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REACTOR MATERIALS PROGRAM PROCESS WATER PIPING INDIRECT FAILURE FREQUENCY (U)

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1. INTRODUCTION

The maximum loss of coolant accident (LOCA) for the Savannah River Production Reactors is the hypothetical double-ended guillotine break (DEGB). The LOCA Definition Project has demonstrated through deterministic analyses that the DEGB is not credible. Complementary probabilistic analyses were performed which support this conclusion (1-4). Therefore, the basis has been established to eliminate the DEGB from SRP safety analyses and an alternate design LOCA has been defined (5).

Following completion of the probabilistic analyses, the LOCA Definition Project has been subject to various external reviews, and as a result the need for several revisions has arisen. This report updates and summarizes the indirect failure frequency analysis for the process water piping. The methodology and conclusions reported in the reference 1 and 2 reports for indirect failure frequency are unchanged. In this report, a conservatism of the earlier analysis is removed, supporting lower failure frequency estimates. The analysis results are also reinterpreted in light of subsequent review comments.

The conclusion that a DEGB is of such a low probability as to not warrant further design consideration remains valid.

2. SUMMARY AND CONCLUSIONS

The probabilistic analysis consists of three separate evaluations: the failure frequency of the piping by direct means, the failure frequency of the piping by indirect means, and the failure frequency of the other process water components. The indirect failure frequency is discussed in this report. Possible sources of indirect pipe failure are earthquake, external missiles and overpressurization accidents. For the relatively low pressure SRS reactors which are vented to atmosphere, overpressurization sufficient to rupture the piping is not considered credible. Similarly, external missiles do not comprise a credible threat since the only possible missile source within the reactor building is the pump blades. The thick pump casing should provide protection from this source. Therefore, earthquakes present the only credible threat of indirectly-induced pipe failure.

The indirect seismic failure scenario postulates an earthquake that causes other components or the building structure to fall on the pipe, or which pulls components to which the pipe is attached away from their anchors. While neither of these indirect failure mechanisms are certain to fail the pipe, such an outcome is conservatively assumed. The median indirect failure frequency is 7.8×10^{-7} per year for L and K reactors, and 1.3×10^{-6} per year for P reactor, based on accelerations up to 1.5g. These values derive from median plant fragility estimates of 0.64g for L and K reactors and 0.59g for P reactor. In other words, one has 50% confidence that the piping has a 50% probability of not experiencing an indirect failure for seismic loads up to 3 times that which they are required to withstand (0.2g).

This evaluation was performed specifically for the process water piping. However, the failure mechanisms considered here also pose a risk to the other process water components. For example, the postulated collapse of the building tower structure onto the plenum inlet piping would also threaten the plenum and reactor tank. Therefore, this indirect failure frequency can be used as an approximate indirect failure estimate for the entire process water system.

The failure frequency estimates in this report are revised from those cited in earlier references (1-3). The basis for the revision is the removal of an unnecessary conservatism in estimating the reactor building fragility. Full credit is now taken for a five foot thick concrete section in the building tower structure that was not fully considered previously. This has resulted in a reduction in the failure frequency estimates from those reported previously.

3. DISCUSSION

The indirect failure frequency has been evaluated by R. P. Kennedy of RPK Structural Mechanics Consulting and D. A. Wesley and S. A. Short of Impell Corporation. This work has been presented in references 1 and 2. Subsequently, as a result of independent reviews, it was identified that one aspect of the analysis was treated conservatively. These individuals amended the analysis to remove this conservatism. The revised analyses for L and P reactors are provided as Attachments 1 and 2. As noted in reference 2, K reactor is seismically the same as L reactor; therefore, the revised indirect large break frequency for L reactor also applies to K reactor. This report, with Attachments 1 and 2, is an update of references 1 and 2.

Approach

In defining the basis for application of Leak-Before-Break (LBB) to commercial reactors, the General Design Criteria GDC-4 (Appendix A, Criterion 4 to 10 CFR 50 General Design Criteria) was modified in 1987 to add "...demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping." This is one of several concerns to be addressed in order to invoke LBB for the elimination of pipe whip restraints and jet impingement shields in commercial nuclear reactors.

In references 1 and 2, the seismic hazard was calculated for earthquakes up to and including 1.5g peak ground acceleration. In comparison, the peak ground acceleration specified for qualification of the SRS reactors is 0.2g. To demonstrate the failure probability is extremely low "under conditions consistent with the design basis for the piping", considerations of peak ground accelerations up to 0.2g meets the intent of GDC-4. However, since the ultimate goal of the LOCA Definition Project is to justify eliminating the DEGB from consideration in all aspects of safety analyses, citing the indirect failure frequency for earthquakes up to 1.5g is appropriate.

The indirect pipe failure frequency characterizes the likelihood of the seismically induced failure of the building or other components producing a break in the piping. Based on a walkdown inspection of each reactor building, several components were identified as presenting a possible indirect threat to the piping, in addition to the building structure itself. These are the reactor tank, heat exchangers, Bingham pumps, and the actuator (forest) and control rods. These components have been evaluated for their seismic capacity, which is often limited by support failure. Component support failure is conservatively postulated as the point at which the attached piping is severed from these components. Since there is some probability that the piping will not fail under these circumstances, this result is conservative.

The component fragility has two uncertainties associated with it, representing the inherent randomness of earthquake characteristics and model uncertainties. These uncertainties are assumed to follow a log-normal distribution and are used to estimate upper and lower confidence levels on the fragility, expressed as a fragility curve. The component and building fragility curves are combined to produce a plant fragility curve.

In order to evaluate the failure frequency, the plant fragility curve is combined with the seismic hazard curve, which gives the probability of occurrence of a particular magnitude earthquake. In fact, the seismic hazard curve is a family of curves, each with a given level of confidence. Combination of the seismic hazard curves with the plant fragility curve gives the total indirect failure frequency.

The failure frequency, and the corresponding plant fragility, can be presented with any desired confidence level, depending on the treatment of uncertainties. A best estimate result is seen in either the median or mean frequency: opinion differs as to which is the more appropriate estimate and both are often presented in the literature. The median value is generally a better nominal result, identifying the value for which there is a 50% confidence level of less than 50% probability of failure. On the other hand, the mean tends to accentuate any uncertainties and gives a somewhat higher estimate. A convenient upper bound estimate is the HCLPF (high confidence of low probability of failure). This estimate provides 95% confidence that the probability of failure is less than 5%. Each of these estimates is provided in Attachments 1 and 2.

Results

In the reference 1 evaluation the contribution to the total indirect failure frequency from the building structure did not account for the five feet thick shear wall between the elevations of 34 and 48 feet located south of the tower region. When the shear wall is included in the analysis, the median building fragility increases from 1.02g to 1.42g for L reactor, and from 0.69g to 0.89g for P reactor. (The P reactor building fragility differs from that of L due to differences in the tower structure.) Hence, the building contribution to the indirect pipe failure frequency is less than previously reported, reducing the overall indirect failure frequency estimate. As stated above, the values for L reactor also apply to K reactor. The fragilities for the building and each component evaluated are presented in Table 1. Also in Table 1 are the reference 1 fragility values, where those values have changed.

The component with the smallest seismic capacity (largest failure likelihood) is the heat exchanger. The heat exchanger capacity is limited by the bolting of the seismic bracing to the floor base plate. Shims are placed between the base plate and bracing and are either solid blocks or thin laminated plates. Because of the difference in loads transmitted to the bolts under seismic deflections, the laminated shims are of lower capacity than the solid shims. Both types are used in P, K and L reactors; therefore, the lower capacity is assumed for all heat exchangers. This gives a median heat exchanger capacity of 0.70g, versus 0.94g for the solid shim case. Since this seismic capacity based on laminated shims is well in excess of the site seismic requirements to meet 0.2g accelerations, a change to all solid shims is not considered necessary.

The reactor tank has a seismic capacity of 1.04g, with the outlet nozzles being most susceptible to failure. The Bingham pumps and the actuator and control rods have a much higher seismic capacity and do not contribute significantly to the plant fragility. The combination of each individual seismic fragility discussed above gives a median L reactor plant fragility of 0.64g for the laminated shim case. For P reactor, the corresponding plant fragility is 0.59g. These median plant fragilities, as well as HCLPF fragilities, are summarized in Table 1.

The plant fragility is obtained by combining the individual building and component fragilities. As seen in Table 1, the HCLPF plant fragility is slightly lower than the lowest component fragility. Therefore, one can see from Table 1 the improvement that would be realized in the plant fragility for various modifications. For example, if the heat exchangers supports were changed to provide a seismic capacity greater than the tank, the HCLPF plant capacity would not increase significantly, since the tank fragility is only slightly higher than the heat exchanger fragility and

would become the controlling factor in the overall plant fragility. Since the increase in plant fragility due to modifications such as replacing all heat exchanger laminated shims with solid shims is small (and of a magnitude similar to the calculation uncertainties) such modification is not warranted.

Combining the plant fragility with the seismic hazard curves gives the total indirect large break frequency. Including earthquakes up to the maximum level of 1.5g gives a median failure frequency of 7.8×10^{-7} per year for L and K reactors and 1.3×10^{-6} for P reactor. These values, as well as mean and HCLPF estimates, are summarized in Table 2. Also given in Table 2 are the failure frequencies reported in reference 1 and the failure frequencies for loads more representative of the seismic loads for which the reactors must show protection. The contribution to the indirect failure frequency for accelerations up to 0.25g is representative of the failure probability under conditions consistent with design requirements. For 0.25g accelerations, the median failure frequency is on the order of 10^{-10} per year or less for all three reactors.

In these calculations, accelerations (1.5g) much higher than those for which the SRS reactors must show protection have been used. Regardless of what the reactor is qualified to withstand (0.2g in this case), the occurrence of a greater earthquake remains credible, although very unlikely. Hence, higher accelerations are included in a total failure probability. The cutoff at 1.5g was selected as a maximum credible level due to the increasing uncertainty in extrapolating seismic hazard curves to higher accelerations, and the decreasing contribution from larger earthquakes, due to their very low frequency of occurrence. In fact, approximately 2/3 of the total median failure frequency derives from earthquakes below 0.75g. Close to 90% of the mean failure frequency is due to earthquakes below 0.75g. The use of values based on accelerations up to 1.5g differs from the reference 1-3 reports, based on reviewer comments.

Significance

This evaluation was performed specifically for the process water piping. However, the failure mechanisms considered here also pose a risk to the other process water components. For example, the largest indirect contribution comes from the heat exchangers. Failure of the heat exchanger supports would endanger the heat exchanger itself and other nearby components in addition to the process water piping. Further, the postulated collapse of the building tower structure onto the plenum inlet piping would also threaten the plenum and reactor tank. Therefore, the indirect piping large break frequency approximates the indirect large break frequency for the entire process water system.

4. REFERENCES

1. DPST-88-400, "Reactor Materials Program Probability of Indirectly - Induced Failure of L and P Reactor Process Water Piping," W. L. Daugherty, Savannah River Laboratory, March 1988.
2. DPST-88-546, "Reactor Materials Program Process Water Piping - K Reactor Indirect Failure Probability," W. L. Daugherty, Savannah River Laboratory, May 1988.
3. DPST-88-469, "Reactor Materials Program Process Water Component Failure Probability," W. L. Daugherty, Savannah River Laboratory, April 1988.
4. DPST-88-468, "Reactor Materials Program Process Water Piping Direct Failure Probability," W. L. Daugherty, Savannah River Laboratory, April 1988.
5. DPST-88-676, "Reactor Materials Program LOCA Definition Project Summary Report," N. G. Awadalla, W. L. Daugherty and R. L. Sindelar, Savannah River Laboratory, November 1988.

Table 1. Building and Component Fragilities.

<u>Component</u>	<u>Median Capacity (g)</u>		<u>HCLPF Capacity (g)</u>	
	<u>L. K Reactors</u>	<u>P Reactor</u>	<u>L. K Reactors</u>	<u>P Reactor</u>
Building	1.42 (1.02)*	0.89 (0.69)*	0.55 (0.34)*	0.34 (0.21)*
Main Tank	1.04	1.04	0.36	0.36
Heat Exchanger (laminated shims)	0.70	0.70	0.30	0.30
(solid shims)	0.94	0.94	0.41	0.41
Bingham Pumps	**	**	> 1	> 1
Actuator & Control Rods	> 3	> 3	> 1	> 1
<hr/>				
Plant Fragility (laminated shims)	0.64 (0.61)*	0.59 (0.53)*	0.28 (0.27)*	0.27 (0.21)*
(solid shims)	0.76 (0.70)*	0.67 (0.59)*	0.33 (0.29)*	0.29 (0.21)*

* Values in parentheses are the estimates reported previously, provided here for comparison. Only those values which differ from those previously reported are noted.

** This value was not reported. It makes an insignificant contribution to the total.

Note: The SRS site requires seismic qualification for peak ground accelerations of 0.2g. The estimated plant fragilities are all in excess of this value.

Table 2. Summary of Indirect PWS Piping Failure Frequency

<u>Confidence Level</u>	Failure Frequency (per year) * **	
	<u>L. K Reactor</u>	<u>P Reactor</u>
1.5g Acceleration ***		
Median Estimate	7.8×10^{-7} (1.2×10^{-6})	1.3×10^{-6} (3.7×10^{-6})
Mean Estimate	6.0×10^{-6} (7.2×10^{-6})	7.6×10^{-6} (1.6×10^{-5})
HCLPF Estimate	3.3×10^{-5} (3.7×10^{-5})	4.1×10^{-5} (8.2×10^{-5})
0.25g Acceleration ***		
Median Estimate	$< 10^{-10}$ (negligible)	1×10^{-10} (8.1×10^{-8})
Mean Estimate	1.4×10^{-7} (2.1×10^{-7})	1.8×10^{-7} (3.1×10^{-6})

* These failure frequencies are based on calculations for the building, main tank and heat exchangers (with laminated shims).

** Values in parentheses are the estimates reported previously, provided here for comparison.

*** The site seismic qualification level for the reactors is 0.2g, approximated by the 0.25g values. The higher estimates for 1.5g envelope all credible seismic loads, including loads beyond those for which the reactors must show protection.

J. M. Stone
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Attachment No. 1

**PROBABILITY OF MAIN COOLANT (PROCESS WATER) PIPE
FAILURE AT THE SAVANNAH RIVER 'L' REACTOR
INDIRECTLY-INDUCED BY EARTHQUAKES**

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REVISION 1

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1. INTRODUCTION

A probabilistic evaluation of pipe break for the Savannah River Project (SRP) L-Reactor main coolant (process water) piping is being conducted by the SRP staff with support from several subcontractors. Included in the evaluation are two general classes of pipe break. The directly-induced pipe break is a pipe break in the reactor coolant piping due to fatigue crack growth resulting from the combined effects of thermal, pressure, seismic, and other cyclic loads. The seismic indirectly-induced pipe break is a pipe break due to causes other than the direct inertia loads in the pipe itself. Causes such as earthquake-induced failures of supports of major components to which the pipe is attached and debris missiles which could impact the piping are being considered.

This report covers the evaluation of seismically-induced indirect pipe break. Seismically-induced indirect pipe break can result primarily from two general modes of failure. The first involves failure of the anchorage of one or more of the components such as a pump, heat exchanger, etc., to which the pipe is anchored. For relatively massive equipment, failure of the component anchorage with the resulting seismic loads and end point motions is conservatively assumed to result in failure of the pipe. A second mode of seismically-induced indirect pipe break involves failure of the pipe due to collapse of the structure or a heavy component onto the pipe with resulting pipe failure even though the pipe anchorage remains intact. The potential for both types of seismically-induced indirect failures were identified in the L-Reactor during a seismic walkdown of the main coolant piping and are discussed in this report. The direct seismically-induced pipe break investigation is being conducted by others and is not reported here.

The general approach to evaluating the probability of a seismically-induced indirect pipe break involved four steps: 1) the critical components to which the piping is attached were identified; 2) any other components or structures whose failure could result in pipe failure were identified; 3) the seismic capacities or "fragilities" of these components were developed, and 4) the component seismic fragilities were convolved with a probabilistic seismic hazard estimate for the site in order to obtain estimates of seismic risk in terms of annual probability of seismic-induced indirect pipe break. Only those components whose failure was considered to have a high probability of pipe failure were considered. The details of this methodology together with several examples and results are discussed in the following sections.

2. SEISMIC RISK METHODOLOGY

The seismic risk of indirect reactor main coolant (RCL) pipe break involves consideration of both the seismic hazard and the seismic capacities (fragilities) of the important components and structures. Seismic fragilities were developed for the components and structures whose seismically-induced failure could be expected to result in failure of the RCL (process water) piping. These components were identified based on discussions with the SRP staff, review of L-Reactor drawings and plant descriptions, and a plant walkdown conducted by Drs. R. P. Kennedy and D. A. Wesley. Fragilities were developed for the following components and structures:

1. Main Tank
2. Main Coolant Pumps
3. Heat Exchangers
4. Forest and Rods
5. Building (Above Elev. 0)

The main tank, main coolant (Bingham) pumps, and the heat exchangers are all end point attachment (anchor) locations for the piping. Each of these items is of sufficient mass that failure (as defined in the following subsection) was conservatively considered to result in failure of the pipe. The location of these components as well as the general plant configuration is shown in Figure 2-1. Failure of the building structure above Elevation 0 as well as failure of the forest support and control rod system was investigated due to the potential for impact-induced pipe failure of the exposed nozzles located above the operating floor slab at Elevation 0. Failure of the building structure below Elevation 0 was not investigated in detail. However, this structure is constructed of massive, reinforced concrete shear walls and is embedded below grade below Elevation 0.

A brief review of the seismic loads in the concrete structure below grade indicated very low seismic stresses such that failure of this portion of the structure was not considered credible at the seismic levels which govern the indirect pipe break plant risk.

No components whose failure could be expected to cause failure of the pipe as a result of impact other than those listed above were identified during the plant walkdown. Those components of sufficient mass such as tanks, etc., whose failure could result in pipe failure were judged to be located far enough away from the pipe that even if their anchorage were lost as a result of an earthquake, impact with the pipe was not considered likely. It is understood the crane above the operating floor is not parked over the main tank during plant operation.

2.1 Definition of Failure

The seismic fragilities and resulting plant risk developed in this investigation are based on breach of the fluid boundary. A complete pipe severance around the circumference as implied by a "double-ended guillotine break, (DEGB)", has a much lower probability of occurrence for some components than simply breach of the pressure boundary with subsequent leakage. No attempt has been made to assess the expected size of the leak area for any mode of failure. For some modes such as potential cracking of a weld in a tank nozzle, the expected leak area will be small. Areas associated with other components and modes of failure can be substantially larger.

For consideration of consequences associated with pipe failure, it is expected that several seconds after the initiation of the earthquake will be required before failure will occur.

The strong motion portion of most earthquakes located any distance from the site does not occur immediately with the first wave motion to reach the site, and some time is required for the structure to reach its maximum response.

Functional failures such as failure of the heat exchanger or main internals or failure of the pump to rotate are not considered failure unless breach of the pressure boundary is expected. Thus, the controlling modes of failure for components to which the pipe is attached, in general, were found to be loss of component anchorage.

2.2 Technical Approach for Fragilities

The approach to developing the conditional probability of RCL pipe break is based on combining the failure probabilities of individual structures and components as defined by their fragility estimates. Component fragilities are treated as either independent or dependent in sensitivity studies. The assumption of independent component fragilities gives a conservative bound on the combined probability of seismic indirect pipe break. If one of the components has a very high probability of failure (low fragility), it tends to dominate the plant fragility. Seismic-induced fragility data are generally unavailable for specific plant components and are certainly unavailable for the specific SRP structures and components evaluated here. This condition generally exists for all nuclear power plants and occurs because the current design codes and standards do not require the calculation of ultimate capacities, but only require the designer to provide assurance that seismic stresses are below specified allowables. Thus, fragility curves must be developed primarily from analysis combined heavily with engineering judgment supported by very limited test data. Such fragility curves will contain a great deal of uncertainty, and it is imperative that this uncertainty be recognized in all subsequent analyses.

Because of this uncertainty, great precision in attempting to define the shape of these curves is unwarranted. Thus, a procedure which requires a minimum amount of information, incorporates uncertainty into the fragility curves, and easily enables the use of engineering judgment, was used in this study.

The entire fragility curve for any mode of failure and its uncertainty can be expressed in terms of the best estimate of the median ground acceleration capacity, $\hat{A}$, times the product of random variables. Thus, the ground acceleration, A , corresponding to failure is given by:

$$A = \hat{A} \epsilon_R \epsilon_U \quad (2-1)$$

in which ϵ_R and ϵ_U are random variables with unit median representing the inherent randomness (failure fraction) about the median and the uncertainty (probability) in the median value, respectively. Equation 2-1 enables the fragility curve and its uncertainty to be represented as shown in Figure 2-2 (i.e., as a set of shifted curves with attached uncertainty levels). Thus, it is assumed that all uncertainty in the fragility curves can be expressed through uncertainty in the median alone.

Next, it is assumed that both ϵ_R and ϵ_U are lognormally distributed with logarithmic standard deviations of β_R and β_U , respectively. The advantages of this formulation are:

1. The entire fragility curve and its uncertainty can be expressed by three parameters - $\hat{A}$, β_R , and β_U . With the very limited available data on fragility, it is much easier to only have to estimate three parameters rather than the entire shape of the fragility curve and its uncertainty.
2. The formulation in Equation 2-1 and the lognormal distribution are very tractable mathematically.

In this study, the guidelines used to estimate the values of β_R and β_U for each variable affecting A were based on considering the inherent randomness, β_R , to be associated primarily with the earthquake characteristics themselves, and β_U to be associated with other lack of knowledge. Thus, such variability as resulting from earthquake response spectra shapes and amplification, earthquake duration, numbers and phasing of peak excitation cycles, etc., together with their contributions to structure ductility and response characteristics was attributed to randomness. In general, it is not considered possible to significantly reduce randomness by additional analysis or test based on current state-of-the-art techniques. Uncertainty, on the other hand, is considered to result primarily from analytical modeling assumptions and other lack of knowledge concerning variables such as material strength, damping, etc., which could in many cases be reduced by additional study or test.

The lognormal distribution can be justified as a reasonable distribution since the statistical variation of many material properties (Refs. 1 and 2) and seismic response (Ref. 3) variables may reasonably be represented by this distribution. In addition, the central limit theorem states that a distribution consisting of products and quotients of distributions of several variables tends to be lognormal even if the individual distributions are not lognormal. Some characteristics are discussed in Appendix A of this report.

It should be noted that the use of the lognormal distribution for estimating failure fractions on the order of five percent or greater is considered to be quite reasonable. However, lower fraction estimates which are associated with the extreme tails of the distributions must be considered less accurate. Use of the lognormal distribution in these regions is conservative

since the low frequency tails of the lognormal distribution generally extend farther from the median than actual structural resistance or response data might indicate. The degree of conservatism introduced into the probability of release is dependent not only on the conservatism in the fragility description, but also on the seismic hazard description at low seismic levels. If the seismic hazard for low seismic input levels is large enough, it is apparent that very low level earthquakes can govern the seismic-induced release. This is considered unrealistic for engineered structures and equipment found in nuclear power plants since such structures and equipment are subjected to various low level dynamic loads on a repetitive basis from a number of sources (i.e., wind and low level earthquakes) which have never been known to produce nuclear power plant failures.

