RISK SIGNIFICANCE EVALUATION OF SERVICE WATER PUMP FAILURES FOR PALISADES NUCLEAR POWER STATION

Final Report

Prepared for

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 *Purpose*

This report documents a risk significance evaluation of two service water (SW) pump failures that occurred at the Palisades Nuclear Power Station on September of 2009 and August of 2011. This independent evaluation is based on information provided to the author on the event descriptions and corrective actions that is presented in Section 2 of this report.

1.2 *Objectives*

The objectives of this study are to:

- Review the available evidence on the SW pump failures including the licensee event reports [1][2], root cause evaluations [3][4], and metallurgical evaluations [5][6] to develop an understanding of the failure modes, mechanisms, and corrective actions.
- Provide an appropriate risk evaluation of the events by establishing the appropriate cause and effect relationships between the events and the Palisades PRA models.
- Estimate the risk impact of the events and the conditions that produced them. This includes a characterization of the time frames and a quantitative estimate of change in risk associated with the events and the conditions that produced them. This is to provide input to the Risk Informed Oversight program on the quantitative risk significance of the events.

1.3 *Report Guide*

A qualitative evaluation of the SW pump failures is provided in Section 2. In Section 3 a quantitative risk evaluation is presented. A limited review of the NRC Preliminary Significance Determination is found in Section 4. The conclusions of these evaluations are provided in Section 5.

2. REVIEW OF SERVICE WATER PUMP FAILURES

2.1 *Summary of Service Water Pump P-7 Coupling Failure Events*

The following summary of the SW pump failures is based on information provided by Palisades to the author. More details on the description of the events may be found in the Licensee Event Reports in References [1] and [2], for the 2009 and 2011 events, respectively, and in the root cause evaluation reports in References [3] and [4], for the 2009 and 2011 events, respectively.

2.2 *Service Water Pump Configuration at Palisades*

The following excerpt from Reference [4] provides a good description of the SW pump configuration at Palisades.

> *The Service Water System (SWS) at Palisades is comprised of three motor driven vertical multistage pumps supplying water from Lake Michigan to three service water headers. Two of the headers are termed critical headers A and B, which provide cooling to safety and non-safety related components. Each critical header supplies cooling water to one set of the redundant components including emergency diesel generator lube oil and jacket water coolers, a control room air-conditioning unit, an air compressor after-cooler and an engineered safeguards room cooler. In addition, critical header A supplies cooling water to the component cooling water heat exchangers while critical header B supplies cooling water to the containment air coolers.(Note that headers A and B are normally cross tied during normal plant operation and would be in this alignment during accident conditons) For accident conditions, either train fed by its associated diesel, is sufficient for accident mitigation. The third header is termed non-critical and provides cooling to non-safety related equipment.*
>
> *Palisades Technical Specifications require that all three pumps be operable. The failure of a single pump requires entry into a 72 hour shutdown LCO Action Statement. A single header combining return streams from the three supply headers discharges into the cooling tower makeup basin. Leakage of radioactive contamination into the SWS is detected by a radiation monitor installed in the discharge line.*
>
> *The three Service Water Pumps (SWPs), P-7A, P-7B, and P-7C, are modified Layne and Bowler pumps. They are comprised of a two stage pump end with stainless steel impellers connected to a discharge head by seven columns for a total height of over 40 feet from suction to discharge. The pump end is coupled to the motor through six line shafts, a packing shaft, and a motor shaft connected by eight couplings all of the same design.*

2.3 *Service Water Pump Failure Event Descriptions*

From April to May of 2009, Palisades replaced the carbon steel components of all three pump rotating assemblies with 416 stainless steel in order to improve corrosion resistance, A timeline of events is presented in Table 2-2 below. The P-7C pump couplings were replaced in June of 2009; on September 29, 2009 the first of two failures occurred. The root cause evaluation for this failure determined the #7 coupling failed due to inter-granular stress corrosion cracking (IGSCC) which resulted from the material having hardness beyond specification [3]. The pump was repaired with couplings that were validated as within the proper hardness specification and placed back in service in October 2009. This coupling is near the top of the pump shaft and in an area that experiences wet conditions when the pump is in operation and dry when the pump is in a shutdown standby mode of operation. Couplings #5, 6, and 7 share these conditions whereas the remaining couplings are always wet.

In August of 2011, the second coupling failure occurred on P-7C, the same pump that failed in 2009. In this event, the #6 coupling failed and again the failure mode was attributed to IGSCC, however, the hardness of the steel was within specification. Upon further evaluation it was determined that out-of-specification hardness was not the root cause of the failures and cracks observed in 2009, although it may have been a contributing factor. It was also discovered that couplings #5 - #7 experienced intermittent cycles of wet and dry conditions depending on if the pump is in operation or standby. This environment in conjunction with the shear stresses on the coupling was identified as root cause of both failures [6]. The metallurgists determined that 416 SS should not be used for this application given the environmental and mechanical stresses on the coupling and the susceptibility of the material to IGSCC [6].

Following the second failure, Palisades has replaced the couplings on all three pumps with 17-4PH stainless steel. The replacements were started in August 2011 and were completed in October 2011 (see Table 2-2 for replacement dates).

2.4 *Root Cause Evaluation*

The 416 stainless steel couplings installed in the P-7A and P-7B pumps in April and May of 2009 were of the same 416 stainless steel as installed in P-7C. When the couplings were removed in August 2011, for replacement with the new material specification, they were sent for metallurgical evaluation. The report concluded that the P-7A couplings had no visual indication of cracking, and if a flaw had initiated on the day the couplings were removed, it would have required at least 54 days for the flaw to propagate through wall (considering the pump remained in continuous operation). Cracks were found in the #5, #6, and #7, couplings (exposed to the wet-dry environment) of the P-7B pump. The report stated it would require approximately 40 additional days of pump operation beyond the day they were removed for the cracks to propagate through wall [5].

It was noted in the 2011 metallurgical reports [5][6] that the P-7A coupling threads had a greater amount Neolube grease applied relative to the couplings examined from pumps P-7B and P-7C. It was postulated that this additional grease enhanced the coupling's pitting resistance by protecting the threads from corrosive agents in the operating environment. The lubricant is applied to the shaft threads in accordance with the pump reinstallation work instruction, but the amount of grease to apply is not specified. The report stated that the maintenance procedure for pump P-7A directed maintenance personnel to avoid lubrication of the last three shaft threads on either side of the coupling, yet it appeared all of the threads were fully lubricated. The maintenance procedure for pumps P-7B, and P-7C did not direct avoiding lubrication of the last three threads, yet these couplings were found with less grease on the threads relative to the P-7A couplings [6].

The time to failure of a given material due to stress corrosion cracking in a given environment is dependent on the applied tensile stress as described in Section 4.4 of the October 2011 metallurgy report [6]. The report states that the time of crack initiation is:

"...highly alloy-environment and applied stress dependent and thus is an unknown without specific test data. The initiation time is also highly dependent upon pre-existing flaws that may have been introduced during heat treatment or thread fabrication. Therefore, predicting initiation time is difficult. Unless there are preexisting flaws, a distribution of 80% initiation and 20% propagation is considered reasonable for the life of a component subject to SCC process..."

This statement implies that the time to failure due to IGSCC is function of multiple stressors that each provides a random contribution to the crack growth rate. Further evidence of the variability in each of the couplings geometry and material properties is shown in Tables 3-1 through 3-8, and variability of the hardening and tempering heat traces is shown in Figures 4-1 and 4-2 of the report [6]. As explained more fully in these supporting reports, the shaft couplings are subject to high tensile stresses during operation due to hydrodynamic forces and are always subjected to tensile stresses due to the weight of the pump shaft and impeller, especially near the top of the pump shafts.

Prior to these two pump failures there had been no actual failures of SW pumps during operation that would have qualified for a failure to run according to the PRA success criteria. As documented in the root cause reports in References [3] and [4], there had been previous instances where a SW pump failed to meet the required flow rate during in-service testing. However the two events in the 2009 to 2011 time period are the only events where an operating SW pump failed to continue operating. In Table 2-1, the operating experience with the SW pumps since January 1, 2005 is summarized. The time line of pump conditions at each of the three pumps is shown in Table 2-2.

Table 2-1 Service Water Pump Operating Time and Experienced Failures to Run

Pump	Pump Run Hours Between Install of 416 SS Couplings and Replacement with 17-4PH SS	Pump Run Hours between 1-1-2005 and 10-18-2011	Number of Run Failures
P-7A	14,999	41,818	0
P-7B	8,909	37,580	0
P-7C	17,521	43,717	2
TOTAL	41,429	123,116	2

Table 2-2 Summary and Timeline of Events

Event	416 SS Coupling Installation Date	Coupling Failure Date	Couplings replaced with 17-4PH SS	Projected Failure Date of 416 SS Couplings from Metallurgy Report	Notes
SW Pump P-7A					
	4-Apr-2009	N/A	24-Aug-2011	>54 days, 17-Oct-2011	The 416 SS couplings did not fail on P-7A. The metallurgy report concluded the additional Neolube applied to the threads may have prevented IGSCC [5].
SW Pump P-7B					
	12-May-2010	N/A	30-Aug-2011	40 days, 9-Oct-2011	The 416 SS couplings did not fail on P-7B. The metallurgy report indicated that IGSCC was beginning to occur and, at the predicted crack propagation rate, the coupling would not have failed for 40 days from the date of removal if the pump were in continuous operation [5].
SW Pump SW Pump P-7C					
1st Failure	12-Jun-2009	29-Sep-2009	N/A	N/A	The evaluation of the first failure stated the couplings failed due to IGSCC. The cause was improper tempering resulting in excessive hardness of the material [3]. Failure occurred approximately 3 months after installation. Further evaluation of the couplings following the second failure in 2011 concluded that the out of specification hardness was not the root cause. The report completed in October 2011 concluded that both the 2009 and 2011 failures were due to IGSCC exacerbated by the wet-dry environment of the #5 - #7 couplings [4] [6]

Event	416 SS Coupling Installation Date	Coupling Failure Date	Couplings replaced with 17-4PH SS	Projected Failure Date of 416 SS Couplings from Metallurgy Report	Notes
2nd Failure	2-Oct-2009	9-Aug-2011	18-Oct-2011	N/A	The couplings met the hardness specification after the second failure, but again failed due to IGSCC. It was found that material toughness was inadequate, and cycle of wet-dry environment in #5 – #7 bearings exacerbated the condition [6]. Recommended change to new material with better toughness (17-4PH SS). This failure occurred approximately 21 months after installation.

