Attachment 1

PROBABILISTIC RISK ASSESSMENT EVALUATION

OF

TORNADO-GENERATED MISSILE IMPACT ON THE SONGS 2/3 AUXILIARY FEEDWATER SYSTEM

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PROBABILISTIC RISK ASSESSMENT EVALUATION OF TORNADO-GENERATED MISSILE IMPACT ON THE SONGS 2/3 AUXILIARY FEEDWATER SYSTEM

PURPOSE:

The purpose of this evaluation is to determine the core damage risk of tornado-generated missile strikes on the SONGS 2/3 Auxiliary Feedwater System.

BACKGROUND:

SCE committed by letter to NRC dated 11/24/80 and UFSAR Section 3.5 (Table 3.5-12) to protect the Units 2 and 3 Auxiliary Feedwater (AFW) System from tornado-generated missiles. An internal audit determined that tornado-generated missile barriers for portions of the AFW pump suction, discharge and miniflow lines dc not fully satisfy this licensing commitment for the worst case tornado-generated missiles (Nonconformance Reports 93070045 & 93070048).

Although the existing barriers may not be adequate to protect against the worst case tornado-generated missiles, the frequency where an adequate barrier would be required is very low. NUREG-0800, "Standard Review Plan," (SRP) Section 2.2.3 (Rev. 2) and 3.5.1.5 (Rev. 1) defines as one of its acceptance criteria 1E-7 per year as an acceptably low risk for "causing radiological consequences greater than 10CFR Part 100 exposure guidelines." Similarly, Section 3.5.1.4, Revision 0 defines a similar criterion. This section looks at the probability of a missile generated by a specific design basis phenomena striking a critical area of the plant. The current revision (Revision 2) of the SRP also allows the use of probability in evaluating the effect of a missile strike but does not have an explicit acceptance criteria. However, based on current criteria for Sections 2.2.3 and 3.5.1.5, it is considered that the SRP Revision 0 criteria of 1E-7 is sufficiently small so as not to have any impact on the health and safety of the public. This evaluation documents that the additional risk of tornado-generated missile impact on the AFW system with the partially inadequate missile barriers is less than 1E-7 per year.

DISCUSSION:

Tornado-generated missile impacts on the AFW system may render the system unavailable to provide sufficient makeup to the steam generators (SG). Sufficient SG makeup is needed to safely transfer post-trip reactor coolant system (RCS) decay heat removal function to the Shutdown Cooling System (SDC). Sufficient SG makeup by the AFW system requires adequate flow and adequate condensate inventory. The requirement for adequate AFW flow and condensate inventory may be impacted by a tornado-generated missile.

From Reference 1, the atmospheric dump valves must be operable with backup nitrogen available for at least eight hours. This is based on the assessment of the various Chapter 15 and other design basis event scenarios where shutdown cooling entry conditions can be entered within 7 hours if remote Atmospheric Dump Valve operation is required plus 1 hour of conservative margin. From Reference 2, the condensate inventory needed to reduce the primary system from post-trip pressure and temperatures to shutdown cooling entry conditions, as well as remove decay heat in 8 hours, is approximately 146,000 gallons. The minimum inventories available in Condensate Storage Tanks (CST) T-120 and T-121 are 280,000 and 144,000 gallons, respectively, for a total of 424,000 gallons (T.S. 3.7.1.3).

A missile which strikes the vulnerable area of the AFW pump suction line tornado-generated missile barrier could cause the barrier to collapse on and fail one of the three suction lines. Suction line failure could result in a loss (approximately 4500 gpm) of the available condensate inventory in less than two hours. Similarly, a failure of Train B motor-driven or the turbine-driven AFW pump discharge piping in the Refueling Water Storage Tank (RWST) T-006 vault due to a tornado-generated missile induced collapse of the protective barrier will also result in premature depletion of the CST.[1] Therefore, a single tornado-generated missile strike on any of the tornado-generated missile barriers protecting the AFW pump suction lines or the Train B motor-driven or the turbine-driven AFW pump discharge lines would fail the AFW system.

A missile which strikes the vulnerable area of the AFW pump miniflow line tornado-generated missile barrier could cause the barrier to collapse on and fail one of the three miniflow lines. Miniflow line failure would result in a small loss (100 gpm) of condensate inventory. Over 8 hours, 48,000 gallons could be lost through the failed miniflow line and 146,000 gallons would be used for SG makeup for a total of 194,000 gallons. Since the available volume from T-121 is 144,000 gallons, additional inventory would be required from T-120. Accordingly, failure of the AFW system requires an additional leak or diversion path so as to render T-120 unavailable. Such an additional leak path could occur if a missile were to impact the exposed condensate transfer piping outside the CST building. A missile strike on exposed condensate transfer piping inside the CST enclosure is not a concern since provisions have been included to deliver water to T-121 from the annulus between T-120 and its enclosure. Therefore, a missile which fails a miniflow line simultaneous with an additional missile striking the condensate transfer piping outside the CST building would fail the AFW system.