A number of the variables, such as material strength data, do not typically fall far below median value but instead, normally exhibit some distinct lower bound (Refs. 1 and 2). Damping data also exhibit lower and upper bounds so that cutoffs on the tails of the fragilities could be expected to exist. For these as well as other variables contributing to the seismic fragility of a given structure or component, it is reasonable to assume that some lower and upper bound cutoffs on the tails of the dispersion exist. However, there is currently no known basis for quantitatively establishing these cutoffs.

When developing the median ground acceleration, it is computationally convenient to work with a median factor of safety, $\hat{F}$, such that:

$$\hat{A} = \hat{F} A_{SSE} \quad (2-2)$$

where A_{SSE} is the peak ground acceleration associated with the Safe Shutdown Earthquake (SSE) or Design Basis Earthquake (DBE). The overall median factor of safety, F , may in turn be broken

down (separation of variables) into individual factors of safety representing the important variables contributing to the seismic strength and response variables associated with each structure or component.

For equipment, the factor of safety can be modeled as the product of the three random variables.

$$F = F_C \cdot F_{RS} \cdot F_{RE} \quad (2-3)$$

The capacity factor, F_C , for the equipment is a product of a strength factor, F_S , and possibly an inelastic energy absorption factor, F_u . The strength factor, F_S , represents the ratio of ultimate strength to the stress calculated for A_{SSE} . In calculating the value of F_S , the non-seismic portion of the total load acting on the support is subtracted from the strength as follows:

$$F_S = \frac{S - P_N}{P_T - P_N} \quad (2-4)$$

where S is the ultimate structural strength for the specific failure mode, P_N is the stress due to the normal operating load, and P_T is the total stress (i.e., sum of the seismic load for A_{SSE} and the normal operating load). Whether an inelastic energy absorption factor, F_u , should be included or not is a function of the failure mode (i.e., brittle or ductile modes). Brittle failures are defined as those failure modes which exhibit little or no system inelastic energy absorption capability. Examples are:

1. Anchor bolt failures
2. Support weld failures
3. Elastic buckling failures

Each of these failure modes has the ability to absorb some inelastic energy on the component level, but the plastic zone is very localized, and the system ductility for an anchor bolt or a support weld is very small. The total capacity of the component failing in a brittle mode is therefore equal to F_S based on the ultimate strength of the material.

Ductile failure modes are those in which the structural system can absorb a significant amount of energy through inelastic deformation. Examples include:

1. Pressure boundary failure of piping
2. Primary equipment supports failing in tension or bending

The total capacity is then the product of a strength factor, F_S , and an inelastic energy absorption factor, F_μ . The strength of the element failing in a ductile mode is taken to be the yield strength of the material for tensile loading while for flexural loading, the strength is defined as the stress at which a plastic hinge is developed.

The inelastic energy absorption factor, F_μ , for an equipment support is a function of the ductility ratio, μ and damping, δ . The median value $\hat{F}_\mu$ is considered to be close to 1.0 for brittle and functional failure modes. For ductile failure modes of equipment subjected to broad frequency response spectra corresponding to essentially ground response spectra, the inelastic energy absorption factor is calculated using the procedure given in Riddell and Newmark (Ref. 15). With narrow frequency input spectra, the procedure suggested by Kennedy (Ref. 16) is used.

The median $\hat{F}_c$ and the variability estimates, $\beta_{C,R}$ and $\beta_{C,U}$ of the capacity factor are obtained as follows:

$$\hat{F}_C = \hat{F}_S \cdot \hat{F}_\mu \quad (2-5)$$

$$\beta_{C,R} = (\beta_{S,R}^2 + \beta_{\mu,R}^2)^{1/2} \quad (2-6)$$

$$\beta_{C,U} = (\beta_{S,U}^2 + \beta_{\mu,U}^2)^{1/2} \quad (2-7)$$

where

$\hat{F}_S$ = Median strength factor

$\hat{F}_\mu$ = Median inelastic energy absorption factor

$\beta_{S,R}$ = Logarithmic standard deviation of the randomness in the strength factor

$\beta_{S,U}$ = Logarithmic standard deviation of the uncertainty in the median value of strength factor.

$\beta_{\mu,R}$ = Logarithmic standard deviation of the randomness in the inelastic energy absorption factor.

$\beta_{\mu,U}$ = Logarithmic standard deviation of the uncertainty in the median value of the inelastic energy absorption factor.

The structural response factor, F_{RS} , recognizes that in the design analyses, the structural response was computed using specific (often conservative) deterministic response parameters for the structure. Because many of these parameters are random (often with a wide variability), the actual response may differ substantially from the response calculated in the design analyses for a given peak ground acceleration level.

The structural response factor, F_{RS} , is expressed as a product of the factors influencing the variability on response.

$$F_{RS} = F_{SA} \cdot F_b \cdot F_M \cdot F_{SD} \cdot F_{SS} \quad (2-8)$$

where

F_{SA} = Spectral shape factor representing the ratio of the median site-specific ground response spectra to the ground spectra used for design.

F_{δ} = Damping factor representing the variability in response due to difference in actual damping and design damping.

F_M = Modeling factor accounting for the uncertainty in response due to modeling assumptions.

F_{SD} = Factor to reflect the reduction of seismic input with depth of embedment of the structure.

F_{SS} = Factor to account for the effect of soil-structure interaction.

The median $\hat{F}_{RS}$ and the variability estimates $\beta_{RS,R}$ and $\beta_{RS,U}$ are calculated using Equations 2-8 and the properties of lognormal probability law:

$$\hat{F}_{RS} = \hat{F}_{SA} \cdot \hat{F}_{\delta} \cdot \hat{F}_M \cdot \hat{F}_{SD} \cdot \hat{F}_{SS} \quad (2-9)$$

$$\beta_{RS,R} = (\beta_{SA,R}^2 + \beta_{\delta,R}^2 + \beta_{M,R}^2 + \beta_{SD,R}^2 + \beta_{SS,R}^2)^{1/2} \quad (2-10)$$

A similar expression exists for $\beta_{RS,U}$.

Similarly, the equipment response factor, F_{RE} , is a measure of the conservatism inherent in the calculation of equipment response in the design analyses. F_{RE} is equal to the ratio of the equipment response calculated during design to the realistic equipment response level based upon the appropriate design floor response spectra. The equipment response factor is also expressed as a product of the factors influencing the variability on response.

$$F_{RE} = F_{SA} \cdot F_{\delta} \cdot F_M \cdot F_{MC} \cdot F_{EC} \quad (2-11)$$

F_{SA} = Spectral shape factor - including the effects of peak broadening and smoothing, and artificial time history generation.

F_{δ} = Damping factor.

F_M = Modeling factor (affects mode shape and frequency results).

F_{MC} = Factor to account for conservatism in method used to combine modal responses.

F_{EC} = Factor to account for conservatism in method used to combine earthquake components.

The median F_{RE} and the variability estimates, β_R and β_U of the equipment response factor are obtained using Equation 2-11 and the properties of the lognormal probability law as described above.

The overall factor of safety F is calculated as the product of the capacity factor and the equipment and structural response factors. Using Equation 2-2, the ground acceleration capacity of the structural element then becomes:

$$\hat{A}_C = \hat{F} \cdot A_{SSE} \quad (2-12)$$

$$\hat{F} = \hat{F}_C \cdot \hat{F}_{RS} \cdot \hat{F}_{RE} \quad (2-13)$$

$$\beta_{A,R} = \beta_{F,R} = (\beta_{C,R}^2 + \beta_{RS,R}^2 + \beta_{RE,R}^2)^{1/2} \quad (2-14)$$

$$\beta_{A,U} = \beta_{F,U} = (\beta_{C,U}^2 + \beta_{RS,U}^2 + \beta_{RE,U}^2)^{1/2} \quad (2-15)$$

Note that the variability in spectral shape and damping in the response factor and in inelastic energy absorption in the capacity factor are interrelated and judgment is employed in the use of Equations 2-14 and 2-15 such that variability is not overestimated. The overall factor of safety is thus decomposed

into factors that can be modeled and for which data and information exist. In some instances, evaluating β values exactly would require detailed analysis and/or more extensive data than is available. For these cases, it is sometimes necessary to use subjective evaluations and engineering judgment to evaluate the β values. As an example, consider the case for which the median value of the factor is known and a lower bound value, below which it is fairly unlikely that the factor will fall, is also known. Given that the factor is lognormally distributed, the β value may be evaluated by assuming the lower bound to be, say, a 5 percentile value. Although this procedure is subjective, it is generally observed that changes in the β value for the particular factor have a small effect on the final probabilities calculated. This results from the fact that the β 's of the overall safety factor are the SRSS of many β 's (Equations 2-14, 2-15) of similar magnitude and therefore, insensitive to minor variations in the individual β 's. Also, the seismic hazard uncertainty tends to dominate the final analysis variability, making the calculated probabilities relatively insensitive to minor changes in the β values estimated for the fragilities.

The ground acceleration capacity of the support for each major equipment component has been expressed in this study as the lowest capacity for all credible failure modes of the component support. This is a realistic assumption since the failure modes are highly correlated due to common structural material and method of fabrication. Again, if one of the failure modes of the component has a very low capacity compared to other modes, this assumption leads to a good approximation of the probability distribution of the capacity.

The approach to developing the civil structure fragility is essentially the same as for equipment fragilities. For the building, F_C is the capacity of the structure rather than the capacity of the equipment item and no equipment response factor, F_{RE} , is included. Consequently, since the variability associated with F_{RE} is also not included in the structure fragility, the overall variability for the civil structure fragility is less than the overall equipment fragility variabilities.

2.3 Seismic Hazard

In addition to consideration of the seismic capacities of the important components, the probability that the peak ground acceleration at the site will exceed a given level must be included. For this study, the set of seismic hazard curves given in Figure 2-3 (from Ref. 4) was used. Each curve is a plot of the annual exceedance probability versus peak free-field ground acceleration. The uncertainty in the earthquake hazard is accounted for by developing a family of curves and assigning a subjective weighting factor (in this case, 0.1) to each curve. In order to develop the seismic risk, the hazard curves developed in Ref. 4 were extrapolated as discussed in Section 5.1.

2.4 Probability of Indirect Pipe Break

Using the previously developed hazard curves for the SRP site together with the fragilities for the important components and structure described here, the probability of a seismically induced indirect pipe break can be calculated. First, the individual component fragilities are combined as a union operation into a plant level fragility. Only those individual fragilities which could be expected to contribute to the overall plant risk were included. The plant fragility is then convolved with the seismic hazard curves to obtain the probability distribution of

the pipe break indirectly-induced by earthquake. The median probability as well as 10% and 90% confidence bounds are developed.

FIGURE 2-1. SRP REACTOR PLANT CONFIGURATION

FIGURE 2-2. FRAGILITY CURVE REPRESENTATIONS

FIGURE 2-3. FAMILY OF 10 HAZARD CURVES AND THE MEAN GENERATED FOR THE SRP SITE. EACH CURVE IS ASSIGNED EQUAL WEIGHT (REF. 4)

3. COMPONENT FRAGILITIES

In this section, the median factors of safety with corresponding median acceleration levels and logarithmic standard deviations for the controlling modes of failure for the tower structure and major equipment items are developed. To the extent they were available, existing dynamic analysis results were used to determine the median factors of safety and logarithmic standard deviations for each of the variables associated with structure and equipment response. These results were supplemented with ultimate strength calculations and seismic response calculations for those cases where the design analyses results were not available. For components where the design calculations were not available, some of the individual factors of safety described in the previous chapter were combined, since median-centered parameters could be directly introduced into the fragility calculations rather than factoring up conservative design values. However, the final acceleration capacity is the same from either approach as is the overall variability since all the strength and response parameters are accounted for in either method. Although inelastic energy dissipation is considered for some modes of failure, all seismic response analyses were based on linear response model results.

3.1 Structure Response

The structure response factor of safety, F_{RS} , and its associated variability influences the fragilities of both the equipment and the structure. The principal variables contributing to this parameter include the considerations of the shape of the response spectra, structure and soil damping, modeling considerations, embedment effects, soil-structure interaction (SSI) effects, and earthquake directional component combinations. The basis for establishing the structural response factor of

safety and variabilities as well as the structure seismic loads is the Quadrex soil-structure interaction model and analysis results described in Ref. 5.

3.1.1 Ground Response Spectra

The soil-structure interaction analysis of the L-Reactor building (Ref. 5) was based on recommended ground response spectra developed by J. A. Blume (Ref. 6) for the SRP site. Although not specifically stated, these spectra (Figure 3-1) appear to be approximately median plus one standard deviation spectra (i.e., 84% nonexceedance). For instance, at 4 Hz, the 5% damped amplification factor is 2.67 which corresponds exactly with the 2.67 amplification for the 84 percentile spectra for similar spectra developed by Newmark (Ref. 3) for alluvium sites. The corresponding median amplification factor for 5% damping and 4 Hz is 2.11. Therefore, it is assumed that the JAB design spectra represent approximately $+1\beta$ spectra. A comparison of 5% damped recommended ground response spectrum with the corresponding expected median spectrum is shown in Figure 3-2. The factor of safety, F_{SA} , for spectral acceleration can therefore be developed for the structure at the fundamental response frequencies in the two horizontal directions and vertical direction. As a result of the radiation of energy from the base slab into the soil (radiation or geometric damping), very high equivalent modal damping ratios (20 to 40 percent of critical) are computed from the Quadrex soil-structure interaction analysis (Ref. 5). In order to develop the factor of safety and variability associated with the response spectra used in the Quadrex analysis, estimated median and 84 percent nonexceedance spectra for 20 and 40% of critical damping were developed. Factors of safety were developed from the ratio of the 84 percent nonexceedance spectra to the median spectra at the fundamental frequencies of the

soil-structure interaction system in the three principal directions. An average factor of safety of about 1.08 result for the equivalent 20% to 40% damping over the 2 to 10 Hz frequency range of interest. In addition, the earthquake record used for the analysis introduced some additional conservatism. In the E-W direction (which controls the building capacity and results in the maximum response for input to the tank, etc.), the average ratio of the spectral acceleration developed by the artificial earthquake time history (Ref. 5) to the specified ground response spectral acceleration is about 1.08 over the frequency range of interest (1 to 5 Hz). The overall factor of safety for the ground response spectra used in the analysis compared to the expected median value is about 1.08×1.08 or about 1.17. Similarly, the lognormal standard deviation of randomness is:

$$\beta_R = \ln 1.17 = 0.16$$

It is recognized that some uncertainty in the shape of median ground response spectra curves also exists. The peaks and valleys associated with response spectra from actual earthquakes compared with the smoothed spectra in Figure 3-1 are accounted for in β_R . However, a value of β_U was developed assuming that the average ratio of spectral accelerations from Refs. 4 and 6 over the frequency range of interest represent one standard deviation, or $\beta_U = 0.07$.

The factor of safety inherent in the analysis based on the JAB response spectra (Ref. 6) is therefore:

$$F_{SA} = 1.17$$

$$\beta_R = 0.16$$

$$\beta_U = 0.07$$

$$HCLP = 0.80$$

The high confidence of low probability of nonexceedance (HCLP) corresponds to a 95% confidence of less than a 5% probability of nonexceedance and indicates it is very unlikely that the spectral amplification in the fundamental soil-structure response range will exceed the median value by more than $1/0.8$ or a factor of 1.25.

3.1.2 Damping

Some conservatism is also expected to be introduced from the assumptions used in the Quadrex analysis results (Ref. 5) compared to the damping levels expected at responses well above the SSE. System damping for the L-Reactor structure is comprised of structure damping, soil hysteretic damping, and geometric (or radiation) damping resulting from radiation of energy into the soil. As response of the structure is increased above the SSE, the structure and soil hysteretic damping may be expected to increase while the geometric damping is expected to remain approximately the same. At the elevations of interest for most of the equipment (i.e., below Elevation 0), most of the damping results from the soil hysteretic and geometric damping since the structure is very lowly stressed at these elevations and the structure damping influence results primarily from the dynamic feedback from the relatively low mass building structure above Elevation 0 to the lower elevations. A comparison of the damping values used in the Quadrex analysis and those expected in the range of severe building distress is:

	Damping (% Critical)	
	<u>QUADREX</u>	<u>FRAGILITY</u>
Structure	4	5
Soil Hysteretic	9	13
Geometric	7 to 27	7 to 27

Since the overall equivalent system damping is quite large (i.e., of the order of 20 to 40%) the dynamic amplification is not significantly affected by moderate increases in system damping. The damping factor of safety, F_s , developed from the ratio of the spectral acceleration from the Quadrex analysis compared to spectral accelerations at the damping expected at structure or equipment failure varies from about 1.0 to 1.04 over the frequency range of interest. In view of the low value of this parameter, an average value of 1.02 was assumed for all three directions of response.

$$F_s = 1.02$$

$$\beta_R = 0.02$$

$$\beta_U = 0.02$$

$$HCLP = 0.96$$

3.1.3 Modeling

The factor of safety corresponding to modeling accounts for any potential conservatism and associated variability resulting from mathematical modeling assumptions for both the building structure as well as possible frequency shifts as a result of soil property variations at high strain levels. The details of the lumped mass model used by Quadrex were not checked as part of the fragilities evaluation. The model was therefore, assumed to be essentially median-centered. Modeling effects include both frequency and mode shape effects. Frequency effects can result in changes in response accelerations based on the deconvolved ground spectra at the base slab and can result from both shifts in the structure frequency and shifts in system frequency due to changes in the soil shear modulus (and hence, soil compliance functions) due to soil shear strain effects at strains above the SSE. However, at the high equivalent damping ratios resulting

for the overall soil-structure interaction model, even very significant shifts in frequency result in very little change in response. Thus, the factor of safety due to modeling is expected to be essentially unity with no randomness. A lognormal standard deviation for uncertainty, β_U , of 0.1 was estimated in order to account for mode shape effects.

$$F_M = 1.0$$

$$\beta_R = 0.0$$

$$\beta_U = 0.10$$

$$HCLP = 0.85$$

3.1.4 Embedment

It is well-known that earthquake accelerations decrease with depth when compared to the free-field surface acceleration. Thus, when a structure is embedded such as the L-Reactor, the earthquake input at the base slab can be expected to be significantly reduced from the surface motion. Since the hazard curves are developed in terms of the free-field surface acceleration levels, a factor of safety, F_{SD} , was developed in order to reflect any conservatism expected in the response computed by Quadrex due to embedment as well as the variabilities associated with this factor.

In the Quadrex analysis (Ref. 5), a deconvolution analysis was performed to determine the expected seismic input at the baseslab of the structure compared to the free-field surface input. The result of this type of analysis is response spectra shapes which vary compared to the surface spectra as well as a reduction in peak ground motion (ZPA) acceleration. These results are considered to be median-centered. However, because of licensing restrictions, the reduction in spectral acceleration was not allowed to decrease below 60 percent of the free-field

acceleration in the Quadrex analysis. To prevent greater reduction, the response of the structure was multiplied by 1.3 in both horizontal directions in the Quadrex analysis. Consequently, a factor of safety of 1.3 for both horizontal directions (1.0 in the vertical direction) is used in the fragility analysis based on the assumption that the Quadrex deconvolution analysis is essentially median-centered. In order to develop the lognormal standard deviation for uncertainty, it was assumed that no reduction with depth represented approximately three standard deviations. This is considered to represent a conservative upper bound on β_U which could probably be reduced if a parametric study were conducted varying several assumptions in the deconvolution model. Some effect of randomness may also be expected in this parameter since different time histories used in the deconvolution analysis are known to result in somewhat different reductions in the ZPA with depth as well as different spectral accelerations. A β_R of 0.08 was estimated to account for this effect. The factors of safety and associated variabilities for horizontal and vertical response are then:

$$F_{SD} = 1.3 \quad \text{(Horizontal)}$$

$$\beta_R = 0.08$$

$$\beta_U = 0.26$$

$$HCLP = 0.74$$

It is considered very unlikely that structure response will exceed the high confidence of low probability of nonexceedance (0.74) value for this parameter by more than $1/0.74$ or 35% of the Quadrex results.

$$F_{SD} = 1.0$$

(Vertical)

$$\beta_R = 0.08$$

$$\beta_U = 0.17$$

$$HCLP = 0.66$$

3.1.5 Soil-Structure Interaction

The soil-structure interaction analysis performed by Quadrex (Ref. 5) was conducted using current state-of-the-art techniques and is considered to be essentially median-centered. Variations due to possible changes in the soil shear modulus at shear strains above the SSE were accounted for in the factor of safety for modeling, F_M , and the effect of embedment was accounted for separately in F_{SD} as previously discussed. Consequently, the factor of safety, F_{SS} , for soil-structure interaction is assumed to be unity. However, since the SSI analysis was conducted using two-dimensional models, a β_U of 0.1 was estimated to account for any three-dimensional structure response effects

$$F_{SS} = 1.0$$

$$\beta_R = 0.0$$

$$\beta_U = 0.10$$

$$HCLP = 0.85$$

3.1.6 Combined Structure Response Effects

The combined factor of safety, F_{RS} , and associated variabilities may then be developed for the above parameters as discussed in Section 2. This results in:

$$F_{RS} = 1.55$$

(Horizontal)

$$\beta_R = 0.18$$

$$\beta_U = 0.31$$

$$HCLP = 0.69$$

$$F_{RS} = 1.19$$

(Vertical)

$$\beta_R = 0.17$$

$$\beta_U = 0.23$$

$$HCLP = 0.62$$

These values indicate for horizontal response, the median response is only about 65% of the calculated Quadrex response. This occurs primarily from the use of median plus one standard deviation ground response spectra for the Quadrex analysis and the fact that the base motion was increased by a factor of 1.3 compared to the analytically predicted reduction of free surface ground motion. It is considered very unlikely that the structure response could exceed the predicted Quadrex response by more than a factor of $1/0.69$ or 1.45.

The variabilities shown above are considered applicable in regards to both the response of the structure as reflected in the relative displacements (story drifts) and input to equipment as applied to the raw (unsmoothed and unbroadened) floor response spectra (Ref. 7).

3.2 Structure Capacity

Since collapse of the building onto the reactor coolant piping can be expected to result in piping failure, the capacity of the structure above Elevation 0 was developed. A brief review of the structure seismic loads below Elevation 0 indicated this

portion of the structure is very lowly stressed so that the fragility of this part of the building was not expressly determined. An estimate of the relative displacements (story drifts) at these lower elevations together with their expected variabilities was developed, however, in order to provide end point anchor displacement of the direct earthquake-induced RCL pipe break investigation being conducted by others. The evaluation of the structure was also restricted to the region of the actuator tower above the reactor tank. Although the building extends outward from this region, it was judged that damage in outlying regions would not contribute to the likelihood of an RCL pipe break.

In this section, the factor of safety on structure capacity is presented. As discussed in Chapter 2, the capacity factor is a product of a strength factor and an inelastic energy absorption factor. The primary lateral load-carrying system of the structure is of reinforced concrete construction. For reinforced concrete structures, the strength factor is a function of material strengths associated with the concrete and the reinforcing steel and relationships expressing strength of concrete walls in flexure and shear. Material strengths and strength relationships along with variabilities are presented in the following three subsections. The strength of the "L" Reactor structure is then presented in Section 3.2.4. Inelastic energy absorption is discussed in Section 3.2.5 and the capacity of "L" Reactor structural elements combining strength and inelastic energy absorption is presented in Section 3.2.6.

