ATTACHMENT 3 TO AEP:NRC:1082K

# Donald C. Cook Nuclear Plant Individual Plant Examination for External Events

## Revised Seismic Probabilistic Risk Assessment

DONALD C. COOK NUCLEAR PLANT UNITS 1 AND 2

ADDENDUM TO

SEISMIC PROBABILITY RISK ASSESSMENT NOTEBOOK

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Preparer — Date: 2/8/95

Reviewer: Joseph L. Bell — Date: 2/8/95

Approved (AEPSC Section Manager) — Date: 2/8/95

## NOTE

This notebook was prepared in accordance with the applicable sections of 10 CFR 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." The documentation and the analysis reported in this notebook utilized guidance information, design and plant information contained in reference documents applicable to Donald C. Cook Nuclear Plant Units 1 and 2. A list of these references is presented in this notebook.

DONALD C. COOK NUCLEAR PLANT

ADDENDUM TO

SEISMIC PROBABILISTIC RISK ASSESSMENT

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# ADDENDUM TO SEISMIC PROBABILITY RISK ASSESSMENT NOTEBOOK

## 1.0 INTRODUCTION

During the July 1994 NRC audit of the Seismic PRA (Reference 1), the NRC cited two related concerns with the Seismic PRA for the Cook Nuclear Plant (Reference 2). First, the seismic fragility analysis was performed with a technique that was not standard in the industry (Reference 3 was cited as an example of the preferred technique). The techniques used in Reference 2 tend to lead to lower median fragilities, with limited randomness and no uncertainty factors utilized. Using these techniques was considered by the NRC to introduce the potential for an improper ranking of seismically important contributors.

The second issue had the same potential impact on the proper ranking of important risk contributors. When the seismically induced event trees were analyzed, the seismic intervals chosen in Reference 2 were considered to be too broad, masking detail needed for a proper ranking. This resulted in seismic interval 2 (.25 to .50g) having nearly 100% failure, while the previous seismic interval 1 nearly none.

This addendum follows the methodology of the original analysis to correct these two problems, but in this case using the preferred fragility calculation methods for select structures and components and smaller seismic quantification intervals. First, the most critical structures and components are chosen. Complete, new fragilities for these structures and components were developed by Westinghouse using the industry standard methodology. Additional structures and components were selected for a partial reevaluation. Using these new fragilities, the seismic core damage frequency was calculated using the original methods. This time, however, interval 2 is broken into five subintervals and interval 3 into three subintervals to provide greater detail. The new results are then analyzed, and a new ranking of seismically important components is developed.

## 2.0 METHODOLOGY

### 2.1 SELECTION OF COMPONENTS FOR REEVALUATION

For the purposes of probabilistic risk assessments, seismic fragility parameters are developed by examining the conservative design basis seismic response analysis, and removing that conservatism by multiplying the design basis acceleration for failure by factors representing the level of conservatism. This technique is explained in more detail in the original analysis. Each factor has an associated randomness and uncertainty, and each factor represents the level of conservatism in one aspect of the design basis calculation. Typical factors are associated with materials properties, modeling techniques, and seismic damping.

In the original Westinghouse fragility analysis, Westinghouse chose to conservatively calculate the margin factors. Since these were conservatively calculated, there was no uncertainty, and the uncertainty factor was set to zero. In a related fashion, the randomness factor could be underestimated or neglected by a conservative choice of a margin factor.

Given that the Westinghouse fragility calculation appears to be conservative, the high confidence of low probability of failure (HCLPF) calculated using the original Westinghouse fragilities should be either similar to or conservative to the HCLPF calculated by the more standard techniques. Since seismic interval 2 (.25 to .50g) is of primary interest, and the HCLPF represents only a 5% failure rate, reevaluating fragilities for components that have HCLPFs of less than .6g using the original Westinghouse techniques was selected in order to capture all significant contributors.

To limit the amount of reanalysis, only those structures and components with originally calculated HCLPFs of .40g or less are chosen for a complete reevaluation. These will fail earlier than the other components, and are more likely to be the dominant contributors. As will be seen, two margin factors that were not considered in the original evaluation are applicable to large sets of components. These margin factors account for interaction between the major structures and the soil and for the estimated of the seismic spectra. They are applied to those components whose HCLPFs fell in the range of .40 to .60g or were otherwise not the limiting failure mode for a structure or component to ensure that appropriate seismic rankings in that interval are obtained.

The choice of HCLPF as a selection criteria for reevaluation is confirmed in the next section. By comparison of a large selection of HCLPFs calculated by the two methods, the HCLPFs were found to be approxiamtely the same. Therefore, structures and components with HCLPFs above .5g by the original Westinghouse method would not become a contributor to failure in seismic interval.2 if their fragilities were reevaluated.

The similarity of the HCLPFs for the two methods can be justified on a qualitative basis. The original fragility analysis was based on the selection of conservative margin factors with no uncertainty. When best estimate margin factors were selected for the current fragility analysis, uncertainty parameters were included. The value of the best estimate margin factor at the lower extreme of the uncertainty range should also be a conservative margin factor. It would not be unreasonable for a conservative margin factor and the conservative end of a best estimate margin factor with uncertainty to be similar. Since the fragility evaluation is based on a combination of these margin factors, again, it is not unreasonable for the HCLPFs of the two methods to be similar. A quantitative proof of this argument would require a detailed evaluation of the methodology used for each margin factor, over all ranges of the application of those methods. Given the close comparison of the HCLPFs of the selection of structure and components that was already performed, and the fact that the selection was based on those structures and components that were most likely to impact the seismic analysis result, we believe that this detailed evaluation is unwarranted.

## 2.2 REVISED FRAGILITY ANALYSIS

The purpose of the fragility analysis is to establish approximate estimates of fragility parameters for use in the SPRA analysis using simplified conservative approaches. For the components selected by the method described above, Westinghouse reevaluated the seismic fragility using the methodology developed at Diablo Canyon (Reference 3). This reevaluation has removed conservatism, and added increased randomness and uncertainty variation in the form of beta factors. The results are presented in Reference 4, (attached as Appendix A).

As can be seen in Appendix A, the HCLPFs for the 11 structures and components reevaluated using the Diablo Canyon techniques are very similar to the HCLPFs originally calculated by Westinghouse. The median failure values increased significantly for all reevaluated structures and components. Note that the fragilities for piping supports at the component cooling water outlet were not reevaluated. The limiting point in the original calculation was the snubbers. Most of the snubbers at this location are being replaced by struts (which typically have more margin to failure than snubbers) as a part of the snubber reduction program (Reference 5). Since the design is not complete, and more margin is expected in the new design, this component is neglected in this analysis.

In the new Westinghouse evaluation (Reference 4), Westinghouse had Rizzo & Associates develop a set of margin factors for building response to an earthquake, taking credit for soil structure interaction. This led to margin factors and associated uncertainties for major structures and

components in these buildings. Since these margin factor were not considered in the original evaluation of the structures and components with HCLPFs in the .40 to .60g interval or were otherwise not the limiting failure mode for the structure or component (Reference 6), these factors were selected and applied to the result of the original Westinghouse fragilities the components selected. In addition, a spectral margin factor was used in the Westinghouse reevaluations. This margin factor compares the LLNL spectral shapes to the Cook specific spectral shapes, establishing margin for each piece of equipment based on its response frequency. Since this was already calculated for each component in the original analysis as part of the sensitivity study, this margin factor is also applied here to these components (References 8 and 9). The results are listed in Table 1.

The seismic failure frequency of each structure or component for each seismic subinterval is now calculated. First, equation 3 of the original analysis is solved for each structure or component. This gives the number of standard deviations from the subinterval midpoint to the median fragility. The failure frequency is then determined assuming that the failure rate is normally distributed about the median. This was performed in a spreadsheet developed for this purpose. Table 3 provides a listing of the current fragility parameters (both original and revised) and Table 4 the standard deviation to the median for the subinterval. Table 5 shows the look up table result of failure frequency given the standard deviation. For reference, the lookup table is shown in Table 6, which used values chosen from Reference 10.

The spreadsheet was also used to associate each of the structure or component failure probabilities calculated on Table 5 with the seismic basic event identifier used as input to the quantification codes. Table 7 provides a list of the basic event identifiers, the Table 5 line numbers which contribute to the failure rate of the basic event, and the failure rate in each subinterval. When more than one Table 5 failure rate contributes to a basic event failure rate, and the magnitude is large, Boolean summation techniques are used.

Table 8 uses the same technique as Table 7 to develop the event tree nodes used in determination of the initiating event frequencies. In addition, small and large break LOCA initiating event frequencies are taken from Figure 1 (Reference 11).

## 2.3 PROBABILITY OF A SEISMIC EVENT IN EACH SUBINTERVAL

The methodology of the original notebook, Section 2.3, is followed here. First, the original seismic interval 2 is broken into 5 subranges, labeled here 2a to 2e. Interval 3 is broken into three subintervals labeled 3a to 3c. The probability of having a seismic event exceeding the given acceleration for each of those intervals and the midpoint of each interval is then calculated.

To calculate the probability of exceedance at each subinterval boundary, an exponential curve fit was developed for the two known points at .25 and .50 g (2.09E-5/year and 1.47E-6/year, respectively), giving the equation.

$$p = 2.97\text{ E-04 } e^{-10.62g}$$

Since the overall seismic initation frequencies in interval 3 are small, less accuracy is required in interval 3, and this fit is used for this interval as well. This equation was solved for each subinterval boundary, and the probability of a seismic event in that subinterval was calculated by subtraction. Table 1 provides a summary of the results.

## 2.4 SEISMICALLY INDUCED INITIATING EVENT FREQUENCY DETERMINATION

This section uses the analysis and method of Section 2.3 of the original analysis. The probability of failures that could initiate a modeled event is calculated for each subinterval on Table 8, as described in Section 2.2. These base initiating event frequencies correspond to the nine failure groups found in Section 2.3 of the original analysis.

The SUPERS (Reference 12) event tree quantification was performed for the five subintervals, resulting in final, hierarchically ranked, initiating event frequencies. These initiating event frequencies are shown in Table 9 for both normal and loss of offsite power cases. As the seismic acceleration increases, the more severe accident initiators become relatively more significant, reducing the fractional contribution of the less severe accident initiators.

## 2.5 SEISMIC CORE DAMAGE FREQUENCY CALCULATION

The seismic quantification process described in Section 2.6 (and developed in Sections 2.4 and 2.5) of the original notebook was performed for the eight seismic subintervals. The input needed for this is the basic event failure rates of Table 7, the initiating event frequencies of Table 9, and the normal random failure rates (revision 0 analysis values were used for consistency, Reference 13). The core damage frequency result for this analysis is found in Appendix C.

By comparing the initiating event frequencies to the event core damage frequency in Appendix C, it can be seen that some event core damage frequencies approximate or exceed the initiating event frequencies. This is due to the use of a cutset editor type code rather than a full quantification. To correct for this, the top cutsets for each event are summed in a Boolean fashion to obtain the correct core damage frequency and reduction in risk for each top contributor result. This correction is performed for subintervals 2e through 3c. The corrected core damage frequencies are summarized on Table 10. Table 11 summarizes the core damage frequency contribution of each significant component in each subinterval, in the form of reduction if core damage frequency if the component were not to fail.

# 3.0 RESULTS AND CONCLUSIONS

The Cook Nuclear Plant-specific seismic hazard curves and fragility analysis results were incorporated into the seismic accident sequence models. The seismic accident sequence quantification was performed for the "normal power available" cases and for the "loss of offsite power" cases, where these two cases reflect whether offsite power is expected to be available immediately following a seismic event.

The results of the accident sequence quantification were combined with the initiating event frequencies for those events which were not specifically quantified (i.e., paths leading to direct core damage - "C1" cases). Table 10 presents the results of the seismic PRA analysis. The results are presented based on each seismic interval and as a total seismic core damage frequency.

As shown in Table 10, the seismic core damage frequency is estimated to be 3.17E-6/yr. The LOSP cases in seismic interval 2 dominant the core damage frequency.

To further define which components, equipment, and buildings are dominating the results, Table 11 offers a summary listing of the importance analysis results. As can be seen from this table, the dominant contributors to seismic core damage are:

1. Auxiliary Building

2. Loss of Electric Power Systems

   a. 600 VAC Transformers
   b. Diesel Generator Fuel Oil Day Tank

3. Turbine-Driven AF Pump (random failures)

To a lesser degree, the following are also shown as contributors:

1. 250 VDC System

2. Reactor Protection System Failures (Misc. Panels)

3. Ice Condenser

Appendix C provides detailed listings of the top cutsets which contribute to the total seismic core damage frequency.

As can be seen from Table 10, the initiating events which dominant the analysis are:

1. Loss of Offsite Power

2. Direct Core Damage (e.g. unrecoverable damage, dominated by containment structural failure)

And of relatively equal magnitude

3a. Steamline/Feedline Break

3b. Loss of Service Water System

3c. Large LOCA

## 3.1 SUMMARY OF RESULTS

The Cook Nuclear Plant results and dominant contributors are comparable and consistent with those reported in other seismic PRAs (see Reference 14 - NUREG/CR-4334).

This section provides a discussion and explanation of the Cook Nuclear Plant Seismic PRA accident sequence results presented in Table 10. Approximately 80% of the CDF comes from 2 initiating events. The top contributor is loss of offsite power at 60% followed by direct core damage at 19%.

Since the seismic analysis is broken into subintervals, and the manual correction was needed to properly determine the rankings of the significant contributors, the screening criteria set forth in NUREG-1335 (Reference 15) are not rigidly followed. Each of the criterion is described below.

<u>Screening Criterion 1</u>

This criterion requires that "any systemic sequence that contributes 1E-7 or more per reactor year to core damage" be identified. Since the seismic core damage frequency is so low, the dominant failures

are listed on Table 11 down to 1.E-8/yr.

Screening Criterion 2

This criterion requires that "all systemic sequences within the upper 95 percent of the total core damage frequency" be identified. These are the failures listed on Tables 10 and 11. Since these are calculated as a risk reduction, the damage frequencies do not sum to near the total core damage frequency. (If any risk significant component was to be strengthened so that it would not fail, the risk reduction value of other components would increase).

Screening Criterion 3

This criterion requires that "all systemic sequences within the upper 95% of the total containment failure probability" be identified.

According to the fragility data, seismic failure of the containment building may occur due to the following causes: failure of the containment rebar or failure due to soil pressures. Of these two failure mechanisms, the soil pressure dominates. Failure of the containment structure was designated as direct damage in Table 10. The sum of the direct damage events for all the seismic intervals is calculated to be 6.08E-07/yr which is approximately a 20% contribution to the total seismic core damage frequency. However, this value represents seismic containment failure and not a containment failure probability after containment is challenged following an accident. A seismic Level II containment performance is not required for the IPEEE (GL 88-20 Supplement 4), but containment performance is assessed as follows using analogies to the internal events Level II analysis.

The dominant contributors listed in Table 11 are examined to determine the type of potential containment failure which exists. Failure is dominated by failure of the auxiliary building or electric power sources. These would fail containment spray as well. Based upon the internal events Level II results, core damage, in general, is expected to occur in the range of 2-to-4 hours after accident initiation if decay heat removal is lost. As for containment performance, containment spray failure greatly reduces the availability of water cooling on the failed core in the containment reactor cavity after vessel failure. With less water in the cavity, containment pressurizes at a much slower rate due to less steaming from the failed core and containment failure occurs much later in the accident.

Some sequences failed due to ice condenser failure. The ice condenser was not modeled within the internal events analysis due to its high availability, thus no analogies can be drawn. However, with Cook Nuclear Plant being an ice condenser containment plant, chances of containment failure following an accident significantly increase after losing the ice condenser and containment failure could occur sooner in an accident. After containment failure, any water inside containment may boil off, thereby preventing ECCS from removing decay heat via recirculation mode, which would lead to core damage.

Screening Criterion 4

This criterion requires that "systemic sequences that contribute to a containment bypass frequency in excess of 1E-8 per reactor year" be identified.

For the seismic PRA, containment bypass is assumed if the Reactor Protection System/Engineered Safeguards Features Actuation System (RPS/ESFAS) fails (e.g., signals fail to isolate the containment). The seismic PRA does not differentiate between signals for containment isolation and signals for ESFAS actuation; thus, the results reported here are conservative. Note that even if the

RPS failure represents component actuation, it could be anticipated that containment cooling systems such as the containment spray system would fail to start, thus eventually leading to a containment bypass failure event.

The RPS/ESFAS is represented in the seismic PRA by a basic event referred to as "Miscellaneous Panels." As presented in Table 11, failure of the miscellaneous panels (RPS/ESFAS) is a significant contributor. RPS failure contributes 4.7E-8/yr to core damage frequency.

## 3.2 COMPARISON TO ORIGINAL ANALYSIS

The current analysis estimated the total core damage frequency as 3.17E-6/year, an 80% reduction from the original analysis value of 1.83E-5/year. This is primarily due to the conservatism that was removed from the seismic fragility calculations. However, the ranking of significant components is very similar. The failures of the auxiliary building and electric power systems dominate both analyses. The original analysis identified the turbine building pedestal and 4kV switchgear failures as being lesser significance, and these were not identified in the current analysis. No new significant contributors were identified in the current analysis.

For initiating events, the current analysis is dominated by loss of station power and direct core damage, with lesser contributions from steamline break, loss of essential service water, and large LOCA. The original analysis identified all of these except for the more severe initiators of direct core damage and large LOCA. This is attributed to the overall lower core damage frequency of the current analysis, making the more severe initiators relatively more important.

In conclusion, even with different fragility calculation methods and the resulting overall differences in core damage frequency, the rankings of significant seismic failure contributors is very similar for the two analyses.

## 4.0 REFERENCES


1. NRC Site Audit for the Cook Nuclear Plant IPEEE, Exit meeting of July 28, 1994.

2. "Donald C. Cook Nuclear Plant, Seismic Probabilistic Risk Assessment Notebook", April 1992.

3. "Seismic Fragility of Civil Structures and Equipment Components at the Diablo Canyon Power Plant," Report No. 1643.02, NTS Engineering, 1988.

4. Westinghouse Letters AEP-94-760, "Fragility Parameter Review" (8/16/94); AEP-94-785 "Transmittal of Fragility Data (9/23/94); and AEP-94-789 "Supplementary Seismic Fragility Estimates" (10/3/94).

5. AEPSC Memo, D. Petro to R. Bennett, Calculated Design Loads (DC-D-0620.5), Dated October 4, 1994.

6. Westinghouse Electric Corporation, "Seismic Fragility Assessment - Donald C. Cook Nuclear Plants," February 1992.

7. Westinghouse letter AEP 94-839, "Transmittal of Fragility Calculations," dated November 16, 1994, Calculation CSE 09-94-0046.

8. Westinghouse Calculation AEP-49, "Fragility Data, LLNL UHS Spectral Shape".

9. Westinghouse Calculation AEP-50, "LLNL UHS Equipment Fragility Data".

10. Rizzo Associates Letter "Seismic Hazard Analysis, Donald C. Cook Nuclear Plant," 8/17/94.

11. M.P. Bohn, et. al., "Analysis of Core Damage Frequency: Surry Power Station, Unit 1 External Events," NUREG/CR-4550, also SAND86-2084, Vol. 3, Rev. 1, Part 3, December 1990 and NUREG/CR 3428, "Application of the SSMRP Methodology to the Seismic Risk at the Zion Nuclear Power Plant", November 1983.

12. "SUPER Code System User Manual for Version 2.0," WCAP-12401, Westinghouse Electric Corporation, Westinghouse Proprietary Class 2, September, 1989.

13. "Donald C. Cook Nuclear Plant, Individual Plant Examination Summary Report", April 1992.

14. R. J. Budnitz, et al, "An Approach to the Quantification of Seismic Margins in Nuclear Power Plants," NUREG/CR-4334, 1985.