2.5 *Qualitative Risk Characterization of SW Pump Failures*

Upon review of the above event descriptions and the supporting references the following conclusions can be reached.

- During the period starting when the carbon steel couplings were replaced by 416 Stainless steel and ending when the 416 stainless steel couplings were replaced with material 17-4PH SS, the SW pumps were in a degraded state in which their failure to run failure rates were elevated in relation to the previous excellent service experience. There is significant evidence from the metallurgical reports to support the conclusion that this period of degraded performance ended with the installation of 17-4PH SS couplings. The plant specific evidence for estimating the SW pump failure rate is 2 failures in 41,429 component-hours of SW pump operation.
- These pump failures are not in any way shape or form to be regarded as common cause failures for three important reasons.

  1. Both failures occurred on one pump as opposed to failures on a redundant pair of pumps. This is a case of repeated failures on the same component due to the failure to correctly diagnose the cause of the first failure. The failed SW pump was not restored to "as good as new" status as assumed in the PRA models.
  2. Even if these two failures occurred on redundant pumps, the times of failure were too far apart to be considered a candidate for a common cause failure. According to the guidelines used by INL to classify events as common cause failure, a self-announced pair of failures would need to occur within 3 mission times to be given any consideration for even a potential common cause failure. Even if one assumes a mission time of 30 days, the failures in this case were separated by almost 23 mission times. This is evidenced by the following criteria listed in Reference [7] with the key part indicated in bold font (author's emphasis):

"For announced failures, the timing factor is based on a time-based model. Thus, the timing factor is assigned values based upon a PRA mission time (the period of time the component is usually required to perform its function in a PRA or individual plant examination [IPE], usually 24 hours). The following classifications may be used for two consecutive degradations of two components contained in a CCF event:

• High (1.0): The component events are separated by no more than the PRA mission time.

• Medium (0.5): The component events did not occur within the PRA mission time and two times the PRA mission time.

• Low (0.1): The component events are separated by more than two times the PRA mission time and less than three times the PRA mission time.

• Not CCF: More than three times the PRA mission time or during the interval between the component events, the component (which was detected, failed, or degraded later) has undergone maintenance, overhaul, or other action that can be regarded as a renewal event for the failure mechanisms. (Note: In this case, the event is not classified as a CCF event.)

3. The root causes of these failures, inter-granular stress corrosion cracking are inherently linked to independent failure modes. Although this damage mechanism was active on all three pumps, the metallurgical reports indicated that a minimum of 40 additional days of operation could be assured on the remaining pumps.

- In the current Palisades PRA model there are two areas where the risk impacts of these events need to be considered: 1). a potential increase in the loss of service water initiating event frequency; and 2) a potential increase in the SW pump failure rate used in a number of PRA model basic events involving failure to run. Even though the SW pump failures did not involve a total loss of service water, under different circumstances the failure of one pump could occur and the remaining pumps could also be unavailable due to various combinations of independent failures, common cause failures, and maintenance unavailability involving the remaining pumps. These failure and unavailability combinations could lead to a total loss of service water. Hence, an increased pump failure rate could result in an increase in the loss of service water initiating event frequency.

3. Quantitative Analysis of Risk Significance

It was concluded in Section 2 that the risk impact of the SW pump failures is best characterized as a change to the SW pump failure rate for failure to continue running while in operation. This in turn may influence the loss of service water initiating event frequency and the basic events in the PRA model for failure to run to complete the various missions following an initiating event. The impact on the pump failure rate is addressed in Section 3.1. An evaluation of the impact of the change in failure rate on the loss of service water initiating event frequency is presented in Section 3.2. Finally, an estimate of the additional risk impacts due to the increase in the failure rate on the safety function mitigation functions modeled in the PRA is provided in Section 3.3.

3.1 *Service Water Pump Failure Rate*

3.1.1 Failure Rate Prior to Installation of 416SS Pump Shaft Couplings

The Palisades PRA data base is in the process of being updated. The PRA model of record is based on a database that was completed in 2001 and includes Palisades plant specific operating experience and service data for the SW pumps from 1994 through 1998. During this period, there were no pump failures to run in 68,571 hours of pump operation [16][17].

The uncertainty distribution for the SW pump failure to run failure rate based on this PRA model of record was developed using generic parameter references from PLG-0500 [19] as a prior and then updated using the above listed run time with zero failures. Details of this update are in Table 3-1.

Table 3-1 Parameters for Model of Record SW Pump Failure Rate Update (Case 1)

Parameter	Prior Distribution from [19]	Posterior Distribution
Data Collection Period	-	1994 through 1998
Number of Failures	-	0
Pump-hours of Operation	-	68,571
Distribution Type	Lognormal	Non-Parametric fit to lognormal
Mean	3.42E-5	1.23E-5
RF = SQRT(95%tile/50%tile)	5.0	3.4
5%tile	4,24E-6	2.62E-6
50%tile	2.12E-5	9.82E-6
95%tile	1.06E-4	3.03E-5

The most recent update of the Palisades PRA Data Notebook was completed in 2009 prior to the occurrence of the SW pump failures in question [9]. The update covers the period of January 1, 2005 to January 23, 2008. During this period there were no SW pump failures to run and the run times associated with each of the SW pumps is indicated in the following table:

Table 3-2 SW Pump Run Data 1-1-05 Through 1-23-2008

Component	Pump Run Failures	Run Time (hours)
SW Pump P-7A	0	18,658
SW Pump P-7B	0	17,640
SW Pump P-7C	0	19,490
Total	0	55,788

The uncertainty distribution for the SW pump failure to run in this more recent update was developed using generic parameter estimates from NUREG/CR-6928 [12] as a prior and Bayes' updated with the service data in Table 3-2. Since the generic distribution is a Gamma Distribution and a Poisson likelihood function was used, the posterior distribution is also a Gamma Distribution. The parameters of the prior and updated Gamma distributions for the SW pump failure rate are shown in Table 3-3.

Table 3-3 Parameters for Recent PRA SW Pump Failure Rate Update (Case 2)

Parameter	Prior Distribution from [12]	Posterior Distribution
Data Collection Period	-	1-1-05 through 1-23-08
Number of Failures	-	0
Pump-hours of Operation	-	55,788
Distribution Type	Gamma	Gamma
Alpha Parameter	1.66	1.66
Beta Parameter	3.65E+05	4.20E+05
Mean	4.54E-06/hr.	3.95E-06/hr.
RF (=95%tile/50%tile)	3.30	4.9

The author has reviewed these data analysis updates, has reproduced the results, and concurs that it meets the applicable requirements of the ASME/ANS PRA Standard for data analysis [13].

Each of the plant specific data updates described above covers a rather limited amount of operating experience. To examine a more complete record of the service experience with the SW pumps prior to the installation of the 416 SS pump shaft couplings, a special case was defined to reflect all the experience back to 1980 covering more than 28 years of experience, which again had zero failures in about 490,000 pump hours of operation. The parameters of this update are presented in Table 3-4. Because much of this time period pre-dates EPIX and the maintenance rule, the prior used here reverts back to PLG-0500 rather than NUREG/CR-6928 because this reference better represents industry generic data over this longer and earlier time period.

In Section 3.2 all three cases of failure rate estimates are used to evaluate the change in risk during the degraded state period.

Table 3-4 Parameters for More Complete SW Pump Failure Rate Update (Case 3)

Parameter	Prior Distribution from [19]	Posterior Distribution
Data Collection Period	-	1980 through 4-3-2009
Number of Failures	-	0
Pump-hours of Operation	-	495,360
Distribution Type	Lognormal	Non-Parametric fit to lognormal
Mean	3.42E-5	3.91E-6
RF = SQRT(95%tile/50%tile)	5.0	2.7
5%tile	4,24E-6	1.17E-6
50%tile	2.12E-5	3.43E-6
95%tile	1.06E-4	8.31E-6

3.1.2 SW Pump Failure Rate During Degraded State Period

The degraded state period is defined for the purposes of this analysis as the time frame when the SW pumps were operating with 416 SS couplings installed. The 416 SS couplings were installed on the first component on April 4, 2009 (P-7A) and were replaced on the last component in October 2011 (P-7C). During this period there were two pump failures to run, both on Pump P-7C, and 41,429 pump hours of operation (see Table 2-1). Obviously, during the degraded state period, the conditions were substantially different than was the case prior to or following this period. The failure rate distribution for the degraded state period was developed based on the following considerations.

