model has been developed for Westinghouse RCPs. However, the GSI-23 closeout memo (Ref. 1) directed the staff to use the Rhodes Model for non-Westinghouse RCP seal assemblies until standard models are developed for these seals. According to the GSI-23 closeout memo, the use of the Rhodes Model is acceptable until better models are developed for all other RCP seal types (e.g., Byron-Jackson, Bingham, etc.)[1].

Conservatism associated with the Rhodes Model

Reference 1 acknowledged that the Rhodes Model is conservative. Our preliminary screening analysis of the operating experience supports this assertion (See Attachment 1 for details). Reference 1 directed the use of the Rhodes Model in NRC staff’s risk analyses, despite its conservatism, since the industry had not provided information for development of a more realistic model.

Reference 1 analyzed the impact of using the Rhodes Model on station blackout (SBO) coping analysis and CDF contributions from loss of component cooling water (CCW) and service water (SW) events. These analyses concluded that when the Rhodes Model is used, the relative CDF contributions from SBOs and loss of CCW or SW events were significantly higher than those estimated in licensees’ IPEs.

RCP Seal LOCA Model Proposed by CEOG and WOG

In July 2000, the Combustion Engineering Owners Group (CEOG) submitted a report entitled “Model for Failure of RCP Seals Given Loss of Seal Cooling,” (Ref. 2) and requested a formal review by the Office of Nuclear Reactor Regulation (NRR). In December 2000, the

[1]This does not imply that the O-ring material used in Bryon-Jackson or Bingham seals is similar to or qualified to the same standard as the improved Westinghouse O-ring material or that the Rhodes Model of the Westinghouse RCP seal assembly reflects the actual behavior of the Byron-Jackson or Bingham RCP seal assembly.

Westinghouse Owners Group (WOG) submitted a report entitled "WOG 2000 Reactor Coolant PUMP Seal Leakage Model for Westinghouse PWRs," (Ref. 3) and requested a formal review by NRR. These reports use operating experience to propose alternate models for RCP seal LOCAs. NRR has provided RES/DET/ERAB and RES/DRAA/PRAB opportunities to review the industry's submittals.

IMPLICATIONS OF USING RHODES MODEL IN ASP AND SDP ANALYSES

The Operating Experience Risk Analysis Branch (OERAB) performed a sensitivity analysis to determine the impact of using the Rhodes RCP seal LOCA model rather than the RCP seal LOCA models currently incorporated in the SPAR models. In addition, OERAB assessed the relative risk significance of the CCW and SW systems using the Rhodes Model and the RCP seal LOCA models currently incorporated in the SPAR models.

Based on these sensitivity analyses, we determined that the risk significance associated with some initiators that result in loss of RCP seal cooling (e.g., loss of CCW, loss of SW) is substantially affected when the Rhodes Model is used. For example, the CDF due to internal events at Millstone Unit 2, calculated using the Revision 3i SPAR model, is 3.5E-05/year. Only about 3% of this CDF is associated with the loss of CCW initiator. Another 3% is associated with the loss of SW initiator. However, when the Rhodes Model is used, the CDF for Millstone Unit 2 increases to 8E-05/year. Approximately 25% of the CDF is associated with the loss of CCW initiator. Another 25% is associated with the loss of SW initiator. Details of our sensitivity analyses are provided in Attachment 2.

Attachment 2 shows that the conditional core damage probability (CCDP) associated with loss of offsite power (LOOP) events did not change significantly for the four plants analyzed due to the use of the Rhodes Model. However, under some circumstances, the CCDP may change significantly. Two of the known circumstances under which the CCDP may change significantly are as follows:

- LOOP events at plants (such as Oconee) where the emergency feedwater can be supplied from sources unaffected by the SBO (e.g., a dedicated safe shutdown facility, cross-ties from other units),

- LOOP events where offsite power can be recovered before the battery-depletion-time following an RCP seal LOCA.

The risk significance determinations of several ASP and SDP analyses performed in the year 2001 are significantly affected by the use of the Rhodes Model. For example, the increases in CDF associated with a postulated HELB condition discovered at Oconee Units 1, 2, and 3 are 9.6E-05, 4.8E-05, and 4.6E-05 per year, respectively (final draft analysis for comment - transmitted via memo dated March 13, 2001 from P. Baranowsky). If the Rhodes Model was not used, the increases in CDF would be 6.5E-05, 1.9E-05, and 1.8E-05 per year, respectively.

ASSISTANCE IN APPLYING RHODES MODEL

The ASP Program is modifying the SPAR models to use the Rhodes Model, on a case-by-case basis. We plan to continue to use the Rhodes Model in our analyses until an agency consensus on using a different model is reached.