15. NUREG-1335, "Individual Plant Examination; Submittal Guidance," U.S. Nuclear Regulatory Commission, 1989.

16. CRC Standard Math Tables, 10th Edition.

**Table 1 - Revised Seismic Fragility Parameters for Limited Evaluation Components**

| Component | Original | | | | Revised | | | |
|---|---|---|---|---|---|---|---|---|
| Screen House | Br | Bu | B | Am | Br | Bu | B | Am |
| - Reinforced Concrete Walls [1] | 0.16 | 0.00 | 0.16 | 0.62 | .32 | .27 | .42 | 1.27 |
| - Columns/Shear Failure [1] | 0.31 | 0.00 | 0.31 | 0.72 | .42 | .27 | .50 | 1.48 |
| Auxiliary Building | | | | | | | | |
| - Foundation Mat [2] | 0.09 | 0.00 | 0.09 | 0.41 | .29 | .27 | .40 | .98 |
| - Concrete Structure [2] | 0.14 | 0.00 | 0.14 | 0.38 | .31 | .27 | .41 | .91 |
| Turbine Pedestal | | | | | | | | |
| - Columns - Bent I, XII [2] | 0.12 | 0.00 | 0.12 | 0.51 | .30 | .27 | .40 | 1.22 |
| - Columns - Bent II, XI [2] | 0.12 | 0.00 | 0.12 | 0.54 | .30 | .27 | .40 | 1.30 |
| - Columns - Bent III, IV, IX, X [2] | 0.12 | 0.00 | 0.12 | 0.53 | .30 | .27 | .40 | 1.27 |
| - Columns - Bent VI, VII [2] | 0.12 | 0.00 | 0.12 | 0.50 | .30 | .27 | .40 | 1.20 |
| Containment | | | | | | | | |
| - Soil Pressure [3] | 0.31 | 0.00 | 0.31 | 0.99 | .42 | .27 | .50 | 2.24 |
| Ice Condenser | | | | | | | | |
| - Top Deck Structure [4] | 0.11 | 0.00 | 0.11 | 0.52 | .30 | .27 | .40 | 1.41 |
| - Ice Baskets [4] | 0.20 | 0.00 | 0.20 | 0.66 | .34 | .27 | .43 | 1.80 |
| - Lower Support Structure [4] | 0.11 | 0.00 | 0.11 | 0.51 | .30 | .27 | .40 | 1.39 |
| - Lattice Frame, Cradles and Columns [4] | 0.39 | 0.00 | 0.39 | 0.91 | .48 | .27 | .55 | 2.48 |
| - Phase Link [4] | 0.39 | 0.00 | 0.39 | 0.87 | .48 | .27 | .55 | 2.37 |
| RCS Primary Components | | | | | | | | |
| - Upper Internals [5] | 0.14 | 0.00 | 0.14 | 0.65 | .42 | .27 | .50 | 2.24 |
| ECCS Pumps | | | | | | | | |
| - Residual Heat Removal [6] | 0.05 | 0.00 | 0.05 | 0.49 | .28 | .20 | .35 | .83 |
| RHR Heat Exchanger [6] | 0.10 | 0.00 | 0.10 | 0.53 | .30 | .20 | .36 | .76 |
| Diesel Generator | | | | | | | | |
| - Switchgear 600V [6] | 0.10 | 0.00 | 0.10 | 0.66 | .30 | .20 | .36 | 1.20 |
| Containment Spray | | | | | | | | |

**Table 1 (Cont'd)**
**Revised Seismic Fragility Parameters for Limited Evaluation Components**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| - Pumps [6] | 0.05 | 0.00 | 0.05 | 0.49 | .28 | .20 | .35 | .96 |
| - Heat Exchanger [6] | 0.10 | 0.00 | 0.10 | 0.40 | .30 | .20 | .36 | .62 |
| Reactor Protection System | | | | | | | | |
| - RPS/Aux Rack/STC [6] | 0.05 | 0.00 | 0.05 | 0.47 | .28 | .20 | .35 | .79 |

per Reference 4 (Rizzo & Associates letter) and References 8 and 9 unless noted.

[1] Screen House Structure factors (SSI: f=1.37, Bu=.27, Spectra: f=1.5, Br=.28)

[2] Auxiliary/Turbine Building Structure factor (SSI: f=1.60, Bu=.27, Spectra: f=1.5, Br=.28)

[3] Containment Structure Factor (SSI: f=1.26, Bu=.15, Spectra f=1.8, Br=.28)

[4] Containment Equipment Factor (SSI: f=2.09, Bu=.27, Spectra f=1.3, Br=.28)

[5] RCS Primary Component Factor (SSI: f=2.09, Bu=.27, Spectra: f=1.3, Br=.28)

[6] Auxiliary Building Equipment Factor (SSI: f=1.30, Bu=.20, Spectra: [RHR Pump=1.3, RHR Hx=1.1, SWGR=1.4, CTS Pump=1.3, CTS Hx=1.2, RPS=1.3, Bu=.28 for all])

TABLE 2

SEISMIC ACCELERATION LEVEL PROBABILITIES

(COOK SITE)

| Event Tree Node | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Seismic Interval "X" | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
| Acceleration Range * | 0.25 - 0.30 | 0.30 - 0.35 | 0.35 - 0.40 | 0.40 - 0.45 | 0.45 - 0.50 | 0.50 - 0.55 | 0.55 - 0.60 | 0.60 - 0.75 |
| Median Accel. ($A_{gm}$) * | 0.275 | 0.325 | 0.375 | 0.425 | 0.475 | 0.525 | 0.575 | 0.675 |
| ** Frequency of Exceedance | 2.09E-05 - 1.23E-05 | 1.23E-05 - 7.22E-06 | 7.22E-06 - 4.25E-06 | 4.25E-06 - 2.50E-06 | 2.50E-06 - 1.47E-06 | 1.47E-06 - 8.63E-07 | 8.63E-07 - 5.08E-07 | 5.08E-07 - 1.03E-07 |
| ** Frequency of Occurrence | 8.6E-06 | 5.1E-06 | 2.97E-06 | 1.75E-06 | 1.03E-06 | 6.07E-07 | 3.56E-07 | 4.05E-07 |

* All accelerations units are g's.
** Frequencies are calculated on a per year basis

Table 3
Seismic Fragility Parameters

| Structure or Component | Fragility Parameters | | | |
|---|---|---|---|---|
| | Beta r | Beta u | Beta | Am |
| **Screen House** | | | | |
| - Reinforced Concrete Wal | 0.32 | 0.27 | 0.42 | 1.27 |
| - Piers | 0.16 | 0 | 0.16 | 1.05 |
| - Base Slabs | 0.31 | 0.35 | 0.47 | 1.06 |
| - Crane Runway Girders | 0.3 | 0 | 0.3 | 1.33 |
| - Columns/Buckling Failur | 0.1 | 0 | 0.1 | 1.4 |
| - Columns/Shear Failure | 0.42 | 0.27 | 0.50 | 1.48 |
| **Auxiliary Building** | | | | |
| - Soil Pressure | 0.3 | 0 | 0.3 | 1.36 |
| - Foundation Mat | 0.29 | 0.27 | 0.4 | 0.98 |
| - Steel Structure | 0.31 | 0.29 | 0.42 | 0.85 |
| - Concrete Structure | 0.31 | 0.27 | 0.41 | 0.91 |
| **Turbine Pedestal** | | | | |
| - Columns - Bent I, XII | 0.3 | 0.27 | 0.40 | 1.22 |
| - Columns - Bent II, XI | 0.3 | 0.27 | 0.40 | 1.3 |
| - Columns - Bent III, IV IX, and X | 0.3 | 0.27 | 0.40 | 1.27 |
| - Columns - Bent V, VIII | 0.12 | 0 | 0.12 | 0.82 |
| - Columns - Bent VI, VII | 0.3 | 0.27 | 0.40 | 1.2 |
| **Containment** | | | | |
| - Containment Rebar | 0.31 | 0 | 0.31 | 1.53 |
| - Soil Pressure | 0.42 | 0.27 | 0.50 | 0.99 |
| **Polar Crane** | | | | |
| - Girder/Trunnion Weld | 0.15 | 0 | 0.15 | 0.39 |
| **Ice Condenser** | | | | |
| - Top Deck Structure | 0.3 | 0.27 | 0.40 | 1.41 |
| - Ice Baskets | 0.34 | 0.27 | 0.43 | 1.8 |
| - Lower Support Structure | 0.3 | 0.27 | 0.40 | 1.39 |
| - Lattice Frame, Cradles and Columns | 0.48 | 0.27 | 0.55 | 2.48 |
| - Embedments on Crane Wal | 0.32 | 0 | 0.32 | 1.21 |
| - Phasing Link | 0.48 | 0.27 | 0.55 | 2.37 |
| **RCS Primary Components** | | | | |
| - Reactor Vessel | 0.13 | 0 | 0.13 | 2.1 |
| - Lower Internals (Therma Shield and Core Barrel) | 0.27 | 0 | 0.27 | 1.17 |
| - Upper Internals | 0.42 | 0.27 | 0.50 | 2.24 |
| - Control Rod Drive Mechanisms with RPI | 0.32 | 0 | 0.32 | 2.3 |
| - Reactor Coolant Pump | 0.32 | 0 | 0.32 | 1.62 |
| - Steam Generator | 0.27 | 0 | 0.27 | 2.84 |
| - Pressurizer and Support | 0.14 | 0.28 | 0.31 | 0.84 |

Table 3 (Cont'd)
Seismic Fragility Parameters

| Line | Structure or Component | Fragility Parameters | | | |
|---|---|---|---|---|---|
| | | Beta r | Beta u | Beta | Am |
| 58 | Reactor Coolant Loop Pipi | 0.14 | 0 | 0.14 | 2.67 |
| 59 | | | | | |
| 60 | Primary Component Supports | | | | |
| 61 | | | | | |
| 62 | - Reactor Vessel | 0.18 | 0 | 0.18 | 3.1 |
| 63 | - Steam Generators | 0.27 | 0 | 0.27 | 1.72 |
| 64 | - Reactor Coolant Pumps | 0.32 | 0 | 0.32 | 1.97 |
| 65 | | | | | |
| 66 | Pressurizer | | | | |
| 67 | | | | | |
| 68 | - Safety Valves | 0.2 | 0.35 | 0.4 | 2.37 |
| 69 | - PORVs | 0.2 | 0.57 | 0.60 | 1.68 |
| 70 | | | | | |
| 71 | Regenerative Heat Exchang | 0.1 | 0 | 0.1 | 0.75 |
| 72 | | | | | |
| 73 | Excess Letdown Heat Excha | 0.1 | 0 | 0.1 | 0.73 |
| 74 | | | | | |
| 75 | Level & Pressure Transmit | 0.1 | 0 | 0.1 | 0.75 |
| 76 | | | | | |
| 77 | Auxiliary Piping Systems | | | | |
| 78 | (Secondary Side) | | | | |
| 79 | - Piping | 0.23 | 0 | 0.23 | 2 |
| 80 | - Supports | 0.31 | 0.28 | 0.42 | 0.81 |
| 81 | | | | | |
| 82 | ECCS Pumps | | | | |
| 83 | | | | | |
| 84 | - Residual Heat Removal | 0.28 | 0.2 | 0.34 | 0.83 |
| 85 | - Centrifugal Charging | 0.1 | 0 | 0.1 | 0.94 |
| 86 | - Safety Injection | 0.1 | 0 | 0.1 | 0.94 |
| 87 | - Boric Acid | 0.1 | 0 | 0.1 | 0.94 |
| 88 | | | | | |
| 89 | ECCS Tanks | | | | |
| 90 | | | | | |
| 91 | - Refueling Water Storage | 0.31 | 0.21 | 0.37 | 0.95 |
| 92 | - Accumulators | 0.19 | 0.45 | 0.49 | 0.9 |
| 93 | - Boron Injection | 0.25 | 0.45 | 0.51 | 1.42 |
| 94 | | | | | |
| 95 | RHR Heat Exchangers | 0.3 | 0.2 | 0.36 | 0.76 |
| 96 | | | | | |
| 97 | ECCS Valves | | | | |
| 98 | | | | | |
| 99 | - Check Valves | 0.2 | 0.35 | 0.4 | 3.79 |
| 100 | - Miscellaneous Isolation | 0.26 | 0.6 | 0.65 | 2.36 |
| 101 | - HPSI Isolation | 0.1 | 0 | 0.1 | 2.25 |

Table 3 (Cont'd)
Seismic Fragility Parameters

| Line | Structure or Component | Fragility Parameters | | | |
|---|---|---|---|---|---|
| | | Beta r | Beta u | Beta | Am |
| 102 | | | | | |
| 103 | Emergency Diesel Generators | | | | |
| 104 | | | | | |
| 105 | - Diesel Oil Pump | 0.25 | 0.27 | 0.37 | 2 |
| 106 | - Fuel Oil Day Tank | 0.34 | 0.3 | 0.45 | 0.66 |
| 107 | - Diesel Generator | 0.25 | 0.31 | 0.4 | 0.91 |
| 108 | - SWGR (600V) | 0.3 | 0.2 | 0.36 | 1.2 |
| 109 | - Transformer | 0.28 | 0.25 | 0.38 | 0.79 |
| 110 | - SWGR (4kV) | 0.31 | 0.37 | 0.48 | 1.77 |
| 111 | - Battery Rack | 0.21 | 0.21 | 0.3 | 0.71 |
| 112 | - Motor Control Center | 0.34 | 0.3 | 0.45 | 0.64 |
| 113 | - Charger AB. CD. N | 0.31 | 0.49 | 0.58 | 1.52 |
| 114 | - Control Panel | 0.48 | 0.74 | 0.88 | 5.9 |
| 115 | - AC Distribution Panel | 0.48 | 0.74 | 0.88 | 5.11 |
| 116 | - Miscellaneous Valves | 0.26 | 0.6 | 0.65 | 2.15 |
| 117 | - Batteries | 0.21 | 0.21 | 0.3 | 0.71 |
| 118 | - Cable Trays | 0.34 | 0.19 | 0.39 | 1.98 |
| 119 | | | | | |
| 120 | Containment Spray | | | | |
| 121 | | | | | |
| 122 | - Pumps | 0.28 | 0.2 | 0.34 | 0.96 |
| 123 | - Spray Additive Tank | 0.2 | 0.35 | 0.4 | 1.46 |
| 124 | - Heat Exchangers | 0.3 | 0.2 | 0.36 | 0.4 |
| 125 | - Spray Additive Tank Vlv | 0.26 | 0.6 | 0.65 | 2.48 |
| 126 | - System Valves | 0.26 | 0.6 | 0.65 | 2.36 |
| 127 | | | | | |
| 128 | Containment Recirc Fans | 0.27 | 0.31 | 0.41 | 0.91 |
| 129 | | | | | |
| 130 | Auxiliary Feedwater | | | | |
| 131 | | | | | |
| 132 | - Motor Driven Pump | 0.21 | 0.27 | 0.34 | 2.28 |
| 133 | - Turbine Driven Pump | 0.21 | 0.27 | 0.34 | 2.28 |
| 134 | - Pump Isolation Valves | 0.31 | 0.34 | 0.46 | 3.9 |
| 135 | - SG Isolation Valves | 0.26 | 0.6 | 0.65 | 4.37 |
| 136 | - Fans (Room Cooling) | 0.27 | 0.31 | 0.41 | 1.09 |
| 137 | | | | | |
| 138 | Reactor Protection System | | | | |
| 139 | | | | | |
| 140 | - MCC | 0.48 | 0.74 | 0.88 | 3.32 |
| 141 | - Crid Inverter | 0.26 | 0.35 | 0.44 | 7.61 |
| 142 | - Miscellaneous Panels | 0.48 | 0.66 | 0.82 | 3.4 |
| 143 | - Cable Trays | 0.34 | 0.19 | 0.39 | 1.98 |
| 144 | - Crid Transformer | 0.28 | 0.3 | 0.41 | 2.22 |
| 145 | - RPS/Aux Rack/STC | 0.28 | 0.2 | 0.34 | 0.79 |
| 146 | - Main Control Board | 0.48 | 0.74 | 0.88 | 5.11 |
| 147 | | | | | |
| 148 | Component Cooling Water | | | | |
| 149 | note - piping supports being reevaluated. ignored for this analysis | | | | |
| 150 | - Pumps (Piping Supports) | 0 | 0 | 0.01 | 0.51 |
| 151 | - Pumps (Water) | 0.21 | 0.27 | 0.34 | 2.28 |
| 152 | - Heat Exchanger | 0.28 | 0.23 | 0.36 | 1.07 |
| 153 | - Surge Tank | 0.2 | 0.35 | 0.4 | 1.3 |
| 154 | - Valves | 0.26 | 0.6 | 0.65 | 2.15 |
| 155 | | | | | |

## Table 3 (Cont'd)
## Seismic Fragility Parameters

| Line | Structure or Component | Fragility Parameters Beta r | Beta u | Beta | Am |
|---|---|---|---|---|---|
| 156 | Essential Service Water Sys | | | | |
| 157 | | | | | |
| 158 | - ESW Pumps | 0.31 | 0.25 | 0.40 | 1.13 |
| 159 | - ESW Valves | 0.26 | 0.6 | 0.65 | 2.15 |
| 160 | - ESW Strainers | 0.22 | 0.32 | 0.39 | 2.01 |
| 161 | | | | | |
| 162 | Main Steam System | | | | |
| 163 | | | | | |
| 164 | - MSIVs | 0.1 | 0 | 0.1 | 1.88 |
| 165 | - PORVs | 0.1 | 0 | 0.1 | 1.75 |
| 166 | - MSIV Isol. Valves | 0.1 | 0 | 0.1 | 3.5 |
| 167 | - Safety Valves | 0.2 | 0.35 | 0.4 | 3.96 |
| 168 | - Steam Generator Dump | 0.1 | 0 | 0.1 | 1.29 |
| 169 | | | | | |
| 170 | Main Feedwater System | | | | |
| 171 | | | | | |
| 172 | - Isolation Valves | 0.26 | 0.6 | 0.65 | 2.1 |
| 173 | - Control Valves | 0.31 | 0.34 | 0.46 | 3.31 |
| 174 | | | | | |
| 175 | Switchyard | | | | |
| 176 | | | | | |
| 177 | - Ceramic Insulators | 0.25 | 0.25 | 0.35 | 0.2 |

Table 4

Standard Deviation from Fragility Median

| Structure or Component | Standard Deviation from Median | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
| Screen House | | | | | | | | |
| | 0.275 | 0.325 | 0.375 | 0.425 | 0.475 | 0.525 | 0.575 | 0.675 |
| - Reinforced Concrete Walls | -3.654 | -3.255 | -2.913 | -2.615 | -2.349 | -2.110 | -1.893 | -1.510 |
| - Piers | -8.374 | -7.330 | -6.435 | -5.653 | -4.958 | -4.332 | -3.764 | -2.761 |
| - Base Slabs | -2.886 | -2.529 | -2.222 | -1.955 | -1.717 | -1.503 | -1.308 | -0.965 |
| - Crane Runway Girders | -5.254 | -4.697 | -4.220 | -3.803 | -3.432 | -3.098 | -2.795 | -2.261 |
| - Columns/Buckling Failure | -16.275 | -14.604 | -13.173 | -11.921 | -10.809 | -9.808 | -8.899 | -7.295 |
| - Columns/Shear Failure | -3.371 | -3.036 | -2.750 | -2.499 | -2.276 | -2.076 | -1.894 | -1.572 |
| Auxiliary Building | | | | | | | | |
| - Soil Pressure | -5.328 | -4.771 | -4.294 | -3.877 | -3.506 | -3.173 | -2.870 | -2.335 |
| - Foundation Mat | -3.177 | -2.759 | -2.402 | -2.089 | -1.811 | -1.560 | -1.333 | -0.932 |
| - Steel Structure | -2.658 | -2.265 | -1.928 | -1.633 | -1.371 | -1.135 | -0.921 | -0.543 |
| - Concrete Structure | -2.911 | -2.505 | -2.156 | -1.852 | -1.581 | -1.338 | -1.117 | -0.727 |
| Turbine Pedestal | | | | | | | | |
| - Columns - Bent I, XII | -3.691 | -3.277 | -2.923 | -2.613 | -2.337 | -2.089 | -1.864 | -1.467 |
| - Columns - Bent II, XI | -3.849 | -3.435 | -3.080 | -2.770 | -2.495 | -2.247 | -2.021 | -1.624 |
| - Columns - Bent III, IV IX, and X | -3.791 | -3.377 | -3.022 | -2.712 | -2.437 | -2.189 | -1.963 | -1.566 |
| - Columns - Bent V, VIII | -9.104 | -7.712 | -6.520 | -5.477 | -4.550 | -3.716 | -2.958 | -1.622 |
| - Columns - Bent VI, VII | -3.650 | -3.236 | -2.882 | -2.572 | -2.296 | -2.048 | -1.823 | -1.426 |
| Containment | | | | | | | | |
| - Containment Rebar | -5.536 | -4.997 | -4.536 | -4.132 | -3.773 | -3.450 | -3.157 | -2.640 |
| - Soil Pressure | -2.565 | -2.231 | -1.944 | -1.694 | -1.471 | -1.270 | -1.088 | -0.767 |
| Polar Crane | | | | | | | | |
| - Girder/Trunnion Weld | -2.329 | -1.215 | -0.261 | 0.573 | 1.314 | 1.982 | 2.588 | 3.657 |
| Ice Condenser | | | | | | | | |
| - Top Deck Structure | -4.050 | -3.636 | -3.281 | -2.971 | -2.696 | -2.448 | -2.222 | -1.825 |
| - Ice Baskets | -4.327 | -3.943 | -3.613 | -3.325 | -3.068 | -2.838 | -2.628 | -2.259 |
| - Lower Support Structure | -4.015 | -3.601 | -3.246 | -2.936 | -2.660 | -2.412 | -2.187 | -1.790 |
| - Lattice Frame, Cradles and Columns | -3.993 | -3.690 | -3.430 | -3.203 | -3.001 | -2.819 | -2.654 | -2.363 |
| - Embedments on Crane Wall | -4.630 | -4.108 | -3.661 | -3.270 | -2.922 | -2.609 | -2.325 | -1.824 |
| - Phasing Link | -3.911 | -3.608 | -3.348 | -3.121 | -2.919 | -2.737 | -2.572 | -2.281 |
| RCS Primary Components | | | | | | | | |
| - Reactor Vessel | -15.638 | -14.353 | -13.252 | -12.289 | -11.434 | -10.664 | -9.964 | -8.731 |
| - Lower Internals (Thermal Shield and Core Barrel) | -5.363 | -4.744 | -4.214 | -3.751 | -3.339 | -2.968 | -2.631 | -2.037 |
| - Upper Internals | -4.201 | -3.866 | -3.580 | -3.329 | -3.106 | -2.906 | -2.724 | -2.402 |
| - Control Rod Drive Mechanisms with RPI | -6.637 | -6.115 | -5.668 | -5.277 | -4.929 | -4.616 | -4.332 | -3.831 |
| - Reactor Coolant Pump | -5.542 | -5.020 | -4.573 | -4.182 | -3.834 | -3.521 | -3.237 | -2.736 |
| - Steam Generator | -8.647 | -8.029 | -7.499 | -7.035 | -6.623 | -6.252 | -5.916 | -5.322 |
| - Pressurizer and Supports | -3.602 | -3.063 | -2.602 | -2.198 | -1.839 | -1.516 | -1.223 | -0.705 |