- The evidence used to develop the current PRA failure rate distribution, including the generic prior evidence from NUREG/CR-6928 and the Palisades service data prior to the installation of the 416 SS couplings has questionable relevance to estimating the failure rate during the degraded state period and hence is not used.
- There is a large degree of uncertainty in establishing an appropriate prior distribution and therefore a non-informative prior distribution is selected. Keeping with the Gamma distribution family of distributions, the Jeffrey's non-informative prior distribution is used. This is characterized by an alpha parameter of 0.5 and a beta parameter of 0 [15]. This is updated using 2 failures in 41,429 pump-hours of operation to produce the parameters of the degraded state SW pump failure rate as shown in the following table.

A comparison of the Base Case 1, 2, and 3 and Degraded State failure rate parameters is provided in Table 3-6 and Figure 3-1. Case 3 is viewed by the author as the most realistic model of the SW pump performance prior to the degraded state period as it uses a more complete representation of the service experience. It can be seen from these comparisons that the failure rate during the degraded period is significantly higher than that used in the Base Case PRA model for each of the three analyzed cases. The mean failure rate increases by a factor of more than 5, 15, and 15 compared to the Base Cases 1, 2, and 3, respectively. In addition, the conservative approach taken to throw out the generic industry evidence and the prior Palisades experience in establishing the prior during the degraded state period is seen to have a large impact in the sense that the updated mean is actually greater than the point estimate of the service data during the degraded operation period. This is regarded by the author as a conservative evaluation of the increased SW pump failure rate during the degraded state period.

Table 3-5 Degraded State SW Pump Failure Rate Distribution

Parameter	Posterior Distribution
Distribution Type	Gamma
Prior Basis	Jeffrey's Non-informative Prior (α=0.5, β=0)
Alpha Parameter	2.5
Beta Parameter	41,429
Point Estimate	4.82E-5/hr
Mean	6.10E-5/hr
5%tile	1.40E-5/hr
50%tile	5.30E-5/hr
95%tile	1.35E-5/hr

Table 3-6 Comparison of Base Case and Degraded State Failure Rate Parameters

Parameter	Palisades PRA Base Case 1	Palisades PRA Base Case 2	Palisades PRA Base Case 3	Palisades Degraded State Case
Distribution Type	Non-Parametric fit to lognormal	Gamma	Non-Parametric fit to lognormal	Gamma
Mean	1.23E-5	3.95E-6	3.91E-6/hr	6.10E-5/hr
5%tile	2.62E-6	5.44E-7	1.17E-6/hr	1.40E-5/hr
50%tile	9.82E-6	3.19E-6	3.43E-6/hr	5.30E-5/hr
95%tile	3.03E-5	9.96E-6	8.31E-6/hr	1.35E-5/hr

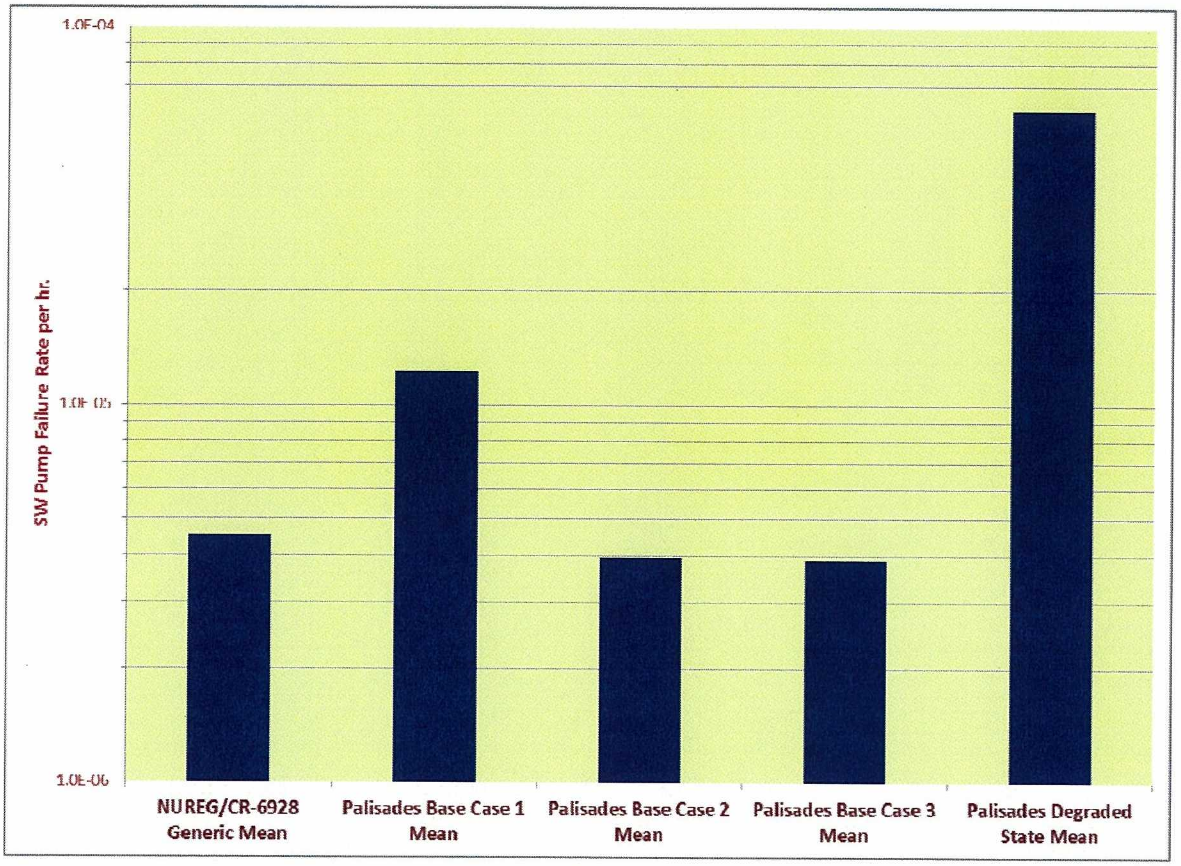

Figure 3-1 Comparison of SW Pump Failure Rate Estimates

3.2 *Loss of Service Water Initiating Event Frequency*

The current Palisades PRA model uses a data based approach to model the loss of service water initiating event frequency. This is a reasonable approach for the baseline PRA but it does not lend itself to evaluating the impact of the increased failure rate. Hence to support this evaluation, a model of the contributions to the loss of SW initiating event frequency due to SW pump failures is developed. The SW pump induced loss of SW model is developed based on the following considerations.

- A SW pump induced loss of service water can be caused by failure of the two normally running pumps and failure or unavailability of the standby pump.
- Failure of the two normally running pumps can occur as a result of a common cause failure of both pumps, or failure of one of the pumps followed by failure of the other running pump during the time frame when the first pump is down for repairs.
- The standby pump can fail to start, fail to continue running while both of the normally operating pumps are down for repairs, or be unavailable for maintenance.

These considerations yield the following simple model for SW pump induced loss of SW.

$$F(LOSWS) = 8766\lambda_{LOSWSIE}A \tag{3.1}$$

$$\lambda_{LOSWIE} = \lambda_{CCFR}(\lambda_S + \lambda_{FR}\tau_{CCF} + Q_{MSP}) + 2\lambda_{IFR}(\lambda_{FR}\tau_{IF})(\lambda_S + \lambda_{FR}\tau_{IF} + Q_{MSP}) \quad (3.2)$$

Where:

$F(LOSWS) =$	Frequency per reactor-calendar-year of loss of service water
$\lambda_{LOSWSIE} =$	Frequency per operating hour of loss of service water
$A =$	Plant availability
$\lambda_{CCFR} = \beta_{FR}\lambda_{FR}$	Failure rate for common cause failures of the two normally running pumps
$\lambda_S =$	Failure rate for failure of the standby pump to start on demand
$\beta_{FR} =$	Common cause beta factor for failure to run of two normally operating pumps
$\lambda_{FR} =$	Failure rate for failure of the standby or operating pump to run
$\lambda_{IFR} = (1-\beta_{FR})\lambda_{FR}$	Failure rate for independent failure to run for each normally running pump
$\tau_{CCF} =$	Mean time to repair of at least one pump after a common cause failure to run
$\tau_{IF} =$	Mean time to repair of a normally operating pump after an independent failure to run
$Q_{MSP} =$	Maintenance unavailability of a Standby pump while plant in operation, not to be confused with the maintenance unavailability of a single SW pump; due to technical specifications and prudent operational practice; any maintenance on all three pumps that is performed with the plant at power is performed on each pump separately while in standby. Hence this is the total maintenance unavailability of all three pumps.

The change in CDF due to changes in the pipe induced loss of SW initiating event frequency can then be estimated using:

$$\Delta CDF_{\Delta LOSWIE} = (F(LOSW_{DS}) - F(LOSW_{Base}))CCDP_{LOSW} \quad (3.3)$$

Where:

$\Delta CDF_{\Delta LOSWIE} =$	Change in CDF due to Change in Pump Induced Loss of SW frequency
$F(LOSW_{DS}) =$	Loss of SW initiating event frequency evaluated with λ_{FR} evaluated using degraded state version of the SW pump failure rate
$F(LOSW_{Base}) =$	Loss of SW initiating event frequency evaluated with λ_{FR} evaluated using Base Case version of the SW pump failure rate
$CCDP_{LOSW} =$	Conditional core damage probability given loss of SW initiating event

The data parameters needed to quantify Equation (3.3) include the different versions of the failure rates defined earlier and other parameters from the Palisades PRA and these are summarized in Table 3-7. The author has reviewed these parameters and finds that they are appropriate for this analysis.