We are available to help the SPAR model users adjust their risk analyses to incorporate the Rhodes Model, when needed. Attachment 2 is a sensitivity analysis that should be helpful to determine whether a given risk analysis is significantly affected due to switching to the Rhodes Model. In addition, three recent ASP analyses issued by RES/DRAA/OERAB on Indian Point 2, Oconee 1,2, 3, and Diablo Canyon 1 show how the Rhodes Model was incorporated in the analyses, when using SPAR models. These three analyses are available in ADAMS (document nos. ML010730213, ML010730195, and ML01070446, respectively).

If you have any questions regarding the implications of using the Rhodes Model in risk analyses, please contact Patrick O'Reilly at 301-415-7570 (email: pdo@nrc.gov) or Sunil Weerakkody at 301-415-6374 (email: sdw1@nrc.gov).

MEMORANDUM DATED: 5/1/01

SUBJECT: IMPLICATIONS OF USING “RHODES” RCP SEAL LOCA MODEL IN RISK ASSESSMENTS

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ADAMS ACCESSION NO.: ML011350077
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Attachment 1

SUMMARY OF RESULTS OF
REVIEW OF OPERATIONAL EXPERIENCE

Review of Operating Experience:

Approach:

Screened approximately 1000 LERs covering period 1984 - 2000 using the following screening criteria:

- Loss of reactor coolant pump seal cooling
- Reactor coolant pump seal problems
- Loss of component cooling water
- Loss of charging flow
- Loss of reactor coolant pump seal injection flow

Reviewed each LER screened in to identify events involving loss of cooling to reactor coolant pump seals.

In addition, reviewed other documentation[2] of RCP seal operating experience covering period 1973 - 1990 that identified cases of loss of cooling to the RCP seals at CE PWRs:

Results[3]:

- LER 389/84-016 (CE) - Loss of component cooling water to 2 RCPs for 30 minutes. Two RCP seals are damaged. Details of damage unavailable.

- LER 382/85-006 (CE) - Loss of RCP seal cooling for 43 minutes, 3 gpm leakage from RCP 1A seals. (Failed seal stage # unavailable). Seals were changed immediately.

- LER 389/85-008 (CE) - Loss of component cooling water. Two RCP seals lost cooling for 4.5 hours. RCP seals are damaged due 3rd stage seal failure.

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2 NUREG-1275, Vol. 2, "Operating Experience Feedback Report - Experience with Pump Seals Installed in Reactor Coolant Pumps Manufactured by Byron Jackson - July 1992," and NUREG/CR-4400, "The Impact of Mechanical- and Maintenance-Induced Failures of Main Reactor Coolant Pump Seals on Plant Safety - December 1985"

3 The events identified do not represent a complete set of relevant operating experience data - loss of RCP seal cooling by itself is not a reportable event under 10 CFR 50.72 or 50.73.

- LER 529/86-015 (CE) - RCP cooling lost for 3 hours. One RCP ran for 10 minutes without seal cooling.
- LER 529/86-041 (CE) - All RCP cooling lost for 3 hours. Pumps operated for 10 minutes without cooling. Third stage of one RCP failed.
- LER 285/87-027 (CE) - Loss of RCP seal cooling for 3.5 minutes, no effect on RCP seals.
- LER 530/89-001 (CE) - Loss of RCP seal injection and component cooling water to all RCPs for 73 minutes, resulting in 6 gpm leakage from a RCP seal due to degradation of 1st stage seal.
- LER 285/92-023 (CE) - Loss of RCP seal cooling for < 1 minute, no effect on RCP seals.
- Ft. Calhoun - 04/17/74 - Isolated component cooling water to the RCPs on an ESFAS signal. 4 RCPs ran for 45 minutes without cooling.
- Ft. Calhoun - 09/20/75 - All 4 RCP seals changed after loss of component cooling water.
- St. Lucie 1 - 04/15/77 - Loss of containment instrument air caused loss of component cooling water.
- St. Lucie 1 - 06/11/80 - Component cooling water to RCPs lost for >8 hours.
- ANO-2 - 06/24/80 - Partial loss of ac power. Loss of cooling to RCPs for 6 minutes. RCP seal leakage of 1.5 - 2.0 gpm from one stage.
- Ft. Calhoun - 1981- Component cooling water lost for 1 hour while in hot standby. RCPs restarted OK.
- Millstone 2 - 11/15/84 - Component cooling water lost for 9 hours. No LER submitted.
- Millstone 2 - 11/16/84 - Component cooling water lost for 6 hours. 1 RCP seal stage reported failed, no leakage.

Summary:

Of the total 16 events, identified 3 events which reported that RCP seals lost cooling for less than 10 minutes. One seal failure occurred in which, an RCP seal leakage of 1.5-2.0 gpm occurred from one seal stage.

Identified 11 events which reported that RCP seals lost cooling for more than 10 minutes. During most of these events, a seal stage did fail or became degraded, resulting in seal leakage, but there were no reported instances of overall RCP seal failure or seal popping.

For the other 2 events, the duration of the loss of cooling was not available.