Table 4 (Cont'd)

Standard Deviation from Fragility Median

| Line | Structure or Component | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| | | Standard Deviation from Median | | | | | | | |
| 58 | Reactor Coolant Loop Piping | -16.236 | -15.043 | -14.021 | -13.127 | -12.332 | -11.617 | -10.968 | -9.822 |
| 59 | | | | | | | | | |
| 60 | Primary Component Supports | | | | | | | | |
| 61 | | | | | | | | | |
| 62 | - Reactor Vessel | -13.458 | -12.530 | -11.735 | -11.039 | -10.421 | -9.865 | -9.360 | -8.469 |
| 63 | - Steam Generators | -6.790 | -6.171 | -5.641 | -5.178 | -4.766 | -4.395 | -4.058 | -3.464 |
| 64 | - Reactor Coolant Pumps | -6.153 | -5.631 | -5.184 | -4.793 | -4.445 | -4.132 | -3.848 | -3.347 |
| 65 | | | | | | | | | |
| 66 | Pressurizer | | | | | | | | |
| 67 | | | | | | | | | |
| 68 | - Safety Valves | -5.385 | -4.967 | -4.609 | -4.296 | -4.018 | -3.768 | -3.541 | -3.140 |
| 69 | - PORVs | -2.996 | -2.719 | -2.483 | -2.275 | -2.091 | -1.926 | -1.775 | -1.509 |
| 70 | | | | | | | | | |
| 71 | Regenerative Heat Exchanger | -10.033 | -8.362 | -6.931 | -5.680 | -4.568 | -3.567 | -2.657 | -1.054 |
| 72 | | | | | | | | | |
| 73 | Excess Letdown Heat Exchanger | -9.763 | -8.092 | -6.661 | -5.410 | -4.297 | -3.296 | -2.387 | -0.783 |
| 74 | | | | | | | | | |
| 75 | Level & Pressure Transmitters | -10.033 | -8.362 | -6.931 | -5.680 | -4.568 | -3.567 | -2.657 | -1.054 |
| 76 | | | | | | | | | |
| 77 | Auxiliary Piping Systems | | | | | | | | |
| 78 | (Secondary Side) | | | | | | | | |
| 79 | - Piping | -8.627 | -7.900 | -7.278 | -6.734 | -6.259 | -5.815 | -5.420 | -4.723 |
| 80 | - Supports | -2.586 | -2.186 | -1.844 | -1.544 | -1.278 | -1.038 | -0.820 | -0.436 |
| 81 | | | | | | | | | |
| 82 | ECCS Pumps | | | | | | | | |
| 83 | | | | | | | | | |
| 84 | - Residual Heat Removal | -3.210 | -2.725 | -2.309 | -1.945 | -1.622 | -1.331 | -1.067 | -0.601 |
| 85 | - Centrifugal Charging | -12.291 | -10.621 | -9.190 | -7.938 | -6.826 | -5.825 | -4.915 | -3.312 |
| 86 | - Safety Injection | -12.291 | -10.621 | -9.190 | -7.938 | -6.826 | -5.825 | -4.915 | -3.312 |
| 87 | - Boric Acid | -12.291 | -10.621 | -9.190 | -7.938 | -6.826 | -5.825 | -4.915 | -3.312 |
| 88 | | | | | | | | | |
| 89 | ECCS Tanks | | | | | | | | |
| 90 | | | | | | | | | |
| 91 | - Refueling Water Storage | -3.311 | -2.865 | -2.483 | -2.148 | -1.851 | -1.584 | -1.341 | -0.913 |
| 92 | - Accumulators | -2.420 | -2.079 | -1.787 | -1.531 | -1.304 | -1.100 | -0.914 | -0.587 |
| 93 | - Boron Injection | -3.219 | -2.891 | -2.611 | -2.365 | -2.147 | -1.951 | -1.773 | -1.458 |
| 94 | | | | | | | | | |
| 95 | RHR Heat Exchangers | -2.819 | -2.356 | -1.959 | -1.612 | -1.304 | -1.026 | -0.774 | -0.329 |
| 96 | | | | | | | | | |
| 97 | ECCS Valves | | | | | | | | |
| 98 | | | | | | | | | |
| 99 | - Check Valves | -6.558 | -6.141 | -5.783 | -5.470 | -5.192 | -4.942 | -4.714 | -4.314 |
| 100 | - Miscellaneous Isolation | -3.307 | -3.050 | -2.830 | -2.637 | -2.466 | -2.312 | -2.172 | -1.926 |
| 101 | - HPSI Isolation | -21.019 | -19.349 | -17.918 | -16.666 | -15.554 | -14.553 | -13.643 | -12.040 |

Table 4 (Cont'd)

Standard Deviation from Fragility Median

| Line | Structure or Component | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| | | Standard Deviation from Median | | | | | | | |
| 102 | | | | | | | | | |
| 103 | Emergency Diesel Generators | | | | | | | | |
| 104 | | | | | | | | | |
| 105 | - Diesel Oil Pump | -5.363 | -4.911 | -4.524 | -4.186 | -3.885 | -3.615 | -3.369 | -2.936 |
| 106 | - Fuel Oil Day Tank | -1.931 | -1.562 | -1.247 | -0.971 | -0.725 | -0.505 | -0.304 | 0.050 |
| 107 | - Diesel Generator | -2.992 | -2.574 | -2.216 | -1.903 | -1.625 | -1.375 | -1.148 | -0.747 |
| 108 | - SWGR (600V) | -4.086 | -3.623 | -3.226 | -2.879 | -2.570 | -2.293 | -2.040 | -1.596 |
| 109 | - Transformer | -2.811 | -2.366 | -1.985 | -1.652 | -1.355 | -1.089 | -0.846 | -0.419 |
| 110 | - SWGR (4kV) | -3.857 | -3.511 | -3.215 | -2.956 | -2.725 | -2.518 | -2.329 | -1.997 |
| 111 | - Battery Rack | -3.162 | -2.605 | -2.128 | -1.711 | -1.340 | -1.006 | -0.703 | -0.169 |
| 112 | - Motor Control Center | -1.863 | -1.494 | -1.179 | -0.903 | -0.658 | -0.437 | -0.236 | 0.117 |
| 113 | - Charger AB. CD. N | -2.948 | -2.660 | -2.413 | -2.197 | -2.005 | -1.833 | -1.676 | -1.400 |
| 114 | - Control Panel | -3.484 | -3.294 | -3.132 | -2.989 | -2.863 | -2.749 | -2.646 | -2.464 |
| 115 | - AC Distribution Panel | -3.321 | -3.131 | -2.968 | -2.826 | -2.700 | -2.586 | -2.482 | -2.300 |
| 116 | - Miscellaneous Valves. | -3.164 | -2.907 | -2.687 | -2.494 | -2.323 | -2.169 | -2.029 | -1.782 |
| 117 | - Batteries | -3.162 | -2.605 | -2.128 | -1.711 | -1.340 | -1.006 | -0.703 | -0.169 |
| 118 | - Cable Trays | -5.062 | -4.633 | -4.266 | -3.946 | -3.660 | -3.404 | -3.170 | -2.759 |
| 119 | | | | | | | | | |
| 120 | Containment Spray | | | | | | | | |
| 121 | | | | | | | | | |
| 122 | - Pumps | -3.633 | -3.148 | -2.732 | -2.368 | -2.045 | -1.754 | -1.490 | -1.024 |
| 123 | - Spray Additive Tank | -4.174 | -3.756 | -3.398 | -3.085 | -2.807 | -2.557 | -2.330 | -1.929 |
| 124 | - Heat Exchangers | -1.039 | -0.576 | -0.179 | 0.168 | 0.477 | 0.754 | 1.007 | 1.451 |
| 125 | - Spray Additive Tank Vlvs | -3.383 | -3.126 | -2.906 | -2.714 | -2.543 | -2.389 | -2.249 | -2.002 |
| 126 | - System Valves | -3.307 | -3.050 | -2.830 | -2.637 | -2.466 | -2.312 | -2.172 | -1.926 |
| 127 | | | | | | | | | |
| 128 | Containment Recirc Fans | -2.919 | -2.511 | -2.162 | -1.857 | -1.586 | -1.342 | -1.120 | -0.729 |
| 129 | | | | | | | | | |
| 130 | Auxiliary Feedwater | | | | | | | | |
| 131 | | | | | | | | | |
| 132 | - Motor Driven Pump | -6.221 | -5.730 | -5.309 | -4.941 | -4.614 | -4.319 | -4.052 | -3.580 |
| 133 | - Turbine Driven Pump | -6.221 | -5.730 | -5.309 | -4.941 | -4.614 | -4.319 | -4.052 | -3.580 |
| 134 | - Pump Isolation Valves | -5.765 | -5.402 | -5.091 | -4.819 | -4.577 | -4.359 | -4.162 | -3.813 |
| 135 | - SG Isolation Valves | -4.255 | -3.998 | -3.778 | -3.585 | -3.414 | -3.260 | -3.120 | -2.874 |
| 136 | - Fans (Room Cooling) | -3.359 | -2.951 | -2.602 | -2.297 | -2.026 | -1.782 | -1.560 | -1.169 |
| 137 | | | | | | | | | |
| 138 | Reactor Protection System | | | | | | | | |
| 139 | | | | | | | | | |
| 140 | - MCC | -2.831 | -2.641 | -2.478 | -2.336 | -2.210 | -2.096 | -1.992 | -1.810 |
| 141 | - Crid Inverter | -7.546 | -7.167 | -6.842 | -6.557 | -6.304 | -6.077 | -5.870 | -5.506 |
| 142 | - Miscellaneous Panels | -3.067 | -2.863 | -2.689 | -2.536 | -2.400 | -2.278 | -2.167 | -1.972 |
| 143 | - Cable Trays | -5.062 | -4.633 | -4.266 | -3.946 | -3.660 | -3.404 | -3.170 | -2.759 |
| 144 | - Crid Transformer | -5.094 | -4.686 | -4.337 | -4.032 | -3.761 | -3.517 | -3.295 | -2.904 |
| 145 | - RPS/Aux Rack/STC | -3.067 | -2.581 | -2.165 | -1.802 | -1.478 | -1.188 | -0.923 | -0.457 |
| 146 | - Main Control Board | -3.321 | -3.131 | -2.968 | -2.826 | -2.700 | -2.586 | -2.482 | -2.300 |
| 147 | | | | | | | | | |
| 148 | Component Cooling Water | | | | | | | | |
| 149 | note - piping supports being reevaluated. ignored for this analysis | | | | | | | | |
| 150 | - Pumps (Piping Supports) | -61.764 | -45.059 | -30.748 | -18.232 | -7.110 | 2.899 | 11.996 | 28.030 |
| 151 | - Pumps (Water) | -6.221 | -5.730 | -5.309 | -4.941 | -4.614 | -4.319 | -4.052 | -3.580 |
| 152 | - Heat Exchanger | -3.749 | -3.288 | -2.894 | -2.548 | -2.241 | -1.965 | -1.714 | -1.271 |
| 153 | - Surge Tank | -3.883 | -3.466 | -3.108 | -2.795 | -2.517 | -2.267 | -2.039 | -1.639 |
| 154 | - Valves | -3.164 | -2.907 | -2.687 | -2.494 | -2.323 | -2.169 | -2.029 | -1.782 |
| 155 | | | | | | | | | |

Table 4 (Cont'd)

Standard Deviation from Fragility Median

| Line | Structure or Component | Standard Deviation from Median | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
| 156 | Essential Service Water Sys | | | | | | | | |
| 157 | | | | | | | | | |
| 158 | - ESW Pumps | -3.549 | -3.129 | -2.770 | -2.455 | -2.176 | -1.925 | -1.696 | -1.294 |
| 159 | - ESW Valves | -3.164 | -2.907 | -2.687 | -2.494 | -2.323 | -2.169 | -2.029 | -1.782 |
| 160 | - ESW Strainers | -5.100 | -4.672 | -4.305 | -3.984 | -3.699 | -3.442 | -3.209 | -2.798 |
| 161 | | | | | | | | | |
| 162 | Main Steam System | | | | | | | | |
| 163 | | | | | | | | | |
| 164 | - MSIVs | -19.223 | -17.552 | -16.121 | -14.869 | -13.757 | -12.756 | -11.847 | -10.243 |
| 165 | - PORVs | -18.506 | -16.835 | -15.404 | -14.153 | -13.041 | -12.040 | -11.130 | -9.527 |
| 166 | - MSIV Isol. Valves | -25.437 | -23.767 | -22.336 | -21.084 | -19.972 | -18.971 | -18.061 | -16.458 |
| 167 | - Safety Valves | -6.668 | -6.250 | -5.893 | -5.580 | -5.302 | -5.052 | -4.824 | -4.423 |
| 168 | - Steam Generator Dump | -15.456 | -13.786 | -12.355 | -11.103 | -9.991 | -8.990 | -8.080 | -6.477 |
| 169 | | | | | | | | | |
| 170 | Main Feedwater System | | | | | | | | |
| 171 | | | | | | | | | |
| 172 | - Isolation Valves | -3.128 | -2.871 | -2.650 | -2.458 | -2.287 | -2.133 | -1.993 | -1.746 |
| 173 | - Control Valves | -5.409 | -5.045 | -4.734 | -4.462 | -4.220 | -4.003 | -3.805 | -3.457 |
| 174 | | | | | | | | | |
| 175 | Switchyard | | | | | | | | |
| 176 | | | | | | | | | |
| 177 | - Ceramic Insulators | 0.910 | 1.387 | 1.796 | 2.154 | 2.472 | 2.757 | 3.017 | 3.475 |

Table 5

Structure and Component
Failure Probability for Each Seismic Interval

| Line | Structure or Component | Failure Probabilities 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| 2 | Screen House | | | | | | | | |
| 3 | | | | | | | | | |
| 4 | - Reinforced Concrete Walls | 0.0000 | 0.0000 | 0.0019 | 0.0047 | 0.0107 | 0.0179 | 0.0359 | 0.0668 |
| 5 | - Piers | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| 6 | - Base Slabs | 0.0022 | 0.0062 | 0.0139 | 0.0287 | 0.0446 | 0.0668 | 0.0968 | 0.1841 |
| 7 | - Crane Runway Girders | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.0030 | 0.0139 |
| 8 | - Columns/Buckling Failure | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 9 | - Columns/Shear Failure | 0.0000 | 0.0013 | 0.0035 | 0.0071 | 0.0139 | 0.0227 | 0.0359 | 0.0668 |
| 10 | | | | | | | | | |
| 11 | Auxiliary Building | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | - Soil Pressure | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0022 | 0.0107 |
| 14 | - Foundation Mat | 0.0000 | 0.0030 | 0.0082 | 0.0227 | 0.0359 | 0.0668 | 0.0968 | 0.1841 |
| 15 | - Steel Structure | 0.0040 | 0.0139 | 0.0287 | 0.0548 | 0.0968 | 0.1357 | 0.1841 | 0.3085 |
| 16 | - Concrete Structure | 0.0019 | 0.0062 | 0.0179 | 0.0359 | 0.0668 | 0.0968 | 0.1357 | 0.2420 |
| 17 | | | | | | | | | |
| 18 | Turbine Pedestal | | | | | | | | |
| 19 | | | | | | | | | |
| 20 | - Columns - Bent I, XII | 0.0000 | 0.0000 | 0.0019 | 0.0047 | 0.0107 | 0.0227 | 0.0359 | 0.0808 |
| 21 | - Columns - Bent II, XI | 0.0000 | 0.0000 | 0.0011 | 0.0030 | 0.0071 | 0.0139 | 0.0227 | 0.0548 |
| 22 | - Columns - Bent III, IV | 0.0000 | 0.0000 | 0.0013 | 0.0035 | 0.0082 | 0.0179 | 0.0287 | 0.0668 |
| 23 | IX, and X | | | | | | | | |
| 24 | - Columns - Bent V, VIII | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0548 |
| 25 | - Columns - Bent VI, VII | 0.0000 | 0.0000 | 0.0022 | 0.0054 | 0.0139 | 0.0227 | 0.0359 | 0.0808 |
| 26 | | | | | | | | | |
| 27 | Containment | | | | | | | | |
| 28 | | | | | | | | | |
| 29 | - Containment Rebar | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0047 |
| 30 | - Soil Pressure | 0.0054 | 0.0139 | 0.0287 | 0.0548 | 0.0808 | 0.1151 | 0.1587 | 0.2420 |
| 31 | | | | | | | | | |
| 32 | Polar Crane | | | | | | | | |
| 33 | | | | | | | | | |
| 34 | - Girder/Trunnion Weld | 0.0107 | 0.1151 | 0.4207 | 0.6915 | 0.9032 | 0.9713 | 0.9946 | 1.0000 |
| 35 | | | | | | | | | |
| 36 | Ice Condenser | | | | | | | | |
| 37 | | | | | | | | | |
| 38 | - Top Deck Structure | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0040 | 0.0082 | 0.0139 | 0.0359 |
| 39 | - Ice Baskets | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0139 |
| 40 | - Lower Support Structure | 0.0000 | 0.0000 | 0.0000 | 0.0019 | 0.0040 | 0.0082 | 0.0179 | 0.0446 |
| 41 | - Lattice Frame, Cradles | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0013 | 0.0026 | 0.0040 | 0.0094 |
| 42 | and Columns | | | | | | | | |
| 43 | - Embedments on Crane Wall | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 | 0.0047 | 0.0107 | 0.0359 |
| 44 | - Phasing Link | 0.0000 | 0.0000 | 0.0000 | 0.0010 | 0.0019 | 0.0035 | 0.0054 | 0.0139 |
| 45 | | | | | | | | | |
| 46 | RCS Primary Components | | | | | | | | |
| 47 | | | | | | | | | |
| 48 | - Reactor Vessel | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 49 | - Lower Internals (Thermal | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0047 | 0.0227 |
| 50 | Shield and Core Barrel) | | | | | | | | |
| 51 | - Upper Internals | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0010 | 0.0019 | 0.0035 | 0.0082 |
| 52 | - Control Rod Drive | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 53 | Mechanisms with RPI | | | | | | | | |
| 54 | - Reactor Coolant Pump | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0035 |
| 55 | - Steam Generator | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 56 | - Pressurizer and Supports | 0.0000 | 0.0011 | 0.0047 | 0.0179 | 0.0359 | 0.0668 | 0.1151 | 0.2420 |
| 57 | | | | | | | | | |

Table 5 (Cont'd)