3.2.1 Strength of Concrete and Reinforcing Steel

The evaluation of the strength of most concrete elements, whether loaded in compression or shear, is based on the concrete compressive strength, f'_c . Concrete compressive strength used for design is normally specified as some minimum value at a specific time from mixing (for example, 28 or 90 days). This value

is verified by laboratory testing of mix samples. The strength must meet specified values allowing a finite number of failures per number of trials. As previously stated, there are two major factors which justify the selection of a median value of concrete strength above the design strength.

1. To meet the design specifications, the contractor attempts to create a mix that has an "average" strength above the design strength.
2. As concrete ages, it increases in strength.

The concrete utilized in the construction of the L-Reactor structure was specified to have a minimum compressive strength of 2500 psi at 28 days. Testing to verify the attainment of this minimum strength is normally conducted on cylinder specimens. Results of concrete compression testing were not available for the structure. The average 28-day strength for 2500 psi concrete was therefore conservatively estimated to be approximately 3000 psi with a logarithmic standard deviation of 0.12. The estimated 3000 psi strength was based on review of commercial nuclear power plant concrete cylinder test data.

As concrete ages, its strength increases. This must also be accounted for in determining the median strength compared to the design strength. Based on the recommendations in Ref. 8, a factor of 1.2 was applied to the 28-day strength to develop the strength of the aged concrete, resulting in a median value of 3600 psi. No information is available on the standard deviation expected for aging. A logarithmic standard deviation associated with aging was estimated to be 0.10. Combining the effects of average 28 day strength with subsequent aging gives an overall β_U of 0.16.

Other effects which could conceivably be included in the concrete strength evaluation include some decrease in strength in the in-place condition as opposed to the test cylinder strength,

and some increase in strength resulting from rate of loading at the seismic response frequencies of the structure. The variation in the strength of in-place concrete compared with the test cylinder strength is accounted for to a large degree in the use of empirical representations of shear wall capacities. These empirical capacities are typically developed by comparing actual wall strengths to the cylinder test strengths of the wall's concrete. Although experimental data on the in-place and rate effects are limited, that which is available would tend to indicate these effects are relatively small and of the same order magnitude. Since the two effects are opposite, they were neglected.

Grade 40 reinforcing steel was used throughout the construction of the structure evaluated here. The results of testing conducted on the reinforcing steel were not available. A review of median yield strengths and variability for reinforcement bars used in other nuclear plants was conducted. Based on this survey, the median yield strengths, f_y , and logarithmic standard deviations, β_u , for the reinforcing steel are 47 ksi and 0.09, respectively. These values were used in the evaluation of the L-Reactor structure.

3.2.2 Strength of Shear Walls in Flexure Under In-Plane Forces

Equations to predict the overturning (in-plane) moment capacity of rectangular shear walls containing uniformly distributed vertical reinforcement are found in Ref. 10. These equations were derived from the basic ultimate strength design provisions for reinforced concrete members subjected to flexure and axial loads contained in Section 10.2 of ACI 318-83 (Ref. 11). These provisions are based upon the satisfaction of force equilibrium and strain compatibility and have been verified by testing. The total moment capacity of reinforced concrete walls including tensile flange steel is given by:

$$M_u = (A_s f_y + N_u) \left(\frac{l_w}{2} - \frac{a}{2} \right) + A_f f_y \left(d - \frac{a}{2} \right) \quad (3-1)$$

where A_s = Total area of vertical reinforcement
in wall

f_y = Yield strength of vertical reinforcement

l_w = Horizontal length of wall

a = the depth of the equivalent rectangular concrete stress block of amplitude $0.85 f'_c$. (evaluated from equilibrium of vertical forces on wall section)

N_u = Axial load, positive in compression

f'_c = Compressive strength of concrete

A_f = Area of flange steel

d = Distance from the extreme compressive fiber to the centroid of tensile flange steel

Equation 3-1 can be used to predict the flexural strength of rectangular walls having uniformly distributed reinforcement. Inspection of Equation 3-1 reveals that the overturning moment capacity of a rectangular wall can be adequately represented by lumping the total area of the uniformly distributed vertical reinforcement at midlength of the wall and applying the basic design provisions in Section 10.2 of ACI 318-83. In addition, this equation includes the effects of concentrated flange reinforcement. Concentrated reinforcement is vertical wall reinforcement bars within the effective flanges of the cross walls cast integrally with the wall evaluated. Effective flange widths may be computed in accordance with the procedures described in Reference 19. The compression flange steel is typically neglected since it is near the neutral axis, and its effect on

the moment capacity is small. Uncertainty in the median flexural strength given by Equation 3-1 is estimated to be β_U of 0.10 based on test data from Reference 14.

3.2.3 Shear Strength of Concrete Walls

Recent studies have shown that the shear strength of low-rise concrete shear walls with boundary elements are conservatively predicted by the ACI 318-83 code provisions (Ref. 11). This is particularly true for walls with height to length ratios in the order of 1 or less. Barda (Ref. 12) determined that the ultimate shear strength of low-rise walls tested could be represented by the following relationship:

$$v_u = 8.3\sqrt{f'_c} - 3.4\sqrt{f'_c} \left(\frac{h_w}{l_w} - 0.5 \right) + \rho_{se} f_y \quad (3-2)$$

where v_u = Ultimate shear strength, psi

ρ_{se} = Effective steel reinforcement ratio

and other quantities as defined previously.

The contribution of the concrete to the ultimate shear strength of the wall as a function of h_w/l_w is shown in Figure 3-3. Also shown in Figure 3-3, are the available test values (Refs. 10, and 12 through 14) and the corresponding ACI 318-83 formulation. The tests included load reversals and varying reinforcement ratios and h_w/l_w ratios. Web crushing generally controlled the failure of the test specimens. Testing was performed with no axial loads, but an increase in shear capacity of $N_u/(4l_w t)$ was recommended, where N_u is the axial load in pounds, and t is the wall thickness in inches.

In order to estimate the effective steel reinforcement ratio (i.e. the relative effects of the horizontal and vertical

steel), the steel contribution to wall shear strength was determined from test values for the range of $0.5 < h_w/l_w < 2$. Test data from the above references were used. The steel effective in shear was assumed to be in the form:

$$\rho_{se} = A\rho_v + B\rho_h \quad (3-3)$$

where A, B are constants, ρ_v is the vertical steel reinforcement ratio, and ρ_h is the horizontal steel reinforcement ratio. The constants A and B were then calculated assuming the concrete contribution to the ultimate strength is given as shown in Equation 3-2. Based on the results of this evaluation, the constants, A and B, can be shown to be:

A = 1	B = 0	$h_w/l_w < 0.5$
$A = -2.0(h_w/l_w) + 2.0$	$B = 2.0(h_w/l_w) - 1.0$	$0.5 < h_w/l_w < 1.0$
A = 0	B = 1	$1.0 < h_w/l_w$

The data used to substantiate the median shear strength equations presented above were derived from tests conducted on cantilever structural walls. The height, h_w , for these walls is known. However, the walls evaluated in this study typically span more than one story. For these walls, the equivalent cantilever wall height, h_{we} , was taken as the ratio of the in-plane moment to the in-plane shear at the section under consideration. The equivalent height, h_{we} , was used to determine the median wall shear strength and provides a more accurate representation of the moment-shear interaction. Based on an evaluation of the same experimental data, the logarithmic standard deviation of the median shear strength equations was estimated to be 0.15.

3.2.4 Structure Strength

As mentioned above, the "L" Reactor building above elevation 0 and in the vicinity of the actuator tower, main tank, heat exchangers, etc has been evaluated herein. In addition, it is judged that this building is significantly weaker to earthquake ground motion in the east-west direction than in the north-south direction where long, thick concrete walls extend from elevation 48 feet down to elevation 0. In the east-west direction below elevation 48, lateral resistance is provided by lower out-of-plane resistance of the north-south running walls as well as additional shear walls to the south of the actuator tower region. Above elevation 48, the structure has more similar lateral force resistance in both east-west and north-south directions. Consequently, the capacity of this structure to resist east-west earthquake ground shaking has been used to compute the risk of seismically induced pipe break from potential building debris. A strength factor for this building is evaluated as the structure capacity determined in the manner described in the preceding subsections divided by the corresponding shear and moment from the Quadrex soil-structure interaction analysis (Reference 5) for east-west earthquake ground shaking.

A cross-section through the tower region of the reactor building is shown in Figure 3-4. This structure was represented essentially as a single stick model for the Quadrex soil-structure interaction analysis (Reference 5). The locations of lumped masses and connecting elements is also shown in Figure 3-4. Note the buttresses added to the tower between Elevations 91.25 and 125 feet as part of a seismic upgrade program a few years ago. These buttresses were included in the Quadrex model.

Lateral force resisting elements at all elevations of this structure are illustrated in Figures 3-5a through 3-5h. The ratios of the lateral load capacity of these elements determined

by the procedures described in Sections 3.2.1, 3.2.3, and 3.2.3 to the demand determined from the Quadrex soil-structure analysis (Ref. 5) are summarized in Table 3-1. Above El. 48 feet, the flexural capacity divided by the bending moment was lower than the shear capacity divided by the shear. Below El. 48 feet, shear behavior governs the building capacity.

The actuator penthouse or tower extends from El. 91.25 feet to El. 148.67 feet. Above El. 125 feet, the penthouse is a 33 foot square section with 1.5 foot thick wall (Fig. 3-5a). From El. 91.25 feet to El. 125 feet the penthouse has been strengthened by buttresses as illustrated in Figures 3-4 and 3-5b. From El. 75 feet to El. 91.25 feet, the structure consists of a 72 by 66 foot box section with 2.5 foot thick walls as shown in Figure 3-5c. From El. 66 feet to El. 75 feet there are additional walls to the south of the tower region as shown in Figure 3-5d. From El. 48 feet to El. 66 feet, the walls of the 72 by 66 foot box section are 5 feet thick instead of the 2.5 foot thickness above El. 66 feet. In addition, there are stairwell walls on both the east and west sides of the building as shown in Figure 3-5e.

From El. 34 feet to El. 48 feet, there are no longer any east-west running walls in the tower region. There is a single 5 foot thick wall located to the south of the tower region as shown in Figure 3-5f, but the capacity to resist lateral loads is significantly less than the section above where there is an additional 5 foot wide by 72 foot long wall. Furthermore, there is a 5 foot thick roof slab at El. 48 feet, which extends to the north of the tower region about 110 feet to an expansion joint which structurally separates this portion of the building from additional structures to the north. In addition, this 5 foot thick slab extends to the south of the tower region to the 5 foot thick shear wall shown in Figure 3-5f. Shear loads from the tower

structure above and from the massive slab at El. 48 feet must be resisted by the shear walls to the south of the tower region and by out-of-plane bending of the underlying north-south running walls.

The capacity of the walls to the south of the tower region as shown in Figure 3-5f for Elevations 34 to 48 feet is a factor of 2.83 times the shear load at this elevation of the building. This factor was evaluated assuming that a portion of the shear load resulting from inertial effects of the slab to the north of the tower region was resisted by the out-of-plane bending capacity of north-south running walls. The remaining shear load is transferred in diaphragm action to the resisting shear walls on the south end of this building. The capacity/demand ratio for this building level is estimated to be 2.83 as shown in Table 3-1.

Below El. 34 feet, there are additional shear walls at the southern portion of this building and to the northwest of the tower region as shown in Figures 3-5g and 3-5h. Consequently, the capacity/demand ratios for lateral load resisting elements from El. 0 to El. 34 feet are larger than for the resisting elements between El. 34 and 48 feet (see Table 3-1).

The median capacity/demand ratio or strength factor for the L-Reactor building is 2.83 as described above. Uncertainty in this median factor results from the following sources: 1) material strength which, in the case of shear, is governed by the square root of concrete strength for which β_U is 0.08 (β_U is 0.16 for concrete strength as described in Section 3.2.1); 2) the strength relationship for shear for which β_U is 0.15 as described in Section 3.2.3; and 3) uncertainty introduced because a simple stick model was used to represent the complex load distribution below El. 48 feet as discussed above. Uncertainty due to modeling is judged to be approximated by β_U of 0.15. Combining all

sources of uncertainty results in a total β_U of 0.22. The median strength factor as well as the uncertainty and randomness along with the high confidence, low probability (HCLP) strength value are summarized below.

$$F_S = 2.83$$

$$\beta_R = 0.0$$

$$\beta_U = 0.22$$

$$\text{HCLP} = 1.97$$

3.2.5 Structure Inelastic Energy Absorption

A more realistic assessment of the seismic capacity of a structure requires that the inelastic energy absorption of the structure is considered in addition to the strength capacity. One tractable method involves the use of ductility modified response spectra to determine the deamplification effect resulting from the inelastic energy dissipation. Early studies indicated the deamplification factor was primarily a function of the ductility ratio, μ , defined as the ratio of maximum displacement to displacement at yield. More recent analytic studies (Ref. 15) have shown that for single-degree-of-freedom systems with resistance functions characterized by elastic-perfectly-plastic, bilinear, or stiffness-degrading models, the shape of the resistance function is, on the average, not particularly important. However, as opposed to the earlier studies, more recent analyses have shown the deamplification factor is also a function of the system damping.

The Riddell-Newmark ductility modified response spectra approach can be used to predict the inelastic energy absorption factor, F_μ , corresponding the system ductility ratio, μ , in the following manner:

$$F_{\mu} = (p\mu - q)^r \quad (3-4)$$

or

$$\frac{S_a}{\mu^{0.13}}$$

1

whichever is smaller.

where $p = q + 1$

$$q = 3.0 \xi^{-0.30}$$

$$r = 0.48 \xi^{-0.08}$$

The above relations apply to the amplified acceleration region of response, ξ is the percent of critical damping, and S_a is the spectral acceleration at the fundamental frequency of the structure. For systems in the amplified acceleration region of the spectrum, Figure 3-6 from Ref. 15, shows the deamplification function for several damping values as a function of the ductility ratio along with a more simple function proposed by Newmark earlier. The Quadrex analysis report (Reference 5) states that the fundamental frequency of the "L" Reactor structure in the east-west direction of shaking is 5.49 Hz. This is apparently a fixed base value as the fundamental frequency appears to be about 3.5 Hz from in-structure spectra developed from the model including SSI effects. In either case, this structure is responding in the amplified region of the ground response spectra as shown in Figures 3-1 and 3-2.

1

The use of the Riddell-Newmark approach for estimating an inelastic energy absorption factor introduces some randomness. This randomness may be approximated by the following relation:

$$\beta_R \sim 0.05(F_\mu - 0.5)$$

(3-5) | 1

One drawback of the ductility modified response spectra approach is that it does not reflect the relationship between earthquake magnitude and ductility. It is well-known that lower magnitude earthquakes are not as damaging to structures and equipment as higher magnitude earthquakes with the same peak ground accelerations. The reason for this is that the lower magnitude response spectra have lower energy content and shorter durations which develop fewer strong response cycles. Structures and equipment are able to withstand larger deformations (i.e., higher ductility) for a few cycles compared to the larger number of cycles resulting from longer duration events.

The method used in the SRP fragilities evaluation to account for this effect was based on the use of an effective ductility, μ^* , in conjunction with the Riddell-Newmark ductility modified spectra approach. The following formulation was developed to calculate the effective ductility.

$$\mu^* = 1.0 + C_d(\mu - 1.0) \quad (3-6)$$

where the duration correction factor, C_d , is a function of the earthquake magnitude. Based on research described in Reference 16, C_d of 1.3 has been selected. This value is appropriate for shear wall structures and earthquake magnitudes on the order of 6 (i.e. $5.3 < M < 6.3$). The majority of seismic risk for the SRP plant is estimated to result from earthquakes in the 5.3 to 6.3 magnitude range.

In order to estimate the system ductility for usage in Equations 3-4 and 3-6, a story drift approach has been utilized, where system ductility is given by:

$$\mu = \frac{\sum_i W_i \Delta_{\mu,i}}{\sum_i W_i \Delta_{e,i}} \quad (3-7)$$

where W_i is the story weight, $\Delta_{\mu,i}$ is the total story drift at failure, and $\Delta_{e,i}$ is the elastic story drift at yield level. The story drifts at failure are estimated by developing a structure deflected shape in which the story with the greatest amount of inelastic behavior (i.e. the smallest capacity/demand ratio) is set to a drift judged to correspond to failure with stories below deforming at yield level and stories above deforming in a manner which is compatible with the inelasticity lower in the structure. It is estimated that the story drift corresponding to structural failure due to shear is between about 0.4 and 1 percent of the story height. If 0.4 and 1 percent are taken to be 10 and 90 percent probability levels, median failure story drift is 0.7 percent of the story height.

For this building, the inelastic energy absorption factor will be evaluated in the manner described above with the median value estimated to be midway between the following two bounding cases:

1. System ductility is evaluated by Equation 3-7 using story weights down to Elevation -40 feet and inelastic energy absorption factor is evaluated by Equation 3-4 using damping of 30 percent which is consistent with combined soil radiation damping and structural damping. This is a conservative, lower bound approach for evaluating the inelastic energy absorption factor.
2. System ductility is evaluated by Equation 3-7 using story weights down to Elevation 0 feet with deformations removed such that displacement at El. 0 feet is zero, and

inelastic energy absorption factor is evaluated by Equation 3-4 using damping of 10 percent which is consistent with structural damping only. Assumptions herein are consistent with the building moving with the free-field ground at Elevation 0 with no soil-structure interaction effects. This is an unconservative, but reasonable upper bound approach for evaluating the inelastic energy absorption factor.

It is estimated that the inelastic energy absorption factor from Case 1 above represents a 5 percent probability of non-exceedance value and the factor from Case 2 above represents a 98 percent probability of non-exceedance value and uncertainty is evaluated accordingly. The median factor is evaluated from the Case 1 and 2 values and the above probabilities.

The deflected shape of the L-Reactor building at yield (i.e. the deflected shape from the Quadrex analysis scaled by the minimum strength factor of 2.83) is illustrated in Figure 3-7. Also, the deflected shape at failure is shown on this same figure. The deflected shape at failure assumes that the story drift between El. 34 and 48 feet is 0.7 percent of the story height and the deflections above El. 48 are compatible with the displacement of the weakest level as shown on Figure 3-7.

Evaluation of the system ductility corresponding to the deflected shapes shown in Figure 3-7 by Equation 3-7 is shown in Table 3-2 for both cases described above. The system ductilities corresponding to Cases 1 and 2 are 1.36 and 3.89, respectively. Utilizing Equation 3-6 to determine effective system ductility levels results in values of 1.47 and 4.76, respectively, for Cases 1 and 2. The inelastic energy absorption factor evaluated in accordance with Equation 3-4 is 1.28 for Case 1 and 2.16 for Case 2. (Note the Case 2 value is governed by a cutoff level to

Equation 3-4 as described in Reference 15). The median inelastic energy absorption factor is evaluated to be 1.62, in a manner consistent with assumptions described above.

Utilizing Equation 3-5, β_R is about 0.06. Uncertainty exists in the story drift value used to evaluate system ductility and in the assumptions used to evaluate system ductility and inelastic energy absorption factor by Cases 1 and 2. Using 0.4 percent story drift, inelastic energy absorption factors of 1.14 and 1.98 are computed by Case 1 and 2 assumptions, respectively. Since, 0.4 percent story drift is a 10% probability value, β_U of 0.08 may be computed as the average value from Case 1 and 2 assumptions. Since inelastic energy absorption factors of 1.28 and 2.16 are 5 and 98 percent probability of non-exceedance values, an additional β_U of 0.14 associated with assumption of the two cases may be computed. Combining these two sources of uncertainty results in a total β_U of 0.16.

$$F_\mu = 1.62$$

$$\beta_R = 0.06$$

$$\beta_U = 0.16$$

$$HCLP = 1.13$$

3.2.6 Structure Capacity

As presented in Chapter 2, the median capacity for the L-Reactor building can be approximated by the median response factor (Section 3.1.6) times the median strength factor (Section 3.2.4) times the median inelastic energy absorption factor (Section 3.2.5) times the design free-field ground acceleration (0.2g). These median factors along with their randomness and uncertainty are summarized below:

Attribute	Factor	β_R	β_U	
Strength	2.83	0.00	0.22	1
Inelastic Energy Absorption	1.62	0.06	0.16	1
Response	1.55	0.18	0.31	

Using the values given above and the method of combination described in Chapter 2, the fragility of the structure as represented by the median capacity, the logarithmic standard deviation associated with randomness, β_R , the logarithmic standard deviation associated with uncertainty, β_U , and the 95 percent confidence of 5 percent probability of failure (HCLPF) level are given by:

$$\hat{A} = 1.42g \quad | \quad 1$$

$$\beta_R = 0.18 \quad | \quad 1$$

$$\beta_U = 0.40 \quad | \quad 1$$

$$\text{HCLPF} = 0.55g \quad | \quad 1$$

3.3 Massive Equipment Capacities and Response Factors

In this section, the capacity factors of safety based on strength, and, if applicable, ductility are developed for relatively massive equipment components along with a discussion of the important variabilities. Also, the component response factors are developed. Where the design basis analysis results were not available and either new stress or response analyses were necessary to develop the fragilities, often times median-centered parameters were used for strength or response variables. In these cases, the factor of safety may be unity although the variability associated with a given parameter is included.

3.3.1 Main Tank

The main tank consists of top tube sheet, a bottom tube sheet, and a cylindrical tank. The top tube sheet is connected to the cylindrical tank wall by a flexible expansion joint and is supported from the concrete by bearing supports at Elevation $-4'-1/34"$. The bottom tube sheet and cylindrical tank are supported on a separate set of bearing pads at Elevation $-22'-8"$. Thus, the bottom tube sheet and tank can respond essentially independently from the top tube sheet during a seismic event. The main tank is a $16'-2-3/4"$ ID by $15'-4"$ high cylindrical vessel with $1/2"$ wall thickness fabricated from 304 stainless steel. The bottom tube sheet is $18'-7-3/4"$ OD by $3'-4"$ high with $1"$ thick face sheets top and bottom. Figure 3-8 from Ref. 17, shows the overall tank configuration. The tank and bottom tube sheet are supported by 12 $8"x12"x1"$ bearing pads, each anchored to the concrete by two $1"$ diameter bolts as shown in Figure 3-9. The design of this detail results in a prying action once net uplift occurs on a pad as a result of the tank seismic overturning moment.

Six outlet nozzles are located just above the top plate of the bottom tube sheet. Figure 3-10 shows the outlet nozzle configuration. These nozzles are embedded in concrete at a $20'-1"$ diameter. This provides a radial clearance of approximately 22 inches between the tank wall and the concrete so that a very stiff connection between the tank wall and the concrete results with correspondingly high nozzle stresses occurring due to increased tank seismic displacements after failure of the bottom anchorage (shown in Figure 3-9) has occurred.

The top tube sheet is independently supported and has a very low height to diameter ratio with corresponding low overturning moment. Also, the upper nozzles have much greater support distances as well as a flexible compound which isolates the

pipe from the concrete. Consequently, seismic loads and stresses in the top tube sheet and nozzle system are much lower than in the main tank and bottom tube sheet assembly.