The models in Equations (3.1) through (3.3) were quantified using Microsoft Crystal Ball™ and Excel 2010 software using 100,000 Monte Carlo samples. The results are shown in Table 3-8, 3-9, and 3-10 and Figures 3-2, 3-3, and 3-4. In Table 3-8 the major contributors to loss of SW initiating event frequency are compared between the Base Case 3 and the degraded state period based on mean point estimates of the listed quantities. The results are seen to be dominated by common cause failure to run of the two normally operating pumps with the standby pump in maintenance. This stems in part from the conservative assumption that the fraction of operating pump common cause failures (beta factor) is assumed to be the same as that assessed in the base PRA model for SW failures in the mitigation of other initiating events. There are two reasons why this is conservative. One is that the increase in the failure rate during the degraded period is due to two independent failures so keeping the ratio of common cause failures to the total failure rate is conservative. The second is that the applied beta factor was developed for the SW system in the mitigation mode and there is substantial evidence to support the hypothesis that the fraction of common cause failures in normally operating systems is much smaller than that for systems that need to operate on demand.

Table 3-9 shows the contributors to the LOSW initiating event frequency with the SW system in different alignments. One alignment, which occurs a fraction of the time equal to Q_{MSP} is with two operating pumps and the third in maintenance, and the other alignment has the third pump available. It is seen from this table that the pump induced LOSW IE frequency increases by almost a factor of 30 as the system changes alignment changes from the standby pump being in service to out of service.

In Table 3-10 the results of the quantitative uncertainty analysis are presented for various cases and metrics. The change in LOSW initiating event frequency from the base case to the degraded state period is seen to be an increase of less than 30% and does not vary appreciably among Cases 1, 2, and 3. Using these results and the CCDP values from Table 3-5, it is seen that the increase in CDF due to changes in the SW pump failure rate in the LOSW initiating event frequency is less than 3% based on the mean change in LOSW IE frequency, and only as high as 9% when the 95%tile values for the change in LOSW IE frequency is assumed. The mean change in CDF is seen to be less than 10^{-6} per reactor-year. The Base Case 3 results provide the largest increase and the most accurate reflection of the SW pump performance prior to the degraded period. However, it is seen from Table 3-10 that the overall results are not particularly sensitive to which version of the Base Case results are used.

Table 3-7 Data Parameters Used to Evaluate LOSW IE Frequency

Parameter	Mean Value	Uncertainty Treatment	Reference
$A =$	.92	None, very little uncertainty	Provided by Palisades for degraded state period
$\lambda_S =$	1.19E-3	Lognormal Distribution with mean = 1.19E-3; RF = 4.0	PLG-0500 [19]
$\beta_{FR} =$	.0243	Beta Distribution with α = 16.5 and β = 661.5	Palisades CCF Analysis [11]
$\lambda_{FR-DS} =$	6.1E-05/hr	Gamma Distribution with α = 2.5 and β = 41,429	Table 3-5
$\lambda_{FR-Base} =$	1.23E-5/hr, Case 1	Lognormal Distribution with mean = 1.23E-5 and RF=3.4	Table 3-1
	3.95E-6/hr, Case 2	Gamma Distribution with α=1.66 and β = 4.2E+05	Table 3-3
	3.91E-6/hr, Case 3	Lognormal Distribution with mean = 3.91E-6 and RF=2.7	Table 3-4, this estimate best represents the SW

Parameter	Mean Value	Uncertainty Treatment	Reference
			pump performance prior to installation of 416SS couplings
$\tau_{CCF} =$	6hr	None	Technical specifications limit operation to 6 hours
$\tau_{IF} =$	72hr	None	Technical specifications limit operation to 72 hours
$Q_{MSP} =$ For Base PRA	P-7A = 4.516E-03 P-7B = 5.387E-03 P-7C = 5.533E-03 Total=1.55E-02	Lognormal Distribution with mean = 1.55E-2 RF=10.0	Palisades Maintenance Data [18]
$Q_{MSP} =$ For Degraded State Period	P-7A =117.2 hrs P-7B=107.1 hrs P-7C=256.6 hrs Total = 480.9hrs over 2.5 year degraded state period	Lognormal Distribution with mean =1.57E-02 RF=1.5	Provided by Palisades; very little uncertainty justifies small range factor
CCDP Given LOSW=	2.68E-3	Uncertainty not included; not affected by change	Provided by Palisades
LOSW per PRA=	1.22E-3/yr	Uncertainty not included; not affected by change	Provided by Palisades