NOTES AND ASSUMPTIONS:

The following notes and assumptions are used in this analysis:

1. Failure of the AFW system concurrent with or following reactor trip is assumed to result in core damage.

2. Currently installed missile barriers are assumed to be inadequate to protect the entire length of AFW piping in the RWST and CST T-120 tank buildings.

3. It is conservatively assumed that vertical missiles are equally likely as horizontal missiles.

4. A tornado which generates a missile striking a AFW missile barrier is also assumed to result in a loss of offsite power.

5. All condensate transfer piping outside of the Condensate Storage Tank Buildings is conservatively assumed to be 8 inches in diameter.

6. It is conservatively assumed that 1/3 of the surface area of condensate transfer piping outside of the T-120 enclosure is shielded by walls and floors from direct tornado-generated missile strikes. Therefore, the remaining 2/3 of the piping surface area can be impacted by tornado-generated missiles. (For Unit 3, the exposure of condensate transfer piping is

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[1] The AFW Train A discharge line does not enter the tank vaults and therefore is not considered here.

minimal in comparison to that of Unit 2. Although this would reduce the risk to Unit 3 in comparison to Unit 2, this calculation is conservatively applied to Unit 3 as well as Unit 2.)

7. The operators are assumed to bring the unit to shutdown cooling conditions within 8 hours.

8. Missiles generated by tornados within Fujita F-Scale categories F'0, F'1, and F'2 (windspeeds up to 157 mph) do not adversely affect the operability of the AFW system [3]. Missiles generated at these windspeeds are not expected to adversely damage the existing tornado-generated missile barriers and the associated piping. Tornados with windspeeds in Fujita category F'6 (windspeeds greater than 318 mph) are deemed to be incredible and are not considered in this study .

9. The steep trajectory missiles which are not attenuated by the wall of the CST building could not puncture CST T-120 such that it would retain less than 200,000 gallons useable volume [4] .

10. All credible missiles are "worst case" missiles as described in UFSAR Table 3.5-6.

11. Approximately 130 ft^2 and 20 ft^2 of the tornado-generated missile barriers protecting the AFW suction/discharge and miniflow lines (for each unit), respectively, are vulnerable to a worst case tornado-generated missile strike [5].

12. The missile strike probability used in the SONGS 1 tornado study is assumed to be applicable to SONGS 2/3 [6]. A walkdown during the SONGS 1 study estimated that the number of potential missiles within a 2000 ft radius of the missile targets was approximately 16,000. This number is used to directly calculate the missile strike probability. The number of potential missiles at SONGS 2/3 would be expected to be on the same order of magnitude as that of SONGS 1 since the administrative, maintenance and operational practices which govern the number of potential missiles are largely site-wide rather than unit-specific practices. Therefore, the SONGS 1 missile strike probability is assumed to be applicable to Units 2 and 3.

OVERVIEW OF METHODOLOGY

From the discussion, tornado-generated missiles will fail the AFW system in either of the following scenarios:

1. A tornado-generated missile strike which collapses the tornado-generated missile barrier and fails any one of three AFW pump *suction* lines (S2(3)-1305-ML-047, 049, 335) or AFW Train B or turbine-driven pump *discharge* lines (S2(3)-1305-ML-099, 101) results in failure of the entire AFW system. The frequency of a damaging tornado strike is described by the following general equation:

   $$F_1 = \text{Frequency of a damaging tornado strike} = \Sigma\,[\,f_i\,(\text{tornado}) * P_i\,(\text{missile strike})\,] * A_{Barrier} \qquad (1)$$

   where the summation is summed over Fujita tornado classifications F'3, F'4, and F'5, and

   f_i (tornado) = frequency of tornado class i [yr^{-1}] i = 3, 4, 5

   P_i (missile strike) = probability of a missile strike per square ft. given the tornado class i [ft^{-2}]

   $A_{Barrier}$ = surface area of the barrier which is susceptible to the worst case missile [ft^2]