The bottom tube sheet and tank assembly were modeled as part of the overall structure seismic model by Quadrex (Ref. 5). A seismic shear load of approximately 330k and an overturning moment of 58,200 in-k were calculated by Quadrex at the bottom of the lower tube sheet. Loads from this model were then applied to a detailed finite element model of a sector of the tank and nozzle (Ref. 17). Seismic loads and stresses developed from these two analyses formed the basis of the fragility evaluation developed here. Buckling of the tank wall was checked by Quadrex and found to have a very high factor of safety so that this mode of failure is not expected to control. At low levels of response, the overturning moment is insufficient to overcome the deadweight on the bearing pads. However, at somewhat above 0.3g ground acceleration, sufficient overturning moment is expected to result in uplift and failure of the 3/8 inch fillet welds attaching the bearing pads to the 1" thick bottom face sheet. Failure of this weld is not expected to result in a propagation of a crack through the bottom plate or 1/2" thick tank wall although the possibility of this can be considered as a lower bound estimate of the fragility. After failure of the bearing pad attachment weld, the bottom tube sheet will uplift and impose additional seismic loads on the bottom nozzles. Since this is a nonlinear response phenomenon, the nozzle stresses computed by Quadrex (Ref. 17) from a linear elastic model with no uplift cannot be scaled directly for accelerations above about 0.3g, particularly for the case of the nozzles nearest the failed pads (i.e., the "bending" case in the Quadrex analysis). The nonlinear effects will be less pronounced for the nozzles at 90 degrees from the failed pads (i.e., the "shear" case) which is the higher

stress case for linear analysis. Somewhat greater flexibility results in the tank nozzle load path for nozzles at 90 degrees due to reduced radial stiffness of the tank wall and the lower moment of inertia and reduced nozzle stiffness of the nozzle for bending in this direction. A very approximate calculation indicates the factor of safety for a nozzle loaded in this manner is somewhat greater than a nozzle located at 90 degrees. Therefore, the fragility of the main tank was based on failure of the nozzles in shear (i.e., trunnion loading). A median yield strength of approximately 35 ksi and a median ultimate strength of about 72 ksi with a β_U of approximately 0.14 were conservatively estimated for the tank and nozzle 304 stainless steel material. Failure was based on extrapolating the elastically calculated midplane nozzle stresses (i.e., local membrane plus primary bending) to ultimate. The location of maximum stress is indicated as regions D and E in Figure 3-10. This conservatively assumes no membrane stress redistribution occurs after yielding initiates since the equivalent elastic stress concentration effects in the nozzle region are retained until assumed failure. A factor of safety on strength of 3.3 with β_U of 0.14 were calculated based on the above assumptions. Combining the factors of safety and variabilities for strength with those for structure and equipment response, the fragility for the main tank was evaluated as:

$$\lambda = 1.04g$$

$$\beta_R = 0.20$$

$$\beta_U = 0.44$$

$$HCLPF = 0.36g$$

The fragility of the main tank is shown graphically on Figure 3-11. The median as well as the 5% and 95% confidence bound curves are shown. Several discrete accelerations are also shown in Figure 3-11. The 0.5 g and 2.15 g values reflect the 95% and 5% uncertainty bounds about the median. Also, the 0.36 g and 1.55 g values reflect similar uncertainty bounds about the .05 failure fraction. Thus, we can say that there is a high confidence of low probability of failure (HCLPF) corresponding to 95% confidence of less than a 5% probability of failure of 0.36 g, or nearly twice the design earthquake.

3.3.2 Main (Bingham) Pumps

The main pumps are very rigid components such that essentially no amplification will occur above the base slab accelerations. Also, the inlet and outlet nozzles are isolated from pipe loads by the presence of the bellows in the lines. It was determined that functionality (i.e., pump operation) was not required so that the fragility of this component was based on breach of the pressure boundary. The pump casing is massive and lowly stressed from seismic inertia loads. Consequently, the fragility investigation was concentrated on the attachment bolts from the pump housing to the baseplate and the concrete anchor bolts. Figure 3-12 shows the pump configuration.

Four high-strength 1-3/4 inch diameter bolts are used to bolt the pump housing to the baseplate. The centerline of the pump is only 18 inches above the baseplate-housing interface so that very low overturning moments result. Shear keys are provided in both directions at this location so that the bolts must resist the overturning moments only without combined shear and tension. The baseplate is anchored to the concrete by 14 1-1/2 inch diameter cinch anchors. The details of these bolts including embedment depth were not available so that somewhat greater uncertainty is associated with this mode of failure compared to

the four high-strength bolts discussed above. Nevertheless, high confidence of low probability of failure ground acceleration capacities above 1 g are expected for both these failure modes, so that seismic failure of the pumps is not a contributor when compared to the fragility estimates for the building, main tank, and heat exchangers.

3.3.3 Control Rods and Forest

Since the upper tank nozzles are exposed above the operating floor (Elev. 0'), a preliminary evaluation was conducted in order to ascertain whether damage to the nozzles could conceivably occur as a result of very high seismic response of the control rod and forest. The control rods are fabricated from aluminum and are laterally supported at approximately Elev. 61' and Elev. 1'-6". In addition, during an earthquake, lateral loads are developed at the top of the forest support frame structure (approximately Elev. 17'). The forest support structure corner columns are located horizontally in both directions by guides at the four corners, but the columns are not bolted to the operating floor and at high seismic responses, rigid body rocking of the forest support structure can occur.

The aluminum control rods have very low mass but are long and flexible with correspondingly low frequencies (less than 1 Hz). The forest support structure, on the other hand, is quite stiff and can be treated as a rigid frame prior to rocking. As a result of the seismic inertia loads in the forest support structure combined with the lateral loads from the 61 control rods, uplift of the forest columns is expected to initiate at somewhat above 0.2g ground acceleration. After uplift starts, friction forces and shear are developed between the rods and the top guide plate of the forest support structure which tend to resist overturning of the forest as shown in Figure 3-13. In addition, the

rocking frequency of the rod and forest support structure assembly is low enough at higher displacements that the earthquake motion reverses before overturning will occur.

The control rods are expected to hinge at the top support as well as at the operating floor in the range of 0.5 g around acceleration. However, the shear forces at the hinge points are very low so that a shear failure of the rods is not expected. After uplift of the forest support structure columns occurs, the lateral forces must be resisted by the column guides on the two opposite corners. These guides are anchored to the concrete by means of four 3/4 inch diameter bolts for each guide. Even if the friction between the guide and the concrete is neglected, the anchor bolts have adequate capacity to resist the lateral forces resulting from the forest support structure columns with HCLP ground acceleration capacities exceeding 1 g. Although the control rods are expected to hinge at high acceleration levels, they are not expected to fail in shear. Also, the lateral capacity of the column guides is adequate to prevent sliding of the forest support structure on the operating floor. Therefore, while rocking of the assembly and damage to the rods are expected at lower ground accelerations, motions which could result in impact with the upper tank nozzles will only occur at median ground accelerations expected to be in excess of about 3 g with HCLP capacity in excess of about 1 g. Therefore, the forest support and control rods are not contributors to the seismic risk of seismic indirect RCL pipe break when their capacities are compared to that of the main tank, heat exchangers, and building.

3.3.4 Heat Exchangers

The heat exchangers are horizontal, saddle-mounted cylindrical tanks with 88-1/2 inch O.D. and overall length of 33'-6-1/2" face to face from the inlet nozzle to outlet nozzle flanges. The shell wall thickness is 1/2 inch and the total

weight of the heat exchangers excluding the rail trucks is approximately 248,000 lbs. The heat exchangers are mounted on four wheel rail trucks such that the centers of the heat exchangers are approximately 7'-2" above the top of the rails. A total weight of two heat exchangers, together with their trucks, was estimated as 536,000 lbs. The heat exchangers are located on the floor at elevation -20 feet of the reactor building. A sketch of the heat exchangers is shown in Figure 3-14.

Seismic bracing has been added to the heat exchangers to provide resistance to overturning (transverse response) or rolling (longitudinal response) in the event of an earthquake. Based on the bracing stiffness and the heat exchanger mass, fundamental horizontal frequencies of 11.6 Hz and 12.9 Hz were calculated in the longitudinal and transverse directions, respectively. The seismic bracing configuration is shown in Figure 3-15. Bracing is bolted to the floor and to steel members connecting it to the heat exchanger as shown in Figure 3-15. Provisions are made for either thin laminated steel shims or solid block shims at base plates and the top of the bents where the bracing is bolted to the floor and to the heat exchanger, respectively. The shims are significant because bending of the bolts at the base of the bracing which is permitted by thin laminated shims governs the seismic capacity of the heat exchanger as described below. Note that in the evaluation described below, it has been assumed that the shim height is 2 inches which is the maximum height permitted on the drawings. Both laminated and block shims at various heights up to 2 inches were observed during the plant walkdown.

The design basis loads throughout the seismic bracing were not available so seismic loads in all the bracing elements were recalculated using the Quadrex floor response spectra (Ref. 7) at Elev. -20 as input (Figures 3-16, 3-17, and 3-18). Seismic

accelerations of about 0.28 g, 0.24 g, and 0.12 g were determined for the heat exchangers in longitudinal (E-W), transverse (N-S) and vertical directions, respectively at the fundamental heat exchanger frequencies based on the Quadrex in-structure response spectra.

Failure modes evaluated included welds of the bracing to the base plate and between the heat exchanger tank and supporting saddles, buckling capacities of bracing members, forces in the various steel members and bolts connecting the heat exchanger saddles to the bracing bents, combined pullout and shear failure of the anchor bolts in the concrete floor, and flexure shear and tension of the threaded portion of these anchor bolts protruding from the concrete floor. Additional potential failure modes included brace element combined axial and bending and web shear failure at the location where bracing members intersected 6 inches above the base plate (see Figure 3-15). With the exception of potential failure of the threaded portion of the anchor bolts protruding from the concrete floor, the factor of safety for all these other failure modes was about 4 or more (i.e. the median capacity was a factor of 4 or greater than the forces computed using acceleration levels from the Quadrex in-structure at Elev. -20). Behavior of the anchor bolts is discussed in the remainder of this section.

The controlling capacity for the heat exchangers was found to be the base plate anchor bolts. The capacity of these bolts is dependent on whether laminated shims or solid block shims are used since the joint behavior under lateral loads is different. For the case of a solid shim, the joint will slip a small amount until the clearances in the shim and plate bolt holes are reached at which time the bolt bears against the shim. For this case, the bolt is loaded in tension and shear but with very limited bending as shown in Figure 3-19a. For the case of

thin shims, the bolt is free to displace laterally a relatively large amount to the point at which plastic hinges are formed at the top and bottom of the bolt. Plastic hinges are formed at a very low load level (about a factor of 0.63 times the loads developed from Quadrex floor spectra). However, the formation of plastic hinges does not constitute failure under transient earthquake loading. The joint will continue to slip until the bolt is stretched sufficiently to provide a clamping force between the shims which then carries the shear loads while the bolt is loaded in axial tension with bending at the base and sole plates. A sketch illustrating this behavior is shown in Figure 3-19b. Note that based on bracing forces evaluated using the Quadrex floor spectra as input, worst case anchor bolt loads are 29.5 kips in tension and 37.4 kips in shear.

For the case of anchor bolts with solid shims, median capacity was evaluated in accordance with the following interaction formula for combined shear and tension (bending is assumed to be negligible):

$$\left(\frac{P_{seismic}}{P_{bolt}} \right)^2 + \left(\frac{V_{seismic}}{V_{bolt}} \right)^2 = 1.0 \quad (3-8)$$

where $P_{seismic}$ is the seismic bolt tensile load (29.5 kips)

P_{bolt} is the bolt tensile capacity

$V_{seismic}$ is the seismic bolt shear load (37.4 kips)

V_{bolt} is the bolt shear capacity

Median bolt tensile and shear capacities are taken as 0.90 and 0.62 times the product of the ultimate strength of the bolt material (68 ksi for A36 bolts) and the stress area through the

bolt threads (0.7627 sq. in. for 1-1/8 in. dia. rod with coarse threads), respectively. These capacities are based on test results presented in Reference 20. The factor of safety for anchor bolts with solid shims is calculated to be 3.02 based on Equation 3-8 and the other values presented above.

In estimating the uncertainty in the factor of safety for the solid block shim condition, it is recognized that the capacity is dominated by the shear term in Equation 3-8. There is uncertainty in the 0.62 coefficient and in the ultimate tensile strength for steel in the expression for V_{bolt} . β_U of 0.09 is used for the coefficient based on it being estimated that there is a 10 percent probability that this coefficient could be as large as 0.7. β_U of 0.06 is used for ultimate strength of low carbon steels. Hence, the combined β_U for the solid shim factor of safety is 0.11. β_R is zero. Combining the heat exchanger factor of safety and uncertainty with the response factor of safety, randomness, and uncertainty as given in Section 3.1.6 in the manner described in Chapter 2 results in the following heat exchanger fragility (solid shim case):

$$A = 0.94g$$

$$\beta_R = 0.18$$

$$\beta_U = 0.33$$

$$HCLPF = 0.41g$$

For the case of the anchor bolts with thin shims, the ultimate shear capacity is given by the horizontal component of the bolt tension as the bolt has been displaced laterally, $P_{bolt} \sin \theta$ plus the clamping force on the shims times a coefficient of friction, $\mu(P_{bolt} \cos \theta - P_{seismic})$. The factor of safety on strength was therefore determined from the relationship:

$$F.S. = \frac{P_{bolt}(\sin \theta + \mu \cos \theta)}{V_{seismic} + \mu P_{seismic}} \quad (3-9)$$

where θ is the angle formed by the offset

μ is the coefficient of friction between the shims and plates

The bolts are threaded over the distance between the base and sole plates so that the strain in the bolt may be assumed to be essentially uniformly distributed. Based on a median coefficient of friction between the laminated shims of about 0.5 (steel on steel sliding friction) and an average strain over the bolt length of 1% at failure, a median factor of safety of the bolts of about 2.27 was calculated for the thin shim condition.

The angle θ is related to the average bolt strain, ϵ_{bolt} by the following relation:

$$\cos \theta = \frac{1}{1 + \epsilon_{bolt}} \quad (3-10)$$

Note that one percent average bolt strain corresponds to a θ of about 8 degrees, which is a reasonable value for median ultimate hinge rotation.

Uncertainty in evaluation of factor of safety by Equation 3-9 includes uncertainty in the 0.9 coefficient and ultimate steel tensile strength making up P_{bolt} and uncertainty in the friction coefficient and average bolt strain at failure. β_U can be approximately evaluated for a relation such as Equation 3-9, which is more complex than the product of the variables by evaluating the individual uncertainties of variables and then combining them by SRSS.

For the strength coefficient, it is estimated that factors of 0.8 to 1.0 cover the 5 to 95% probability range such that

β_U is 0.07. Combined with the uncertainty in ultimate tensile strength as discussed above, the overall β_U for P_{bolt} is 0.09. To estimate uncertainty in friction and failure strain, it is judged that there is a 5% chance that the actual friction could be as low as 0.4 and 10% chance that the actual failure strain could be as low as 0.5 percent. For these variables, individual uncertainty is evaluated by calculating factor of safety from Equation 3-9 using the -1β value for the variable of interest and median values for all other variables. The β_U value is then calculated from the resulting factor of safety and the median factor of safety. Uncertainties evaluated in this manner are β_U values for friction and failure strain of 0.07 and 0.05, respectively. The overall β_U for the heat exchanger factor of safety (thin shim case) combining uncertainty in all variables is 0.12.

Including the building response factor of safety and variabilities (Section 3.1.6), the fragility for the thin shim condition is:

$$A = 0.70g$$

$$\beta_R = 0.18$$

$$\beta_U = 0.33$$

$$HCLPF = 0.30g$$

Figures 3-20 and 3-21 show the heat exchanger fragilities graphically for the two cases described above. Also shown on these figures, are the discrete accelerations corresponding to .05 and .50 frequency of failure for the median and 5% and 95% confidence bounds.

TABLE 3-1

CAPACITY-DEMAND RATIOS FOR LATERAL LOAD RESISTING ELEMENTS AT
EACH STORY LEVEL OF THE L-REACTOR BUILDING

STORY LEVEL	CAPACITY/DEMAND
EL 125' - EL 148.67'	3.49
EL 107.5' - EL 125'	3.80
EL 91.25' - EL 107.5'	3.73
EL 75' - EL 91.25'	3.94
EL 66' - EL 75'	3.74
EL 48' - EL 66'	3.39
EL 34' - EL 48'	2.83
EL 15' - EL 34'	3.30
EL 0' - EL 15'	3.41

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TABLE 3-2
EVALUATION OF INELASTIC ENERGY ABSORPTION FACTOR

CASE 1						
Elevation (feet)	Weight, W (kips)	$\Delta_{Quadrex}$ (inches)	Δ_s (inches)	$W \cdot \Delta_s$	Δ_μ (inches)	$W \cdot \Delta_\mu$
148.67	530	1.153	3.263	1729	4.259	2257
125.00	894	0.991	2.805	2507	3.801	3398
107.50	1121	0.870	2.462	2760	3.458	3877
91.25	3885	0.760	2.151	8356	3.147	12227
75.00	4957	0.628	1.777	8810	2.774	13749
66.00	9390	0.585	1.656	15546	2.652	24901
48.00	18852	0.472	1.336	25182	2.332	43965
34.00	24011	0.364	1.030	24734	1.030	24734
15.00	26059	0.249	0.705	18363	0.705	18363
0.00	49548	0.179	0.507	25100	0.507	25100
-20.00	51446	0.088	0.249	12812	0.249	12812
				145898		185383

CASE 2						
Elevation (feet)	Weight, W (kips)	$\Delta_{Quadrex}$ (inches)	Δ_s (inches)	$W \cdot \Delta_s$	Δ_μ (inches)	$W \cdot \Delta_\mu$
148.67	530	0.309	0.874	463	1.870	991
125.00	894	0.253	0.715	639	1.711	1530
107.50	1121	0.210	0.594	666	1.590	1783
91.25	3885	0.173	0.489	1898	1.485	5769
75.00	4957	0.113	0.321	1590	1.317	6529
66.00	9390	0.111	0.313	2940	1.309	12296
48.00	18852	0.078	0.221	4172	1.395	26298
34.00	24011	0.033	0.093	2232	0.093	2232
15.00	26059	0.003	0.008	212	0.008	212
				14814		57641

CASE 1	CASE 2
$\mu = \frac{185,383}{145,898} = 1.36$	$\mu = \frac{57,641}{14,814} = 3.89$
$\mu^* = 1.47$	$\mu^* = 4.76$
Eq. 3-6	Eq. 3-6
$F_\mu = 1.28$	$F_\mu = 2.16$
Eq. 3-4	Eq. 3-4

FIGURE 3-1. RECOMMENDED FREE-FIELD SPECTRA FOR THE SRP SITE (NORMALIZED TO 1.0G PEAK GROUND ACCELERATION) - (TAKEN FROM REF. 6)

FIGURE 3-2.

RECOMMENDED AND EXPECTED MEDIAN GROUND RESPONSE SPECTRA

FIGURE 3-4

CROSS SECTION THROUGH ACTUATOR TOWER REGION OF "L" REACTOR BUILDING

a. Cross Section from EL. 125' to EL. 148.67'

b. Cross Section from EL. 91.25' to EL. 107.5'

FIGURE 3-5

LATERAL FORCE RESISTING ELEMENTS OF "L" REACTOR BUILDING

c. Cross Section from EL. 75 to EL. 91.25

d. Cross Section from EL. 66' to EL. 75'

FIGURE 3-5

LATERAL FORCE RESISTING ELEMENTS OF L REACTOR BUILDING (CONT'D)

e. Cross Section from EL. 48' to EL. 66'

FIGURE 3-5

LATERAL FORCE RESISTING ELEMENTS OF "L" REACTOR BUILDING (CONT'D)

f. Cross Section from EL. 34' to EL. 48'

FIGURE 3-5

LATERAL FORCE RESISTING ELEMENTS OF "L" REACTOR BUILDING (CONT'D)

g. Cross Section from EL. 15' to EL. 34'

FIGURE 3-5

LATERAL FORCE RESISTING ELEMENTS OF "L" REACTOR BUILDING (CONT'D)

h. Cross Section from EL. 0' to EL. 15'

Figure 3-5

LATERAL FORCE RESISTING ELEMENTS OF "L" REACTOR BUILDING (CONT'D)

NOTE: $F_\mu = 1/\phi_\mu$

FIGURE 3-6

DEAMPLIFICATION FACTORS FOR ELASTIC-PERFECTLY-PLASTIC
SYSTEMS IN THE ACCELERATION AMPLIFIED RANGE
(From Ref. 15)

FIGURE 3-7.

DEFLECTED SHAPES AT YIELD AND AT FAILURE FOR L-REACTOR BUILDING

FIGURE 3-8
MAIN TANK CONFIGURATION
(Ref. 17)

FIGURE 3-9. MAIN TANK BEARING PAD AND BOLT CONFIGURATION

FIGURE 3-10
MAIN TANK OUTLET NOZZLE CONFIGURATION
(Reference 17)

FIGURE 3-11. COMPONENT FRAGILITY - MAIN TANK

FIGURE 3-12. PUMP CONFIGURATION

FIGURE 3-13
FOREST AND CONTROL ROD CONFIGURATION

FIGURE 3-14. HEAT EXCHANGER CONFIGURATION
(SEISMIC BRACING NOT SHOWN)

FIGURE 3-16.
IN-STRUCTURE RESPONSE SPECTRA - E-W - ELEVATION -20
(REFERENCE 7)

FIGURE 3-17.
IN-STRUCTURE RESPONSE SPECTRA - N-S - ELEVATION -20
(REFERENCE 7)

FIGURE 3-18.
IN-STRUCTURE RESPONSE SPECTRA - VERTICAL - ELEVATION -20
(REFERENCE 7)

a. Solid Shims

b. Thin, Laminated Shims

FIGURE 3-19. LAMINATED AND SOLID (BLOCK) SHIM SCHEMATIC BEHAVIOR

FIGURE 3-20.
COMPONENT FRAGILITY - HEAT EXCHANGER W/LAMINATED SHIMS

FIGURE 3-21.

COMPONENT FRAGILITY - HEAT EXCHANGER W/SOLID SHIMS

4. PLANT DAMAGE STATE FRAGILITIES

Plant damage state fragilities for seismic-induced indirect RCL pipe are developed from the individual component fragilities described in the previous section. Following the rules of Boolean algebra, the individual component fragilities were combined, two at a time, using the Discrete Probability Distribution (DPD) approach of Ref. 18 to form plant damage state fragility curves. For plant damage states corresponding to seismic-induced indirect RCL pipe break, the Boolean expression is:

$$\text{Pipe Break} = \text{Tank} \cup \text{Heat Exchanger} \cup \text{Building}$$

indicating that the plant damage state consists of the union of the tank with the heat exchangers with the building. The pumps and the forest support and rods were not included as previously discussed. Two general conditions were evaluated: the first condition included only the union of the tank and the heat exchangers. This condition was evaluated in order to establish plant fragility and subsequent risk due to failure of components only. This investigation was conducted since failure of the 'L' Reactor building has much more severe consequences than simply pipe break. The second condition includes the fragility of the structure in combination with the tanks and heat exchangers.

With the DPD approach, the individual component fragility curves are first discretized into a family of fragility curves, each with a probabilistic weighting, representing the uncertainty (characterized by the β_U value) in the fragility evaluation. Each one of the, say n , curves of one component is then combined, according to the rules of Boolean algebra, with each one of the n curves of the second component. The resulting nxn curves are then condensed back to n curves, which are then combined with the

n curves of the third component. This process is continued for all the components in the Boolean expression, such that the end result is n plant damage state fragility curves.