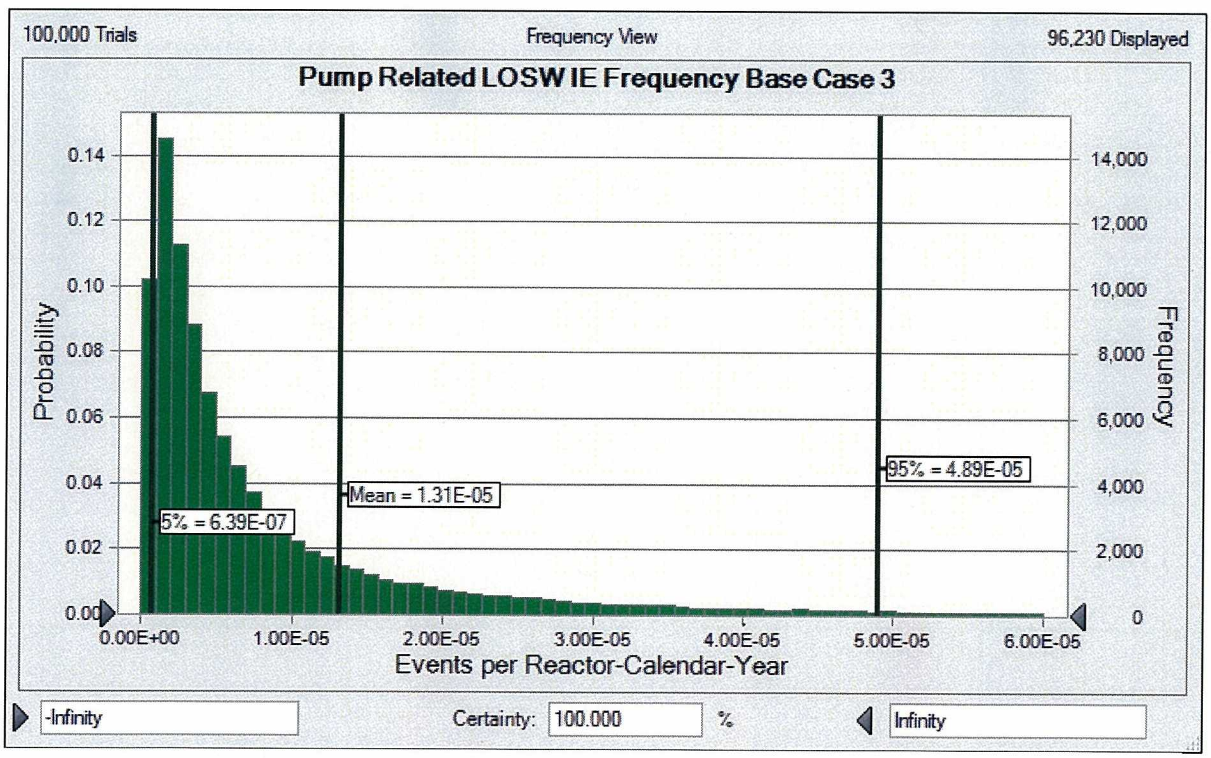

Figure 3-2 LOSW Initiating Event Frequency for Base Case 3

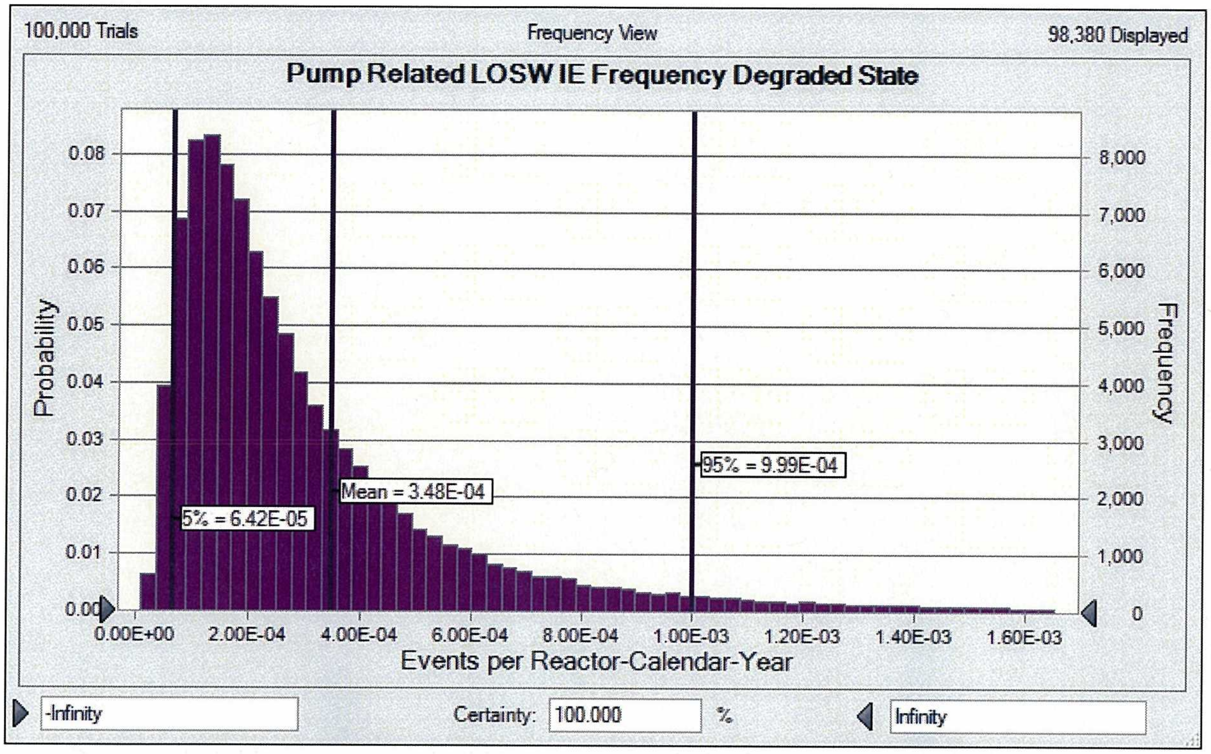

Figure 3-3 LOSE Initiating Event Frequency for Degraded State

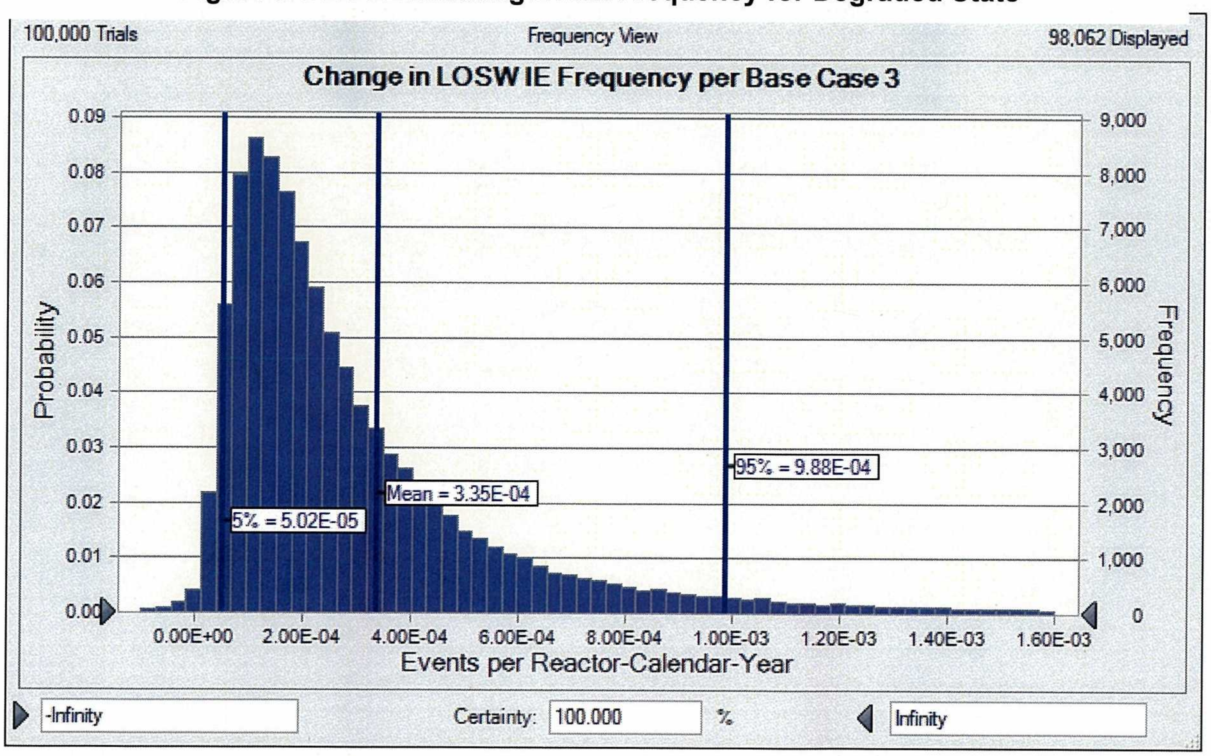

Figure 3-4 Uncertainty in Change in LOSW IE Frequency per Base Case 3

Table 3-8 Major Contributors to LOSW IE Frequency (Point Estimate)

Contributing Cut-sets	Events per Operating hour		Events per Reactor-Calendar Year	
	Case 3	Degraded	Case 3	Degraded
CCF-FR*QMSP	1.47E-09	3.12E-08	1.18E-05	2.51E-04
2xIFR*IFR*QMSP[1]	3.24E-11	1.06E-08	2.61E-07	8.57E-05
CCF-FR*SFS	1.13E-10	1.75E-09	9.12E-07	1.41E-05
CCF-FR*SFR	2.23E-12	5.32E-10	1.80E-08	4.29E-06
2xIFR*IFR*SFS[1]	2.49E-12	5.95E-10	2.01E-08	4.80E-06
2xIFR*IFR*SFR[1]	5.90E-13	2.17E-09	4.76E-09	1.75E-05
Total	1.62E-09	4.68E-08	1.31E-05	3.78E-04

CCF-FR = Common cause failure of both operating pumps
IFR = Independent failure to run of an operating pump
SFS= Standby pump failure to start
SFR=Standby pump failure to run until operating pump failure restored
QMSP= Fraction of time plant operates with Standby SW pump in maintenance
Note 1. Combination of two identical cut-sets

Table 3-9 Major Contributors to LOSW IE Frequency with SW System in Different Alignments (Point Estimate)

Contributing Cut-sets	Events per Operating hour		Events per Reactor-Calendar Year	
	Case 3	Degraded	Case 3	Degraded
Results in Alignment with Standby Pump in Maintenance which occurs QMSP fraction of the time				
CCF-FR	9.50E-08	1.47E-06	7.66E-04	1.18E-02
2xIFR*IFR[1]	2.10E-09	5.00E-07	1.69E-05	4.03E-03
Total	9.71E-08	1.97E-06	7.83E-04	1.59E-02
Results in Alignment with Standby Pump Available which occurs (1-QMSP) fraction of the time				
CCF-FR*SFS	1.13E-10	1.75E-09	9.12E-07	1.41E-05
CCF-FR*SFR	2.23E-12	5.32E-10	1.80E-08	4.29E-06
2xIFR*IFR*SFS[1]	2.49E-12	5.95E-10	2.01E-08	4.80E-06
2xIFR*IFR*SFR[1]	5.90E-13	2.17E-09	4.76E-09	1.75E-05
Total	1.18E-10	5.05E-09	9.55E-07	4.07E-05

CCF-FR = Common cause failure of both operating pumps
IFR = Independent failure to run of an operating pump
SFS= Standby pump failure to start
SFR=Standby pump failure to run until operating pump failure restored
Note 1. Combination of two identical cut-sets

3.3 *Impact of Increased SW Pump Failure Rate on PRA Mitigation Functions*

The other source of potential risk impacts from increased SW pump failure rates is in the mitigation functions for initiating events other than loss of SW. This is best evaluated by revising the PRA model with the revised failure rate and then comparing the results. However an estimate of the risk impact from such changes can be estimated using the Fussell-Vesely importance metric for basic events involving SW pump failure to run. Palisades has provided this value which is 9.09E-6. Since the F-V importance is approximately equal to the fraction of the CDF with basic events involving SW pump failure, the change in CDF can be estimated using the following equations:

$$\Delta CDF_{SWP} = (CDF_{New} - CDF_{old}) = FV_{SWP}CDF_{BASE}\left(\frac{\lambda_{FR-DS}}{\lambda_{FR-Base}}\right) - FV_{SWP}CDF_{Base}$$
$$= FV_{SWP}CDF_{Base}\left(\frac{\lambda_{FR-DS}}{\lambda_{FR-Base}} - 1\right) \tag{3.4}$$

Table 3-10 Evaluation of LOSW Initiating Event Models and CDF Impacts

Parameter[4]	Point Estimate[1]	Mean[2]	5%tile	50%tile	95%tile	RF[3]
Pump Related LOSW IE Freq. Case 1	4.32E-05	4.56E-05	1.67E-06	1.44E-05	1.70E-04	10.1
Pump Related LOSW IE Freq. Case 2	1.32E-05	1.37E-05	5.66E-07	4.56E-06	5.03E-05	9.4
Pump Related LOSW IE Freq. Case 3	1.31E-05	1.31E-05	6.39E-07	4.66E-06	4.89E-05	8.8
Pump Related LOSW IE Freq. - Degraded	3.78E-04	3.48E-04	6.42E-05	2.27E-04	9.99E-04	3.9
Change in LOSW IE Freq. Case 1	3.35E-04	3.02E-04	4.18E-06	1.94E-04	9.63E-04	15.2
Change in LOSW IE Freq. Case 2	3.65E-04	3.34E-04	4.99E-05	2.15E-04	9.87E-04	4.4
Change in LOSW IE Freq. Case 3	3.65E-04	3.35E-04	5.02E-05	2.15E-04	9.88E-04	4.4
Change in LOSW IE Freq. Case 1 %	27.4%	24.8%	0.3%	15.9%	78.9%	15.2
Change in LOSW IE Freq. Case 2 %	29.9%	27.4%	4.1%	17.6%	80.9%	4.4
Change in LOSW IE Freq. Case 3 %	29.9%	27.4%	4.1%	17.7%	81.0%	4.4
Change in CDF Case 1	8.97E-07	8.11E-07	1.12E-08	5.21E-07	2.58E-06	15.2
Change in CDF Case 2	9.78E-07	8.96E-07	1.34E-07	5.76E-07	2.65E-06	4.4
Change in CDF Case 3	9.78E-07	8.98E-07	1.35E-07	5.78E-07	2.65E-06	4.4
Change in CDF Case 1 (%)	3.2%	2.9%	0.0%	1.8%	9.1%	15.2
Change in CDF Case 2 (%)	3.5%	3.2%	0.5%	2.0%	9.3%	4.4
Change in CDF Case 3 (%)	3.5%	3.2%	0.5%	2.0%	9.4%	4.4

Notes:
[1] Point estimate based on mean values of input parameters
[2] Mean and Percentiles calculated via Monte Carlo on Crystall Ball with 100,000 trials
[3] RF = SQRT(95%tile/5%tile)
[4] Change in CDF results do not include the uncertainty in the CCDP given loss of service water; All frequencies in units of events per reactor-calendar-year

Using the data above for the Fussell-Vesely value, the data developed previously for the failure rates, and a baseline CDF value provided by Palisades of 2.83×10^{-5}, the change in CDF due to changes in the PRA mitigation model from increased SW failure rates is estimated to be an increase of $3.7x10^{-9}$ per reactor calendar year using the Case 3 failure rate model, which is about 0.1% of the current baseline CDF. Hence there is no significant risk increase from the mitigation side of the model.