Structure and Component
Failure Probability for Each Seismic Interval

| Line | Structure or Component | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| | | Failure Probabilities | | | | | | | |
| 58 | Reactor Coolant Loop Piping | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 59 | | | | | | | | | |
| 60 | Primary Component Supports | | | | | | | | |
| 61 | | | | | | | | | |
| 62 | - Reactor Vessel | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 63 | - Steam Generators | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 64 | - Reactor Coolant Pumps | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 65 | | | | | | | | | |
| 66 | Pressurizer | | | | | | | | |
| 67 | | | | | | | | | |
| 68 | - Safety Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0010 |
| 69 | - PORVs | 0.0016 | 0.0035 | 0.0071 | 0.0139 | 0.0227 | 0.0287 | 0.0446 | 0.0668 |
| 70 | | | | | | | | | |
| 71 | Regenerative Heat Exchanger | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0040 | 0.1587 |
| 72 | | | | | | | | | |
| 73 | Excess Letdown Heat Exchanger | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0094 | 0.2420 |
| 74 | | | | | | | | | |
| 75 | Level & Pressure Transmitters | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0040 | 0.1587 |
| 76 | | | | | | | | | |
| 77 | Auxiliary Piping Systems | | | | | | | | |
| 78 | (Secondary Side) | | | | | | | | |
| 79 | - Piping | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 80 | - Supports | 0.0054 | 0.0179 | 0.0359 | 0.0668 | 0.1151 | 0.1587 | 0.2119 | 0.3446 |
| 81 | | | | | | | | | |
| 82 | ECCS Pumps | | | | | | | | |
| 83 | | | | | | | | | |
| 84 | - Residual Heat Removal | 0.0000 | 0.0035 | 0.0107 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2742 |
| 85 | - Centrifugal Charging | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 86 | - Safety Injection | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 87 | - Boric Acid | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 88 | | | | | | | | | |
| 89 | ECCS Tanks | | | | | | | | |
| 90 | | | | | | | | | |
| 91 | - Refueling Water Storage | 0.0000 | 0.0022 | 0.0071 | 0.0179 | 0.0359 | 0.0668 | 0.0968 | 0.1841 |
| 92 | - Accumulators | 0.0082 | 0.0227 | 0.0446 | 0.0668 | 0.0968 | 0.1587 | 0.1841 | 0.3085 |
| 93 | - Boron Injection | 0.0000 | 0.0022 | 0.0047 | 0.0094 | 0.0179 | 0.0287 | 0.0446 | 0.0808 |
| 94 | | | | | | | | | |
| 95 | RHR Heat Exchangers | 0.0026 | 0.0094 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2420 | 0.3821 |
| 96 | | | | | | | | | |
| 97 | ECCS Valves | | | | | | | | |
| 98 | | | | | | | | | |
| 99 | - Check Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100 | - Miscellaneous Isolation | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| 101 | - HPSI Isolation | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 5 (Cont'd)

Structure and Component
Failure Probability for Each Seismic Interval

| Line | Structure or Component | Failure Probabilities 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| 102 | | | | | | | | | |
| 103 | Emergency Diesel Generators | | | | | | | | |
| 104 | | | | | | | | | |
| 105 | - Diesel Oil Pump | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 |
| 106 | - Fuel Oil Day Tank | 0.0287 | 0.0668 | 0.1151 | 0.1841 | 0.2420 | 0.3085 | 0.3821 | 0.5000 |
| 107 | - Diesel Generator | 0.0016 | 0.0054 | 0.0139 | 0.0287 | 0.0548 | 0.0968 | 0.1357 | 0.2420 |
| 108 | - SWGR (600V) | 0.0000 | 0.0000 | 0.0000 | 0.0022 | 0.0054 | 0.0139 | 0.0227 | 0.0668 |
| 109 | - Transformer | 0.0026 | 0.0094 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2119 | 0.3446 |
| 110 | - SWGR (4kV) | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0035 | 0.0062 | 0.0107 | 0.0287 |
| 111 | - Battery Rack | 0.0000 | 0.0047 | 0.0179 | 0.0446 | 0.0968 | 0.1587 | 0.2420 | 0.4602 |
| 112 | - Motor Control Center | 0.0359 | 0.0808 | 0.1357 | 0.1841 | 0.2742 | 0.3446 | 0.4207 | 0.5398 |
| 113 | - Charger AB. CD. N | 0.0019 | 0.0040 | 0.0082 | 0.0179 | 0.0227 | 0.0359 | 0.0548 | 0.0968 |
| 114 | - Control Panel | 0.0000 | 0.0000 | 0.0010 | 0.0016 | 0.0022 | 0.0035 | 0.0047 | 0.0071 |
| 115 | - AC Distribution Panel | 0.0000 | 0.0010 | 0.0016 | 0.0026 | 0.0040 | 0.0054 | 0.0071 | 0.0107 |
| 116 | - Miscellaneous Valves | 0.0000 | 0.0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |
| 117 | - Batteries | 0.0000 | 0.0047 | 0.0179 | 0.0446 | 0.0968 | 0.1587 | 0.2420 | 0.4602 |
| 118 | - Cable Trays | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| 119 | | | | | | | | | |
| 120 | Containment Spray | | | | | | | | |
| 121 | | | | | | | | | |
| 122 | - Pumps | 0.0000 | 0.0010 | 0.0035 | 0.0094 | 0.0227 | 0.0446 | 0.0808 | 0.1587 |
| 123 | - Spray Additive Tank | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.0026 | 0.0054 | 0.0107 | 0.0287 |
| 124 | - Heat Exchangers | 0.1587 | 0.3085 | 0.4602 | 0.5398 | 0.6554 | 0.7580 | 0.8413 | 0.9192 |
| 125 | - Spray Additive Tank Vlvs | 0.0000 | 0.0010 | 0.0019 | 0.0035 | 0.0062 | 0.0094 | 0.0139 | 0.0227 |
| 126 | - System Valves | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| 127 | | | | | | | | | |
| 128 | Containment Recirc Fans | 0.0019 | 0.0062 | 0.0179 | 0.0359 | 0.0668 | 0.0968 | 0.1357 | 0.2420 |
| 129 | | | | | | | | | |
| 130 | Auxiliary Feedwater | | | | | | | | |
| 131 | | | | | | | | | |
| 132 | - Motor Driven Pump | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 133 | - Turbine Driven Pump | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 134 | - Pump Isolation Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 135 | - SG Isolation Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0010 | 0.0022 |
| 136 | - Fans (Room Cooling) | 0.0000 | 0.0016 | 0.0047 | 0.0139 | 0.0227 | 0.0446 | 0.0668 | 0.1357 |
| 137 | | | | | | | | | |
| 138 | Reactor Protection System | | | | | | | | |
| 139 | | | | | | | | | |
| 140 | - MCC | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0139 | 0.0227 | 0.0287 | 0.0359 |
| 141 | - Crid Inverter | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 142 | - Miscellaneous Panels | 0.0011 | 0.0022 | 0.0040 | 0.0062 | 0.0082 | 0.0139 | 0.0179 | 0.0287 |
| 143 | - Cable Trays | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| 144 | - Crid Transformer | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 |
| 145 | - RPS/Aux Rack/STC | 0.0011 | 0.0054 | 0.0179 | 0.0359 | 0.0808 | 0.1357 | 0.1841 | 0.3446 |
| 146 | - Main Control Board | 0.0000 | 0.0010 | 0.0016 | 0.0026 | 0.0040 | 0.0054 | 0.0071 | 0.0107 |
| 147 | | | | | | | | | |
| 148 | Component Cooling Water | | | | | | | | |
| 149 | note - piping supports being reevaluated. ignored for this analysis | | | | | | | | |
| 150 | - Pumps (Piping Supports) | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9978 | 1.0000 | 1.0000 |
| 151 | - Pumps (Water) | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 152 | - Heat Exchanger | 0.0000 | 0.0000 | 0.0022 | 0.0062 | 0.0139 | 0.0287 | 0.0446 | 0.1151 |
| 153 | - Surge Tank | 0.0000 | 0.0000 | 0.0010 | 0.0030 | 0.0062 | 0.0139 | 0.0227 | 0.0548 |
| 154 | - Valves | 0.0000 | 0.0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |
| 155 | | | | | | | | | |

Table 5 (Cont'd)

Structure and Component
Failure Probability for Each Seismic Interval

| Line | Structure or Component | Failure Probabilities 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| 156 | Essential Service Water Sys | | | | | | | | |
| 157 | | | | | | | | | |
| 158 | - ESW Pumps | 0.0000 | 0.0010 | 0.0030 | 0.0071 | 0.0179 | 0.0287 | 0.0548 | 0.1151 |
| 159 | - ESW Valves | 0.0000 | 0.0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |
| 160 | - ESW Strainers | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| 161 | | | | | | | | | |
| 162 | Main Steam System | | | | | | | | |
| 163 | | | | | | | | | |
| 164 | - MSIVs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 165 | - PORVs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 166 | - MSIV Isol. Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 167 | - Safety Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 168 | - Steam Generator Dump | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 169 | | | | | | | | | |
| 170 | Main Feedwater System | | | | | | | | |
| 171 | | | | | | | | | |
| 172 | - Isolation Valves | 0.0010 | 0.0022 | 0.0040 | 0.0071 | 0.0139 | 0.0179 | 0.0287 | 0.0446 |
| 173 | - Control Valves | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 174 | | | | | | | | | |
| 175 | Switchyard | | | | | | | | |
| 176 | | | | | | | | | |
| 177 | - Ceramic Insulators | 0.8159 | 0.9032 | 0.9554 | 0.9821 | 0.9929 | 0.9970 | 0.9987 | 1.0000 |
| | LOCA initiators from Notebook Fig. 3 | | | | | | | | |
| | - small break | 0.007 | 0.02 | 0.03 | 0.05 | 0.08 | 0.12 | 0.15 | 0.2 |
| | - medium break | 0.0002 | 0.001 | 0.002 | 0.004 | 0.008 | 0.013 | 0.015 | 0.03 |

Table 6

Normal Error Lookup Table

| Deviation | Area |
|---|---|
| 0 | 0 |
| 0.1 | 0.0398 |
| 0.2 | 0.0793 |
| 0.3 | 0.1179 |
| 0.4 | 0.1554 |
| 0.5 | 0.1915 |
| 0.6 | 0.2258 |
| 0.7 | 0.258 |
| 0.8 | 0.2881 |
| 0.9 | 0.3159 |
| 1 | 0.3413 |
| 1.1 | 0.3643 |
| 1.2 | 0.3849 |
| 1.3 | 0.4032 |
| 1.4 | 0.4192 |
| 1.5 | 0.4332 |
| 1.6 | 0.4452 |
| 1.7 | 0.4554 |
| 1.8 | 0.4641 |
| 1.9 | 0.4713 |
| 2 | 0.4773 |
| 2.1 | 0.4821 |
| 2.2 | 0.4861 |
| 2.3 | 0.4893 |
| 2.35 | 0.4906 |
| 2.4 | 0.4918 |
| 2.45 | 0.4929 |
| 2.5 | 0.4938 |
| 2.55 | 0.4946 |
| 2.6 | 0.4953 |
| 2.65 | 0.496 |
| 2.7 | 0.4965 |
| 2.75 | 0.497 |
| 2.8 | 0.4974 |
| 2.85 | 0.4978 |
| 2.9 | 0.4981 |
| 2.95 | 0.4984 |
| 3 | 0.4987 |
| 3.05 | 0.4989 |
| 3.1 | 0.499 |
| 3.15 | 0.5 |
| 100 | 0.5 |

Extracted from Reference 16

Table 7

Basic Event Seismic Failure Rates

| Basic Event | Uses Lines | Seismic Subinterval 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| S-AC-ACC-FA | 92 | 0.0082 | 0.0227 | 0.0446 | 0.0668 | 0.0968 | 0.1587 | 0.1841 | 0.3085 |
| S-ACDP-120VAC-FA | 115 | 0.0000 | 0.0010 | 0.0016 | 0.0026 | 0.0040 | 0.0054 | 0.0071 | 0.0107 |
| S-ACDP-1AB/CD-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-AUX-BLDG-FA | 13-16 | 0.0059 | 0.0230 | 0.0539 | 0.1094 | 0.1874 | 0.2715 | 0.3645 | 0.5769 |
| S-B-250VDC-FA | 111 | 0.0000 | 0.0047 | 0.0179 | 0.0446 | 0.0968 | 0.1587 | 0.2420 | 0.4602 |
| S-BR-250VDC-FA | 111 | 0.0000 | 0.0047 | 0.0179 | 0.0446 | 0.0968 | 0.1587 | 0.2420 | 0.4602 |
| S-BC-250VDC-FA | 113 | 0.0019 | 0.0040 | 0.0082 | 0.0179 | 0.0227 | 0.0359 | 0.0548 | 0.0968 |
| S-CT-120VAC-FA | 118 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| S-CH-HPI-FA | 85 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-CP-1AB/CD-FA | 114 | 0.0000 | 0.0000 | 0.0010 | 0.0016 | 0.0022 | 0.0035 | 0.0047 | 0.0071 |
| S-CT-11-FA | 118 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| S-CT-T11-FA | 118 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| S-CT-250VDC-FA | 118 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |
| S-CV-ACC-FA | 99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-CV-HPI-FA | 99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-CV-RHR-FA | 99 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-DG-1AB/CD-FA | 105 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 |
| S-DOP-1AB/CD-FA | 105 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 |
| S-FODT-1AB/CD-FA | 106 | 0.0287 | 0.0668 | 0.1151 | 0.1841 | 0.2420 | 0.3085 | 0.3821 | 0.5000 |
| S-HE-CCW-FA | 152 | 0.0000 | 0.0000 | 0.0022 | 0.0062 | 0.0139 | 0.0287 | 0.0446 | 0.1151 |
| S-HE-CTS-FA | 124 | 0.1587 | 0.3085 | 0.4602 | 0.5398 | 0.6554 | 0.7580 | 0.8413 | 0.9192 |
| S-HE-RHR-FA | 96 | 0.0026 | 0.0094 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2420 | 0.3821 |
| S-IC-EMBEDMEN-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-IC-ICE-BASB-FA | 38-45 | 0.0000 | 0.0000 | 0.0000 | 0.0045 | 0.0141 | 0.0294 | 0.0554 | 0.1456 |
| S-IC-LF-WP-CO-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-IC-LS-STRUT-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-IC-PHAS-LNK-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-IC-TOP-DECK-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-IMOV-MS1-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-MC-11-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-MC-120VAC-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-MC-250VDC-FA | 115 | 0.0000 | 0.0010 | 0.0016 | 0.0026 | 0.0040 | 0.0054 | 0.0071 | 0.0107 |
| S-MC-1AB/CD-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-MSIV-MS1-FA | 164 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-MV-RHR-FA | 100 | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| S-OT-11-FA | 109 | 0.0026 | 0.0094 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2119 | 0.3446 |
| S-OT-120VAC-FA | 142+145 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0019 |
| S-OT-T11-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-PIV-AFW-FA | 134 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-PM-AFW-FA | 132 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-PM-CCW-FA | 150+151 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9978 | 1.0000 | 1.0000* |
| S-PM-CTS-FA | 122 | 0.0000 | 0.0010 | 0.0035 | 0.0094 | 0.0227 | 0.0446 | 0.0808 | 0.1587 |
| S-PM-RHR-FA | 84 | 0.0000 | 0.0035 | 0.0107 | 0.0287 | 0.0548 | 0.0968 | 0.1587 | 0.2742 |
| S-PT-ESW-FA | 158 | 0.0000 | 0.0010 | 0.0030 | 0.0071 | 0.0179 | 0.0287 | 0.0548 | 0.1151 |
| S-TK-RWST-FA | 91 | 0.0000 | 0.0022 | 0.0071 | 0.0179 | 0.0359 | 0.0668 | 0.0968 | 0.1841 |
| S-SGIV-AFW-FA | 135 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0010 | 0.0022 |
| S-SI-HPI-FA | 86 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-SV-MS1-FA | 167 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-SWGR-11-FA | 108 | 0.0000 | 0.0000 | 0.0000 | 0.0022 | 0.0054 | 0.0139 | 0.0227 | 0.0668 |
| S-SWGR-T11-FA | 110 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0035 | 0.0062 | 0.0107 | 0.0287 |
| S-TK-CCW-FA | 153 | 0.0000 | 0.0000 | 0.0010 | 0.0030 | 0.0062 | 0.0139 | 0.0227 | 0.0548 |
| S-TRB-PED-FA | 20-25 | 0.0000 | 0.0000 | 0.0065 | 0.0165 | 0.0393 | 0.0750 | 0.1191 | 0.2956 |
| S-V-1AB/CD-FA | 154 | 0.0000 | 0.0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |
| S-V-CCW-FA | 154 | 0.0000 | 0.0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |

* Piping supports are being reevaluated, this is ignored for this analysis. Note that this failure is not included in the quanitification results.

Table 7 (Cont'd)

Basic Event Seismic Failure Rates

| Basic Event | Uses Lines | Seismic Subinterval | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
| S-V-CTS-FA | 126 | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| S-V-ESW-FA | 159 | 0.0000 | 0:0019 | 0.0040 | 0.0071 | 0.0107 | 0.0179 | 0.0227 | 0.0446 |
| S-V-HPI-FA | 101+102 | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| S-V-RHR-FA | 100 | 0.0000 | 0.0011 | 0.0026 | 0.0047 | 0.0071 | 0.0107 | 0.0179 | 0.0287 |
| S-TK-BIT-FA | 93 | 0.0000 | 0.0022 | 0.0047 | 0.0094 | 0.0179 | 0.0287 | 0.0446 | 0.0808 |
| S-MC-T11-FA | 0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S-PT-AFW-FA | 132+136 | 0.0000 | 0.0016 | 0.0047 | 0.0139 | 0.0227 | 0.0446 | 0.0668 | 0.1357 |
| S-MISC-PAN-FA | ** | 0.0048 | 0.0132 | 0.0303 | 0.0546 | 0.1046 | 0.1716 | 0.2272 | 0.3946 |
| S-CEQ-FA | 128 | 0.0019 | 0.0062 | 0.0179 | 0.0359 | 0.0668 | 0.0968 | 0.1357 | 0.2420 |
| S-ST-ESW-FA | ...160 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0030 |

Table 8

Event Tree Node Seismic Failure Rates

| Tree Node | Uses Lines | Seismic Subinterval 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|---|
| Event Tree Nodes | | | | | | | | | |
| CSF | 29.30.55.63 | 0.0054 | 0.0139 | 0.0287 | 0.0548 | 0.0808 | 0.1151 | 0.1587 | 0.2467 |
| PVP | 48.58.62 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| RCF | 56.64 | 0.0000 | 0.0011 | 0.0047 | 0.0179 | 0.0359 | 0.0668 | 0.1151 | 0.2420 |
| MPB | 181 | 0.0002 | 0.0010 | 0.0020 | 0.0040 | 0.0080 | 0.0130 | 0.0150 | 0.0300 |
| SPB | 54+180 | 0.0070 | 0.0200 | 0.0300 | 0.0500 | 0.0800 | 0.1200 | 0.1500 | 0.2035 |
| SHF | 4-9 | 0.0022 | 0.0075 | 0.0192 | 0.0401 | 0.0680 | 0.1054 | 0.1635 | 0.3063 |
| SSP | 79.80 | 0.0054 | 0.0179 | 0.0359 | 0.0668 | 0.1151 | 0.1587 | 0.2119 | 0.3446 |
| OSP | 177 | 0.8159 | 0.9032 | 0.9554 | 0.9821 | 0.9929 | 0.9970 | 0.9987 | 1.0000 |
| ROD | 49.51.52 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0010 | 0.0035 | 0.0082 | 0.0307 |

## Table 9

### Seismically Induced Initiating Event Frequencies by Seismic Subinterval

| Event | Seismic Subinterval 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c |
|---|---|---|---|---|---|---|---|---|
| Transient w/o power conversion | 1.61E-6 | 4.79E-7 | 1.31E-7 | 2.75E-8 | | | | |
| Small LOCA | | 1.00E-8 | | | | | | |
| Loss of Station Power | 6.87E-6 | 4.31E-6 | 2.50E-6 | 1.35E-6 | 6.82E-7 | 3.26E-7 | 1.45E-7 | 7.86E-8 |
| Small LOCA# | | 9.03E-8 | 8.17E-8 | 7.93E-8 | 7.19E-8 | 5.90E-8 | 3.88E-8 | 4.43E-8 |
| Large LOCA# | | | 1.28E-8 | 2.90E-8 | 3.38E-8 | 3.58E-8 | 3.44E-8 | 7.38E-8 |
| Steamline Break# | 3.73E-8 | 7.86E-8 | 9.30E-8 | 9.66E-8 | 8.86E-8 | 6.16E-8 | 3.90E-8 | 4.14E-8 |
| Loss of Essential Service Water# | 1.52E-8 | 3.32E-8 | 5.07E-8 | 6.04E-8 | 5.62E-8 | 4.54E-8 | 3.60E-8 | 5.29E-8 |
| Direct Damage | 4.64E-8 | 7.09E-8 | 8.52E-8 | 9.59E-8 | 8.32E-8 | 6.98E-8 | 5.66E-8 | 1.00E-7 |

# - Event without offsite power

Only frequencies greater than 1.E-8 are listed.