These plant damage state fragility curves, like a component fragility curve, represent the frequency with which the occurrence of the plant damage state (failure) is expected to occur, given the occurrence of an earthquake of a particular peak ground acceleration. When one component dominates the seismic risk (i.e., has a very low seismic capacity compared to the remaining components), the plant fragility curves are essentially identical with the fragility curves of the lowest capacity component. For those cases where two or more component capacities are similar, and the failures are independent (i.e., the failure of any one component leads to a pipe break), the acceleration capacities of the plant fragility are below those of the lowest capacity individual component. This occurs because single component failures can lead to the plant level damage state. In cases where more than one component failure must occur in order to lead to plant damage, the reverse is true, but no such conditions were identified for the components considered here.

4.1 Plant Damage Fragilities Excluding Building

In order to establish the risk RCL pipe break indirectly-induced by earthquakes without the potentially much more serious consequences associated with building failure, plant damage states and subsequently the plant risk were evaluated without considering building failure. In general, most of the variability associated with failures of the two remaining components investigated here is considered to be independent. The components are highly dissimilar insofar as they consist of the horizontal, saddle-mounted heat exchangers, and the flat-bottomed, main tank. These components have widely different frequencies, different materials and controlling modes of failure,

and are in different locations in the structure. Hence, correlation in the seismic responses and capacities of these components were assumed to be minimal, and the component failures were treated as statistically independent for the most likely condition evaluated here. As previously noted, both laminated and solid (block) shims were observed in the heat exchanger bracing. The capacity of this component is different depending on which condition exists for a given heat exchanger. Consequently, plant fragilities were developed for both cases of the heat exchangers in conjunction with the main tank. A plot of the plant fragility median, 95% and 5% confidence curves for the case of the tank and the heat exchanger with laminated shims is shown in Figure 4-1. Note that the median capacity is reduced from approximately 0.7 g for the heat exchanger alone, to 0.65 when the effect of the tank is included. Similarly, the 95% confidence of less than 5% failure is reduced from about 0.3 g to 0.28 g.

Since the components are located in the same structure, and much of the variability for all components results from the uncertainty associated with the deconvolution analysis performed to determine the base input motion, it was decided to run a bounding case to evaluate the significance of the assumption of perfect independence. In order to evaluate this effect, a case with all uncertainty considered as dependent was run; again, assuming the randomness is all independent. Tables 4-1 through 4-4 show the plant level fragilities for four cases. Table 4-1 is for the "base case" of laminated shims and perfect independence. Table 4-2 is for the case of solid shims and perfect independence. Tables 4-3 and 4-4 are for the cases of laminated shims and dependent uncertainty, and solid shims and dependent uncertainty, respectively. Table 4-5 shows a comparison of the median and HCLP capacities for several plant conditions and

assumptions on dependency. For instance, the median plant capacity is increased from about 0.65 g to about 0.7 g if the uncertainty is considered as dependent rather than independent for the case of the tank and heat exchangers with laminated shims. Similarly, the HCLP capacity is increased from about 0.28 g to about 0.3 g. A similar trend is observed for the case of the heat exchanger with solid block shims. This comparison gives an indication of the range of conservatism which may be present in assuming all variability is independent. Similarly, an indication of the improvement which could potentially be gained by further strengthening the heat exchanger bracing can be gained by a comparison of the HCLP capacities for the plant fragilities with the heat exchangers with and without laminated shims and main tank than with the main tank fragility alone. This comparison would indicate the HCLP capacity from the 0.28 g to 0.3 g range (laminated shims) could be increased to about 0.33 to 0.35 g if the laminated shims were changed out to solid block shims. Further improvement of the heat exchanger bracing would not lead to an improvement in the plant damage state HCLPF fragility as seen by comparing to the HCLPF of 0.36 g for the tank alone.

4.2 Plant Damage Fragilities Including Building

The potential consequences of failure of a large portion of the building are considerably more serious than RCL pipe break. Section 4.1 discussed the plant fragilities for a series of assumptions concerning combinations of components and whether the variabilities were independent or dependent. In this section, a similar series of plant fragilities are developed including the fragility of the building structure.

Tables 4-6 through 4-11 show the plant level fragilities for several cases including the building fragility. Table 4-6 is for the condition of heat exchangers with thin laminated shims,

the tank, and the building with independent randomness and uncertainty for all components. A median acceleration capacity of about 0.64 g with a high confidence, low probability of seismic failure of about 0.28 g is indicated.

If solid block shims are assumed, the median capacity is seen in Table 4-7 to increase to about 0.76 g with a HCLPF of about 0.33 g. If the heat exchangers are strengthened to the extent they do not influence the plant fragility, the plant fragility is seen in Table 4-8 to increase to about 0.93 g with a HCLPF of 0.36 g, again for both the randomness and uncertainty assumed independent (conservative).

Tables 4-6 through 4-8 assume both the randomness and uncertainty are independent while Tables 4-9 through 4-11 show the plant level fragilities for the cases where the randomness is assumed independent and the uncertainty is assumed to be dependent. Comparison of these assumptions show similar trends to the cases without the building insofar as the assumption to independency for both randomness and uncertainty leads to conservative values.

The effects of including the building for a number of cases can be seen from the comparisons in Table 4-12. For instance, for independent randomness and uncertainty for the case of the heat exchangers with laminated shims and the tank indicates including the building reduces the median capacity from about 0.65 g to 0.64 g (less than 2%), while the HCLPF is essentially unchanged at about 0.28 g. This occurs because the building capacity is substantially greater than the heat exchanger (with thin shims). On the other hand, if the heat exchangers are assumed to be further strengthened so that they do not influence the plant fragility and only the tank and building are considered, the addition of the building compared to the tank alone results in a decrease in the median acceleration from 1.04g

to about 0.93 g (11% reduction), but the HCLPF is again essentially unchanged at about 0.36 g. Somewhat greater influence is indicated here by including the building, since these two components have very similar capacities.

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TABLE 4-1. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/LAMINATED SHIMS) AND MAIN TANK
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.104E-06	9.540E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	2.235E-02	7.436E-07	1.531E-05	4.268E-04	3.479E-03	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.325E-07
	7.291E-06	1.611E-04	1.331E-03	1.232E-02	7.248E-02	
.300	1.000E-20	1.000E-20	1.000E-20	1.192E-08	9.742E-07	2.621E-05
	3.847E-04	3.934E-03	1.959E-02	9.027E-02	3.274E-01	
.350	1.000E-20	1.000E-20	4.766E-03	1.609E-06	4.129E-05	6.388E-04
	5.428E-03	3.123E-02	1.031E-01	2.913E-01	6.622E-01	
.400	1.000E-20	3.040E-07	1.621E-06	4.276E-05	6.631E-04	5.959E-03
	3.264E-02	1.215E-01	2.842E-01	5.603E-01	9.779E-01	
.450	1.000E-08	4.992E-06	3.066E-05	6.116E-04	5.066E-03	2.902E-02
	1.108E-01	2.924E-01	5.295E-01	7.531E-01	9.659E-01	
.500	6.219E-07	4.944E-05	3.046E-04	3.417E-03	2.247E-02	9.936E-02
	2.535E-01	5.064E-01	7.326E-01	9.124E-01	9.921E-01	
.550	6.786E-06	3.221E-04	1.866E-03	1.458E-02	6.762E-02	1.989E-01
	4.396E-01	7.035E-01	8.738E-01	9.699E-01	9.984E-01	
.600	4.925E-05	1.504E-03	7.959E-03	4.402E-02	1.505E-01	3.489E-01
	6.284E-01	9.452E-01	9.483E-01	9.909E-01	9.197E-01	
.650	2.595E-04	5.363E-03	2.462E-02	1.023E-01	2.716E-01	5.164E-01
	7.915E-01	9.396E-01	9.912E-01	9.976E-01	1.000E+00	
.700	1.046E-03	1.072E-02	6.095E-02	1.956E-01	4.174E-01	6.727E-01
	6.349E-01	9.798E-01	9.948E-01	9.994E-01	1.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-1 (CONTINUED)

.750	3.375E-03 9.451E-01	3.642E-02 9.893E-01	1.246E-01 9.983E-01	3.171E-01 9.999E-01	5.673E-01 1.000E+00	7.978E-01
.800	9.043E-03 9.761E-01	7.421E-02 9.965E-01	2.179E-01 9.996E-01	4.550E-01 1.000E+00	7.018E-01 1.000E+00	8.855E-01
.850	2.072E-02 9.904E-01	1.329E-01 9.989E-01	3.356E-01 9.999E-01	5.914E-01 1.000E+00	8.090E-01 1.000E+00	9.401E-01
.900	4.159E-02 9.964E-01	2.132E-01 9.997E-01	4.855E-01 1.000E+00	7.116E-01 1.000E+00	8.858E-01 1.000E+00	9.710E-01
.950	7.459E-02 9.989E-01	3.120E-01 9.999E-01	5.934E-01 1.000E+00	8.075E-01 1.000E+00	9.362E-01 1.000E+00	9.869E-01
1.000	1.216E-01 9.996E-01	4.220E-01 1.000E+00	7.064E-01 1.000E+00	8.787E-01 1.000E+00	9.664E-01 1.000E+00	9.944E-01
1.050	1.827E-01 9.999E-01	5.342E-01 1.000E+00	7.985E-01 1.000E+00	9.275E-01 1.000E+00	9.833E-01 1.000E+00	9.977E-01
1.100	2.562E-01 1.000E+00	6.400E-01 1.000E+00	8.676E-01 1.000E+00	9.590E-01 1.000E+00	9.921E-01 1.000E+00	9.991E-01
1.150	3.384E-01 1.000E+00	7.329E-01 1.000E+00	9.168E-01 1.000E+00	9.778E-01 1.000E+00	9.964E-01 1.000E+00	9.997E-01
1.200	4.251E-01 1.000E+00	8.095E-01 1.000E+00	9.497E-01 1.000E+00	9.864E-01 1.000E+00	9.984E-01 1.000E+00	9.999E-01
1.250	5.118E-01 1.000E+00	8.690E-01 1.000E+00	9.707E-01 1.000E+00	9.942E-01 1.000E+00	9.993E-01 1.000E+00	1.000E+00
1.300	5.945E-01 1.000E+00	9.130E-01 1.000E+00	9.833E-01 1.000E+00	9.972E-01 1.000E+00	9.997E-01 1.000E+00	1.000E+00
1.350	6.701E-01 1.000E+00	9.441E-01 1.000E+00	9.908E-01 1.000E+00	9.987E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00
1.400	7.369E-01 1.000E+00	9.651E-01 1.000E+00	9.950E-01 1.000E+00	9.994E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.450	7.939E-01 1.000E+00	9.788E-01 1.000E+00	9.974E-01 1.000E+00	9.997E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.500	8.411E-01 1.000E+00	9.874E-01 1.000E+00	9.986E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00

TABLE 4-2. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/SOLID SHIMS) AND MAIN TANK
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.265E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	5.516E-07	4.640E-06	9.259E-04	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	5.563E-08	2.784E-05	8.305E-05	6.091E-04	2.115E-02	
.300	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.123E-07
	7.456E-06	1.364E-04	1.902E-03	1.179E-02	1.319E-01	
.350	1.000E-20	1.000E-20	1.000E-20	1.000E-20	4.292E-07	1.045E-05
	2.990E-04	2.024E-03	1.602E-02	7.319E-02	3.657E-01	
.400	1.000E-20	1.000E-20	1.000E-20	9.225E-07	1.303E-05	1.973E-04
	2.292E-03	1.376E-02	6.992E-02	2.240E-01	6.291E-01	
.450	1.000E-20	2.980E-08	3.379E-07	1.345E-05	1.671E-04	1.512E-03
	1.310E-02	5.436E-02	1.920E-01	4.387E-01	9.225E-01	
.500	1.000E-20	4.619E-07	5.311E-06	1.251E-04	1.193E-03	9.195E-03
	4.700E-02	1.451E-01	3.766E-01	6.489E-01	9.279E-01	
.550	5.066E-08	4.901E-06	5.152E-05	7.490E-04	5.076E-03	2.860E-02
	1.200E-01	2.897E-01	5.793E-01	9.070E-01	9.741E-01	
.600	6.735E-07	3.453E-05	3.293E-04	3.103E-03	1.605E-02	7.460E-02
	2.374E-01	4.658E-01	7.497E-01	9.073E-01	9.917E-01	
.650	5.293E-06	1.799E-04	1.495E-03	1.032E-02	4.088E-02	1.551E-01
	3.874E-01	6.375E-01	9.676E-01	9.603E-01	9.976E-01	
.700	3.009E-05	7.076E-04	5.200E-03	2.695E-02	2.719E-02	2.674E-01
	5.428E-01	7.776E-01	9.389E-01	9.847E-01	9.993E-01	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-2 (CONTINUED)

.750	1.323E-04 6.951E-01	2.380E-03 8.745E-01	1.452E-02 9.721E-01	5.899E-02 9.948E-01	1.602E-01 9.998E-01	4.025E-01
.800	4.556E-04 8.092E-01	6.518E-03 9.356E-01	3.356E-02 9.885E-01	1.117E-01 9.984E-01	2.596E-01 1.000E+00	5.439E-01
.850	1.328E-03 8.888E-01	1.534E-02 9.695E-01	6.804E-02 9.956E-01	1.872E-01 9.995E-01	3.783E-01 1.000E+00	6.744E-01
.900	3.556E-03 9.393E-01	3.175E-02 9.856E-01	1.207E-01 9.984E-01	2.835E-01 9.999E-01	5.043E-01 1.000E+00	7.821E-01
.950	7.507E-03 9.688E-01	5.884E-02 9.944E-01	1.930E-01 9.994E-01	3.937E-01 1.000E+00	6.249E-01 1.000E+00	8.626E-01
1.000	1.512E-02 9.853E-01	9.921E-02 9.978E-01	2.825E-01 9.998E-01	5.085E-01 1.000E+00	7.303E-01 1.000E+00	9.177E-01
1.050	2.780E-02 9.935E-01	1.542E-01 9.992E-01	3.838E-01 9.999E-01	6.183E-01 1.000E+00	8.151E-01 1.000E+00	9.531E-01
1.100	4.723E-02 9.972E-01	2.233E-01 9.997E-01	4.878E-01 1.000E+00	7.172E-01 1.000E+00	8.788E-01 1.000E+00	9.745E-01
1.150	7.486E-02 9.989E-01	3.042E-01 9.999E-01	5.875E-01 1.000E+00	7.987E-01 1.000E+00	9.248E-01 1.000E+00	9.867E-01
1.200	1.117E-01 9.995E-01	3.929E-01 1.000E+00	6.794E-01 1.000E+00	8.620E-01 1.000E+00	9.556E-01 1.000E+00	9.933E-01
1.250	1.580E-01 9.998E-01	4.846E-01 1.000E+00	7.594E-01 1.000E+00	9.091E-01 1.000E+00	9.748E-01 1.000E+00	9.967E-01
1.300	2.131E-01 9.999E-01	5.746E-01 1.000E+00	8.255E-01 1.000E+00	9.423E-01 1.000E+00	9.863E-01 1.000E+00	9.984E-01
1.350	2.756E-01 1.000E+00	6.584E-01 1.000E+00	8.775E-01 1.000E+00	9.646E-01 1.000E+00	9.927E-01 1.000E+00	9.993E-01
1.400	3.434E-01 1.000E+00	7.331E-01 1.000E+00	9.167E-01 1.000E+00	9.790E-01 1.000E+00	9.963E-01 1.000E+00	9.997E-01
1.450	4.141E-01 1.000E+00	7.969E-01 1.000E+00	9.449E-01 1.000E+00	9.880E-01 1.000E+00	9.981E-01 1.000E+00	9.999E-01
1.500	4.852E-01 1.000E+00	8.493E-01 1.000E+00	9.645E-01 1.000E+00	9.937E-01 1.000E+00	9.991E-01 1.000E+00	9.999E-01

TABLE 4-3. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/LAMINATED SHIMS) AND MAIN TANK
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.150	1.085E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.200	4.281E-03	4.703E-05	1.132E-06	5.960E-08	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.250	9.159E-02	3.963E-03	2.481E-04	1.478E-05	4.768E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.300	4.155E-01	5.290E-02	6.868E-03	7.825E-04	5.311E-05	1.252E-06
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.350	7.826E-01	2.382E-01	5.548E-02	1.065E-02	1.267E-03	5.949E-05
	1.311E-06	5.960E-08	0.000E+00	0.000E+00	0.000E+00	
.400	9.531E-01	5.418E-01	2.049E-01	5.023E-02	1.143E-02	9.476E-04
	3.956E-05	1.490E-06	5.960E-08	0.000E+00	0.000E+00	
.450	9.935E-01	8.038E-01	4.506E-01	1.889E-01	5.285E-02	7.114E-03
	4.957E-04	2.986E-05	1.311E-06	0.000E+00	0.000E+00	
.500	9.994E-01	9.392E-01	7.001E-01	3.939E-01	1.527E-01	3.109E-02
	3.331E-03	3.031E-04	1.931E-05	4.172E-07	0.000E+00	
.550	1.000E+00	9.958E-01	9.709E-01	6.185E-01	3.152E-01	9.122E-02
	1.449E-02	1.870E-03	1.679E-04	5.603E-06	0.000E+00	
.600	1.000E+00	9.973E-01	9.554E-01	7.991E-01	5.099E-01	1.990E-01
	4.459E-02	7.948E-03	9.590E-04	4.625E-05	1.192E-07	
.650	1.000E+00	9.996E-01	9.873E-01	9.109E-01	6.920E-01	3.473E-01
	1.049E-01	2.436E-02	3.931E-03	2.654E-04	1.371E-06	
.700	1.000E+00	9.999E-01	9.999E-01	9.661E-01	9.299E-01	5.128E-01
	2.004E-01	5.948E-02	1.235E-02	1.133E-03	9.298E-06	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-3 (CONTINUED)

.750	1.000E+00 3.252E-01	1.000E+00 1.199E-01	9.993E-01 3.124E-02	9.888E-01 3.796E-03	9.170E-01 4.864E-05	6.630E-01
.800	1.000E+00 4.647E-01	1.000E+00 2.073E-01	9.999E-01 6.627E-02	9.967E-01 1.041E-02	9.638E-01 2.011E-04	7.932E-01
.850	1.000E+00 6.015E-01	1.000E+00 3.166E-01	1.000E+00 1.216E-01	9.991E-01 2.417E-02	9.858E-01 6.827E-04	8.820E-01
.900	1.000E+00 7.215E-01	1.000E+00 4.378E-01	1.000E+00 1.979E-01	9.999E-01 4.878E-02	9.949E-01 1.951E-03	9.390E-01
.950	1.000E+00 8.170E-01	1.000E+00 5.590E-01	1.000E+00 2.918E-01	1.000E+00 8.749E-02	9.983E-01 4.893E-03	9.698E-01
1.000	1.000E+00 8.867E-01	1.000E+00 6.700E-01	1.000E+00 3.968E-01	1.000E+00 1.420E-01	9.995E-01 1.075E-02	9.863E-01
1.050	1.000E+00 9.338E-01	1.000E+00 7.642E-01	1.000E+00 5.045E-01	1.000E+00 2.118E-01	9.998E-01 2.128E-02	9.942E-01
1.100	1.000E+00 9.633E-01	1.000E+00 8.388E-01	1.000E+00 6.075E-01	1.000E+00 2.942E-01	1.000E+00 3.840E-02	9.977E-01
1.150	1.000E+00 9.806E-01	1.000E+00 8.945E-01	1.000E+00 6.999E-01	1.000E+00 3.845E-01	1.000E+00 6.393E-02	9.991E-01
1.200	1.000E+00 9.903E-01	1.000E+00 9.337E-01	1.000E+00 7.782E-01	1.000E+00 4.775E-01	1.000E+00 9.920E-02	9.997E-01
1.250	1.000E+00 9.953E-01	1.000E+00 9.599E-01	1.000E+00 8.414E-01	1.000E+00 5.681E-01	1.000E+00 1.447E-01	9.999E-01
1.300	1.000E+00 9.978E-01	1.000E+00 9.767E-01	1.000E+00 8.902E-01	1.000E+00 6.522E-01	1.000E+00 2.001E-01	1.000E+00
1.350	1.000E+00 9.990E-01	1.000E+00 9.869E-01	1.000E+00 9.262E-01	1.000E+00 7.268E-01	1.000E+00 2.638E-01	1.000E+00
1.400	1.000E+00 9.996E-01	1.000E+00 9.923E-01	1.000E+00 9.518E-01	1.000E+00 7.906E-01	1.000E+00 3.339E-01	1.000E+00
1.450	1.000E+00 9.998E-01	1.000E+00 9.962E-01	1.000E+00 9.694E-01	1.000E+00 8.432E-01	1.000E+00 4.073E-01	1.000E+00
1.500	1.000E+00 9.999E-01	1.000E+00 9.981E-01	1.000E+00 9.811E-01	1.000E+00 8.852E-01	1.000E+00 4.817E-01	1.000E+00

TABLE 4-4. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/SOLID SHIMS) AND MAIN TANK
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.150	2.245E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.200	8.323E-06	2.146E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.250	2.209E-02	2.594E-04	4.411E-05	5.960E-08	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.300	1.475E-01	5.600E-03	2.215E-04	7.153E-06	1.192E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.350	4.333E-01	4.316E-02	3.393E-03	2.026E-04	5.901E-06	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.400	7.424E-01	1.679E-01	2.375E-02	2.391E-03	1.229E-04	1.567E-06
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.450	9.211E-01	3.992E-01	9.487E-02	1.504E-02	1.257E-03	3.546E-05
	5.354E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.500	9.829E-01	6.570E-01	2.474E-01	5.896E-02	7.541E-03	3.528E-04
	9.295E-06	1.788E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00
.550	9.972E-01	9.476E-01	4.644E-01	1.598E-01	2.994E-02	2.181E-03
	7.969E-05	3.099E-06	5.960E-06	0.000E+00	0.000E+00	0.000E+00
.600	9.996E-01	9.466E-01	6.811E-01	3.235E-01	9.585E-02	9.296E-03
	5.049E-04	2.712E-05	1.073E-06	0.000E+00	0.000E+00	0.000E+00
.650	1.000E+00	9.944E-01	9.413E-01	5.205E-01	1.895E-01	2.947E-02
	1.287E-03	1.659E-04	9.941E-06	1.789E-07	0.000E+00	0.000E+00
.700	1.000E+00	9.967E-01	9.331E-01	7.076E-01	7.383E-01	7.354E-02
	7.903E-03	7.525E-04	5.297E-06	1.771E-06	0.000E+00	0.000E+00

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-4 (CONTINUED)