According to the Rhodes Model, after a 10-minute loss of RCP seal cooling, there is a 20% chance of seal popping, which leads to RCP seal failure. Therefore, if 11 events occurred with loss of seal cooling longer than 10 minutes, we would expect to observe about 2 gross seal failures due to popping, if the Rhodes Model accurately predicts seal performance. None were reported. For some of these events, the RCPs continued to run after loss of seal cooling, which is a more severe condition than the condition postulated in the Rhodes Model (pumps tripped).

Therefore, these results imply that the use of the Rhodes RCP Seal LOCA Model may be pessimistic, especially for the plants, which have Byron-Jackson or Bingham seals installed in their reactor coolant pumps.

Summary of Sensitivity Analyses to Determine the Effect of the Rhodes Model

Approach:

To determine the effect of the Rhodes Model on the estimated conditional core damage probability (CCDP), a set of sensitivity studies was performed using the Revision 3i SPAR models. Initiating events which could lead to a loss of cooling to the reactor coolant pump seals were analyzed. The events were loss of offsite power events (plant-centered, grid-centered, severe weather, and extremely severe weather) events, loss of CCW, and loss of SW. The approach used is summarized below:

- Used two Westinghouse PWRs [Prairie Island (old O-rings),Braidwood (new O-rings)]; one CE PWR [Millstone 2 (BJ seal w/o seal injection)]; and one B&W PWR [Davis-Besse (BJ seal w/seal injection)].

- Performed six analyses for each plant:

  - Four types of LOOP initiators (plant-centered, grid-centered, severe weather, extremely severe weather).
  - Loss of component cooling water initiator.
  - Loss of service water initiator.

- For each initiator, subtracted contribution of dominant RCP seal failure sequences from the total CCDP.

- Recalculated contribution from dominant RCP seal failure sequences using Rhodes Model.

- Combined recalculated RCP seal failure contribution with contribution from non-RCP seal failure sequences to obtain estimated total CCDP using Rhodes Model.

- Compared total CCDP obtained using Rhodes Model with CCDP obtained using old seal LOCA model.

Results:

- Summary of results (refer to Table 1):

  - For LOOP initiators:

    - Most CCDPs either decreased slightly (~ 2-5%) using Rhodes Model or showed no discernible change.

    - CCDPs for Braidwood showed the largest change (decreases ranging from 2% to 16%) using the Rhodes Model.

- For the loss of component cooling water initiator, with no recovery of CCW:

  - CCDPs for Prairie Island (45%) and Braidwood (83%) increased significantly using the Rhodes Model.

  - CCDPs for Millstone 2 (1900%) and Davis-Besse (3100%) increased significantly using the Rhodes Model.

  - CCDP for this initiator for all four plants is dominated by sequences involving RCP seal failure.

- For the loss of service water initiator, with no recovery of SWS :

  - CCDPs for all plants increased significantly (Prairie Island by 334%; Braidwood by 813%; Millstone 2 by 1900%; Davis-Besse by 3100%) using the Rhodes Model.

  - As in the loss of CCW case, the CCDP for this initiator for all four plants is dominated by sequences involving RCP seal failure.

Table 1: Sensitivity Study Using the CCDP for Initiators

		CCDP given the Initiator			
Initiator		Prairie Island (Old W O-rings)	Braidwood (Improved W O-rings)	Millstone 2 (BJ seal w/o seal injection)	Davis-Bessie (BJ seal w/seal injection)
LOOP- Extremely severe weather	Current Model	5.5E-04	9.2E-03	9.8E-04	1.4E-03
	Rhodes Model	5.5E-04	8.4E-03	1.0E-03	1.4E-03
	Increase	no change	-9.5%	2%	no change
LOOP- Severe weather	Current Model	3.9E-04	6.2E-03	5.2E-04	7.1E-04
	Rhodes Model	3.7E-04	5.5E-03	5.2E-04	6.9E-04
	Increase	-5%	-11%	no change	-3%
LOOP- Grid related	Current Model	6.2E-05	6.3E-04	1.9E-04	1.0E-04
	Rhodes Model	6.0E-05	6.2E-04	1.9E-04	1.0E-04
	Increase	-3%	-2%	no change	no change
LOOP- Plant centered	Current Model	4.2E-05	7.7E-04	1.3E-04	7.8E-05
	Rhodes Model	4.1E-05	6.5E-04	1.3E-04	7.8E-05
	Increase	-2%	-16%	no change	no change
Loss of CCW (non recoverable)	Current Model	3.8E-05	4.0E-05	1.0E-02	6.2E-03
	Rhodes Model	5.6E-05	7.3E-05	.2	.2
	Increase	**45%**	**83%**	**1900%**	**3100%**
Loss of SW (non recoverable)	Current Model	4.6E-02	2.3E-02	1.0E-02	6.2E-03
	Rhodes Model	.2	.2	.2	.2
	Increase	**334%**	**813%**	**1900%**	**3100%**

Note 1: Revision 3i of SPAR models were used.

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IMPLICATIONS OF USING "RHODES" RCP SEAL LOCA MODEL IN RISK ASSESSMENTS

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