2. A tornado-generated missile strike which collapses the tornado-generated missile barrier and fails any one of three AFW pump *miniflow* lines (S2(3)-1305-ML-048, 050, 340) combined with a complete unrecoverable loss of condensate from Condensate Storage Tank T-120 results in failure of the AFW system. The unrecoverable loss of inventory in T-120 may occur as a result of tornado-generated missile strikes to exposed condensate transfer piping outside the T-120 tank building. General Equation (1), used to calculate the frequency of core damage for Scenario 1, is modified for Scenario 2 to account for the additional failure of the condensate transfer piping:

   $$F_2 = \Sigma\,\{\,f_i\,(\text{tornado}) * [P_i\,(\text{missile strike}) * A_{Barrier}] * [P_i\,(\text{missile strike}) * A_{Cond}]\} \qquad (2)$$

   This can be re-written as:

   $$F_2 = \Sigma\,\{\,f_i * [P_i * A_{Barrier}] * [P_i * A_{Cond}]\} \qquad (3)$$

   $$= \Sigma\,\{\,f_i * P_i^2 * A_{Barrier} * A_{Cond}\,\}$$

   $$= A_{Barrier} * A_{Cond}\,\Sigma\,\{\,f_i * P_i^2\,\}$$

   where A_{Cond} = the surface area of the condensate transfer piping vulnerable to a tornado-generated missile strike [ft^2]

The total frequency of core damage can be described by combining Equations (1) and (3):

$$F_{Total} = F_1 + F_2 \qquad (4)$$

ANALYSIS:

SCENARIO 1: CORE DAMAGE DUE TO A TORNADO-GENERATED MISSILE STRIKE ON AN AFW PUMP SUCTION LINE, OR AN AFW TRAIN B OR TURBINE-DRIVEN PUMP DISCHARGE LINE MISSILE BARRIER

The tornado frequencies used are from the Tornado Hazard Review - San Onofre Unit 1 [6], completed by ERIN Engineering and Research, Inc. In the study, three sources of tornado frequencies were referenced. The study applied the most conservative hazard curve (NRC) . These conservative frequencies are replicated in Table 1.

TABLE 1

Fujita Scale	Windspeed (mph)	Frequency (f_i)	Probability of Missile Strike (P_i) (see note 1)	f_i * P_i
F'3	158-206	1.5E-6/yr	1.45E-6	2.18E-12/yr*ft^2
F'4	207-260	3.5E-7/yr	1.83E-6	6.41E-13/yr*ft^2
F'5	261-318	8.0E-8/yr	2.23E-6	1.78E-13/yr*ft^2
			Total = $\Sigma f_i * P_i$ =	3.0E-12/yr*ft^2

[1]The missile strike probability is based on a SONGS Unit 1 missile population of 16,040.

From Equation (1) and Table 1, the core damage frequency due to a tornado-generated missile strike on one of the three AFW pump suction line barriers or the Train B or turbine driven pump discharge line barriers is:

F_1 = Frequency of a damaging tornado strike = Σ [f_i (tornado) * P_i (missile strike)] * $A_{Barrier}$ (5)

= 3.0E-12/yr*ft^2 * 130 ft^2 = <u>3.9E-10/yr</u>

SCENARIO 2: CORE DAMAGE DUE TO CONCURRENT TORNADO-GENERATED MISSILE STRIKES ON ONE OF THE AFW PUMP MINI-FLOW LINE BARRIERS AND CONDENSATE TRANSFER PIPING

From Table 1,

TABLE 2

Fujita Scale	Windspeed (mph)	Frequency (f_i)	Probability of Missile Strike (P_i)[1]	P_i^2	$f_i * P_i^2$
F'3	158-206	1.5E-6/yr	1.45E-6	2.10E-12	3E-18/yr*ft²
F'4	207-260	3.5E-7/yr	1.83E-6	3.35E-12	1E-18/yr*ft²
F'5	261-318	8.0E-8/yr	2.23E-6	4.97E-12	4E-19/yr*ft²
				Total = $\Sigma f_i * P_i^2$ =	4.4E-18/yr*ft⁴

[1]The missile strike probability is based on a SONGS Unit 1 missile population of 16,040.

Condensate Transfer Piping Surface Area

Piping Length = 378.1 ft

A_{Cond} = Exposed piping area = $\Pi DL = \Pi$ * [8 in pipe * 2/3 * 1ft /12 in] * 378.1 ft (6)
= 527.9 ft²

(Note: Although a large portion of the piping is less than 8 inches in diameter, it is assumed that the entire piping length is made up of 8 inch diameter pipe)

From Equation (3), the frequency of core damage from Scenario 2 is:

$$F_2 = A_{Barrier} * A_{Cond} \Sigma \{ f_i * P_i^2 \} = 20 \text{ ft}^2 * 527.9 \text{ ft}^2 * 4.4E\text{-}18 / \text{yr ft}^4 \quad (7)$$

$$= \underline{5E\text{-}14/yr}$$

From Equation (4), the total core damage frequency from tornado-generated missile strikes on AFW piping is:

$$F_{Total} = F_1 + F_2 = 3.9E\text{-}10 + 5E\text{-}14 = \underline{\mathit{3.9E\text{-}10 / year}} \text{ or } \underline{\mathit{4E\text{-}10/year}} \quad (8)$$