.750	1.000E+00 2.189E-02	9.999E-01 2.673E-03	9.757E-01 2.394E-04	9.398E-01 8.345E-05	8.093E-01 0.000E+00	1.500E-01
.800	1.000E+00 5.052E-02	9.999E-01 7.759E-03	9.922E-01 8.690E-04	9.237E-01 3.952E-05	6.717E-01 1.192E-07	2.627E-01
.850	1.000E+00 1.001E-01	1.000E+00 1.901E-02	9.978E-01 2.619E-03	9.675E-01 1.533E-04	8.014E-01 6.557E-07	3.998E-01
.900	1.000E+00 1.743E-01	1.000E+00 4.041E-02	9.994E-01 6.738E-03	9.875E-01 4.994E-04	8.909E-01 3.040E-05	5.443E-01
.950	1.000E+00 2.719E-01	1.000E+00 7.610E-02	9.999E-01 1.516E-02	9.956E-01 1.394E-03	9.451E-01 1.210E-05	6.798E-01
1.000	1.000E+00 3.866E-01	1.000E+00 1.292E-01	1.000E+00 3.041E-02	9.985E-01 3.426E-03	9.745E-01 4.137E-05	7.891E-01
1.050	1.000E+00 5.079E-01	1.000E+00 2.006E-01	1.000E+00 5.523E-02	9.996E-01 7.525E-03	9.990E-01 1.235E-04	8.706E-01
1.100	1.000E+00 6.247E-01	1.000E+00 2.863E-01	1.000E+00 9.205E-02	9.999E-01 1.498E-02	9.955E-01 3.286E-04	9.256E-01
1.150	1.000E+00 7.279E-01	1.000E+00 3.875E-01	1.000E+00 1.424E-01	1.000E+00 2.738E-02	9.983E-01 7.896E-04	9.597E-01
1.200	1.000E+00 8.122E-01	1.000E+00 4.915E-01	1.000E+00 2.062E-01	1.000E+00 4.641E-02	9.994E-01 1.733E-03	9.793E-01
1.250	1.000E+00 8.764E-01	1.000E+00 5.932E-01	1.000E+00 2.819E-01	1.000E+00 7.362E-02	9.999E-01 3.508E-03	9.899E-01
1.300	1.000E+00 9.222E-01	1.000E+00 6.865E-01	1.000E+00 3.665E-01	1.000E+00 1.101E-01	9.999E-01 6.609E-03	9.953E-01
1.350	1.000E+00 9.521E-01	1.000E+00 7.672E-01	1.000E+00 4.556E-01	1.000E+00 1.564E-01	1.000E+00 1.167E-02	9.979E-01
1.400	1.000E+00 9.726E-01	1.000E+00 8.332E-01	1.000E+00 5.462E-01	1.000E+00 2.121E-01	1.000E+00 1.646E-02	9.991E-01
1.450	1.000E+00 9.849E-01	1.000E+00 8.845E-01	1.000E+00 6.298E-01	1.000E+00 2.761E-01	1.000E+00 3.078E-02	9.996E-01
1.500	1.000E+00 9.917E-01	1.000E+00 9.271E-01	1.000E+00 7.071E-01	1.000E+00 3.464E-01	1.000E+00 4.449E-02	9.999E-01

TABLE 4-5
COMPARISON OF PLANT LEVEL FRAGILITIES (NO BUILDING)

	PLANT CONDITION				
	Heat Exchanger (with laminated shims) and Main Tank		Heat Exchanger (with solid shims) and Main Tank		Main Tank Only
	Independent Randomness & Uncertainty	Independent Randomness - Dependent Uncertainty	Independent Randomness & Uncertainty	Independent Randomness - Dependent Uncertainty	
Median Capacity	0.65g	0.70g	0.78g	0.88g	1.04g
HCLPF	0.28g	0.30g	0.33g	0.35g	0.36g

TABLE 4-6. PLANT LEVEL FRAGILITY
HEAT EXCHANGER (W/LAMINATED SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.104E-06	8.640E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	2.235E-08	7.436E-07	1.531E-05	4.268E-04	3.478E-03	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.550E-08	4.801E-07
	7.378E-06	1.612E-04	1.332E-03	1.232E-02	7.248E-02	
.300	1.000E-20	1.000E-20	1.788E-09	1.096E-07	2.581E-06	4.348E-05
	3.909E-04	3.940E-03	1.970E-02	9.028E-02	3.294E-01	
.350	1.000E-20	1.073E-08	3.052E-07	6.636E-06	8.220E-05	9.313E-04
	5.536E-03	3.134E-02	1.032E-01	2.914E-01	6.622E-01	
.400	5.752E-08	6.123E-07	8.806E-06	1.291E-04	1.037E-03	7.854E-03
	3.347E-02	1.222E-01	2.848E-01	5.606E-01	8.780E-01	
.450	1.099E-06	1.109E-05	1.187E-04	1.203E-03	6.827E-03	3.528E-02
	1.143E-01	2.944E-01	5.219E-01	7.837E-01	9.660E-01	
.500	1.234E-05	1.112E-04	9.040E-04	6.604E-03	2.785E-02	1.025E-01
	2.623E-01	5.100E-01	7.346E-01	9.130E-01	9.922E-01	
.550	8.714E-05	7.060E-04	4.461E-03	2.420E-02	7.949E-02	2.194E-01
	4.538E-01	7.078E-01	8.756E-01	9.704E-01	9.985E-01	
.600	4.249E-04	3.139E-03	1.576E-02	6.469E-02	1.717E-01	3.753E-01
	6.442E-01	8.498E-01	9.496E-01	9.912E-01	9.997E-01	
.650	1.601E-03	1.051E-02	4.296E-02	1.377E-01	3.027E-01	5.447E-01
	7.954E-01	9.322E-01	9.821E-01	9.977E-01	1.000E+00	
.700	4.883E-03	2.806E-02	9.534E-02	2.449E-01	4.563E-01	6.987E-01
	8.951E-01	9.729E-01	9.944E-01	9.994E-01	1.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-6 (CONTINUED)

.750	1.071E-03 7.349E-01	8.048E-03 8.989E-01	3.655E-02 9.753E-01	1.023E-01 9.953E-01	2.338E-01 9.998E-01	4.702E-01
.800	3.026E-03 8.414E-01	1.973E-02 9.507E-01	7.364E-02 9.903E-01	1.785E-01 9.986E-01	3.544E-01 1.000E+00	6.120E-01
.850	7.377E-03 9.121E-01	4.173E-02 9.782E-01	1.311E-01 9.964E-01	2.790E-01 9.996E-01	4.864E-01 1.000E+00	7.355E-01
.900	1.587E-02 9.546E-01	7.804E-02 9.910E-01	2.101E-01 9.988E-01	3.966E-01 9.999E-01	6.150E-01 1.000E+00	8.320E-01
.950	3.066E-02 9.782E-01	1.315E-01 9.965E-01	3.078E-01 9.996E-01	5.204E-01 1.000E+00	7.271E-01 1.000E+00	9.005E-01
1.000	5.404E-02 9.904E-01	2.026E-01 9.987E-01	4.170E-01 9.999E-01	6.381E-01 1.000E+00	8.178E-01 1.000E+00	9.445E-01
1.050	8.798E-02 9.960E-01	2.893E-01 9.996E-01	5.295E-01 1.000E+00	7.101E-01 1.000E+00	8.857E-01 1.000E+00	9.708E-01
1.100	1.336E-01 9.985E-01	3.862E-01 9.999E-01	6.365E-01 1.000E+00	8.232E-01 1.000E+00	9.321E-01 1.000E+00	9.853E-01
1.150	1.910E-01 9.994E-01	4.851E-01 1.000E+00	7.317E-01 1.000E+00	8.860E-01 1.000E+00	9.620E-01 1.000E+00	9.930E-01
1.200	2.589E-01 9.998E-01	5.823E-01 1.000E+00	8.111E-01 1.000E+00	9.303E-01 1.000E+00	9.799E-01 1.000E+00	9.968E-01
1.250	3.349E-01 9.999E-01	6.730E-01 1.000E+00	8.730E-01 1.000E+00	9.594E-01 1.000E+00	9.899E-01 1.000E+00	9.986E-01
1.300	4.155E-01 1.000E+00	7.531E-01 1.000E+00	9.184E-01 1.000E+00	9.775E-01 1.000E+00	9.951E-01 1.000E+00	9.994E-01
1.350	4.973E-01 1.000E+00	8.202E-01 1.000E+00	9.497E-01 1.000E+00	9.882E-01 1.000E+00	9.977E-01 1.000E+00	9.998E-01
1.400	5.766E-01 1.000E+00	8.735E-01 1.000E+00	9.702E-01 1.000E+00	9.940E-01 1.000E+00	9.990E-01 1.000E+00	9.999E-01
1.450	6.506E-01 1.000E+00	9.140E-01 1.000E+00	9.831E-01 1.000E+00	9.971E-01 1.000E+00	9.996E-01 1.000E+00	1.000E+00
1.500	9.256E-01 1.000E+00	9.954E-01 1.000E+00	9.996E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00 1.000E+00	1.000E+00

TABLE 4-7. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/SOLID SHIMS), MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.265E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	6.616E-07	4.640E-06	8.259E-04	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	4.172E-09
	3.966E-07	2.998E-06	8.313E-05	6.092E-04	2.115E-02	
.300	1.000E-20	1.000E-20	1.000E-20	1.000E-20	4.247E-08	7.888E-07
	2.360E-05	1.636E-04	1.909E-03	1.180E-02	1.319E-01	
.350	1.000E-20	1.000E-20	1.000E-20	1.140E-07	2.447E-06	2.751E-05
	4.370E-04	2.568E-03	1.613E-02	7.328E-02	3.658E-01	
.400	1.000E-20	1.000E-20	2.706E-07	4.416E-06	4.845E-05	3.877E-04
	3.747E-03	1.759E-02	7.063E-02	2.246E-01	6.294E-01	
.450	1.192E-08	1.565E-07	4.879E-06	6.309E-05	4.653E-04	2.851E-03
	1.844E-02	6.790E-02	1.943E-01	4.403E-01	8.230E-01	
.500	1.848E-07	2.433E-06	4.941E-05	5.016E-04	2.672E-03	1.300E-02
	6.017E-02	1.745E-01	3.812E-01	6.516E-01	9.283E-01	
.550	2.003E-06	2.430E-05	3.250E-04	2.407E-03	1.025E-02	4.163E-02
	1.441E-01	3.334E-01	5.865E-01	8.099E-01	9.745E-01	
.600	1.438E-05	1.600E-04	1.521E-03	8.196E-03	2.983E-02	1.013E-01
	2.723E-01	5.154E-01	7.577E-01	9.097E-01	9.919E-01	
.650	7.658E-05	7.575E-04	5.417E-03	2.251E-02	6.990E-02	1.986E-01
	4.293E-01	6.832E-01	8.744E-01	9.622E-01	9.977E-01	
.700	3.176E-04	2.750E-03	1.545E-02	5.172E-02	1.371E-01	3.264E-01
	5.922E-01	8.126E-01	9.419E-01	9.858E-01	9.994E-01	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-7 (CONTINUED)

.750	1.071E-03 7.349E-01	8.048E-03 8.989E-01	3.655E-02 9.753E-01	1.023E-01 9.953E-01	2.338E-01 9.998E-01	4.702E-01
.800	3.026E-03 8.414E-01	1.973E-02 9.507E-01	7.364E-02 9.903E-01	1.785E-01 9.986E-01	3.544E-01 1.000E+00	6.120E-01
.850	7.377E-03 9.121E-01	4.173E-02 9.782E-01	1.311E-01 9.964E-01	2.790E-01 9.996E-01	4.864E-01 1.000E+00	7.355E-01
.900	1.587E-02 9.546E-01	7.804E-02 9.910E-01	2.101E-01 9.988E-01	3.966E-01 9.999E-01	6.150E-01 1.000E+00	8.320E-01
.950	3.066E-02 9.782E-01	1.315E-01 9.965E-01	3.078E-01 9.996E-01	5.204E-01 1.000E+00	7.271E-01 1.000E+00	9.005E-01
1.000	5.404E-02 9.904E-01	2.026E-01 9.987E-01	4.170E-01 9.999E-01	6.381E-01 1.000E+00	8.178E-01 1.000E+00	9.445E-01
1.050	8.798E-02 9.960E-01	2.893E-01 9.996E-01	5.295E-01 1.000E+00	7.101E-01 1.000E+00	8.857E-01 1.000E+00	9.708E-01
1.100	1.336E-01 9.985E-01	3.862E-01 9.999E-01	6.365E-01 1.000E+00	8.232E-01 1.000E+00	9.321E-01 1.000E+00	9.853E-01
1.150	1.910E-01 9.994E-01	4.851E-01 1.000E+00	7.317E-01 1.000E+00	8.860E-01 1.000E+00	9.620E-01 1.000E+00	9.930E-01
1.200	2.589E-01 9.998E-01	5.823E-01 1.000E+00	8.111E-01 1.000E+00	9.303E-01 1.000E+00	9.799E-01 1.000E+00	9.968E-01
1.250	3.349E-01 9.999E-01	6.730E-01 1.000E+00	8.730E-01 1.000E+00	9.594E-01 1.000E+00	9.899E-01 1.000E+00	9.986E-01
1.300	4.155E-01 1.000E+00	7.531E-01 1.000E+00	9.184E-01 1.000E+00	9.775E-01 1.000E+00	9.951E-01 1.000E+00	9.994E-01
1.350	4.973E-01 1.000E+00	8.202E-01 1.000E+00	9.497E-01 1.000E+00	9.882E-01 1.000E+00	9.977E-01 1.000E+00	9.998E-01
1.400	5.766E-01 1.000E+00	8.735E-01 1.000E+00	9.702E-01 1.000E+00	9.940E-01 1.000E+00	9.990E-01 1.000E+00	9.999E-01
1.450	6.506E-01 1.000E+00	9.140E-01 1.000E+00	9.831E-01 1.000E+00	9.971E-01 1.000E+00	9.996E-01 1.000E+00	1.000E+00
1.500	7.171E-01 1.000E+00	9.434E-01 1.000E+00	9.908E-01 1.000E+00	9.987E-01 1.000E+00	9.998E-01 1.000E+00	1.000E+00

TABLE 4-8. PLANT LEVEL FRAGILITY

MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.265E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	2.146E-06	8.257E-04	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	7.451E-09	7.831E-07	4.378E-06	2.517E-04	2.113E-02	
.300	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	2.682E-08
	9.671E-07	4.794E-05	2.211E-04	5.128E-03	1.315E-01	
.350	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.006E-06
	2.858E-05	7.306E-04	3.361E-03	3.629E-02	3.638E-01	
.400	1.000E-20	1.000E-20	1.000E-20	1.000E-20	3.894E-07	1.975E-05
	3.678E-04	5.174E-03	2.204E-02	1.301E-01	6.254E-01	
.450	1.000E-20	1.000E-20	1.000E-20	9.686E-08	6.458E-06	1.938E-04
	2.571E-03	2.174E-02	8.089E-02	2.966E-01	8.186E-01	
.500	1.000E-20	1.000E-20	1.000E-20	1.244E-06	6.181E-05	1.168E-03
	1.139E-02	6.312E-02	1.972E-01	4.984E-01	9.249E-01	
.550	1.000E-20	1.788E-08	2.186E-07	1.220E-05	3.844E-04	4.861E-03
	3.562E-02	1.397E-01	3.601E-01	6.831E-01	9.724E-01	
.600	1.000E-20	2.503E-07	1.915E-06	8.194E-05	1.704E-03	1.518E-02
	8.519E-02	2.522E-01	5.359E-01	8.200E-01	9.908E-01	
.650	1.490E-08	2.290E-06	1.310E-05	3.904E-04	5.766E-03	3.777E-02
	1.648E-01	3.899E-01	6.913E-01	9.073E-01	9.971E-01	
.700	8.941E-08	1.374E-05	6.729E-05	1.427E-03	1.569E-02	7.835E-02
	2.708E-01	5.354E-01	8.100E-01	9.557E-01	9.991E-01	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-8 (CONTINUED)

.750	6.467E-07 3.939E-01	6.377E-05 6.688E-01	2.751E-04 8.907E-01	4.250E-03 9.801E-01	3.570E-02 9.998E-01	1.404E-01
.800	3.406E-06 5.201E-01	2.373E-04 7.793E-01	9.255E-04 9.405E-01	1.068E-02 9.916E-01	6.929E-02 9.999E-01	2.236E-01
.850	1.455E-05 6.403E-01	6.777E-04 8.616E-01	2.675E-03 9.696E-01	2.330E-02 9.966E-01	1.184E-01 1.000E+00	3.223E-01
.900	5.171E-05 7.432E-01	1.673E-03 9.188E-01	6.698E-03 9.852E-01	4.507E-02 9.987E-01	1.841E-01 1.000E+00	4.309E-01
.950	1.579E-04 8.253E-01	3.700E-03 9.549E-01	1.479E-02 9.931E-01	7.878E-02 9.995E-01	2.647E-01 1.000E+00	5.409E-01
1.000	4.224E-04 8.869E-01	7.447E-03 9.762E-01	2.927E-02 9.968E-01	1.262E-01 9.998E-01	3.565E-01 1.000E+00	6.439E-01
1.050	1.008E-03 9.301E-01	1.383E-02 9.881E-01	5.267E-02 9.986E-01	1.877E-01 9.999E-01	4.541E-01 1.000E+00	7.345E-01
1.100	2.180E-03 9.585E-01	2.392E-02 9.944E-01	8.722E-02 9.994E-01	2.617E-01 1.000E+00	5.514E-01 1.000E+00	8.096E-01
1.150	4.253E-03 9.764E-01	3.896E-02 9.975E-01	1.343E-01 9.998E-01	3.450E-01 1.000E+00	6.430E-01 1.000E+00	8.684E-01
1.200	7.484E-03 9.870E-01	6.022E-02 9.989E-01	1.938E-01 9.999E-01	4.333E-01 1.000E+00	7.248E-01 1.000E+00	9.122E-01
1.250	1.244E-02 9.931E-01	8.870E-02 9.995E-01	2.644E-01 1.000E+00	5.219E-01 1.000E+00	7.942E-01 1.000E+00	9.434E-01
1.300	1.969E-02 9.965E-01	1.251E-01 9.998E-01	3.434E-01 1.000E+00	6.065E-01 1.000E+00	8.506E-01 1.000E+00	9.645E-01
1.350	2.985E-02 9.983E-01	1.695E-01 9.999E-01	4.270E-01 1.000E+00	6.838E-01 1.000E+00	8.944E-01 1.000E+00	9.784E-01
1.400	4.353E-02 9.992E-01	2.218E-01 1.000E+00	5.113E-01 1.000E+00	7.515E-01 1.000E+00	9.274E-01 1.000E+00	9.871E-01
1.450	6.130E-02 9.996E-01	2.807E-01 1.000E+00	5.927E-01 1.000E+00	8.088E-01 1.000E+00	9.511E-01 1.000E+00	9.926E-01
1.500	8.360E-02 9.998E-01	3.449E-01 1.000E+00	6.654E-01 1.000E+00	8.576E-01 1.000E+00	9.679E-01 1.000E+00	9.958E-01

TABLE 4-9. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/LAMINATED SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.150	1.085E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.200	4.281E-03	4.703E-05	1.132E-06	5.960E-08	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.250	9.159E-02	3.963E-03	2.481E-04	1.478E-05	4.768E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.300	4.156E-01	5.290E-02	6.868E-03	7.825E-04	5.311E-05	1.252E-06
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.350	7.836E-01	2.382E-01	5.548E-02	1.065E-02	1.267E-03	5.949E-05
	1.511E-06	5.960E-08	0.000E+00	0.000E+00	0.000E+00	
.400	9.545E-01	5.420E-01	2.049E-01	6.023E-02	1.143E-02	9.476E-04
	3.856E-05	1.490E-06	5.960E-08	0.000E+00	0.000E+00	
.450	9.942E-01	8.044E-01	4.507E-01	1.888E-01	5.285E-02	7.114E-03
	4.857E-04	2.986E-05	1.311E-06	0.000E+00	0.000E+00	
.500	9.995E-01	9.403E-01	7.004E-01	3.940E-01	1.527E-01	3.109E-02
	3.331E-03	3.031E-04	1.931E-05	4.172E-07	0.000E+00	
.550	1.000E+00	9.866E-01	8.716E-01	6.187E-01	3.152E-01	9.122E-02
	1.449E-02	1.870E-03	1.679E-04	5.603E-06	0.000E+00	
.600	1.000E+00	9.977E-01	9.562E-01	7.994E-01	5.100E-01	1.990E-01
	4.459E-02	7.848E-03	9.590E-04	4.625E-05	1.192E-07	
.650	1.000E+00	9.997E-01	9.879E-01	9.114E-01	6.921E-01	3.473E-01
	1.049E-01	2.436E-02	3.931E-03	2.654E-04	1.371E-06	
.700	1.000E+00	1.000E+00	9.972E-01	9.668E-01	8.302E-01	5.129E-01
	2.004E-01	5.948E-02	1.235E-02	1.133E-03	9.298E-06	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-9 (CONTINUED)

.750	1.000E+00 3.252E-01	1.000E+00 1.199E-01	9.995E-01 3.124E-02	9.893E-01 3.796E-03	9.174E-01 4.864E-05	6.680E-01
.800	1.000E+00 4.647E-01	1.000E+00 2.073E-01	9.999E-01 6.627E-02	9.970E-01 1.041E-02	9.644E-01 2.011E-04	7.934E-01
.850	1.000E+00 6.015E-01	1.000E+00 3.166E-01	1.000E+00 1.216E-01	9.993E-01 2.417E-02	9.863E-01 6.827E-04	8.823E-01
.900	1.000E+00 7.215E-01	1.000E+00 4.378E-01	1.000E+00 1.979E-01	9.998E-01 4.878E-02	9.952E-01 1.961E-03	9.384E-01
.950	1.000E+00 8.171E-01	1.000E+00 5.590E-01	1.000E+00 2.918E-01	1.000E+00 8.749E-02	9.985E-01 4.883E-03	9.702E-01
1.000	1.000E+00 8.869E-01	1.000E+00 6.700E-01	1.000E+00 3.968E-01	1.000E+00 1.420E-01	9.996E-01 1.075E-02	9.867E-01
1.050	1.000E+00 9.340E-01	1.000E+00 7.642E-01	1.000E+00 5.045E-01	1.000E+00 2.118E-01	9.999E-01 2.128E-02	9.945E-01
1.100	1.000E+00 9.636E-01	1.000E+00 8.389E-01	1.000E+00 6.075E-01	1.000E+00 2.942E-01	1.000E+00 3.840E-02	9.978E-01
1.150	1.000E+00 9.809E-01	1.000E+00 8.946E-01	1.000E+00 6.999E-01	1.000E+00 3.845E-01	1.000E+00 6.393E-02	9.992E-01
1.200	1.000E+00 9.905E-01	1.000E+00 9.339E-01	1.000E+00 7.783E-01	1.000E+00 4.775E-01	1.000E+00 9.920E-02	9.997E-01
1.250	1.000E+00 9.955E-01	1.000E+00 9.601E-01	1.000E+00 8.415E-01	1.000E+00 5.681E-01	1.000E+00 1.447E-01	9.999E-01
1.300	1.000E+00 9.980E-01	1.000E+00 9.769E-01	1.000E+00 8.902E-01	1.000E+00 6.522E-01	1.000E+00 2.001E-01	1.000E+00
1.350	1.000E+00 9.991E-01	1.000E+00 9.871E-01	1.000E+00 9.263E-01	1.000E+00 7.268E-01	1.000E+00 2.638E-01	1.000E+00
1.400	1.000E+00 9.996E-01	1.000E+00 9.930E-01	1.000E+00 9.520E-01	1.000E+00 7.906E-01	1.000E+00 3.338E-01	1.000E+00
1.450	1.000E+00 9.999E-01	1.000E+00 9.964E-01	1.000E+00 9.696E-01	1.000E+00 8.432E-01	1.000E+00 4.073E-01	1.000E+00
1.500	1.000E+00 9.999E-01	1.000E+00 9.982E-01	1.000E+00 9.813E-01	1.000E+00 8.852E-01	1.000E+00 4.817E-01	1.000E+00