3.4 *Guidance for More Accurate Estimate of Risk Impacts*

It is recommended that Palisades re-run their current baseline PRA model with the following instructions.

- Modify the current LOSW initiating event frequency by adding a variable for the increase in the LOSW IE frequency using the data for Case 3 in Table 3-8 (7th row of data). When reporting a single value, the mean of the distribution should be used as all relevant CDF acceptance criteria refer to mean values.
- Change the failure rate distribution for "SW pump failure to run" to reflect the degraded conditions by using the Gamma Distribution parameters in Table 3-5.
- Keep all remaining data parameters the same as in the base case.
- Calculate the increase in CDF due to these changes; they should be comparable to those estimated in the previous sections.

4. Review of NRC Preliminary Significance Determination

At the request of Palisades, a limited review was performed of the NRC Preliminary Significance Determination of the SW pump coupling which included an estimate of the impact of the degraded pump performance on the core damage frequency as documented in Reference [20] It is noted that these comments are based solely on the information presented in that reference as the details of the supporting calculations were not available to support the review. This review resulted in the following comments and a limited comparison that is provided in Table 4-1.

1. The loss of SW initiating event frequency calculation described in Reference [20] is suspect. The NRC analysts are using a ratio of calculated unavailability from a fault tree of the SW system developed for the mitigation function of the system in response to initiating events other than LOSW, and then multiplying the ratio of unavailabilities calculated using different failure rates times the existing IE frequency. In the opinion of this author, this method is incorrect and is not capable of estimating the loss of SW initiating event frequency. The method does not appear to be capable of meeting ASME/ANS PRA Standard Supporting Requirements IE C-9 and IEC-10. It is well known among PRA practitioners that fault tree models that are developed for establishing the unavailability of a system in response to an initiating event cannot be manipulated this way to produce a correct estimate of the initiating event frequency. Both the structure of the tree and the computational algorithm must be modified to provide an appropriate model. This in fact the motivation behind SRs IEC-9 and IE C-10. In addition the success criteria and mission time assumptions are fundamentally different.
2. The SW system has a different configuration during normal operation than is the case following most initiating events. In the mode of normal operation there are two normally operating pumps and one pump in standby which may or may not be in maintenance at the time of the initiating event. Which pumps are in which mode are rotated periodically. After most initiating events, the configuration is changed due to various signals yielding a symmetrical configuration. The common cause models, success criteria, and mission times all need to be modified when converting from one configuration to another.
3. The NRC model evaluates the CDF over a one year period, whereas this analysis covers the entire period when the wrong SS material was in which is about 2.5 years. The configurations looked at in the NRC analysis only covered one of the pump failures whereas this analysis covered both pump failures and other periods of pump maintenance unavailability.
4. The NRC analysis is only point estimate whereas this analysis includes a quantification of uncertainty. This is important for the run-run cutsets due to the state of knowledge correlation.
5. It appears that the NRC analysis did not adequately isolate the contributions to LOSW IE frequency from pump related and non-pump related failure causes whereas the current analysis did. This is critical to the question of how much of an impact changes in pump performance impact the LOSW IE frequency.
6. It is not clear that the NRC analysis is calculating the change in the average CDF due to pump issues. This is evidenced by the fact that they add up two different CDF cases for two different pump alignments but do not discuss how or whether the fraction of time in each alignment is taken into account. Adding up two configuration specific CDF estimates that are not weighted by the fraction of time in that configuration is not appropriate. If one is to estimate the change in CDF both CDF estimates should be on

the same basis. This concern may be due to insufficient details provided to explain how the numbers were calculated.

7. While they state that they assessed some kind of common cause potential to the two SW pump failures, there is insufficient information to understand how they modeled that potential. A reasonable way to do this would be to assess an impact vector for each SW pump failure event in the same format as is done when CCF events are coded into INL CCF database. If they just assumed that the two failure events were common cause failures of all three pumps that would be inconsistent with the engineering evaluations that were performed by Palisades. Each event obviously involved failure of a single pump. Such an impact would express the probability that if similar failures occurred in the future that the other SW pumps would also be failed at the same time or same time frame. The probability that reoccurrence of a pump failure would have resulted in failures of 1 or both additional pumps must be extremely low. In summary the method and weight given to the common cause potential is not available to review. In the current analysis in this report, common cause failures dominate the estimated change in CDF and the assumptions behind this are clearly documented.
8. The approach taken to evaluate the revised SW pump failure rate is very similar to that described in this report which was developed prior to the receipt of the NRC letter in Reference [20]. Not clear what the reason is for the small discrepancy in the assumed pump exposure.

Of the comments listed above, Item 1 is most important and needs to be resolved before meaningful numerical comparisons can be made.

Table 4-1 Comparison of Service Water Pump Evaluations

Parameter	Palisades per This Report	NRC per Reference [20]
SW pump failure rate base case per hour	3.91E-06	Not provided
SW pump failure rate in degraded period per hour	6.04E-05	6.15E-05
Prior used for degraded state failure rate estimate	Jeffreys non-informative	Jeffreys non-informative
Evidence used for Bayes' update	2 failures in 41,429 hrs.	2 failures in 40,505 hrs
Period over which change in CDF is evaluated	2.5 years	≈ 1 year
Base CDF per RCY	2.83E-05	Not provided
Base CDF due to LOSW IE per RCY	3.27E-06	Not provided
Base CDF due other IE per RCY	2.50E-05	Not provided
CCDP given LOSW IE Base	2.68E-03	Not provided
CCDP given LOSW IE in degraded period	2.68E-03	Not provided
Base LOSW IE Frequency (average) per RCY	1.22E-03	2.50E-04
Base LOSW IE Frequency due pumps per RCY	1.31E-05	Not provided
Base LOSW IE Frequency due non pump related causes per RCY	1.21E-03	Not provided
Base LOSW IE Frequency with 3rd pump OOS per RCY	1.99E-03	Not provided
Base LOSW IE Frequency with 3rd pump in service per RCY	1.21E-03	Not provided
Degraded LOSW IE Frequency per RCY	1.58E-03	Not provided but can be estimated at 3.68E-03
Increase in LOSW IE Frequency in degraded period per RCY	3.65E-04	Not provided but can be estimated at 3.43E-03
Degraded LOSW IE Frequency with 3rd pump OOS per RCY	1.71E-02	4.00E-01
Degraded LOSW IE Frequency with 3rd pump in service per RCY	1.25E-03	8.06E-04
Common Cause Treatment	Beta factor for two running pumps assumed to be the same as for the base case unavailability model	Some potential is assessed but how this is quantified is unknown
Change in CDF due to degraded SW couplings	8.98E-07	4.70E-06

5. CONCLUSIONS

Based on the evaluation performed in this study, the following conclusions are reached.

- The two SW pump failures are clearly random independent failures of the same pump and are not in any way shape or form to be regarded as common cause failures. The nature of the cause, the capability of the pumps that did not fail to continue to operate for a minimum of 40 days after the second failure and the separation in time of the two failures by more than 22 30-day mission times are more than sufficient evidences to support this conclusion.
- The appropriate risk characterization of the SW pump failures evaluated in this study is an increase in the SW pump failure rate for failure to continue running during the time frame when SW shaft couplings were using 416 SS material that was susceptible to inter-granular stress corrosion cracking (Degraded State Period). It is estimated in this study that the SW pump mean failure rate for failure to run increased by a factor of about 15 compared to the failure rates used in the current PRA model of record (Case 2) and that based on the more complete set of plant specific data (Case 3).
- Even though the SW pump failures of interest were clearly independent failures, the fraction of the elevated failure rate due to common cause (i.e. the beta factor for pump failure to run) was assumed to be the same as in the base case model. Furthermore, that beta factor is viewed to be highly conservative for normally operating pumps. There is scant historical evidence of common cause failures of normally operating components. It should be noted that due to the conservative treatment of common cause failures in this evaluation, the change in CDF calculated in this study is actually dominated by cut-sets involving common cause failure of the two normally operating pumps. A more realistic assessment that took credit for the fact that the two pump failures are clearly classified as independent failures would result in a much smaller increase in CDF than what has been estimated in this study.
- There are two areas in the risk model where an increased SW pump failure rate may contribute to increases in CDF and LERF. One area is a potential increase in the loss of service water initiating event due to SW pump failures and the other is an increase in basic event probabilities associated with SW pump failure to operate during each mission modeled as part of a service water mitigating function. It is estimated in this study that the LOSW initiating event frequency increased by about 30% during the degraded state period.
- The total risk impact of the increased SW pump failure rate during the applicable degraded state period is conservatively estimated in this study to be an increase of about 3% mostly arising from an increase to the LOSW initiating event frequency. Even if the 95%tile value is used, the increase is only as high as about 9%. The changes in CDF due to changes in the mitigation part of the model are much smaller than those from the initiating event model due to the extremely small Fussell-Vesely value for the SW pump failure to run in the mitigating side of the model. The small increase in CDF during the degraded state period of the SW pumps is consistent with a GREEN finding in the Significance Determination Process.
- A set of instructions has been developed to perform a confirmatory estimate of the risk impact by adding a term to the LOSW initiating event frequency model and by changing the SW failure rate distribution for failure to run.