The calculated frequency is conservative and could be reduced further by considering 1) the protection of the AFW pump suction, discharge and mini-flow lines by the tank building walls from horizontally and some vertically projected missiles (since no credit is taken for missile protection provided by concrete walls other than the one to which the piping is attached), 2) elimination of those missiles in each tornado class incapable of damaging the AFW piping barriers (such as utility poles and automobiles), and 3) other sources of makeup to CST T-121 such as firewater via the Unit 2/3 fire water tanks and the demineralized storage tanks above Unit 3. These considerations would be expected to reduce the total core damage frequency by at least two orders of magnitude.

UNCERTAINTY ANALYSIS:

Two sources of uncertainty are present in this analysis: modeling uncertainty and fundamental uncertainty. Modeling uncertainty originates in the inherently imperfect mathematical modeling of the behavior of tornado-generated missiles. The degree of modeling uncertainty is dependent on the available empirical data and the mathematical characterization of the data. Fundamental uncertainty is the natural, inherent uncertainty arising from nondeterministic phenomena such as tornado occurrence, potential missile locations, and windfield turbulence. This type of uncertainty cannot be reduced by additional data or improved mathematical models. Each type of uncertainty is initially addressed in References 6 and 7, and further treated in this study.

The reported tornado frequencies and missile strike probabilities in References 6 and 7 are presented as expected or mean values. Distributions for the tornado frequencies were not presented. Therefore, a lognormal distribution with an error factor of 10 was arbitrarily assigned to the tornado frequencies to capture the fundamental uncertainty. This represents a wide distribution with a 5/95 probability interval which spans two orders of magnitude.

Reference 6 states that the form of the uncertainty distributions for the 25 random variables used to simulate tornado-generated missile strikes (TORMIS code) were either uniform or normal. When random variables are propagated through mathematical correlations, the final form of the distribution (i.e. the missile strike probability) rarely resembles any classical distribution whose parameters can be easily determined. However, from the missile strike simulations in Reference 6, it was noted that the 95 percentile probability was on the order of 2 to 3 times the expected value. Therefore, for the purposes of this analysis, a lognormal distribution with an error factor of 3 was chosen for the missile strike probabilities. The classical lognormal distribution is used due to its simplicity in use and its ability to span over several orders of magnitude.

The LHS (Latin Hypercube Sampling) and TEMAC (Top Event Matrix Analysis Code) subroutines within the PRA code REBECA were used to propagate the uncertainty distributions through Equation (4). The results are presented below:

Sampling Mean	=	3.11E-10 /year
Standard Deviation	=	6.13E-10 /year
Lower 5%	=	1.04E-11 /year
Median (50%)	=	1.06E-10 /year
Upper 5%	=	1.29E-9 /year
Mean from Method of Moments	=	3.6E-10 /year

RESULTS AND CONCLUSIONS:

The core damage risk of a tornado-generated missile strike on the SONGS 2/3 AFW system is conservatively calculated to be approximately 4E-10/year. Based on the acceptance criteria of 1E-7/year as stated in NUREG-0800, "Standard Review Plan," Section 2.2.3 (Evaluation of Potential Accidents) and 3.5.1.5 (Site Proximity Missiles), the core damage risk of the as-built AFW system against tornado-generated missiles is acceptably low.

REFERENCES:

[1] Letter from B. Carlisle to M. A. Wharton, "Atmospheric Dump Valve Requirements," March 6, 1990.

[2] MAAP Analysis of SONGS 2/3 Cooldown to Mode-4 Entry (Support Calculation For Tornado Missile Protection Study), Prepared by Nuclear Safety Group, Report No. T/H-2/3-MAAP93-048, Revision 1, December 2, 1993.

[3] E-mail from T. Yee to G. Chung, "Tornado Missile Barriers for AFW Piping," December 10, 1993.

[4] Letter from M. A. [illegible]on to B. Katz, "Tornado Missile Protection Design, SONGS 2/3," April 16, 1993.

[5] E-mail from P. Kousharian to G. Chung, "Vulnerable Areas of Existing Tornado Barriers," December 6, 1993.

[6] Tornado Hazard Review, San Onofre Unit 1, Final Report, Prepared by Erin Engineering and Research, Inc. June 1990.

[7] Tornado Missile Risk Analysis, Prepared by Carolina Power and Light Company, EPRI NP-768, May 1978.