TABLE 4-10. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/SOLID SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency Occurrence*					
.050	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.100	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.150	2.265E-06 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.200	8.328E-04 0.000E+00	2.146E-06 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.250	2.208E-02 0.000E+00	2.596E-04 0.000E+00	4.411E-06 0.000E+00	5.960E-08 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.300	1.478E-01 0.000E+00	5.600E-03 0.000E+00	2.215E-04 0.000E+00	7.153E-06 0.000E+00	1.192E-07 0.000E+00	0.000E+00
.350	4.357E-01 0.000E+00	4.318E-02 0.000E+00	3.393E-03 0.000E+00	2.026E-04 0.000E+00	5.901E-06 0.000E+00	0.000E+00
.400	7.501E-01 0.000E+00	1.683E-01 0.000E+00	2.376E-02 0.000E+00	2.391E-03 0.000E+00	1.228E-04 0.000E+00	1.967E-06
.450	9.297E-01 5.364E-07	4.003E-01 0.000E+00	9.497E-02 0.000E+00	1.505E-02 0.000E+00	1.257E-03 0.000E+00	3.546E-05
.500	9.873E-01 8.285E-06	6.630E-01 1.788E-07	2.482E-01 0.000E+00	5.900E-02 0.000E+00	7.542E-03 0.000E+00	3.528E-04
.550	9.985E-01 7.969E-05	8.562E-01 3.099E-06	4.671E-01 5.960E-08	1.601E-01 0.000E+00	2.995E-02 0.000E+00	2.181E-03
.600	9.999E-01 5.049E-04	9.535E-01 2.712E-05	6.871E-01 1.073E-06	3.247E-01 0.000E+00	8.592E-02 0.000E+00	9.297E-03
.650	1.000E+00 2.287E-03	9.884E-01 1.659E-04	8.494E-01 8.941E-06	5.237E-01 1.788E-07	1.898E-01 0.000E+00	2.948E-02
.700	1.000E+00 7.903E-03	9.977E-01 7.525E-04	9.405E-01 5.287E-05	7.094E-01 1.371E-06	3.394E-01 0.000E+00	7.358E-02

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-10 (CONTINUED)

.750	1.000E+00 2.189E-02	9.996E-01 2.673E-03	9.805E-01 2.394E-04	8.473E-01 8.345E-06	5.122E-01 0.000E+00	1.509E-01
.800	1.000E+00 5.053E-02	1.000E+00 7.758E-03	9.947E-01 8.690E-04	9.308E-01 3.952E-05	6.765E-01 1.192E-07	2.632E-01
.850	1.000E+00 1.001E-01	1.000E+00 1.901E-02	9.988E-01 2.618E-03	9.728E-01 1.533E-04	8.079E-01 6.557E-07	4.011E-01
.900	1.000E+00 1.744E-01	1.000E+00 4.042E-02	9.997E-01 6.738E-03	9.907E-01 4.984E-04	8.978E-01 3.040E-06	5.473E-01
.950	1.000E+00 2.724E-01	1.000E+00 7.612E-02	1.000E+00 1.516E-02	9.972E-01 1.394E-03	9.512E-01 1.210E-05	6.829E-01
1.000	1.000E+00 3.875E-01	1.000E+00 1.293E-01	1.000E+00 3.041E-02	9.992E-01 3.426E-03	9.789E-01 4.137E-05	7.945E-01
1.050	1.000E+00 5.096E-01	1.000E+00 2.008E-01	1.000E+00 5.523E-02	9.998E-01 7.525E-03	9.918E-01 1.235E-04	8.767E-01
1.100	1.000E+00 6.274E-01	1.000E+00 2.887E-01	1.000E+00 9.207E-02	1.000E+00 1.498E-02	9.971E-01 3.286E-04	9.314E-01
1.150	1.000E+00 7.317E-01	1.000E+00 3.882E-01	1.000E+00 1.424E-01	1.000E+00 2.738E-02	9.990E-01 7.896E-04	9.645E-01
1.200	1.000E+00 8.169E-01	1.000E+00 4.927E-01	1.000E+00 2.063E-01	1.000E+00 4.641E-02	9.997E-01 1.733E-03	9.829E-01
1.250	1.000E+00 8.816E-01	1.000E+00 5.951E-01	1.000E+00 2.821E-01	1.000E+00 7.362E-02	9.999E-01 3.508E-03	9.923E-01
1.300	1.000E+00 9.273E-01	1.000E+00 6.892E-01	1.000E+00 3.669E-01	1.000E+00 1.101E-01	1.000E+00 6.609E-03	9.967E-01
1.350	1.000E+00 9.576E-01	1.000E+00 7.706E-01	1.000E+00 4.563E-01	1.000E+00 1.564E-01	1.000E+00 1.167E-02	9.987E-01
1.400	1.000E+00 9.764E-01	1.000E+00 8.372E-01	1.000E+00 5.460E-01	1.000E+00 2.122E-01	1.000E+00 1.946E-02	9.995E-01
1.450	1.000E+00 9.875E-01	1.000E+00 8.889E-01	1.000E+00 6.315E-01	1.000E+00 2.762E-01	1.000E+00 3.079E-02	9.998E-01
1.500	1.000E+00 9.937E-01	1.000E+00 9.270E-01	1.000E+00 7.094E-01	1.000E+00 3.466E-01	1.000E+00 4.649E-02	9.999E-01

TABLE 4-11. PLANT LEVEL FRAGILITY

MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.150	2.265E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.200	8.257E-04	2.146E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.250	2.113E-02	2.516E-04	4.292E-06	5.960E-08	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.300	1.317E-01	5.123E-03	2.019E-04	6.378E-06	1.192E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.350	3.664E-01	3.621E-02	2.830E-03	1.629E-04	4.292E-06	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.400	6.363E-01	1.298E-01	1.790E-02	1.715E-03	7.784E-05	8.941E-07
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.450	8.379E-01	2.970E-01	6.559E-02	9.713E-03	7.041E-04	1.389E-05
	1.192E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.500	9.439E-01	5.034E-01	1.635E-01	3.514E-02	3.836E-03	1.242E-04
	1.490E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.550	9.847E-01	6.966E-01	3.097E-01	9.140E-02	1.428E-02	7.176E-04
	1.341E-05	2.384E-07	0.000E+00	0.000E+00	0.000E+00	
.600	9.966E-01	8.405E-01	4.812E-01	1.858E-01	3.974E-02	2.958E-03
	8.351E-05	1.907E-06	0.000E+00	0.000E+00	0.000E+00	
.650	9.994E-01	9.278E-01	6.476E-01	3.136E-01	8.819E-02	9.337E-03
	3.841E-04	1.216E-05	2.384E-07	0.000E+00	0.000E+00	
.700	9.999E-01	9.717E-01	7.844E-01	4.599E-01	1.640E-01	2.380E-02
	1.379E-03	5.889E-05	1.490E-06	0.000E+00	0.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-11 (CONTINUED)

.750	1.000E+00 4.044E-03	9.902E-01 2.277E-04	8.814E-01 7.451E-06	6.052E-01 5.960E-08	2.655E-01 0.000E+00	5.103E-02
.800	1.000E+00 1.002E-02	9.970E-01 7.288E-04	9.411E-01 3.064E-05	7.329E-01 2.980E-07	3.850E-01 0.000E+00	9.506E-02
.850	1.000E+00 2.160E-02	9.992E-01 1.990E-03	9.735E-01 1.057E-04	8.329E-01 1.490E-06	5.112E-01 0.000E+00	1.579E-01
.900	1.000E+00 4.137E-02	9.998E-01 4.746E-03	9.891E-01 3.141E-04	9.033E-01 5.662E-06	6.323E-01 0.000E+00	2.385E-01
.950	1.000E+00 7.176E-02	9.999E-01 1.009E-02	9.959E-01 8.199E-04	9.480E-01 1.901E-05	7.387E-01 0.000E+00	3.332E-01
1.000	1.000E+00 1.144E-01	1.000E+00 1.941E-02	9.985E-01 1.913E-03	9.740E-01 5.609E-05	8.247E-01 5.960E-08	4.362E-01
1.050	1.000E+00 1.698E-01	1.000E+00 3.430E-02	9.995E-01 4.048E-03	9.878E-01 1.481E-04	8.889E-01 1.788E-07	5.407E-01
1.100	1.000E+00 2.372E-01	1.000E+00 5.627E-02	9.998E-01 7.866E-03	9.946E-01 3.545E-04	9.334E-01 5.364E-07	6.400E-01
1.150	1.000E+00 3.143E-01	1.000E+00 8.658E-02	1.000E+00 1.418E-02	9.977E-01 7.786E-04	9.621E-01 1.609E-06	7.288E-01
1.200	1.000E+00 3.981E-01	1.000E+00 1.260E-01	1.000E+00 2.393E-02	9.991E-01 1.584E-03	9.795E-01 4.411E-06	8.037E-01
1.250	1.000E+00 4.847E-01	1.000E+00 1.745E-01	1.000E+00 3.810E-02	9.997E-01 3.011E-03	9.894E-01 1.121E-05	8.635E-01
1.300	1.000E+00 5.703E-01	1.000E+00 2.317E-01	1.000E+00 5.760E-02	9.999E-01 5.384E-03	9.947E-01 2.635E-05	9.086E-01
1.350	1.000E+00 6.512E-01	1.000E+00 2.961E-01	1.000E+00 8.320E-02	1.000E+00 9.114E-03	9.975E-01 5.788E-05	9.411E-01
1.400	1.000E+00 7.246E-01	1.000E+00 3.660E-01	1.000E+00 1.154E-01	1.000E+00 1.469E-02	9.988E-01 1.199E-04	9.634E-01
1.450	1.000E+00 7.885E-01	1.000E+00 4.392E-01	1.000E+00 1.543E-01	1.000E+00 2.264E-02	9.995E-01 2.349E-04	9.780E-01
1.500	1.000E+00 8.419E-01	1.000E+00 5.131E-01	1.000E+00 1.999E-01	1.000E+00 3.354E-02	9.998E-01 4.377E-04	9.872E-01

TABLE 4-12

**COMPARISON OF PLANT LEVEL FRAGILITIES WITH AND WITHOUT THE BUILDING
(INDEPENDENT RANDOMNESS AND UNCERTAINTY)**

	Heat Exchanger (with laminated shims) and Main Tank		Heat Exchanger (with solid shims) and Main Tank		Main Tank		Building Only
	W/Building	W/O Building	W/Building	W/O Building	W/Building	W/O Building	
Median Capacity (g)	0.64	0.65	0.76	0.78	0.93	1.04	1.42
HCLPF (g)	0.28	0.28	0.33	0.33	0.36	0.36	0.55

PEAK GROUND ACCELERATION (g)

FIGURE 4-1.

PLANT FRAGILITY - HEAT EXCHANGERS (W/LAMINATED SHIMS) AND MAIN TANK
(INDEPENDENT UNCERTAINTY)

5. SEISMIC RISK

The seismic risk of RCL pipe failure indirectly-induced by earthquakes is developed by a convolution of the seismic hazard curves with fragility curves representing the plant damage states developed in the previous section. Seismic risk is developed for the two overall plant fragilities with and without considering building failure.

5.1 Seismic Hazard Used for Risk Evaluations

The seismic hazard developed in Ref. 4 for the SRP site is described by the ten equally weighted curves shown in Figure 2-3. Due to the high capacity of the plant fragilities, the hazard curves shown in Figure 2-3 had to be extrapolated to lower annual frequency of exceedances than shown in Figure 2-3 in order to compute the low seismic risks. These curves were linearly extrapolated on semi-log paper down to 10^{-9} for this risk study. In addition, these extrapolated curves were truncated at 1.5 g peak ground acceleration, since hazard curves in excess of 1.5 g are not considered credible for the SRP site. The effect of truncation from 1.5 g to 1.0 g was found to have negligible effect on the expected mean seismic risk. An influence on the expected median risk was observed however, so all results reported here are based on the 1.5 g truncation level. The effects of the hazard curve extrapolations and truncations tend to show up significantly at risk estimates of less than 10^{-7} and risk estimates less than about 10^{-7} are thus somewhat suspect. No credence should be given to risk numbers below about 10^{-8} .

5.2 Plant Damage States

In order to obtain the annual occurrence frequencies of the plant damage states, the family of plant damage state fragility curves discussed above are convolved with the family of seismic hazard curves (Fig. 2-2) described in Section 2.4. In this way, a set of doublets for the plant damage state frequency are obtained.

$$\{ \langle P_{ij}, f_{ij} \rangle \} \quad (5-1)$$

where f_{ij} is the seismically-induced severe core damage frequency and p_{ij} is the discrete probability of this frequency, given by

$$P_{ij} = q_i p_j \quad (5-2)$$

$$f_{ij} = - \int_0^{\infty} f_i(a) \frac{dH_j}{da} da \quad (5-3)$$

Here, H_j represents the j^{th} hazard curve, f_i the i^{th} plant damage state fragility curve, q_i is the probability associated with the i^{th} fragility curve and p_j is the probability associated with the j^{th} hazard curve.

The above equations state that the convolution (Eq. 5-3) between the seismic hazard and the plant damage state fragility is carried out by selecting a hazard curve j and a fragility curve i ; the probability assigned to the plant damage frequency resulting from the convolution is the product of the probabilities p_i and q_j assigned to these two curves. The convolution operation given by Eq. 5-3 consists of multiplying the frequency of occurrence of an earthquake peak ground acceleration between a and $a+da$ (obtained as the derivative of H_j with respect to a) with the conditional frequency of the plant damage state, and integrating such products over the entire range of peak ground accelerations 0 to 1.5 g.

In this manner, a probabilistic distribution on the frequency of plant damage can be obtained. Tables 5-1 through 5-11 summarize these results for the plant damage states at the 'L' Reactor for various cases of laminated shims and solid shims for the heat exchanger bracing with the main tank, with and without the building. The tables show the median, mean, 90% and 95% upper confidence bounds and 10% lower confidence bound on the annual occurrence frequency. The 95% lower confidence bound in every case was less than 10^{-8} and can be considered to be essentially zero. Note, again, that this statistical description of

every case was less than 10^{-8} and can be considered to be essentially zero. Note, again, that this statistical description of the occurrence frequency results from uncertainty in the hazard (represented by 10 subjectively weighted curves, Fig. 2-3) and uncertainty in the damage state fragility (represented by 11 weighted curves).

5.3 Seismic Risk without Including Building

The mean risk of main coolant pipe failure indirectly-induced by earthquake for the case with the heat exchanger (w/laminated shims) and the main tank with independent randomness and uncertainty is about 5.9×10^{-6} . The median risk is about 6.2×10^{-7} and the 90% and 10% confidence bounds are 1.3×10^{-5} and less than 10^{-8} , respectively. For the case with solid heat exchanger shims, the mean risk is reduced by approximately a factor of two to about 2.8×10^{-6} while the median is reduced to about 2×10^{-7} . Similar reductions are observed for the confidence bounds.

If the uncertainty is treated as being dependent, the mean risk is reduced to about 5×10^{-6} and the median to about 4×10^{-7} for the case with laminated shims and 2.3×10^{-6} and 6.9×10^{-8} , respectively for the case of solid shims.

For comparison, the mean risk due to the main tank alone is about 1.8×10^{-6} and the median about 2×10^{-8} . Thus, assuming independent variability, the mean risk could be reduced by a factor of two if the laminated shims were replaced with solid shims and about a factor of three if the heat exchangers were further strengthened to eliminate any contribution to risk. These improvements are not considered significant.

5.4 Seismic Risk Including Risk from Building

Including the risk from the building in the overall plant seismic risk results in only a small increase for all cases compared to the cases discussed in Section 5.3. Thus, the mean frequency of failure for the case of heat exchangers with laminated shims and main tank (with independent randomness) is

seen to increase to about 6.0×10^{-6} or only about 2% greater. The median risk is about 7.8×10^{-7} or 26% greater, and the 90% and 10% confidence bounds are 1.4×10^{-5} and less than 10^{-8} , respectively.

Comparisons of the seismic risk of RCL Pipe Failure for several cases including and excluding the contribution of the building are shown in Table 5-13. For instance, for the case of the heat exchangers (with thin shims) and the main tank, the median frequency of failure is seen to increase approximately 26% if the building is included and the mean bound increases about 2%. The 95% confidence bound remains essentially unchanged. Considered another way, the mean and 95% confidence risk is seen to increase by nearly a factor of 7 from the case where the building is considered alone to the case of the building and main tank, and increase by a factor of 3 again for the case of the heat exchangers with thin laminated shims, main tank, and building. This indicates the expected gain from replacing the heat exchanger shims with solid blocks could be expected to result in a reduction of risk of about two. Further gain from additional strengthening of the heat exchanger bracing or attempting to strengthen the tank, while resulting in some further small reduction in risk, is likely unwarranted.

5.5 Contribution to Seismic Risk from Different Acceleration Ranges

The annual occurrence frequencies of the plant damage states are obtained, as mentioned earlier, by convolving (i.e., integrating over the entire range of acceleration values) the seismic hazard curves with the plant damage state fragility curves. It is of interest to determine what ranges of acceleration contribute most significantly to the overall frequency of occurrence of the damage state. For small accelerations, the frequency of occurrence of the earthquake is large, while the frequency of plant damage is small. For large accelerations, the frequency of occurrence of the earthquake is small while the frequency of plant damage is relatively large.

This question can be addressed by performing the convolution (integration) over small acceleration ranges and comparing the occurrence frequency obtained with that obtained by integrating over the entire range of accelerations. Figure 5-1 illustrates the result of this analysis for the case without the building, and Figure 5-2 for the case where the building is included. Figures 5-1 and 5-2 give the percent contributions from various acceleration ranges assuming a maximum credible peak ground acceleration of 1.5 g. The 1.5 g is considered to be a conservative upper bound expected for the site. If more thorough investigations were performed which indicated a reduced upper bound acceleration for the site (for instance, 1.0 or 1.2 g), then not only would different (slightly lower) seismic risk values result; but also different percent contributions to the total risk from the various acceleration ranges would also be indicated.

Note that for both cases shown in Figures 5-1 and 5-2, most of the contribution comes from acceleration ranges above the design basis (SSE) earthquake as would be expected. Also, an important observation is that the contribution from the acceleration ranges below 0.25 g is very small for both the mean and median seismic risk. For instance, for the case without the building, only about 2.3% of the mean risk results from earthquakes with peak accelerations less than 0.25 g, with the majority of the mean risk resulting primarily from earthquakes with peak ground accelerations in the 0.25 g to 0.85 g range, centered about 0.4 g. Similarly, the median risk occurs primarily from earthquakes in the 0.35 to 1.5 g range and is centered at about 0.6 g. If the building is included, again, about 2.3% of the mean risk results from earthquakes less than 0.25 g. Seismic ground motions well in excess of the 0.2 g design level are required to produce substantial risk due to indirect pipe

| 1

failure. This indicates that very large earthquakes must occur before any significant probability of pipe failure is expected as a result of indirectly-induced failure due to earthquakes.

TABLE 5-1

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (W/LAMINATED SHIMS) AND MAIN TANK (NO
BUILDING) INDEPENDENT RANDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.59 E - 05
Median Frequency of Failure	0.62 E - 06
90% Confidence Bound	0.13 E - 04
95% Confidence Bound	0.33 E - 04
10% Confidence Bound	< E - 08

TABLE 5-2

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (W/SOLID SHIMS) AND MAIN TANK (NO BUILD-
ING) INDEPENDENT RANDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.28 E - 05
Median Frequency of Failure	0.20 E - 06
90% Confidence Bound	0.55 E - 05
95% Confidence Bound	0.16 E - 04
10% Confidence Bound	< E - 08

TABLE 5-3

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (W/LAMINATED SHIMS) AND MAIN TANK (NO
BUILDING) INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.50 E - 05
Median Frequency of Failure	0.40 E - 06
90% Confidence Bound	0.11 E - 05
95% Confidence Bound	0.27 E - 04
10% Confidence Bound	< E - 08

TABLE 5-4

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (W/SOLID SHIMS) AND MAIN TANK (NO BUILD-
ING) INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.23 E - 05
Median Frequency of Failure	0.69 E - 06
90% Confidence Bound	0.48 E - 05
95% Confidence Bound	0.11 E - 04
10% Confidence Bound	< E - 08

TABLE 5-5

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES FROM MAIN TANK ONLY (NO BUILDING)

Mean Frequency of Failure	0.18 E - 05
Median Frequency of Failure	0.20 E - 06
90% Confidence Bound	0.38 E - 05
95% Confidence Bound	0.85 E - 05
10% Confidence Bound	< E - 08

TABLE 5-6

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (WITH LAMINATED SHIMS) MAIN TANK AND
BUILDING,
INDEPENDENT RAMDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.60 E - 05
Median Frequency of Failure	0.78 E - 06
90% Confidence Bound	0.14 E - 04
95% Confidence Bound	0.33 E - 04
10% Confidence Bound	< E - 08

1

TABLE 5-7

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES - HEAT EXCHANGERS (WITH SOLID SHIMS) MAIN TANK AND BUILD-
ING,
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.29 E - 05
Median Frequency of Failure	0.29 E - 06
90% Confidence Bound	0.64 E - 05
95% Confidence Bound	0.16 E - 04
10% Confidence Bound	< E - 08

1

TABLE 5-8

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES
- MAIN TANK AND BUILDING - INDEPENDENT RAMDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.20 E - 05
Median Frequency of Failure	0.74 E - 07
90% Confidence Bound	0.39 E - 05
95% Confidence Bound	0.06 E - 05
10% Confidence Bound	< E - 08

1

TABLE 5-9

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES

- HEAT EXCHANGERS (WITH LAMINATED SHIMS) MAIN TANK AND BUILDING -
INDEPENDENT RAMDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.51 E - 05
Median Frequency of Failure	0.40 E - 06
90% Confidence Bound	0.11 E - 04
95% Confidence Bound	0.27 E - 04
10% Confidence Bound	< E - 08

1

TABLE 5-10

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES

- HEAT EXCHANGERS (WITH SOLID SHIMS) MAIN TANK AND BUILDING -
INDEPENDENT RAMDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.23 E - 05
Median Frequency of Failure	0.69 E - 07
90% Confidence Bound	0.48 E - 05
95% Confidence Bound	0.11 E - 04
10% Confidence Bound	< E - 08

1

TABLE 5-11

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES

- MAIN TANK AND BUILDING -
INDEPENDENT RAMDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.18 E - 05
Median Frequency of Failure	0.20 E - 07
90% Confidence Bound	0.39 E - 05
95% Confidence Bound	0.87 E - 05
10% Confidence Bound	< E - 08

1

TABLE 5-12

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES

- BUILDING ONLY -

Mean Frequency of Failure	0.29 E - 06
Median Frequency of Failure	0.39 E - 09
90% Confidence Bound	0.36 E - 06
95% Confidence Bound	0.14 E - 05
10% Confidence Bound	< E - 08

1

TABLE 5-13

'L'-REACTOR SEISMIC RISK OF RCL PIPE FAILURE
(INDEPENDENT RANDOMNESS AND UNCERTAINTY)

	Heat Exchangers (W/Laminated Shims) & Main Tank		Heat Exchangers (W/Solid Shims) & Main Tank		Main Tank		Bldg. Only
	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	
Mean Frequency of Failure	6.0×10^{-6}	5.9×10^{-6}	2.9×10^{-6}	2.8×10^{-6}	2.0×10^{-6}	1.8×10^{-6}	2.9×10^{-7}
Median Frequency of Failure	7.8×10^{-7}	6.2×10^{-7}	2.9×10^{-7}	2.0×10^{-7}	7.4×10^{-8}	2.0×10^{-8}	3.4×10^{-10}
95% Upper Confidence Bound*	3.3×10^{-5}	3.3×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	9.6×10^{-6}	8.5×10^{-6}	1.4×10^{-6}

* 5% Lower Confidence Bounds are all less than 10^{-8}

FIGURE 5-1.