Table 10

Seismic Core Damage Frequencies

| Event | Seismic Subinterval 2a | 2b | 2c | 2d | 2e | 3a | 3b | 3c | sum |
|---|---|---|---|---|---|---|---|---|---|
| Transient w/o power conversion | 2.32E-8 | 2.77E-8 | 2.08E-8 | | | | | | 7.17E-8 |
| Small LOCA | | | | | | | | | small |
| Loss of Station Power | 1.00E-7 | 2.43E-7 | 3.68E-7 | 4.25E-7 | 3.15E-7 | 2.10E-7 | 1.15E-7 | 7.62E-8 | 1.85E-6 |
| Large LOCA# | | | | | 1.43E-8 | 1.86E-8 | 2.20E-8 | 5.95E-8 | 1.14E-7 |
| Small LOCA# | | | 1.69E-8 | 2.92E-8 | 3.33E-8 | 3.55E-8 | 2.82E-8 | 3.98E-8 | 1.83E-7 |
| Steamline Break# | | | 1.94E-8 | 3.57E-8 | 4.12E-8 | 3.74E-8 | 2.83E-8 | 4.76E-8 | 2.10E-7 |
| Loss of Essential Service Water# | | | | 1.38E-8 | 2.07E-8 | 2.53E-8 | 2.57E-8 | 5.04E-8 | 1.35E-7 |
| Direct Damage | 4.64E-8 | 7.09E-8 | 8.52E-8 | 9.59E-8 | 8.32E-8 | 6.98E-8 | 5.66E-8 | 1.00E-7 | 6.08E-7 |
| Total | 1.70E-7 | 3.42E-7 | 5.10E-7 | 6.00E-7 | 5.08E-7 | 3.97E-7 | 2.75E-7 | 3.74E-7 | 3.17E-6 |
| Conditional | 0.020 | 0.067 | 0.172 | 0.343 | 0.493 | 0.654 | 0.772 | 0.923 | |

# - Event without offsite power

Only frequencies greater than 1.E-8 are listed.

Seismic Failures Dominating the Initiating Events

| | |
|---|---|
| Transient w/o power conversion | Seismic Event Alone |
| Loss of Station Power | Ceramic Insulators |
| Large LOCA# | Pressurizer supports |
| Small LOCA# | Pipe Break |
| Steamline Break# | Secondary Piping/ supports |
| Loss of Essential Service Water# | Screenhouse Failure |
| Direct Damage | Containment Failure - Soil Pressure |

Table 11
Basic Events Contribution to
Seismic Core Damage Frequency

| Interval | Normal all | LOSP 2a-2d | 2e | 3a | 3b | 3c | Total |
|---|---|---|---|---|---|---|---|
| S-AUX-BLDG-FA | 3.08E-8 | 4.69E-07 | 1.17E-7 | 7.66E-8 | 2.53E-8 | 2.20E-8 | 7.41E-7 |
| S-OT-11-FA | 1.40E-8 | 2.25E-07 | 5.24E-8 | 3.46E-8 | 1.67E-8 | 7.75E-8 | 3.50E-7 |
| S-FODT-1AB/CD-FA | | 2.23E-07 | 3.36E-8 | 2.86E-8 | 2.47E-8 | 2.83E-8 | 3.38E-7 |
| DNPT-----PP4PS | | 1.32E-07 | | | | | 1.32E-7 |
| S-BC-250VDC-FA | 6.54E-9 | 7.53E-08 | 8.63E-9 | 4.35E-9 | 1.75E-9 | 2.59E-9 | 9.90E-8 |
| S-MISC-PAN-FA | 1.64E-8 | 3.08E-08 | | | | | 4.72E-8 |
| A-CB-11AC-BDCC | | 1.53E-08 | | | | | 1.53E-8 |
| S-B-250VDC-FA | | | 3.94E-8 | 2.20E-8 | 9.61E-9 | 2.05E-9 | 7.30E-8 |
| S-BR-250VDC-FA | | | 3.94E-8 | 2.20E-8 | 9.61E-9 | 2.05E-9 | 7.30E-8 |
| S-IC-ICE-8ASB-FA | | | | | | 2.00E-9 | n/a |

Key

| | |
|---|---|
| S-AUX-BLDG-FA | Auxiliary Building |
| S-FODT-1AB/CD-FA | Fuel Oil Day Tank (block wall) |
| S-OT-11-FA | Transformer (block wall) |
| S-B-250VDC-FA | Battery Rack |
| S-BR-250VDC-FA | Battery Rack |
| DNPT-----PP4PS | TDAFP random failure |
| S-BC-250VDC-FA | Battery Charger |
| S-MISC-PAN-FA | MCC and RPS Racks |
| S-IC-ICE-8ASB-FA | Misc Ice Condenser |

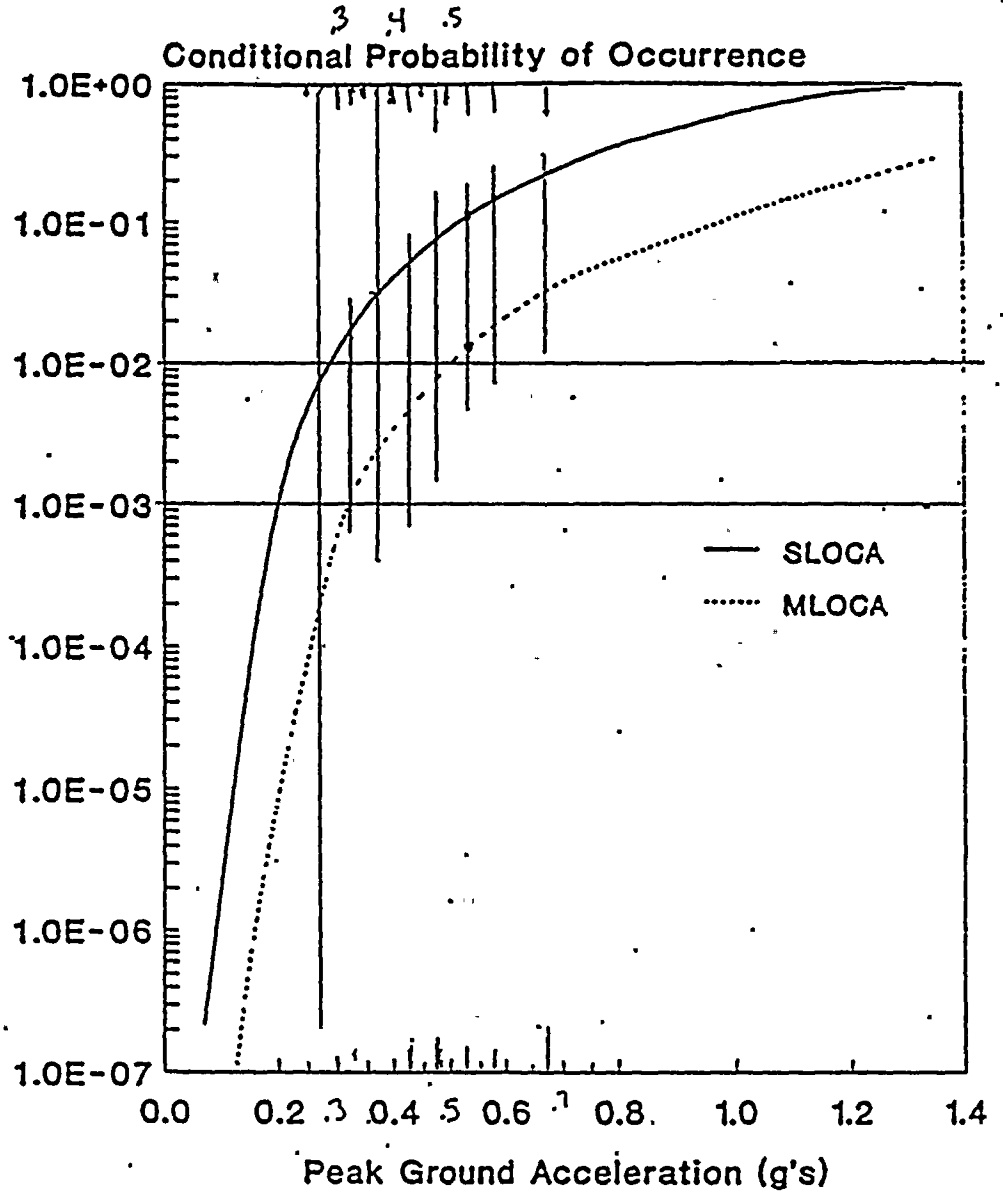



Figure 1 Seismically Induced Small and Medium LOCA Probabilities

# APPENDIX A

## WESTINGHOUSE FRAGILITY ANALYSIS

Westinghouse Letters

1) AEP-94-760, "Fragility Parameter Review" (8/16/94)

2) AEP-94-785 "Transmittal of Fragility Data (9/23/94)

and

3) AEP-94-789 "Supplementary Seismic Fragility Estimates" (10/3/94).

Westinghouse Electric Corporation

Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

Mr. R. Bennett
Nuclear Safety Section
American Electric Power Service Corporation
One Riverside Plaza
Columbus, OH 43216-6631

August 19, 1994

AEP-94-760

NTD-NSRLA-OPL-94-214

AMERICAN ELECTRIC POWER SERVICE CORPORATION
DONALD C. COOK UNITS 1 AND 2
<u>Fragility Parameters Review</u>

Ref. : 1. AEP-94-746
2. "Seismic Fragility Assessment, Donald C. Cook Nuclear Plants," Rev. 1, March 1993.
3. "Seismic Fragilities of Civil Structures and Equipment Components at the Diablo Canyon Power Plant," NTS Engineering, Report No. 1643.02, Sept. 1988.

Dear Mr. Bennett:

Fragility data has been regenerated for four components following the approach used by Diablo Canyon(3) in response to a request by AEPSC, as described in Reference 1. This information is required for the effort to demonstrate that the conservative fragility parameters given in Reference 2 have not masked any dominant contributors or effected ranking for the Donald C. Cook seismic IPEEE PRA evaluation. No significant difference has been found between the regenerated HCLPF values and those previously reported. HCLPF refers to High Confidence of Low Probability of Failure values.

The four components reviewed are:

1. Masonry wall around EDG Diesel Fuel Day Tank
2. 4 KV switchgear anchorage
3. CCW HX supports including cracks identified during the A46 walkdown
4. Auxiliary Building

Comparison of the fragility data are as follows, (old data from Ref. 2):

| COMPONENT | REVISED VALUES | | | | OLD VALUES | | | |
|---|---|---|---|---|---|---|---|---|
| | HCLPF | $A_m$ | $\beta r$ | $\beta u$ | HCLPF | $A_m$ | $\beta r$ | $\beta u$ |
| Masonry Wall | 0.26g | 0.95g | 0.28 | 0.27 | 0.25g | 0.27g | 0.05 | 0.00 |
| 4 KV Switchgear Anchorage | 0.58g | 1.77g | 0.31 | 0.37 | 0.55g | 0.66g | 0.10 | 0.00 |
| CCW HX Supports | 0.46g | 1.07g | 0.28 | 0.23 | 0.45g | 0.54g | 0.10 | 0.00 |
| Auxiliary Building | 0.32g | 0.85g | 0.31 | 0.29 | 0.30g | 0.38g | 0.13 | 0.00 |

The following sheets provide a detailed summary of the fragility parameters. Note that the references for the attached summary are different than those listed on the first page of this letter. A list of summary references is attached at the end of the summary. Also included is a copy of the Rizzo Associates letter on spectral fragility data used in this reevaluation, and referenced in the attached summary. In addition, a copy of the Diablo Canyon seismic fragilities report is included.

If you have any questions or comments, please call Robin Lapides (412/374-5683) or me.

Very truly yours,

BLapides/for
Keith F. Matthews
Senior Sales Engineer
Power Systems Field Sales

RSL/bbp

cc: J. Kingseed - AEPSC
D. Malin - AEPSC
V. VanderBurg - AEPSC
R. Lapides - W
E. Lewis - AEPSC
T. Georgantis - AEPSC
J. McNanie - AEPSC
M. Wilken - AEPSC

# ATTACHMENT 1

**AEP-94-760**
**NTD-NSRLA-OPL-94-214**

## 4KV SWITCHGEAR FRAGILITY ESTIMATE

As noted in Section 4.49 of Reference 1, the 4KV switchgear is mounted on the 609' level of the AEP Auxiliary Building. The equipment assembly has a frequency between 5 and 10 Hz. The applicable spectral acceleration at 5Hz and 5% damping for the 609' level is 0.42g with a floor ZPA of 0.22g. The corresponding free field ZPA acceleration is 0.2g. The analysis tabulated below defines the spectral HCLPF value at the mounting location of the switchgear. Now the HCLPF values reported in Reference 1 correspond to the plant free field ZPA values. Since the floor level is above the Auxiliary Building base, the HCLPF value must be lowered: the spectral values must be scaled to represent the free field ZPA value. This factor is developed in two stages: first the spectral value is scaled to be representative of the floor ZPA; and second, the floor ZPA is scaled to be representative of the free field acceleration. This factor is given for the switchgear mounting as (0.22/0.42)*(0.2/0.22), and is equal to 0.48. This factor is deterministic since two other parameters ,spectral effects and modeling effects, already take into account the variability of the earthquake and building dynamic characteristics.

| MARGIN | F median | $\beta_R$ | $\beta_U$ | $\beta_C$ | Reference/(NOTES) |
|---|---|---|---|---|---|
| SPECTRA | 1.4 | 0.28 | 0 | 0.28 | AEP-050 & RIZZO(4) |
| MATERIAL | 1.09 | 0 | 0.12 | 0.12 | Ref. 4, (1) |
| DUCTILITY | 1.77 | 0.14 | 0.11 | 0.18 | WELD Duc (2) |
| MODELING | 1.0 | 0 | 0.27 | 0.27 | (3) |
| SSI | 1.3 | 0 | 0.20 | 0.20 | RIZZO (4) |
| | | | | | |
| Resultant | 3.51 | 0.31 | 0.37 | 0.47 | median values |

Values above are applicable to switchgear at the 609' level

The floor median spectral acceleration capacity = seismic design capacity (Ref. 2) times median margin factor = 1.05*3.51 = 3.69g

The HCLPF floor value is

HCLPF(floor) = 3.69*e(-1.65*(0.31 + 0.37) = 1.20g

The free field median spectral acceleration capacity
= 3.69 * 0.48 = 1.77g

For free field , the HCLPF value is

HCLPF(free field) = 0.48* HCLPF(floor) = 0.48*1.20 = 0.58g

4KV SWITCHGEAR FRAGILITY ESTIMATE
NOTES

1. The yield strengths of steel materials vary randomly; Table 1 (Steel Yield Strength Characteristics) of Reference 4 shows the mean and coefficient of variability (COV) for various steels. The COV is defined as the ratio of the standard deviation divided by the mean value. After reviewing the data on Table 1 of Reference 4 it was determined that reasonable values for these parameters, mean and standard deviation, are 1.1 and 0.11 respectively The material is defined in terms of the mean value and has been converted to median value using a relationship described in Equation 2.4 of Reference 1.

$$F' = 1.1 * e(-0.11^2/2) = 1.09$$

2. Sheets 393 through 395 of Appendix C of Reference 5 describe the mounting details used on this equipment. The corners of the cabinet are plug welded to shim plates which are fillet welded together and to the floor. Because of the joint conditions, it is felt that gross deformability of the connection is limited. For the purpose of this evaluation, it is assumed that the connection median ductility is 2.0. From the data reported in Section 4.49 of Reference 1, it is clear that the equipment is flexible and damping has an effect on the response; a value of 5% is considered to be reasonable. TABLE 5-1 of Reference 3 is used to define the ductility margin factors used in the fragility analysis.

3. The variability in modeling lies primarily in the ability of the analytical model to estimate system frequencies. For this evaluation the median factor is taken equal to 1 since the models are adequate. This evaluation follows the approach set forth in Reference 3 and is used to define variability. In this approach equation 4-33 of Reference 3 is used to estimate $\beta_u$; the value for modeling can be calculated as follows:

$\beta_u$ = ln(spectral acceler. at 85% exceedence probability frequency/spectra acceleration at median frequency).

The estimated median frequency was taken as 5 Hz; the system frequency has been defined in Section 4.49 of Reference 1. The 85% exceedence frequency has been calculated following the suggestion given on page 4-52 of Reference 3. The 85% exceedence frequency, $f_\beta$ is given by

$$5 * e^{-0.25} = 3.9 \text{ Hz}$$

Using the floor response given in Reference 2 and 5% damping, we have

$f = 5$ HZ RRS = 0.42g
$f_\beta = 3.9$ Hz RRS = 0.55g

and $\beta_u = \ln(0.55/0.42) = 0.27$

4. The $\beta$ values used were provided by RIZZO Associates, Reference 9

FRAGILITY ESTIMATE FOR THE AUXILIARY BUILDING

A review of the calculations given in Reference 6 indicates that the steel columns supporting the crane girders in the auxiliary Building control the fragility value and were designed on the basis of the actual material strengths reported in the mill certifications, ie, the measured yield strengths of the A-36 steel used, varied between 36 ksi and 50 ksi. According to the calculation, Reference 6, a concrete wall is attached to one of the column flanges which supplies some lateral resistance to weak axis bending of the crane girder columns. This report also indicates that under seismic design conditions some of the peak calculated steel stresses exceed 80% of the design allowable stress.

For this reason, it was concluded that the critical members used in the design of the Auxiliary Building would be the steel columns supporting the crane rails.

Because the steel yield strengths used were mill certified, there is only minimal reserve material strength reserve above that used in the design. The median margin factor for the material was taken as 1 with zero variance.

| MARGIN | F median | $\beta_R$ | $\beta_U$ | $\beta_C$ | Reference/(NOTES) |
|---|---|---|---|---|---|
| SPECTRA | 1.50 | 0.28 | 0 | 0.28 | AEP-049 & RIZZO(4) |
| MATERIAL | 1.0 | 0 | 0 | 0. | (1) |
| DUCTILITY | 1.77 | 0.14 | 0.10 | 0.17 | (2) |
| MODELING | 1.0 | 0 | 0. | 0. | (3) |
| SSI | 1.6 | 0 | 0.27 | 0.27 | RIZZO (4) |
| | | | | | |
| Resultant | 4.25 | 0.31 | 0.29 | 0.42 | median values |

Values above are applicable to Auxiliary Building steel columns

The auxiliary building was designed (Ref. 6) based on a median ZPA acceleration design capacity requirement of 0.2g. The ZPA capacity = seismic design capacity required times the median margin factor = 0.20*4.25 = 0.85g

The ZPA HCLPF value is

$$\text{HCLPF(ZPA)} = 0.85 * e(-1.65 * (0.31 + 0.29)) = 0.32g$$

FRAGILITY ESTIMATE FOR STEEL COLUMNS IN AUXILIARY BUILDING

NOTES

1. As noted above, the yield strengths of the column materials used in the strength analysis were based on mill cert. tensile strengths of the individual steel columns; thus it is concluded that a deterministic median strength factor equal to 1 is appropriate.

2. References 10 and 11 describe the seismic response characteristics of the auxiliary building. It is clear from the auxiliary building floor spectra given in Reference 11 that the Auxiliary Building has a fundamental frequency between 2 Hz and 3.3 Hz For the purpose of this evaluation, it is assumed that the steel median ductility was 2.0. Since the structure is flexible, damping also has an effect on the column response; a value of 5% was considered to be reasonable. TABLE 5-1 of Reference 3 was used to define the ductility factors used in this analysis.

3. The variability in modeling lies primarily in the ability of the analytical model to estimate system frequencies. For this evaluation the median factor was taken equal to 1. This evaluation follows the approach set forth in Reference 3. In this approach equation 4-33 of Reference 3 is used to estimate $\beta_u$; the value for modeling can be calculated as follows:

   $\beta_u$ = ln(spectral acceler. at 85% exceedence probability frequency/spectra acceleration at median frequency).