- Based on a limited review, the methodology used in the NRC evaluation does not appear to be capable of providing an accurate estimate of the change in CDF due to the SW pump issues addressed in this report.

6. REFERENCES

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[2] Letter from Entergy Nuclear Operations to US NRC, LER 2011-005, Palisades Nuclear Plant, "Service Water Pump Shaft Coupling Failure", October 3, 2011

[3] Palisades Operations, "Root Cause Evaluation Report – Service Water Pump 7-C Line Shaft Coupling Failure", CR-PLP-2009-04519, 03-04-10, Rev. 1

[4] Palisades Operations, "Root Cause Evaluation Report – Service Water Pump 7-C Line Shaft Coupling Failure", CR-PLP-2011-03902, 09-08-11, Rev. 0

[5] Lucius Pitkin Inc. (LPI) report F11358-LR-001 Rev.0, "Past Operability Assessment of Service Water Pumps P-7A and P-7B associated with As-found Evaluation of Pump Shaft Couplings – Palisades Nuclear Plant", September 28, 2011

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[7] Idaho National Laboratory, "Common-Cause Failure Database and Analysis System: Event Data Collection, Classification, and Coding", NUREG/CR-6268, Rev. 1, September 2007

[8] Palisades Nuclear Plant Probabilistic Safety Assessment PSA Notebook, "Initiating Event Notebook", NB-PSA-IA (Rev 1), October 21, 2009

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[10] American Society of Mechanical Engineers and American Nuclear Society, Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS RA-Sa-2009, New York (NY), February 2009.

[11] ERIN Engineering and Research Inc., "Palisades Nuclear Application Common Cause Application, July 2004

[12] Idaho National Laboratory, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants", NUREG/CR-6928, February 2007.

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[14] U.S. NRC, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making", NUREG-1855, November 2007

[15] Idaho National Laboratory, "Handbook of Parameter Estimation for Probabilistic Risk Assessment", NUREG/CR-6823, September 2003

[16] EA-PSA-1999-0008 Rev. 0, "Palisades PSA Model – Power Operations – Data Collection – Plant Specific Data"

[17] EA-PSA-1999-0010 Rev. 0, "Palisades PSA Bayesian Update"

[18] EA-PSA-1999-011 Rev. 0, "Palisades PSA Model – Equipment Out of Service"

[19] PLG-0500, "Database for Probabilistic Risk Assessment for Light Water Nuclear Power Plants,", Pickard Lowe and Garrick, 1989

[20] Letter from Steven West U.S. Nuclear Regulatory Commission to Anthony Vitale. Entergy Nuclear Operations, Inc, " Palisades Nuclear Plant, NRC Inspection Report 05000255/2011016; Preliminary White Finding", November 29, 2011

Attachment 2: Service Water Pump Run Time PI Data Analysis

Run Hours Calculation Macro

```
Sub valve_pos_0()
'Modified to extract service water pump run time only
'routine to extract pump change states and run time from PI
'  10/19/2011 by smongea
'when setting up the sheet use a tag with a large number of values in column B
'when entering a new PI into the inital array PI cannot make the array larger
'only smaller.  After running the macro make sure the last rows data is not cut off.

'
Dim Count As Integer
Dim reposition As Integer
Dim changetag As String
Dim compstates As String
Dim currentstate As String
Dim checkvalue As String
Dim checkminusone As String
Dim runchange As String
Dim Time1 As Date
Dim Time2 As Date
Dim TimeDiff As String
Dim TimeTot As Variant

Application.ScreenUpdating = False

Count = 1

'start Get pump Tag from 'pump tags' sheet loop
'loop count is the number of tags
Do Until Count = 2  'set count to 37 to run all pumps
    Sheets("Pump Tags").Select
    Range("A1").Select
    ActiveCell.Offset(Count, 0).Range("A1").Select
    Selection.Copy
    Sheets("PI Archive Data").Select
    Range("B2").Select
    ActiveSheet.Paste

    'Find pump change state to look for
    compstates = Range("B7")
    currentstate = Range("B8")


    changetag = "Stopped"
    runchange = "Started"

    Range("B9").Value = changetag
    Range("C12").Select
    checkvalue = Range("C12")
```

```
reposition = 0
TimeTot = 0

 If ActiveCell.Value = runchange Then
   ActiveCell.Offset(0, -1).Activate
   Time1 = ActiveCell.Value
   ActiveCell.Offset(0, 1).Activate
   ActiveCell.Offset(1, 0).Activate
 End If



'check down data column until a change state is found
'eval previous cell to ensure a change state has occurred
'color change states yellow and increase reposition count
'record change state time (start or stop)
Do Until checkvalue = " " Or checkvalue = Null Or checkvalue = ""
   checkvalue = ActiveCell.Value
   checkminusone = ActiveCell.Offset(-1, 0).Value
   If ActiveCell.Value = runchange And checkminusone = changetag _
      And checkminusone <> "Shutdown" _
      And checkminusone <> "Invalid Data" _
      And checkminusone <> "Pt Created" _
      And checkminusone <> "I/O Timeout" Then
      reposition = reposition + 1
      ActiveCell.Select
      With Selection.Interior
      .ColorIndex = 6
      .Pattern = xlSolid
      End With
      ActiveCell.Offset(0, -1).Activate
      Time1 = ActiveCell.Value
      ActiveCell.Offset(0, 1).Activate
      ActiveCell.Offset(1, 0).Activate
   Else:
      ActiveCell.Offset(1, 0).Activate
   End If
'Continue down data column until oppostie change state is found
'eval previous cell to ensure a change state has occurred
'color change states and record start stop time
'add start stop time difference to total run time
   checkminusone = ActiveCell.Offset(-1, 0).Value
   If ActiveCell.Value = changetag And checkminusone = runchange _
      And checkminusone <> "Shutdown" _
      And checkminusone <> "Invalid Data" _
      And checkminusone <> "Pt Created" _
      And checkminusone <> "I/O Timeout" Then
      ActiveCell.Offset(0, -1).Activate
      Time2 = ActiveCell.Value
      ActiveCell.Offset(0, 1).Activate
      ActiveCell.Select
      TimeDiff = (Time2 - Time1) * 24
      TimeTot = TimeTot + TimeDiff
```

```
            ' Filter short run times less than 1 minute
            If TimeDiff > 0 And TimeDiff < 0.0167 Then
            reposition = reposition - 1
            TimeTot = TimeTot - TimeDiff
               With Selection.Interior
               .ColorIndex = 10
               .Pattern = xlSolid
               End With
            Else:
               With Selection.Interior
               .ColorIndex = 8
               .Pattern = xlSolid
               End With
            End If
          End If
      Loop

      'paste total stop-start count and run time at top of column
      Range("B1").Value = reposition
      Range("B10").Value = TimeTot
      'copy and paste PI data as "values" into next available column
      Columns("B:C").Select
      Selection.Copy
      Range("B12").Select
      Selection.End(xlToRight).Select
      ActiveCell.Offset(-11, 1).Range("A1").Select
      Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
         :=False, Transpose:=False
      Selection.PasteSpecial Paste:=xlPasteFormats, Operation:=xlNone, _
         SkipBlanks:=False, Transpose:=False
      Columns("C:C").Select
      Selection.Interior.ColorIndex = xlNone
      Count = Count + 1
Loop

End Sub
```

Input and Output of Run-Hours Calculation Spreadsheet

Number of Pump StartsThrough 10-18-2011	**108**		137		77		108	
Minus Starts After 17-4PH SS Coupling Replacemnt			**132**		**69**		**108**	
Tag Name	YSP7C_D		YSP7A_D		YSP7B_D		YSP7C_D	
Tag Description	Service Water Pump P-7C		Service Water Pump P-7A		Service Water Pump P-7B		Service Water Pump P-7C	
Start Date	06/12/09		04/04/09		05/12/10		06/12/09	
Number of Data Points to Retrieve	59000		59000		59000		59000	
Date Tag Made Active	4/23/2001		4/23/2001		4/23/2001		4/23/2001	
Digitalset	STOPPEDSTARTED		STOPPEDSTARTED		STOPPEDSTARTED		STOPPEDSTARTED	
Current Status	Started		Started		Started		Stopped	
Change Position	Stopped		Stopped		Stopped		Stopped	
Total Run Hours Through 10-18-2011	17520.80		16184.44		10000.11		17520.80	
Minus Hours After 17-4PH SS Coupling Replacemnt			**14998.64**		**8909.4**		**17520.8**	
	12-Jun-09 05:05:00	Stopped	04-Apr-09 00:59:13	Stopped	12-May-10 05:26:18	Stopped	12-Jun-09 05:05:00	Stopped
	12-Jun-09 12:22:52	Started	04-Apr-09 08:49:16	Stopped	12-May-10 13:16:22	Stopped	12-Jun-09 12:22:52	Started
	12-Jun-09 12:23:06	Stopped	04-Apr-09 16:49:16	Stopped	12-May-10 17:43:22	Started	12-Jun-09 12:23:06	Stopped
	12-Jun-09 15:03:17	Started	05-Apr-09 00:49:16	Stopped	12-May-10 17:43:27	Stopped	12-Jun-09 15:03:17	Started
	12-Jun-09 15:33:59	Stopped	05-Apr-09 08:39:19	Stopped	12-May-10 17:49:43	Started	12-Jun-09 15:33:59	Stopped
	12-Jun-09 15:34:18	Started	05-Apr-09 14:07:00	Started	12-May-10 17:56:15	Stopped	12-Jun-09 15:34:18	Started
	12-Jun-09 23:24:21	Started	05-Apr-09 14:07:11	Stopped	12-May-10 22:58:16	Started	12-Jun-09 23:24:21	Started
	13-Jun-09 07:24:21	Started	05-Apr-09 18:56:46	Started	12-May-10 22:58:18	Stopped	13-Jun-09 07:24:21	Started
	13-Jun-09 15:14:25	Started	05-Apr-09 19:03:37	Stopped	13-May-10 05:47:25	Started	13-Jun-09 15:14:25	Started
	13-Jun-09 23:04:33	Started	05-Apr-09 19:04:26	Started	13-May-10 06:44:14	Stopped	13-Jun-09 23:04:33	Started
	14-Jun-09 06:54:37	Started	05-Apr-09 22:00:05	Stopped	13-May-10 07:32:52	Started	14-Jun-09 06:54:37	Started