   The estimated median building frequency was taken as 2.5 Hz. The 85% exceedence frequency has been calculated following the suggestion given on page 4-52 of Reference 3. The 85% exceedence frequency, $f_{\beta}$, is given by

   $$2.5*e^{-0.25} = 1.95 \text{ Hz}$$

   Reviewing the floor response spectra given in Reference 11 for 5% damping, it is clear that there is no significant change in the spectral value in this frequency range. Indeed a frequency shift outside this range will result in a drop in the spectral level. From this it is clear that $\beta_u$ can be set equal to

   $$\beta_u = 0.0$$

4. The $\beta$ values used were provided by RIZZO Associates, Reference 9.

# DIESEL GENERATOR DIESEL FUEL DAY TANK MASONRY WALL

## INTRODUCTION

The fuel day tank is located in the diesel generator room at the 591' level. It is enclosed by a masonry block wall which has been stiffened by the presence of an angle bolted to the inside face of the wall. The concern exists (Section 4.40 of Ref. 1) that the wall could fail during a seismic event and damage the day tank. Reference 12 contains details related to the seismic design of the wall. The wall consists of a 13' wall parallel to the tank's long axis integral with 6 foot side walls at each end. The wall was assembled using DUR-O-WAL reinforcement placed at a sixteen inch spacing. The wall is not supported at the top edge by the ceiling. The bending frequency of the wall acting as a horizontal one way beam with fixed ends is 11 Hz. A wall stiffener beam consisting of one 5" angle is bolted to the inside of the masonry wall (Ref. 5 Appendix C page 301).. Since the stiffener is located only on one wall face, it can develop only a limited amount of moment resistance at the wall base where it is connected to floor slab.

Since the tank level is above the Auxiliary Building base, the HCLPF value must be lowered: the spectral values must be scaled to represent the free field ZPA value. This factor is done in two stages: first the spectral value is scaled to be representative of the floor ZPA; and second, the floor ZPA is scaled to be representative of the free field acceleration. This factor (based on 2% spectral damping) is (0.22/0.29)*(0.2/0.22), and is equal to 0.69. This factor is treated as deterministic since two other parameters, spectral effects and modeling effects, already take into account the variability of the earthquake and building dynamic characteristics.

## BASIC WALL STRENGTH

The stiffener is bolted to the wall at the top and bottom and breaks up the wall into two panels (5'x10.16' and the other 5'x3.17'). Since the angle connection to the floor has limited moment capacity, this restraint will not be considered in this evaluation. Since the wall continues around the tank sides, these corners will provide additional bending restraint to the long wall. This strength reserve factor had not previously been considered in Reference 12.

To reduce the conservatism reported in References 1 and 12, the wall has been reanalyzed. For the purpose of the present evaluation, it is assumed that the wall can be modeled as a one way slab fixed at each end. Assume a one foot wide section of masonry wall spans the full distance of 13.33'. Use the cross sectional properties given in Appendix A of Reference 12 to estimate the bending frequency of the wall acting as a one way slab. The beam frequency is calculated using the following equation (Ref.13).

$$f = 3.56*\sqrt{[EI/(mL^4)]} = 11.2 \text{ Hz}$$

where $E = 1.195*10^6$ psi

$I = 76.8$ in$^4$

$L = 13.33*12 = 159.96$ in

$m = W/g = 5.5/386 = 0.0142$ lb-sec$^2$/in$^2$

BASIC STRENGTH cont.

Since no spectra is available for the 591' level, this analysis will make conservative use of the spectral curve for the 609' level. It is assumed that the applicable spectral damping is 2% and the required spectral acceleration is 0.29g

The ultimate strength of the DUR-O-WAL masonry is given in Reference 12 & 14. For an 8 inch wall constructed using #9 wire spaced at 16 inches, the ultimate resisting moment is 5694 in-lbs per foot of wall height (TABLE 15 of Ref. 14).

Considering a 12" height of wall with fixed ends, the maximum moment is

$$M = \alpha * W * L^2/12 = \alpha * 5.5 * 159.96^2/12 = \alpha * 11727 \text{ in-lb/ ft. of wall height}$$

where $\alpha$ defines the design g level used.

$\alpha$ = design seismic capacity = 5694/11727 = 0.49g

FRAGILITY PARAMETERS

| MARGIN | F median | $\beta_R$ | $\beta_U$ | $\beta_C$ | Reference/(NOTES) |
|---|---|---|---|---|---|
| SPECTRA | 1.3 | 0.28 | 0 | 0.28 | AEP-050 & RIZZO(4) |
| MATERIAL | 1.09 | 0 | 0.13 | 0.13 | Ref. 4, (1) |
| DUCTILITY | 1.054 | 0.02 | 0.01 | 0.02 | (2) |
| MODELING | 1.0 | 0 | 0.13 | 0.13 | (3) |
| SSI | 1.3 | 0 | 0.20 | 0.20 | RIZZO (4) |
| | | | | | |
| Resultant | 1.94 | 0.28 | 0.27 | 0.39 | median values |

Values above are applicable to masonry wall at 591' level

The floor median spectral acceleration capacity = seismic design capacity times median margin factor = 0.49*1.94 = 0.95g

The HCLPF floor value is

HCLPF(floor) = 0.95*e(-1.65*(0.28 + 0.33)) = 0.38g

The free field median spectral acceleration capacity

= 0.95 * 0.69 = 0.66g

For free field , the HCLPF value is

HCLPF(free field) = 0.69* HCLPF(floor) = 0.69*0.43 = 0.26g

DIESEL GENERATOR DIESEL FUEL DAY TANK MASONRY WALL

NOTES

1. For the DUR-O- WAL material, the nominal yield strength is 70000 psi (Attachment B of References 12 and 14). For this case the controlling factor is steel yield. Now Table 1 (Steel Yield Strength Characteristics) of Reference 4 shows the mean and coefficient of variability (COV) for various steels. The COV is defined as the ratio of the standard deviation divided by the mean value. After reviewing the data on Table 1 of Reference 4 it was determined that reasonable values for these parameters , mean and standard deviation (for a high strength material), are 1.1 and 0.13 respectively. The material is defined in terms of the mean value and has been converted to median value using a relationship described in Equation 2.4 of Reference 1

$$F' = 1.1*e(-0.13^2/2) = 1.09$$

2. The main source of ductility in the masonry wall during bending arises from the ductility of the DUR-O-WAL steel and its bond to the masonry. For the purpose of this evaluation, it is assumed that the connection median ductility is 1.5. Due to the high calculated frequency for the wall, it is assumed that damping effects will not effect ductility. TABLE 5-1 of Reference 3 is used to define the ductility margin factors used in the fragility analysis.

3. The variability in modeling lies primarily in the ability of the analytical model to estimate system frequencies. For this evaluation the median factor is taken equal to 1 since the models are adequate.. This evaluation follows the approach set forth in Reference 3 and is used to define variability. In this approach equation 4-33 of Reference 3 is used to estimate $\beta_u$; the value for modeling can be calculated as follows:

$\beta_u$ = ln(spectral acceler. at 85% exceedence probability frequency/spectra acceleration at median frequency).

The estimated median frequency was taken as 11 Hz; the system frequency has been defined in Section 4.49 of Reference 1. The 85% exceedence frequency has been calculate following the suggestion given on page 4-52 of Reference 3. The 85% exceedence frequency, $f_\beta$ is given by

$$11*e^{-0.25} = 8.6 \text{ Hz}$$

Using the floor response given in Reference 2 and 2% damping, we have

$f$ = 11 HZ RRS = 0.29g
$f_\beta$ = 8.6 Hz RRS = 0.33g

and $\beta_u = \ln(0.33/0.29) = 0.13$

4. The $\beta$ values used were provided by RIZZO Associates, Reference 9

## CCW HEAT EXCHANGER SUPPORTS

### Anchorage

The heat exchanger is mounted on a pedestal at each end, on the 609' floor elevation of the auxiliary building. One pedestal has additional anchorage and the equipment is considered fixed, while the second end is free to slide to accommodate thermal growth. The heat exchanger is anchored by 2 J-Bolts on each pedestal, embedded into the floor concrete below the pedestal. The J-Bolt has an embedment length of 24", before the bend, while the pedestal is 7" high, so the bend lies 17" below the concrete floor surface. The equipment is welded to two saddle supports made up of angles which rest on a 1-1/2" thick layer of grout, which caps the pedestal top. The pedestal concrete edge distance is a minimum of 6".

Cracks have been found in a plane between the concrete and grout interface and on a number of vertical planes passing through the pedestals at each end. The pedestals were designed to provide for free axial thermal growth of the heat exchanger; one end was designed to be fixed while the other end could slide axially. The cracks found are inconsistent with the expected pedestal deformation under the design condition loads. The cracking condition must have occurred due to normal deadweight and the tank heat up condition, since no seismic loading for which the pedestals were designed has yet occurred. With the deadweight load of 40 kips at each support point and $\mu$ ranging from 0.3 to 0.7 for steel on concrete, a frictional shear load of 28 kips can be induced in the concrete before sliding, while resisting the thermal growth of the tank. This load should be sufficient to crack the bond between surfaces. As a result it is concluded that the cracking was produced by thermal heat up.

Thermal loads are self equilibrating and thus need not be additive to the design loads under the Faulted Condition; the presence of the thermal axial loads indicates that the sliding support was not free to slide. Finally, the presence of the vertical cracks will not effect the development of bending resistance, and the presence of the horizontal crack at the grout/pedestal interface is considered in this evaluation.

The strength of the interface between grout and concrete is maintained by the frictional resistance. The resisting frictional force is equal to the deadweight or normal force at the support times the coefficient of friction. Using $\mu = 0.6$ from Section 11.7.4 of ACI-349, the $V_n = 0.6(40)$, but must not exceed $0.2f_c'A_c$ per Section 11.7.5 of ACI-349, using $A_c$ equal to the concrete area under the saddle. The resulting shear capacity is the MIN[24, 157.5] or 24 kips.

CCW HEAT EXCHANGER SUPPORTS
Spectral Floor Acceleration Capacity

Consider additional margins based on Ref. 18.

Reference 15 applies a prying factor of two in the determination of the seismic design capacity based on anchor bolt tensile strength, for a median spectral floor acceleration capacity of 0.45g. This factor is conservative since the weight of the heat exchanger will aid in reducing the lifting of the plate and therefore prying. A computer model of the base plate (saddle base) was developed with the stiffener plates represented. Loads were determined based on the seismic design capacity of Reference 15. The anchor in tension has a pullout load of 10.13 kips, per Ref. 18. The ultimate load will be used as the steel capacity. The steel capacity will be considered to control over the concrete for tension since the J-Bolt is deeply embedded. The capacity of the steel, $F_t$, is $S_uA_t$ or 26.8 kips, where $A_t = 0.462$ in.$^2$, $S_u = 58$ ksi. A factor of safety of 26.8/10.13 = 2.65 is obtained.

Shear-Tension interaction should also be considered. The concrete shear capacity for the free edge distance is $(1.1)2(f_c')^{1/2}\pi\ m^2$, from ACI-349 Appendix B, Section B.5.1.2 and Commentary, where m is the edge distance, $f_c'$ is the concrete compressive strength, and m is the distance to the free edge. A minimum edge distance of 6" is applied and the strength is 14.7 kips per anchor bolt.

The ultimate shear strength for the anchor bolt steel is $0.42S_u$ per the ASME Code, Appendix F, Section F-1335.2. The capacity, $F_v$, is $0.42S_uA_t$ or 14.64 kips, where $A_t = 0.601$ in.$^2$, considering the bolts to act in combination with load redistribution, the factor of safety for 0.45g loading is (2x14.64)/18 = 1.63. The nominal bolt area is used since the bolt shear strength must be developed at the grout/pedestal interface, since the grout relies on frictional strength. Drawing 12-3285-23 shows the thread ending at the grout/pedestal interface.

Consider parabolic shear/tension interaction similar to the ASME Code, NF-3324.6:

$$(1/2.65)^2+(1/1.63)^2 \leq 1.0 = 0.520$$

Obtaining a similar relationship in terms of variable $A_H$ :

$$[(62.3A_H - 13.33)0.689/F_t]^2 + [80A_H /2F_v]^2 = 1.0$$

a iterative solution of 0.587g is obtained, where $A_H$ is the horizontal g value and the vertical g is assumed to be 2/3 $A_H$.

Scale Factor

The median free field spectral acceleration capacity equals the median floor spectral acceleration capacity times a scale factor. The heat exchanger is mounted at the 609' level of the AEP auxiliary building, per Ref. 1, page 27. The applicable frequency for the support is 33 Hz. and 2% damping is applied per Ref. 15 page 4. The nominal seismic spectral acceleration at the equipment frequency is 0.22g, equivalent to the floor ZPA since the support frequency resides in the rigid range. The corresponding free field ZPA is 0.2g. The scale factor is 0.22/0.22 * 0.2/0.22 = 0.91

FRAGILITY PARAMETERS

| MARGIN | F median | $\beta_R$ | $\beta_U$ | $\beta_C$ | Reference/(NOTES) |
|---|---|---|---|---|---|
| SPECTRA | 1.2 | 0.28 | 0 | 0.28 | (1) |
| DUCTILITY(2) | 1.0 | 0 | 0 | 0 | (3) |
| MATERIAL | 1.28 | 0 | 0.123 | 0.123 | (4). |
| MODELING | 1.0 | 0 | 0 | 0 | (5) |
| SSI | 1.3 | 0 | 0.20 | 0.20 | (6) |
| | | | | | |
| Resultant | 2.0 | 0.28 | 0.23 | 0.37 | median values |

Values above are applicable to the heat exchanger anchorage at the 609' level

The floor median spectral acceleration capacity = seismic design capacity times median margin factor = 0.587*2.0 = 1.17g.

The HCLPF floor value is

HCLPF(floor) = 1.17*e(-1.65*(0.28 + 0.23)) = 0.50g

The free field median spectral acceleration capacity

= 1.17 * 0.91 = 1.07g

For free field , the HCLPF value is

HCLPF(free field) = 0.91* HCLPF(floor) = 0.91*0.50 = 0.46g

CCW HEAT EXCHANGER SUPPORTS

NOTES

1. UHS factor from Westinghouse Calc. No. AEP-050, Ref. 7. Adjustment to reflect the conservatism of the DC Cook FSAR SSE ground Design Spectra w.r.t the LLNL UHS 10,000 year median spectral shape. $\beta r$ was provided in Ref. 9, by Rizzo Associates.

2. Inelastic Energy Absorption Factor for the critical element, the anchor bolts. See Note 3.

3. From Westinghouse Calc. # AEP-036, Ref. 15, the tensile capacity of the 7/8" diameter J-Bolt controls, over the concrete capacity indicating a ductile mode of failure. A reasonable conclusion despite the cracking of the pedestal, since the J-Bolt is embedded in the concrete floor, and the shear capacity is not degraded by the cracks in the pedestal. However, brittle failure must be considered as described in Section 5.1.1.1 of the Ref. 3. Considering the system ductility, the inelastic energy absorption associated with the anchor bolts is small. Since the supported equipment is massive, the equipment will typically be stressed below the yield point, while the bolts are stressed at a level well above the yield point. The amount of inelastic energy absorption derived from the bolts is therefore minimal. Since the failure is considered brittle, a factor of 1.0 is applied.

4. Similar random strength material factors are found for the concrete and the steel. Ref. 3, Section 4.1.1.1, page 4-8, provides an average value for strength increase due to aging and batch strength. Table 4-1 provides values for fc = 3000 psi, but not for 3500 psi, per Ref. 15. As a result, the value for 3000 psi will be used. Note that on page 4-10 of Ref. 3, it is stated that the strength may increase for the rate of loading at seismic response frequency, however the increase factor is cancelled by the in-place strength reduction factor. This in-place strength reduction factor is based on the difference in strength between in place concrete and the test cylinder concrete.

   For the steel, a mean factor of 1.189 can be found in Table 1 of Ref. 4, with a COV of 0.0871. A median value of 1.18 is obtained, and a dynamic increase factor of 1.1 can be applied per Ref. 16, resulting in a median value of 1.3. The concrete controls.

5. Variability in modelling based on analytical model frequency estimates is not applicable since the pedestal and heat exchanger is rigid.

6. From Ref. 9.

REFERENCES


1. Calc AEP-025, "Auxiliary Bldg Equipment Fragility," dated 12-05-91.

2. CALC AEP-032, "Seismic Margin for 600V and 4KV Switchgears," Dated 10-14-91.

3. Report No. 1643.02, "Seismic Fragilities of Civil Structures and Equipment Components at the Diablo Canyon Power Plant," September 1988.

4. ASME Conference- Pressure Vessel and Piping Technology Conference-A Decade of Progress, L. Greimann and F. Fanous,"Reliability of Containments Under Over Pressure," 1985.

5. EQE Engineering Consultants, 52077.01-R-002, Rev. 0, "Walkdown of Auxiliary Building in Support of Cook Nuclear Plant IPEEE, Units 1 and 2," 2 Volumes, January 1992.

6. AEP Calculation DC-D-30535-193, "Structural Design Section Calculations for Auxiliary Building Steel Structure Part of Steam Generator Replacement Program," 12/8/86.

7. Calculation AEP-50, "LLNL UNS Equipment Fragility Data," 11/20/91.

8. Calculation AEP-49, "Fragility Data - LLNL UNS Spectra Shape"

9. Rizzo Associates Letter "Seismic Hazard Analysis, Donald C. Cook Nuclear Plant," 08/17/94.

10. Report from Rizzo Associates 89-654, "Effects of ground Spectral Shape on Plant Response," Revision 1,Feb. 1992.

11.. AEP Letter AEP-1955, "Seismic Design of Equipment Located Auxiliary Building," Dated February 5, 1971.

12. Calculation AEP-029, "Seismic Margin, for various Masonry Walls, dated 10-91.

13. Rogers,G.L., "Introduction to the Dynamics of Framed Structures," John Wiley and Sons, 1959, Figure 5.8.

14. DURO-O-WAL Catalog, "4 Unit Masonry Ties and Reinforcement," G/C 1979

15. Calculation AEP-036, "Seismic Margin for Various Components - CCW HX," Rev. 0, dated 12-91.

16. R.S. Orr, Proposed Addition to: "Commentary on Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-76)," ACI Committee 349.

17. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF, and Appendix F, 1989 Edition.

18. Calculation No. CSE-08-94-0042, "Additional Margins for the CCW Heat Exchanger Supports," Rev. 0, Aug. 1994.

# ATTACHMENT 2

## AEP-94-760
## NTD-NSRLA-OPL-94-214

R. ORR

Filed separately

Report Number 1643.02

QA Report Number 34001.01-R014

CENTRAL ENGINEERING FILE
APR 1040
I.12.3 AR
ENGINEER: W.S. Lee

# SEISMIC FRAGILITIES OF CIVIL STRUCTURES AND EQUIPMENT COMPONENTS AT THE DIABLO CANYON POWER PLANT

Prepared For

Pacific Gas and Electric Company
One California Street
San Francisco, California 94106

Prepared By


T.R. Kipp
D.A. Wesley
D.K. Nakaki

NTS Engineering
6695 East Pacific Coast Highway
Long Beach, CA 90803

Fragility Consultant
Dr. R.P. Kennedy
RPK Structural Mechanics Consulting
18971 Villa Terrace
Yorba Linda, CA 92686


September 1988

Westinghouse Electric Corporation

Energy Systems

Nuclear Technology Division

Box 355
Pittsburgh Pennsylvania 15230-0355

Mr. R. Bennett
Nuclear Safety Section
American Electric Power Service Corporation
One Riverside Plaza
Columbus, OH 43216-6631

September 23, 1994

AEP-94-785

NTD-NSRLA-OPL-94-285

AMERICAN ELECTRIC POWER SERVICE CORPORATION
DONALD C. COOK UNITS 1 AND 2
<u>Transmittal of Fragiity Data</u>

Ref. :
1. AEPSC letter from R.B. Bennett to K.F. Matthews, 9/2/94
2. AEP-94-771
3. "Seismic Fragilities of Civil Structures and Equipment Components at the Diablo Canyon Power Plant," NTS Engineering, Report No. 1643.02, Sept. 1988.
4. AEP-94-760, 8/19/94
5. "Seismic Fragility Assessment, Donald C. Cook Nuclear Plants," Rev. 1, March 1993.

Dear Mr. Bennett:

Attached for your information and use are the seismic fragility data [median capacity (Am), $\beta r$, $\beta u$ and high confidence in low probability of failure (HCLPF)] for the Task 1 items delineated in Ref. 2. These data have been developed following the approach used by Diablo Canyon and described in Reference 3.

The Task 1 items for which fragility data are provided are:

1. Screen House Base Slab
2. Auxiliary Piping Supports
3. Refueling Water Storage Tank
4. Emergency Diesel Generator, Transformers (Wall controls)
5. Emergency Diesel Generator, Motor Control Center
6. Essential Service Water Pumps
7. Pressurizer PORV's (generic data review)

Also provided for completeness are the fragility data previously transmitted in Reference 4 for:

1. Masonry wall around EDG Diesel Fuel Day Tank
2. 4 KV switchgear anchorage
3. CCW HX supports including cracks identified during the A46 walkdown
4. Auxiliary Building

Note that the median capacity of the masonry wall around the EDG Diesel Fuel Day Tank has been corrected (value changed from 0.95g to 0.66g) from that given in Reference 4.

Comparisons of the revised fragility values are made with the "old" values documented in Reference 5 are given on the attached sheet.

If you have any questions or comments, please call Robin Lapides (412/374-5683) or me.

Very truly yours,

RSLapides/for

Keith F. Matthews
Senior Sales Engineer
Power Systems Field Sales

RSL/bbp

cc: J. Kingseed - AEPSC
D. Malin - AEPSC
R. Lapides - W
E. Lewis - AEPSC
T. Georgantis - AEPSC

Task 1 equipment fragility data.

| COMPONENT | REVISED VALUES | | | | OLD VALUES | | | |
|---|---|---|---|---|---|---|---|---|
| | HCLPF | $A_m$ | $\beta r$ | $\beta u$ | HCLPF | $A_m$ | $\beta r$ | $\beta u$ |
| Screen House Base Slab | 0.35g | 1.06g | 0.31 | 0.35 | 0.34g | 0.44g | 0.16 | 0.00 |
| Auxiliary Piping Supports | 0.31g | 0.81g | 0.31 | 0.28 | 0.30g | 0.44g | 0.23 | 0.00 |
| Refueling Water Storage Tank | 0.40g | 0.95g | 0.31 | 0.21 | 0.37g | 0.44g | 0.10 | 0.00 |
| EDG Transformer Wall | 0.33g | 0.79g | 0.28 | 0.25 | 0.36g | 0.38g | 0.048 | 0.00 |
| EDG Motor Control Center | 0.22g | 0.64g | 0.34 | 0.30 | 0.22g | 0.29g | 0.17 | 0.00 |
| Essential Service water Pumps | 0.45g | 1.13g | 0.31 | 0.25 | 0.39g | 0.46g | 0.10 | 0.00 |
| Pressurizer PORV's (*) | 0.47g | 1.68g | 0.20 | 0.57 | 0.31g | 1.29g | 0.26 | 0.60 |

* The fragility data for the PORV are based on generic fragility data. The old data are from NUREG/CR-3558, and the new data from NUREG/CR-3892. The standard deviation values $\beta r$ and $\beta u$ are essentially the same; the higher capacity reflected by NUREG/CR-3892 is due to the higher Am value given. It is noted that if the seismic capacity is based on the UHS spectra, then Am and HCLPF can be increased by 1.3.

Previously provided seismic fragility data.

| COMPONENT | REVISED VALUES | | | | OLD VALUES | | | |
|---|---|---|---|---|---|---|---|---|
| | HCLPF | $A_m$ | $\beta r$ | $\beta u$ | HCLPF | $A_m$ | $\beta r$ | $\beta u$ |
| Masonry Wall (EDG Fuel Day Tank) | 0.26g | 0.66g | 0.28 | 0.27 | 0.25g | 0.27g | 0.05 | 0.00 |
| 4 KV Switchgear Anchorage | 0.58g | 1.77g | 0.31 | 0.37 | 0.55g | 0.66g | 0.10 | 0.00 |
| CCW HX Supports | 0.46g | 1.07g | 0.28 | 0.23 | 0.45g | 0.54g | 0.10 | 0.00 |
| Auxiliary Building | 0.32g | 0.85g | 0.31 | 0.29 | 0.30g | 0.38g | 0.13 | 0.00 |

Westinghouse Electric Corporation
Energy Systems
Nuclear Technology Division
Box 355
Pittsburgh Pennsylvania 15230-0355

Mr. R.B. Bennett
Nuclear Safety Section
American Electric Power Service Corporation
One Riverside Plaza
Columbus, OH 43216-6631

October 3, 1994

AEP-94-789
NTD-NSRLA-OPL-94-300

Ref: 1. AEP-94-771

AMERICAN ELECTRIC POWER SERVICE CORPORATION
DONALD C. COOK NUCLEAR PLANT
Supplementary Seismic Fragility Estimation

Dear Mr. Bennett:

Attached for your information and use is the summary report for the supplementary seismic fragility estimation for the Donald C. Cook Nuclear Plant. This completes the deliverable described in Reference 1 for the Task 1 items. Per your request, Task 2 (Reference 1) was removed from the scope of effort, since the component cooling water piping system was included in their ongoing snubber reduction program. Assessing the effect of snubber failures within this line on plant seismic capacity has no meaning since the snubbers of issue are being removed.

The additional soil liquification analyses and soil slope stability evaluations are still ongoing (Reference 1, Task 3). This work is being performed by Rizzo Associates. Currently, Rizzo Associates is waiting for input from AEPSC.

If you have any questions or comments, please call Robin Lapides (412/374-5683) or me.

Very truly yours,

Keith F. Matthews
Senior Sales Engineer
Power Systems Field Sales

RSL/bbp

Attachment

cc: J. Kingseed - AEPSC
D. Malin - AEPSC
N. Vaidya - Rizzo Associates
T. Georgantis - AEPSC
E. Lewis - AEPSC

AEP789/NSRLA300L

# Supplementary Seismic Fragility Estimation
# Donald C. Cook Nuclear Plants

## Purpose

Additional seismic fragility estimation was requested by the NRC staff to supplement the information previously provided as part of the plant PRA IPEEE. Specifically, of issue is the methodology used in the evaluation of component fragilities. The NRC staff has requested further component seismic fragility analyses including both random and uncertainty variability following similar methodology that is used for the evaluation of Diablo Canyon (Reference 1). This evaluation is to be based on realistic behavior and not conservative assumptions. The purpose of this supplementary seismic fragility assessment is to demonstrate that the process and methodology used for the Donald C. Cook Nuclear Plant IPEEE (individual plant examination of external events) program to identify seismic vulnerabilities did not mask the importance of nonseismic failures, operator recovery actions, or effect the ranking of dominant sequences and contributors.

## Scope

The scope of this investigation is limited to those components identified during the NRC audit (4 KV switchgear anchorage, component cooling water heat exchanger [CCW HX] supports, reactor coolant system pressurizer relief valve [PORV]), and important components with high confidence in low probability of failure (HCLPF) values less than 0.4g. The selection of components with HCLPF values less than 0.4g for further evaluation is based on the 1993 seismic fragility results on which the plant PRA IPEEE program is based. This is acceptable because:

- o the HCLPF values are a measure of importance with respect to seismic ranking and dominant contributors;
- o the HCLPF values are found in the these supplementary analyses to be basically unchanged following Reference 1 methodology, and therefore, remain important components with respect to defining plant seismic capability.

The PORV is included even though its seismic capacity is based on generic fragility data, because the NRC thought that the $\beta u$ value is large (0.60). The CCW HX support is included because cracks were found during the SQUG walk down activity after the completion of the seismic fragility analysis. The cracks are in a plane between the concrete and grout interface, and on a number of vertical planes passing through the pedestal at each end.

Eleven components were selected and are listed below:

1. Screen House Base Slab
2. Piping Supports
3. Refueling Water Storage Tank
4. Emergency Diesel Generator, Transformers (Wall controls)
5. Emergency Diesel Generator, Motor Control Center

6. Essential Service Water Pumps
7. Pressurizer PORV's (generic data review)
8. Masonry wall around EDG Diesel Fuel Day Tank
9. 4 KV switchgear anchorage
10. CCW HX supports including cracks identified during the SQUG plant walkdown
11. Auxiliary Building

The NRC staff had asked if higher seismic capacity of the component cooling water piping system could be shown assuming failure of the snubbers having a low seismic capacity (HCLPF = 0.24g). However, this task was not preformed because this piping system has been included into the AEPSC on-going snubber reduction program. The subject snubbers are being removed and replaced by other types of supports which will increase the piping system seismic capacity.

Methodology

Seismic fragility data [median capacity (Am), βr, βu and high confidence in low probability of failure (HCLPF) for the identified scope were developed following the approach used for Diablo Canyon and described in Reference 1. To develop the fragility data, design/analysis reserve margin factors along with their standard deviations were defined for each of the components and structures. The margin factors employed can be grouped into five general categories as described below:

- o Spectral Shape
- o Soil-Structure Interaction
- o Material
- o Ductility
- o Modeling

Each of these are discussed below.

Spectral Shape

In Reference 3, Section 3.1.1.2 it is stated:

> Most seismic PRA's use peak ground acceleration as the hazard parameter. If this is done, spectral shapes that are consistent with current estimates of ground motion should be used. In the Central and Eastern United States, current spectral estimates can be found in the LLNL and EPRI hazard studies. Since similar spectral shapes are obtained from LLNL and EPRI hazard studies, separate analyses using both spectral shapes are not needed. Median spectral shapes of 10,000 year return period provided in NUREG/CR-5250 [Reference 4] along with variability estimates are recommended for use in the analyses ... ."

In Figure 1, a comparison is shown of the plant design ground spectrum and 10,000 year LLNL (Lawrence Livermore National Laboratory) median Uniform Hazard Spectrum (UHS) for the Donald C. Cook site. The spectra are normalized to the plant DBE level of 0.2g and are associated with 5% damping. Margin factors were developed based on the plant seismic design response spectra. These margin factors are determined by the difference in component seismic response as defined by the difference in the plant design seismic spectra and the plant spectra associated with the UHS. For the Donald C. Cook plant site these factors are all equal to or above one, since the significant seismic

response of the structures and components are in the frequency range where the plant specific ground design response spectrum envelope the 10,000 year median UHS.

The random uncertainty in the response results from the earthquake to earthquake differences in ground motion which account for the variability in the spectral shape peaks and valleys. On the basis of the SSMRP analysis documented in Reference 2, a seismic fragility estimate is defined for structures and equipment referenced to peak ground acceleration levels. A randomness variability of 0.28 ($\beta r = 0.28$) over the entire frequency range of interest is defined. It is noted that a margin factor of 1.0 is assumed associated with the response results that account for the specific ground spectral shape.

Soil-Structure Interaction

These margin factors (response factors) are functions of modeling of the soil-structure interaction effect. The median response can be approximated on the basis of the design response by using response factors which account for conservatism in the design methodology. Of the several factors that lead to this conservatism, two factors are most important and are considered. They are:

1. the manner in which foundation embedment and wave incoherence was treated in the soil-structure interaction analysis, and

2. the method used to account for soil-structure interaction radiation damping.

Modeling uncertainties are a function of the structure-specific response factors accounting for the subsurface conditions at the site. Factors, with uncertainties, were defined for the structures and components within the scope of this assessment. They are:

- Containment Building/Internal Structure
- Auxiliary/diesel Building
- Pump/Screen House
- Refueling Water Storage Tank

These structures are discussed individually below.

It is noted that structure specific response factors account for the subsurface conditions at the site. The finished grade at the plant site is 608' 0". The site subsurface consists of about 15 feet of fill underlain by very dense slightly cemented fine to medium sand approximately 35 feet in thickness between Elevations 594' 0" and 556' 0". This is underlain by a 50 foot layer of hard to very stiff silty clay on a very compact till stratum. Plant structures are founded on the dense sand layer. The response factors associated with soil-structure interaction assumes a simplified soil profile represented by a 110 foot soil layer with a characteristic shear wave velocity of 1000 feet per second overlying bedrock.

- Containment Building/Internal Structure

The Containment Building/Internal Structure is supported on a foundation mat that is about 140 feet in diameter. The bottom of the foundation is at an average Elevation of 574' 0". The design evaluation used a soil shear modulus of 2,880 kips/ft (approximate shear wave velocity of 1,000 ft/sec) and a soil

damping of 5 percent in the soil-structure interaction analysis. Additionally, the design analysis conservatively applied the control motion at the foundation elevation. The embedment ratio (embedment depth/structure radius) is about 0.45. The soil-structure interaction damping has a likelihood to be as high as 15 to 20 percent.

- Auxiliary/Diesel Building

The Auxiliary/Diesel Building has an equivalent foundation radius of 138 feet and an average embedment of 34 feet. The embedment ratio is 0.25. The design analysis assumed fixed base conditions in calculating the building seismic forces. This assumption was found to yield conservative seismic loading. Soil-structure interaction was included in a subsequent calculation to obtain floor response spectra for equipment evaluation. The soil-structure interaction analysis used a soil shear modulus of 2,880 kip/ft (approximate shear wave velocity of 1,000 ft/sec) and soil damping of 20 percent. The control motion was applied at the foundation elevation and the effects of wave incoherence were not included.

- Pump/Screen House

The Pump/Screen House is substantially an embedded concrete shear wall structure with an above grade steel building enclosing the Pump House. The Pump/Screen House structure is about 210 feet by 108 feet in plan. Its foundation is approximately 40 feet below grade which is at elevation 580' 0". The Response Reduction Factors for the Pump/Screen House associated with soil structure interaction are based on the assumption that the design seismic analysis included some soil-structure interaction, but did not include the effects of the embedment. The embedment ratio is 0.37. Variation of ground motion through the embedment depth and the attendant wave scattering effects are expected to result in a reduction of the seismic response calculated on the basis of the conservative assumption that the control motion is applied at the foundation elevation. No response reduction is taken for radiation damping.

- Refueling Water Storage Tank

The Refueling Water Storage Tank is an above grade structure supported on a concrete mat. The tank is 48 feet in diameter with a liquid height of 31 feet. A fixed base analysis resulted in a fundamental frequency of about 5.5 hz. Consistent with the foundation compliance for a rigid base, the natural frequency of the foundation mass in the horizontal soil-structure mode is about 15 hz. On the basis of these results, the foundation is rigid relative to the structure, and the assumption of a fixed base for the seismic analysis is appropriate. Therefore, the effects of soil structure interaction on the seismic response of the Refueling Water Storage Tank is ignored.

In Table 1 are provided the estimates of the response factors and modeling uncertainties for the individual structures and equipment contained within.

Material

A material strength factor is used that accounts for the difference between code mandated minimum material values used for design and the actual material properties. The factors that are used consider:

- o material construction (steel or concrete)

- critical failure mode associated with the component or structure
- material properties used in the design and qualification analyses
- dynamic loading response characteristics.

Recognized material reserve margin fragility parameters (median and coefficient of variation) available from the public literature are used (eg., Reference 5). As used in the Diablo Canyon analyses, the standard deviation is considered to be related to uncertainty.

Ductility

The margin factor used for ductility reflects the reserve strength in a structure due to energy absorption caused by inelastic response. Ductility fragility parameters as defined in Reference 1 are used. The factors were chosen using the following approach:

- define failure mode and determine if sufficient energy absorption will occur due to system ductility to justify inclusion; if not, then brittle failure is defined and there is no reserve margin attributed to ductility;

- determine if system (component) response is in the amplified or rigid region; in the rigid region damping has little effect;

- define reasonable median ductility factor (note that 5% damping is considered for response in the amplified region, this is a reasonable value);

- based on amplified or rigid component response region, median ductility factor, and damping, determine the ductility factor and associated standard deviations associated with randomness and uncertainty as given in Reference 1; this factor is adjusted to reflect hysteretic (pinching) effect when appropriate (eg., concrete structures);

- hysteretic adjustment (reduction in ductility factor of safety) is based on recommendations given in Reference 1 following the Riddell-Newmark approach:

$$F\mu = 1 + CD(F\mu' - 1)$$

where,

CD = 0.6 correction factor
$F\mu$ = median ductility factor adjusted for hysteretic effects
$F\mu'$ = median ductility factor that has not been adjusted for hysteretic effects.

Modelling

The fragility parameters associated with modeling are based on the ability of the analytical model to give realistic/conservative seismic response characteristics. The significant factors that contribute to model variability are described below. They are used as appropriate.

- Analytical model frequency

Variability is defined following section 4.1.3 of Reference 1. An estimate of uncertainty standard deviation is defined as the natural log of the ratio of the spectral acceleration at 84% exceedence probability frequency and the spectral acceleration at the median frequency.

- o Mode shape variability

  This factor is also discussed in section 4.1.3 of Reference 1. It is applicable where the model is used to estimate system response.

- o Damping

  A damping factor is used when the analysis (analytical model) has used a conservative damping value. Care is taken to assure that this factor has not already been reflected in the ductility margin factor. This factor is discussed in Reference 1, section 5.1.1.2.

Results and Conclusions

The results are presented in Table 2. The components and structures are arranged in the table in ascending order of "original" HCLPF values with the exception of the pressurizer PORV. The PORV fragility data are placed at the end of the table since the fragility parameters are based on generic data.

The following conclusions are made related to the fragility data summarized in Table 2 developed following the Diablo Canyon methodology.

- o The revised HCLPF values are essentially the same as the original values. The largest differences are the EDG transformer wall which has the only lower HCLPF value which is only 8% lower than the original HCLPF value, and the essential service water pumps whose HCLPF value is only 15% higher.

  The small change in HCLPF values is expected because the fragility parameters used in the PRA IPEEE analysis:

  - yielded lower bound estimates of the HCLPF values, recognizing that realistic values will not be far removed;
  - used margin factors that have a deterministic basis, and not factors based on engineering judgement that may unrealistically bias the results;
  - reflected spectral shape variability since they were based on plant specific spectra and not the 10,000 year median Uniform Hazard Spectrum.

  Further, the sensitivity studies previously performed and documented in past submittals (AEP: NRC 1082G, question 17) showed that the HCLPF values do not significantly change when margin factors with appropriate standard deviations are introduced to reflect other factors not considered. These factors were not used in the development of the original fragility data in order that "lower bound" HCLPF would be reflected in the plant PRA IPEEE results.

- o The ratio of revised median capacity and the HCLPF value is between 2.3 and 3.

- The fragility data for the PORV are based on generic fragility data. The old data are from NUREG/CR-3558, and the new data from NUREG/CR-3892. The standard deviation values, βr and βu, are essentially the same; the higher capacity reflected by NUREG/CR-3892 is due to the higher median capacity given. The fragility data used in the IPEEE PRA for the PORV is considered appropriate since the use of generic data is acceptable, but there is no basis to use a higher capacity.

Based on the results summarized above, the following conclusions can be made related to the purpose of this investigation to demonstrate that the process and methodology used in the IPEEE program to identify seismic vulnerabilities did not mask the importance of nonseismic failures, or operator recovery actions, or effect the ranking of dominant sequences and contributors.

Significant change in the fragility data is the median capacity, and the βr and βu values. The increase in median capacity was fairly uniform between 2 and 2.5 (rounded off). Since the HCLPF values remain essentially the same as calculated from the original fragility data, and the median capacities increase, the core melt frequency as well as component/structural failure probability at higher seismic levels will be lower than obtained using the original fragility data.

It was found from the PRA IPEEE results and the sensitivity study previously reported, that the HCLPF values are representative of the order of ranking. Therefore, since the revised HCLPF values are essentially the same, the dominant contributors will remain the same, and the ranking of the dominant contributors will remain the same or change insignificantly.

The same conclusion is reached as reported in the referenced sensitivity study. The results of the seismic PRA are conservative and the dominant contributors will not change. No nonseismic failures or operator recovery actions are masked. The IPEEE seismic analysis and the seismic fragility data used for it are appropriate for satisfying the requirements of NUREG-1407.