Formula View of Input and Output of Run-Hours Calculation Spreadsheet

Number of Pump StartsThrough 10-18-2011	**108**	
Minus Starts After 17-4PH SS Coupling Replacemnt		
Tag Name	YSP7C_D	
Tag Description	=PITagAtt(B3,"descriptor","plpapetsp008")	
Start Date	39976	
Number of Data Points to Retrieve	59000	
Date Tag Made Active	=PITagAtt(B3,"creationdate","plpapetsp008")	
Digitalset	=PITagAtt(B3,"digitalset","plpapetsp008")	
Current Status	=PICurrVal(B3, 0,"plpapetsp008")	
Change Position	Stopped	
Total Run Hours Through 10-18-2011	17520.8041666671	
Minus Hours After 17-4PH SS Coupling Replacemnt		
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")
	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")	=PINCompDat(B3,B5,B6, 1,"plpapetsp008","inside")

137	77		108	
=D1-5	**=F1-8**		**=H1**	
YSP7A_D	YSP7B_D		YSP7C_D	
Service Water Pump P-7A	Service Water Pump P-7B		Service Water Pump P-7C	
39907	40310		39976	
59000	59000		59000	
37004.4993865741	37004.4993865741		37004.4993865741	
STOPPEDSTARTED	STOPPEDSTARTED		STOPPEDSTARTED	
Started	Started		Stopped	
Stopped	Stopped		Stopped	
16184.4397222236	10000.1094444441		17520.8041666671	
=D11+((D7091-D7092)*24+(D7093-D7136)*24+(D7152-D7153)*24+(D7154-D7179)*24+(D7180-D7271)*24)	**=F11+((F3493-F3494)*24+(F3495-F3514)*24+(F3518-F3519)*24+(F3520-F3536)*24+(F3537-F3628)*24+(F3629-F3630)*24+(F3631-F3632)*24+(F3633-F3657)*24)**		**=H11**	
39907.0411226851	40310.2265972222	Stopped	39976.2118055556	Stopped
39907.3675462963	40310.5530324074	Stopped	39976.5158796296	Started
39907.7008796296	40310.7384490741	Started	39976.5160416667	Stopped
39908.034212963	40310.7385069444	Stopped	39976.6272800926	Started
39908.3606365741	40310.7428587963	Started	39976.648599537	Stopped
39908.5881944444	40310.7473958333	Stopped	39976.6488194444	Started
39908.5883217593	40310.9571296296	Started	39976.9752430556	Started
39908.7894212963	40310.9571527778	Stopped	39977.3085763889	Started
39908.7941782407	40311.2412615741	Started	39977.6350115741	Started
39908.7947453704	40311.2807175926	Stopped	39977.9614930556	Started
39908.916724537	40311.3144907407	Started	39978.2879282407	Started
39908.9169212963	40311.6409143519	Started	39978.6143402778	Started
39908.9629050926	40311.9673842593	Started	39978.9407523148	Started

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary
IPE (1993)	1.0E-9	5.07E-05	Palisades IPE (R-0481)[c]	
PSAR1 (1999)	1.0E-9	5.95E-05[a]	EA-PSA-SAPH-99-18 (R-0843)	Switchyard modifications to reduce potential for plant centered loss of offsite power Moved the internal events CDF model from SETS to SAPHIRE.
PSAR1a (2000)	1.0E-9	5.47E-05[a]	EA-PSA-SAPH-00-0011 (R-0479)	The AFW alternate steam supply line to AFW pump P-8B was removed from the model as a result of a plant modification. Updated selected Main Steam Line Break initiating event data as well as the SGTR initiating event value. Selected human error probabilities (HEPs) were updated.

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary
PSAR1b (2000)	1.0E-9	6.18E-05[a]	EA-PSA-PSAR1B-00-22 (R-0472)	Selected common cause failure logic for control and solenoid valves was updated. A plant modification that swapped High Pressure Air power supplies from MCC-7 to MCC-8 was incorporated. Open circuit bus faults were added to the DC system logic. The summertime EDG HVAC success criteria was set to True for all nominal baseline calculations. The independent ATWS event trees were eliminated. Transfers from all event trees to a single ATWS event tree was created, taking advantage of SAPHIRE's event tree linking options. DC power demand logic was added.
PSAR1b-Modified (2001)	1.0E-9	6.16E-05[a]	EA-PSA-PSAR1B-01-12 (R-0835)	Corrected a conservative Shutdown Cooling Heat Exchanger modeling assumption. Revision of ISLOCA model including realistic low pressure piping capacity.
PSAR1b-Modified w/HELB (2002)	1.0E-9	6.24E-05[b]	EA-PSA-CCW-HELB-02-17 (R-1452)	The model was updated to account for main steam line breaks into the CCW room(s). Steam/feedwater line breaks in the CCW rooms with door 167 or door 167B to CCW room 123 open were included. A new initiating event (IE-MSLB-D-CCW) was created to represent the steam lines downstream of the MSIVs but in the CCW room as separate from remaining lines in the turbine building.

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary
PSAR1c (SAMA; 2004)	1.0E-9	4.05E-05[b]	EA-PSA-PSAR1C-01-003 (R-0703)	Diesel generator repair/recovery logic corrected. PCP seal LOCA model added. The Recirculation Actuation System plant modification was incorporated. HEP dependency modeling was explicitly included. Removed modeling conservatism in the critical SW header valve logic. FPS makeup to P-8C was updated to include tank T-2 failure. Traveling screen logic under FPS was updated. The auto MSIV close logic 'CHP' and 'low SG pressure' were correlated to the correct initiating event categories. Spurious bypass valve opening was added to both single and double steam generator blow down models. The gland seal condenser or air ejector after condenser rupture logic was updated. EQ logic was added to CCW pumps P-52A, P-52B and P-52C. DC bus D11-2 logic was corrected. Diversion path failure modes were added to selected air/N2 sources. Inadvertent PCS safety relief valve opening was added to the model. Failure of the AFW flow control valves to close was added to the system logic. The plant instrument air compressor modification was added to the model. The common cause data were updated.

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary
PSAR2 (2004)	1.0E-9	4.65E-05[a]	EA-PSA-PSAR2-04-02 (R-1710)	Updated turbine driven AFW pump failure data. Addressed CST flow diversion. Updated Initiating Event data. Updated spurious actuation of MSIV model. Updated of RPS and MTC data. Re-assess the HEP stress evaluation in context of the accident sequences being recovered. Reassessed the Load Shed logic.
PSAR2a (2006)	1.0E-9	4.49E-05[a]	EA-PSA-PSAR2a-05-18 (R-1822)	Added SW containment isolation valves to the SW fault tree to support MSPI. Added additional logic for leg injection (HLI) to support MSPI. Added logic for various equipment recoveries during loss of offsite power events to remove over-conservatism. Modified EDG load/run failures to support MSPI. Added instrument air dryer bypass to remove conservatism in EOOS model. Improved fidelity for AFW model logic. Improved fidelity for diesel start model logic. Added control circuit contact pairs to support MSPI. Added human error modeling to support logic additions above. Added new failure rate and probability models to support the logic additions above.

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary
PSAR2b (2006)	1.0E-9	4.36E-05[a]	EA-PSA-PSAR2b-06-07 (R-1823)	Added control room and C33 panel hand switches to support MSPI. Added CV-3001 and CV-3002 inline circuit scheme fuses for model improvement. Added new failure rate and probability models to support the logic additions above.
PSAR2c (2006)	1.0E-9	2.49E-05[a]	EA-PSA-PSAR2c-06-10 (R-1706)	Added logic for the non-safety related diesel logic. Addition of time phased offsite power recovery during SBO. Separated the load/run and run logic in the LOOP event tree to better characterize failures. Added operator action for diesel fuel oil recovery to address the proceduralized recovery of fuel oil to T-25A and B. Added bypass regulator model to address AFW low suction pressure trip failure given station battery discharge at 4 hours. Added plant modification automating switchover to RAS. Added credit for containment backpressure for providing HPSI NPSH to reduce conservatism. Added human error modeling to support logic additions above. Added new failure rate and probability models to support the logic additions above. Addition of sump strainer blockage.

Attachment 6: PRA Model Updates Since the Individual Plant Evaluation (IPE)

Palisades Model (date)	Truncation	CDF/yr	Reference	Hi Level Change Summary

a. subsumed cutset solution
b. non-subsumed cutset solution
c. "R-" is an internal reference label