References

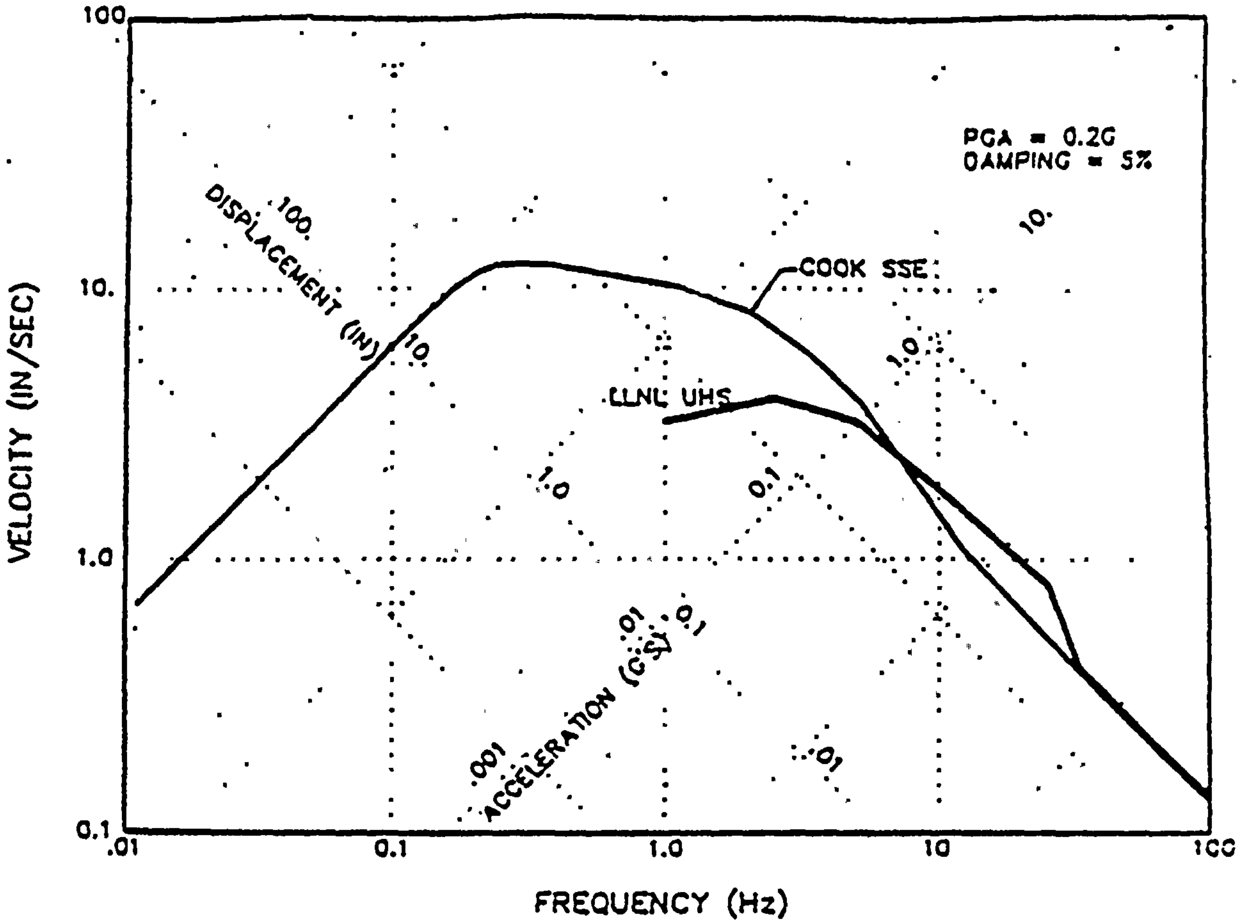
1. "Seismic Fragilities of Civil Structures and Equipment Components at the Diablo Canyon Power Plant," NTS Engineering, Report No. 1643.02, Sept. 1988.

2. NUREG/CR-4331, "Simplified Seismic Probabilistic Risk Assessment: Procedures and Limitations," Lawrence Livermore National Lab., Ca., UCID-20468, August, 1985.

3. NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," Final Report, U.S. Nuclear Regulatory Commission, June 1991.

4. NUREG-5250, "Seismic Hazard Characterization of 69 Nuclear Power Plant Sites East of the Rocky Mountains," Vols. 1-8, January 1989.

5. Greimann, Lowell and Fouad Fanous, "Reliability of Containments Under Overpressure," Pressure Vessel & Piping Technology, A Decade of Progress, 1985.




Legend:

Cook SSE: Ground Design Response Spectrum
LLNL UHS: Lawrence Livermore National Laboratory 10,000 year Median UHS

Figure 1 - Comparison of Plant Design Ground Spectrum and 10,000 year Median Uniform Hazard Spectrum for the Donald C. Cook Site

Table 1
Soil Structure Interaction Effects
Response Factors and Modeling Uncertainties

| Structure | Building | | Equipment | |
|---|---|---|---|---|
| | Response Factor | βu | Response Factor | βu |
| Containment Building/Internal Structure | | | | |
| - SSI Embedment | 1.26 | 0.15 | 1.25 | 0.15 |
| - SSI Damping | 1.00 | 0.00 | 1.67 | 0.22 |
| Auxiliary/Diesel Building | | | | |
| - SSI Embedment | 1.60 | 0.27 | 1.30 | 0.20 |
| - SSI Damping | 1.00 | 0.00 | 1.00 | 0.00 |
| Pump/Screen House | | | | |
| - SSI Embedment | 1.37 | 0.27 | 1.30 | 0.20 |
| - SSI Damping | 1.00 | 0.00 | 1.00 | 0.00 |
| Refueling Water Storage Tank | | | | |
| - SSI Embedment | 1.00 | 0.00 | - | - |
| - SSI Damping | 1.00 | 0.00 | - | - |

Table nomenclature:

SSI = Soil Structure Interaction
βu = Standard deviation associated with uncertainty

Table 2
Seismic Fragility Parameter Summaries

| COMPONENT | REVISED VALUES | | | | ORIGINAL VALUES | | | |
|---|---|---|---|---|---|---|---|---|
| | HCLPF | $A_m$ | βr | βu | HCLPF | $A_m$ | βr | βu |
| EDG Motor Control Center | 0.22g | 0.64g | 0.34 | 0.30 | 0.22g | 0.29g | 0.17 | 0.00 |
| Masonry Wall (EDG Fuel Day Tank) | 0.26g | 0.66g | 0.28 | 0.27 | 0.25g | 0.27g | 0.05 | 0.00 |
| Auxiliary Building | 0.32g | 0.85g | 0.31 | 0.29 | 0.30g | 0.38g | 0.13 | 0.00 |
| Piping Supports | 0.31g | 0.81g | 0.31 | 0.28 | 0.30g | 0.44g | 0.23 | 0.00 |
| Screen House Base Slab | 0.35g | 1.06g | 0.31 | 0.35 | 0.34g | 0.44g | 0.16 | 0.00 |
| EDG Transformer Wall | 0.33g | 0.79g | 0.28 | 0.25 | 0.36g | 0.38g | 0.048 | 0.00 |
| Refueling Water Storage Tank | 0.40g | 0.95g | 0.31 | 0.21 | 0.37g | 0.44g | 0.10 | 0.00 |
| Essential Service water Pumps | 0.45g | 1.13g | 0.31 | 0.25 | 0.39g | 0.46g | 0.10 | 0.00 |
| CCW HX Supports | 0.46g | 1.07g | 0.28 | 0.23 | 0.45g | 0.54g | 0.10 | 0.00 |
| 4 KV Switchgear Anchorage | 0.58g | 1.77g | 0.31 | 0.37 | 0.55g | 0.66g | 0.10 | 0.00 |
| | | | | | | | | |
| Pressurizer PORV's | 0.47g | 1.68g | 0.20 | 0.57 | 0.31g | 1.29g | 0.26 | 0.60 |

Table nomenclature:

HCLPF = component/structure high confidence in low probability of failure

defined as,

$$HCLPF = Am\ e^{[-1.65(\beta r + \beta u)]}$$

Am = component/structure median seismic capacity

βr = standard deviation attributed to randomness variability

βu = standard deviation attributed to uncertainty variability

# APPENDIX B

## SEISMIC INITIATING EVENT QUANTIFICATION

## FOR EACH EVENT TREE

( Note : This Appendix contains computer output.
It was not included to reduce the volume of the submittal.)

[illegible]

# APPENDIX C

## QUANTIFICATION OUTPUT FOR SEISMIC

## CORE DAMAGE FREQUENCY

**( Note : This Appendix contains computer output.
It was not included to reduce the volume of the submittal.)**

# APPENDIX D

# CORRECTION OF SEISMIC CORE DAMAGE FREQUENCY

# AND RISK REDUCTION RANKINGS

# FOR HIGH CONDITIONAL FAILURE SEISMIC SUBINTERVALS

Description of Calculation

The uncorrected core damage frequency is taken from the interval.OUT files. It had been calculated in the WALT code by summation of the individual cutsets. This is divided here by the initiation event frequency to calculate the conditional failure rate (labeled uncorrected ratio).

Since simple summation of the large failure rates is inappropriate, the top five cutsets are used to reevaluate the correct summation. The basic events and their failure rates are listed. These failure rates are summed, and the sum is subtracted from the uncorrected ratio to find an equivalent failure rate for the remaining basic events (or combinations of basic events) which are not specifically listed. In a couple of instances, the remainder is a small negative number, which can be attributed to roundoff error.

The corrected conditional failure rate (labeled corrected ratio) is now calculated using the appropriate equations

$$r = 1 - \prod_i (1-f_i),$$

where $f_i$ are the basic event failure rates (including the "remaining" basic event). The corrected core damage frequency is calculated by multiplying this corrected ratio by the initiating event frequency.

For each basic event, the risk reduction is calculated. The risk reduction is the reduction in core damage frequency if the basic event were not to fail. It is calculated by calculating a conditional core damage frequency as above with the basic event failure rate set to zero, and subtracting this from the conditional failure rate. The reduction in core damage frequency is then calculated by multiplying this result by the initiation event frequency. Note that the sum of these risk reduction ratios does not equal unity, since there is significant overlap in the failures.

Correction of event frequencies

| Interval 2e | uncorrect | corrected | cdf reduc |
|---|---|---|---|
| losp cdf | 3.97E-07 | 3.15E-07 | |
| ief | 6.82E-07 | | |
| ratio | 0.582111 | 0.462583 | |
| basic event | fail rate | import | cdf reduc |
| S-AUX-BLDG-FA | 0.187 | 0.123612 | 8.43E-08 |
| S-OT-11-FA | 0.097 | 0.057729 | 3.94E-08 |
| S-BR-250VDC-FA | 0.097 | 0.057729 | 3.94E-08 |
| S-B-250VDC-FA | 0.097 | 0.057729 | 3.94E-08 |
| S-BC-250VDC-FA | 0.023 | 0.012652 | 8.63E-09 |
| remaining | 0.081111 | 0.047438 | 3.24E-08 |

| Interval 2e | uncorrect | corrected | | |
|---|---|---|---|---|
| slb cdf | 5E-08 | 4.12E-08 | | |
| ief | 8.86E-08 | | | |
| ratio | 0.564334 | 0.464855 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.187 | 0.12309 | | 1.09E-08 |
| S-OT-11-FA | 0.097 | 0.057485 | | 5.09E-09 |
| S-FODT-1AB/CD-FA | 0.242 | 0.170851 | | 1.51E-08 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.038334 | 0.021332 | | 1.89E-09 |

| Interval 2e | uncorrect | corrected | | |
|---|---|---|---|---|
| slo cdf | 4.04E-08 | 3.33E-08 | | |
| ief | 7.19E-08 | | | |
| ratio | 0.561892 | 0.463495 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.187 | 0.123403 | | 8.87E-09 |
| S-OT-11-FA | 0.097 | 0.057631 | | 4.14E-09 |
| S-FODT-1AB/CD-FA | 0.242 | 0.171285 | | 1.23E-08 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.035892 | 0.019973 | | 1.44E-09 |

| Interval 2e | uncorrect | corrected | | |
|---|---|---|---|---|
| sws cdf | 2.38E-08 | 2.07E-08 | | |
| ief | 5.62E-08 | | | |
| ratio | 0.423488 | 0.368264 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.187 | 0.145307 | | 8.17E-09 |
| S-OT-11-FA | 0.097 | 0.067861 | | 3.81E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.139488 | 0.102403 | | 5.76E-09 |

| Interval 2e | uncorrect | corrected | |
|---|---|---|---|
| llo cdf # | 1.67E-08 | 1.43E-08 | |
| ief | 3.38E-08 | | |
| ratio | 0.494083 | 0.423854 | |
| basic event | fail rate | import | cdf reduc |
| S-AUX-BLDG-FA | 0.187 | 0.132521 | 4.48E-09 |
| | 0 | 0 | 0 |
| S-FODT-1AB/CD-FA | 0.242 | 0.183941 | 6.22E-09 |
| | | 0 | 0 |
| | | 0 | 0 |
| remaining | 0.065083 | 0.040108 | 1.36E-09 |

# 4.7e-9 removed - overlapping cutsets 23 &

Correction of event frequencies

| Interval 3a | uncorrect | corrected | | |
|---|---|---|---|---|
| losp cdf | 3.03E-07 | 2.1E-07 | | |
| ief | 3.26E-07 | | | |
| ratio | 0.929448 | 0.642856 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.272 | 0.133438 | | 4.35E-08 |
| S-OT-11-FA | 0.159 | 0.067522 | | 2.2E-08 |
| S-BR-250VDC-FA | 0.159 | 0.067522 | | 2.2E-08 |
| S-B-250VDC-FA | 0.159 | 0.067522 | | 2.2E-08 |
| S-BC-250VDC-FA | 0.036 | 0.013337 | | 4.35E-09 |
| remaining | 0.144448 | 0.060299 | | 1.97E-08 |

| Interval 3a | uncorrect | corrected | | |
|---|---|---|---|---|
| slb cdf | 4.99E-08 | 3.74E-08 | | |
| ief | 6.16E-08 | | | |
| ratio | 0.810065 | 0.606579 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.272 | 0.146993 | | 9.05E-09 |
| S-OT-11-FA | 0.159 | 0.074381 | | 4.58E-09 |
| S-FODT-1AB/CD-FA | 0.309 | 0.175929 | | 1.08E-08 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.070065 | 0.029642 | | 1.83E-09 |

| Interval 3a | uncorrect | corrected | | |
|---|---|---|---|---|
| slo cdf | 4.77E-08 | 3.55E-08 | | |
| ief | 5.8E-08 | | | |
| ratio | 0.822414 | 0.611803 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.272 | 0.145041 | | 8.41E-09 |
| S-OT-11-FA | 0.159 | 0.073393 | | 4.26E-09 |
| S-FODT-1AB/CD-FA | 0.309 | 0.173593 | | 1.01E-08 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.082414 | 0.034866 | | 2.02E-09 |

| Interval 3a | uncorrect | corrected | | |
|---|---|---|---|---|
| sws cdf | 3.22E-08 | 2.53E-08 | | |
| ief | 4.52E-08 | | | |
| ratio | 0.712389 | 0.560032 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.272 | 0.164384 | | 7.43E-09 |
| S-OT-11-FA | 0.159 | 0.083181 | | 3.76E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.281389 | 0.17228 | | 7.79E-09 |

* combined w/ other failures

| Interval 3a | uncorrect | corrected | | |
|---|---|---|---|---|
| llo cdf # | 2.24E-08 | 1.86E-08 | | |
| ief | 3.58E-08 | | | |
| ratio | 0.625698 | 0.519437 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.272 | 0.179551 | | 6.43E-09 |
| | 0 | 0 | 0 | |
| S-FODT-1AB/CD-FA | 0.309 | 0.214897 | | 7.69E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.044698 | 0.022485 | | 8.05E-10 |

# 3.3e-9 removed - overlapping cutsets 26 &

Correction of event frequencies

| | | | | |
|---|---|---|---|---|
| Interval 3b | uncorrect | corrected | | |
| losp cdf | 1.96E-07 | 1.15E-07 | | |
| ief | 1.45E-07 | | | |
| ratio | 1.351724 | 0.792356 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.365 | 0.119355 | | 1.73E-08 |
| S-OT-11-FA | 0.212 | 0.055864 | | 8.1E-09 |
| S-BR-250VDC-FA | 0.242 | 0.066293 | | 9.61E-09 |
| S-B-250VDC-FA | 0.242 | 0.066293 | | 9.61E-09 |
| S-BC-250VDC-FA | 0.055 | 0.012085 | | 1.75E-09 |
| remaining | 0.235724 | 0.064043 | | 9.29E-09 |

| | | | | |
|---|---|---|---|---|
| Interval 3b | uncorrect | corrected | | |
| slb cdf | 4.19E-08 | 2.83E-08 | | |
| ief | 3.9E-08 | | | |
| ratio | 1.074359 | 0.726438 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.365 | 0.157244 | | 6.13E-09 |
| S-OT-11-FA | 0.212 | 0.073598 | | 2.87E-09 |
| S-FODT-1AB/CD-FA | 0.382 | 0.169095 | | 6.59E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.115359 | 0.035673 | | 1.39E-09 |

| | | | | |
|---|---|---|---|---|
| Interval 3b | uncorrect | corrected | | |
| slo cdf | 4.16E-08 | 2.82E-08 | | |
| ief | 3.88E-08 | | | |
| ratio | 1.072165 | 0.72576 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.365 | 0.157634 | | 6.12E-09 |
| S-OT-11-FA | 0.212 | 0.07378 | | 2.86E-09 |
| S-FODT-1AB/CD-FA | 0.382 | 0.169514 | | 6.58E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.113165 | 0.034995 | | 1.36E-09 |

| | | | | |
|---|---|---|---|---|
| Interval 3b | uncorrect | corrected | | |
| sws cdf | 3.82E-08 | 2.57E-08 | | |
| ief | 3.6E-08 | | | |
| ratio | 1.061111 | 0.712933 | | |
| basic event | fail rate | import | cdf reduc | |
| S-AUX-BLDG-FA | 0.365 | 0.165007 | | 5.94E-09 |
| S-OT-11-FA | 0.212 | 0.077231 | | 2.78E-09 |
| S-FODT-1AB/CD-FA* | 0.27 | 0.106176 | | 3.82E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.214111 | 0.07821 | | 2.82E-09 |

* combined w/ other failures

| | | | | |
|---|---|---|---|---|
| Interval 3b | uncorrect | corrected | | |
| llo cdf # | 2.84E-08 | 2.2E-08 | | |
| ief | 3.44E-08 | | | |
| ratio | 0.825581 | 0.638408 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.365 | 0.207844 | | 7.15E-09 |
| | 0 | 0 | 0 | |
| S-FODT-1AB/CD-FA | 0.382 | 0.223509 | | 7.69E-09 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.078581 | 0.030838 | | 1.06E-09 |

# 4.7e-9 removed - overlapping cutsets 23 &

Correction of event frequencies

| Interval 3c | uncorrect | corrected | | |
|---|---|---|---|---|
| losp cdf | 1.98E-07 | 7.62E-08 | | |
| ief | 7.86E-08 | | | |
| ratio | 2.519084 | 0.969365 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.577 | 0.041788 | | 3.28E-09 |
| S-OT-11-FA | 0.345 | 0.016136 | | 1.27E-09 |
| S-BR-250VDC-FA | 0.46 | 0.026097 | | 2.05E-09 |
| S-B-250VDC-FA | 0.46 | 0.026097 | | 2.05E-09 |
| S-BC-250VDC-FA | 0.097 | 0.003291 | | 2.59E-10 |
| remaining | 0.580084 | 0.04232 | | 3.33E-09 |

| Interval 3c | uncorrect | corrected | | |
|---|---|---|---|---|
| slb cdf | 9.07E-08 | 4.76E-08 | | |
| ief | 5.29E-08 | | | |
| ratio | 1.714556 | 0.899037 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.577 | 0.13772 | | 7.29E-09 |
| S-OT-11-FA | 0.345 | 0.053179 | | 2.81E-09 |
| S-FODT-1AB/CD-FA | 0.5 | 0.100963 | | 5.34E-09 |
| S-IC-ICE-BASB-FA | 0.14 | 0.016436 | | 8.69E-10 |
| | 0 | 0 | 0 | |
| remaining | 0.152556 | 0.018175 | | 9.61E-10 |

| Interval 3c | uncorrect | corrected | | |
|---|---|---|---|---|
| slo cdf | 7.59E-08 | 3.98E-08 | | |
| ief | 4.43E-08 | | | |
| ratio | 1.713318 | 0.89889 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.577 | 0.137921 | | 6.11E-09 |
| S-OT-11-FA | 0.345 | 0.053257 | | 2.36E-09 |
| S-FODT-1AB/CD-FA | 0.5 | 0.10111 | | 4.48E-09 |
| S-IC-ICE-BASB-FA | 0.14 | 0.01646 | | 7.29E-10 |
| | | 0 | 0 | |
| remaining | 0.151318 | 0.018028 | | 7.99E-10 |

| Interval 3c | uncorrect | corrected | | |
|---|---|---|---|---|
| sws cdf | 1.14E-07 | 5.04E-08 | | |
| ief | 5.29E-08 | | | |
| ratio | 2.155009 | 0.95308 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.577 | 0.064003 | | 3.39E-09 |
| S-OT-11-FA | 0.345 | 0.024714 | | 1.31E-09 |
| S-FODT-1AB/CD-FA* | 0.64 | 0.083414 | | 4.41E-09 |
| S-IC-ICE-BASB-FA | 0.14 | 0.007638 | | 4.04E-10 |
| | | 0 | 0 | |
| remaining | 0.453009 | 0.038859 | | 2.06E-09 |

* combined w/ other failures

| Interval 3c | uncorrect | corrected | | |
|---|---|---|---|---|
| llo cdf # | 8.57E-08 | 5.95E-08 | | |
| ief | 7.38E-08 | | | |
| ratio | 1.161247 | 0.806318 | | |
| basic event | fail rate | import | | cdf reduc |
| S-AUX-BLDG-FA | 0.577 | 0.264195 | | 1.95E-08 |
| | 0 | 0 | 0 | |
| S-FODT-1AB/CD-FA | 0.5 | 0.193682 | | 1.43E-08 |
| | | 0 | 0 | |
| | | 0 | 0 | |
| remaining | 0.084247 | 0.017818 | | 1.31E-09 |

# 3.43e-8 removed - overlapping cutsets 16 &