PERCENT CONTRIBUTION OF DIFFERENT ACCELERATION RANGES
HEAT EXCHANGER (W/LAMINATED SHIMS) AND MAIN TANK (INDEPENDENT
RANDOMNESS AND UNCERTAINTY

FIGURE 5-2. PERCENT CONTRIBUTION OF DIFFERENT ACCELERATION RANGES -
HEAT EXCHANGER (W/LAMINATED SHIMS, MAIN TANK, AND BUILDING) -
INDEPENDENT RANDOMNESS AND UNCERTAINTY

6. CONCLUSIONS

An evaluation of the probability of main coolant (process water) pipe failure at the Savannah River 'L' Reactor indirectly-induced by earthquakes was conducted. Pipe break failure in the main coolant piping resulting from potential failure of the main tank, heat exchangers, main pumps, forest support frame and control rods, and the building structure above Elev. 0 was included. Seismic inertia loads on the piping itself were not considered in this evaluation.

The probability of main coolant pipe break was developed by first determining the expected seismic fragilities of the individual components listed above. The main pumps and the control rods and forest assembly were found to have very high seismic capacities related to potential pipe failure. Plant damage state fragilities were then developed from several combinations of the remaining individual components. Since the consequences associated with collapse of the building structure extend well beyond pipe break, the probability of seismically indirectly-induced pipe break was evaluated both including and excluding the contribution to risk by the building.

If the most conservative assumptions regarding independency of the randomness and uncertainty are used, the mean conditional frequency of indirect seismically-induced failure of the RCL piping is approximately 6×10^{-6} per year and the median frequency is about 8×10^{-7} per year for the 'L' Reactor with thin laminated shims installed in the heat exchanger supports. If solid block shims are installed in all locations, the risk is decreased somewhat to a mean of about 3×10^{-6} per year and a median of about 3×10^{-7} per year. Neglecting the contribution of the building to the seismic risk, the mean value is about 6×10^{-6} per year and the median about 6×10^{-7} per year, again for the case

of the laminated shims and independent randomness and uncertainty. These values are all quite low and are not substantially out-of-line with estimates for commercial nuclear power plants. Therefore, for seismic indirectly-induced pipe failure, no plant modifications appear warranted.

REFERENCES

1. Freudenthal, A. M., J. M. Garrelts, and M. Shinozuka, "The Analysis of Structural Safety", **Journal of the Structural Division**, ASCE, ST 1, pp. 267-325, February 1966.
2. Kennedy, R. P., **A Statistical Analysis of the Shear Strength of Reinforced Concrete Beams**, Technical Report No. 78, Department of Civil Engineering, Stanford University, Stanford, California, April 1967.
3. Newmark, N. M., "A Study of Vertical and Horizontal Earthquake Spectra", **WASH 1255**, Nathan M. Newmark Consulting Engineering Services, prepared for USAEC, April 1973.
4. McCann, M. W. Jr., **Historic Seismicity Analysis for the Savannah River Site**, JBA 153-010-02 prepared for E. I. du Pont-de Nemours & Company, Inc., April 1986.
5. Tang, C. C., **Seismic Analysis of 'L' Reactor Buildings at the Savannah River Site**, QUAD-1-85-016, Vol. I, prepared for E. I. du Pont de Nemours and Company, November 1985.
6. URS/John A. Blume & Associates, Engineers, "Update of Seismic Criteria for the Savannah River Plant," Volume 1 of 2: Geotechnical, prepared for E. I. du Pont de Nemours & Company, September 1982.
7. Tang, C. C., **Seismic Analysis of 'L' Reactor Buildings at the Savannah River Site**, QUAD-1-85-016, Vol. IV, prepared for E. I. du Pont de Nemours and Company, November 1985.
8. Troxell, G. E., H. E. Davis and J. W. Kelly, **Composition and Properties of Concrete**, McGraw-Hill, 1968.
9. Mirza, S. A., M. Hatzinikolas, and J. G. MacGregor, "Variability of Mechanical Properties of Reinforcing Bars", **Journal of Structural Division**, ASCE, May 1979.
10. Cardenas, A. E., et al, "Design Provisions for Shear Walls", **ACI Journal**, Vol. 70, No. 3, March 1973.
11. ACI 318-83, "Building Code Requirements for Reinforced Concrete", American Concrete Institute, 1983.
12. Barda, F., J. M. Hanson and W. G. Corley, "Shear Strength of Low-Rise Walls with Boundary Elements", ACI Symposium, "Reinforced Concrete Structures in Seismic Zones", ACI, Detroit, Michigan, 1976.

13. Shiga, T., A. Shibata and J. Tabahashi, "Experimental Study on Dynamic Properties of Reinforced Concrete Shear Walls", 5th World Conference on Earthquake Engineering, Rome, Italy, 1973.
14. Oesterle, R. G., et al, "Earthquake-Resistant Structural Walls - Tests of Isolated Walls - Phase II", Construction Technology Laboratories (Division of PCA), Skokie, Illinois, October 1979.
15. Riddell, R., and N. M. Newmark, "Statistical Analysis of the Response of Nonlinear Systems Subjected to Earthquakes", Department of Civil Engineering, Report UILU 79-2016, Urbana, Illinois, August 1979.
16. Kennedy, R. P., et al, **Engineering Characterization of Ground Motion -- Task 1**, NUREG/CR-3805, Vol. 1, Nuclear Regulatory Commission, May 1984.
17. Tang, C. C., Seismic Analysis and Evaluation of 105-L Reactor Tank Savannah River Plant, QUAD-1-85-017, prepared for E. I. du Pont de Nemours & Company, December 1985.
18. Kaplan, S., **On the Method of Discrete Probability Distributions in Risk and Reliability Calculations, Risk Analysis**, Vol. 1, 1981.
19. Hadjian, A. H. and T. S. Atalik, **Discrete Modeling of Symmetric Box-Type Structures**, International Symposium on Earthquake Structural Engineering, St. Louis, Missouri, August 1976.
20. Kulak, G. L., J. W. Fisher, and J. H. A. Struick, **Guide to Design Criteria for Bolted and Riveted Joints**, John Wiley & Sons, New York, 1987.

APPENDIX A

CHARACTERISTICS OF THE LOGNORMAL DISTRIBUTION

CHARACTERISTICS OF THE LOGNORMAL DISTRIBUTION

Some of the characteristics of the lognormal distribution which are useful to keep in mind when generating estimates of $\bar{A}$, β_R , and β_U are summarized in References A1 and A2. A random variable X is said to be lognormally distributed if its natural logarithm Y given by:

$$Y = \ln(X) \quad (A-1)$$

is normally distributed with the mean of Y equal to $\ln \bar{X}$ where $\bar{X}$ is the median of X , and with the standard deviation of Y equal to β , which will be defined herein as the logarithmic standard deviation of X . Then, the coefficient of variation, COV, is given by the relationship:

$$COV = \sqrt{\exp(\beta^2) - 1} \quad (A-2)$$

For β values less than about 0.5, this equation becomes approximately:

$$COV \approx \beta \quad (A-3)$$

and COV and β are often used interchangeably.

For a lognormal distribution, the median value is used as the characteristic parameter of central tendency (50 percent of the values are above the median value and 50 percent are below the median value). The logarithmic standard deviation, β , or the coefficient of variation, COV, is used as a measure of the dispersion of the distribution.

The relationship between the median value, $\bar{X}$, logarithmic standard deviation, β , and any value x of the random variable can be expressed as:

$$x = \bar{X} \cdot \exp(n \cdot \beta) \quad (A-4)$$

where n is the standardized Gaussian random variable, (mean zero, standard deviation one). Therefore, the frequency that X is less than any value x' equals the frequency that n is less than n' where:

$$n' = \frac{\ln(x'/\bar{X})}{\beta} \quad (A-5)$$

Because n is a standardized Gaussian random variable, one can simply enter standardized Gaussian tables to find the frequency that n is less than n' which equals the probability that X is less than x' . Using cumulative distribution tables for the standardized Gaussian random variable, it can be shown that $\bar{X} \cdot \exp(+\beta)$ value of a lognormal distribution corresponds to the 84th percentile value (i.e., 84 percent of the data fall below the $+\beta$ value). The $\bar{X} \cdot \exp(-\beta)$ value corresponds to the value for which 16 percent of the data fall below.

One implication of the usage of the lognormal distribution is that if A , B , and C are independent lognormally distributed random variables, and if

$$D = \frac{A^r \cdot B^s}{C^t} \cdot q \quad (A-6)$$

where q , r , s and t are given constants, then D is also a lognormally distributed random variable. Further, the median value of D , denoted by $\bar{D}$, and the logarithmic variance β_D^2 , which is the square of the logarithmic standard deviation, β_D , of D , are given by:

$$\bar{V}_D = \frac{\bar{V}_r \cdot \bar{V}_s}{\bar{V}_t} \quad q \quad (A-7)$$

and

$$\beta_D^2 = r^2 \beta_A^2 + s^2 \beta_B^2 + t^2 \beta_C^2 \quad (A-8)$$

where $\bar{A}$, $\bar{B}$, and $\bar{C}$ are the median values, and β_A , β_B , and β_C are the logarithmic standard deviations of A, B, and C, respectively.

The formulation for fragility curves given by Equation 2-1 and shown in Figure 2-1 and the use of the lognormal distribution enables easy development and expression of these curves and their uncertainty. However, expression of uncertainty as shown in Figure 2-1 in which a range of peak accelerations are presented for a given failure fraction is not very usable in the systems analyses for frequency of radioactive release. For the systems analyses, it is preferable to express uncertainty in terms of a range of failure fractions (frequencies of failure) for a given ground acceleration. Conversion from the one description of uncertainty to the other is easily accomplished as illustrated in Figure A-1 and summarized below.

With perfect knowledge (i.e., only accounting for the random variability, β_A), the failure fraction, $f(a)$, for a given acceleration a can be obtained from:

$$f(a) = \Phi \left(\frac{\ln(a/\bar{A})}{\beta_R} \right) \quad (A-9)$$

in which $\Phi(\cdot)$ is the standard Gaussian cumulative distribution function, and β_R is the logarithmic standard deviation associated with the underlying randomness of the capacity.

For simplicity, denote $f = f(a)$. Similarly, f' is the failure fraction associated with acceleration a' , etc. Then, with perfect knowledge (no uncertainty in the failure fractions), the ground acceleration a' corresponding to a given frequency of failure f' is given by:

$$a' = \bar{A} \exp \left[\beta_R \Phi^{-1}(f') \right] \quad (A-10)$$

The uncertainty in ground acceleration capacity corresponding to a given frequency of failure as a result of uncertainty of the median capacity can then be expressed by the following probability statement:

$$P \left[A > a'' | f' \right] = 1 - \Phi \left[\frac{\ln(a''/\bar{A})}{\beta_U} \right] \quad (A-11)$$

in which $P[A > a'' | f']$ represents the probability that the ground acceleration A exceeds a'' for a given failure fraction f' . This probability is shown shaded in Figure A-1. However, it is desirable to transform this probability statement into a statement on the probability that the failure fraction f is less than f' for a given ground acceleration a'' , or in symbols $P[f \leq f' | a'']$. This probability is also shown shaded in Figure A-1. It follows that:

$$P[f \leq f' | a''] = P[A > a'' | f'] \quad (A-12)$$

Thus, from Equations A-10 and A-11:

$$P[f \leq f' | a''] = 1 - \Phi \left[\frac{\ln \left(a'' / \bar{A} \exp \left[\beta_R \Phi^{-1}(f') \right] \right)}{\beta_U} \right] \quad (A-13)$$

from which:

$$P\{f > f' | a''\} = \Phi \left(\frac{\left(\ln a'' / \bar{A} \exp[\beta_R \Phi^{-1}(f')] \right)}{\beta_U} \right) \quad (A-14)$$

which is the basic statement expressing the probability that the failure fraction exceeds f' for a ground acceleration a'' given the median ground acceleration capacity $\bar{A}$, and the logarithmic standard deviations β_R and β_U associated with randomness and uncertainty, respectively.

As an example, if:

$$\bar{A} = 0.77, \quad \beta_R = 0.36, \quad \beta_U = 0.39$$

then from Equation A-14 for typical values of f and a'' .

$$P\{f > 0.5 | a'' = 0.40g\} = 0.05$$

which says that there is a 5 percent probability that the failure frequency exceeds 0.5 for a ground acceleration of 0.40g.

Figure A-1. Relationship Between Uncertainty in Ground Acceleration for a Given Failure Fraction and Uncertainty in Failure Fraction for a Given Ground Acceleration

REFERENCES

- A.1 Benjamin, J. R., and C. A. Cornell, Probability, Statistics and Decision for Civil Engineers, McGraw Hill Book Company, New York, 1970.
- A.2 Kennedy, R. P., and C. V. Chelapati, "Conditional Probability of a Local Flexural Wall Failure of a Reactor Building as a Result of Aircraft Impact", Holmes and Narver, Inc., prepared for General Electric Company, San Jose, California, June, 1970.

J. M. Stone
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Attachment No. 2

**PROBABILITY OF MAIN COOLANT (PROCESS WATER) PIPE
FAILURE AT THE SAVANNAH RIVER "P" REACTOR
INDIRECTLY-INDUCED BY EARTHQUAKES**

by

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for

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1. INTRODUCTION

A probabilistic evaluation of seismic indirectly-induced pipe break for the Savannah River Project (SRP) L-Reactor main coolant (process water) piping has been performed and results have been presented in Reference 1. Since the SRP P-Reactor is quite similar to the L-Reactor, material from Reference 1 has been utilized to assess the probability of main coolant pipe failure indirectly induced by earthquakes for the P-Reactor. The results of a walkdown and drawing review for the P-Reactor are reported in Reference 2. In this reference, it is concluded that the fragilities reported in Reference 1 for the control rod and forest assembly, the main tank, the main coolant (Bingham) pumps, and the heat exchangers can be utilized for P-Reactor evaluation. However, the building structure, while similar, is sufficiently

different that the fragility of the P-Reactor building must be independently evaluated. The fragility of the P-Reactor building structure and the corresponding probability of seismic indirectly-induced pipe break for the P-Reactor are presented in this report.

It should be noted that this evaluation of the probability of main coolant pipe failure indirectly induced by earthquakes for the P-Reactor is not as rigorous as that performed for the L-Reactor. The fragility of the P-Reactor building has been independently evaluated as described herein. However, it has been assumed for this evaluation that the seismic load and displacement distribution throughout the structure is the same as that calculated by Quadrex for the L-Reactor building (Reference 3). Furthermore, it is assumed that the frequency and weight distribution for the P-Reactor building is the same as that for the L-Reactor building. Seismic response analyses are not available for P-Reactor and frequency and weight distributions have not been computed. Hence, the probability of pipe break reported herein is a best estimate value using information which is readily available or can be relatively easily generated.

This report does not repeat information from Reference 1 on methodology, or fragility of components such as the control rod and forest assembly, the main tank, the main coolant (Bingham) pumps, and the heat exchangers. In addition, to enable easy comparison of L and P-Reactor results, tables and figures which depend on building fragility are included in this report with the same number as in Reference 1 plus and additional "P" designation. For example, Figure 3-5P in this report can be compared with Figure 3-5 of Reference 1 to see the differences in lateral force resisting elements for the P and L-Reactor buildings.

2. SEISMIC RISK METHODOLOGY

The methodology employed to evaluate the probability of main coolant pipe failure indirectly induced by earthquakes for the P-Reactor is the same as that described in Chapter 2 of Reference 1 for the L-Reactor probabilistic evaluation.

3. STRUCTURE CAPACITY

Evaluation of P-Reactor building seismic fragility considered only the structure above Elevation 0 and was restricted primarily to the region of the actuator tower above the reactor tank. Similar to the L-Reactor structure, the lower portion of the structure is expected to be very lowly stressed and it was judged that damage in outlying regions would not contribute to the likelihood of a reactor main coolant (RCL) pipe break. In this chapter, the factor of safety on structure capacity is presented. As discussed in Reference 1, the capacity factor is a product of a strength factor and an inelastic energy absorption factor. P-Reactor building geometry is described below followed by descriptions of the strength factor and the inelastic energy absorption factor. Finally, the capacity of the governing P-Reactor story level is presented combining strength and inelastic energy absorption contributions along with the structural response factor of safety as computed in Section 3.1 of Reference 1.

The P-Reactor building is significantly weaker to earthquake ground motion in the north-south direction. The P-Reactor orientation is 90 degrees counter-clockwise relative to the L-Reactor building which was weakest in the east-west direction. Consequently, the capacity of the "P" structure to resist north-south earthquake ground shaking has been used to compute the risk of seismically induced pipe break from potential building debris. A strength factor for this building is evaluated as the structure capacity divided by the corresponding shear and moment from the Quadrex soil-structure interaction analysis (Reference 3) for

north-south earthquake ground shaking. As discussed in Chapter 1, this Quadrex analysis was performed only for the L-Reactor such that it is assumed herein that loads and displacements are approximately the same for the P and L structures.

Lateral force resisting elements at all elevations of the P-Reactor structure are illustrated in Figures 3-5Pa through 3-5Ph. The actuator penthouse or tower extends from El. 91.25 feet to El. 149.5 feet. Above El. 135 feet, the penthouse is a 34 foot square section with 2.0 foot thick walls (Fig. 3-5Pa). From El. 91.25 feet to El. 135 feet, the penthouse has been strengthened by buttresses as illustrated in Figure 3-5Pb. From El. 75 feet to El. 91.25 feet, the structure consists of a 72 by 66 foot box section with 5.0 foot thick walls as shown in Figure 3-5Pc. From El. 66 feet to El. 75 feet, there are additional walls to the west of the tower region as shown in Figure 3-5Pd. At El. 48 feet, a roof slab extends from the tower region to the east to fan and duct rooms. Also, at this elevation, there are stairwell walls on both the north and south sides of the building as shown in Figure 3-5Pe.

From El. 34 feet to El. 48 feet, there are no longer any north-south running walls in the tower region. There is a single 5 foot thick wall located to the west of the tower region as shown in Figure 3-5Pf, but the capacity to resist lateral loads is significantly less than the section above where there are additional 5 foot wide and 3 foot wide by 72 foot long walls. Furthermore, there is a 5 foot thick roof slab at El. 48 feet, which extends to the east of the tower region about 183 feet to an expansion joint which structurally separates this portion of the building from additional structures to the north. In addition, this 5 foot thick slab extends to the south of the tower region to the 5 foot thick shear wall shown in Figure 3-5Pf. Shear loads from the tower structure above and from the massive

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slab at El. 48 feet must be resisted by the shear walls to the south of the tower region and by out-of-plane bending of the underlying north-south running walls.

The capacity of the walls to the west of the tower region (the 5 foot by 72 foot wall plus adjacent stairwell walls) as shown in Figure 3-5Pf for Elevations 34 to 48 feet is a factor of 1.70 times the shear loads at this elevation of the building. This factor was evaluated assuming that a portion of the shear load resulting from inertial effects of the slab to the north of the tower region was resisted by the out-of-plane bending capacity of north-south running walls. The remaining shear load is transferred in diaphragm action to the resisting shear walls on the south end of this bending. The governing capacity/demand ratio for this building level is estimated to be 1.70.

Below El. 34 feet, there are many additional shear walls as shown in Figures 3-5Pg and 3-5Ph. Consequently, the capacity/demand ratios for lateral load resisting elements from El. 0 to El. 34 feet are significantly larger than for the resisting elements between El. 34 and 48 feet. Also, the capacity/demand ratios for lateral load resisting elements above El. 48 are much larger than for the resisting elements between El. 34 and 48 feet. Above El. 48 and below El. 34, the P-Reactor structure is significantly stronger than the L-Reactor structure. However, between El. 34 and El. 48, the P structure is much weaker than the L structure.

The median capacity/demand ratio or strength factor for the P-Reactor building is 1.70 as described above. Uncertainty in this median factor is the same as for the L-Reactor building strength (Reference 1). Uncertainty results from the following sources: 1) material strength which, in the case of shear, is governed by the square root of concrete strength for which β_U is 0.08 (β_U is 16 for concrete strength as described in Section 3.2.1 of Reference 1); 2) the strength relationship for shear for which β_U is 0.15; and 3) uncertainty introduced because a simple

stick model was used to represent the complex load distribution below El. 48 feet as discussed above. Uncertainty due to modeling is judged to be approximated by β_U of 0.15. Combining all sources of uncertainty results in a total β_U of 0.22. The median strength factor as well as the uncertainty and randomness along with the high confidence, low probability (HCLP) strength value are summarized below.

$$F_S = 1.70$$

$$\beta_R = 0.0$$

$$\beta_U = 0.22$$

$$HCLP = 1.18$$

A more realistic assessment of the seismic capacity of a structure requires that the inelastic energy absorption of the structure is considered in addition to the strength capacity. Inelastic energy absorption in the P-Reactor building has been considered in a identical manner to that described in Reference 1. For this building, the inelastic energy absorption factor will be evaluated in the manner described in Reference 1 with the median value estimated to be midway between the following two bounding cases:

1. System ductility is evaluated by Equation 3-7 of Reference 1 using story weights down to Elevation -40 feet and inelastic energy absorption factor is evaluated by Equation 3-4 of Reference 1 using damping of 30 percent which is consistent with combined soil radiation damping and structural damping. This is a conservative, lower bound approach for evaluating the inelastic energy absorption factor.
2. System ductility is evaluated by Equation 3-7 of Reference 1 using story weights down to Elevation 0 feet with soil deformations removed such that displacement at Elevation 0 feet is zero, and inelastic energy absorption factor is

evaluated by Equation 3-4 of Reference 1 using damping of 10 percent which is consistent with structural damping only. Assumptions herein are consistent with the building moving with the free field ground at Elevation 0 with no soil-structure interaction effects. This is an unconservative, but reasonable upper bound approach for evaluating the inelastic energy absorption factor.

It is estimated that the inelastic energy absorption factor from case 1 above represents a 5 percent probability of non-exceedance value and the factor from case 2 above represents a 98 percent probability of non-exceedance value and uncertainty is evaluated accordingly. The median factor is evaluated from the Case 1 and 2 values and the above probabilities.

The deflected shape of the P-Reactor building at yield (i.e. the deflected shape from the Quadrex analysis scaled by the minimum strength factor of 1.70) is illustrated in Figure 3-7P. Also, the deflected shape at failure is shown on this same figure. The deflected shape at failure assumes that the story drift between El. 34 and 48 feet is 0.7 percent of the story height and the deflections above El. 48 are compatible with the displacement of the weakest level as shown on Figure 3-7P.

Evaluation of the system ductility corresponding to the deflected shapes shown in Figure 3-7P by Equation 3-7 of Reference 1 is shown in Table 3-2P for both cases described above. The system ductilities corresponding to Cases 1 and 2 are 1.62 and 6.21, respectively. Utilizing Equation 3-6 of Reference 1 to determine effective system ductility levels results in values of 1.80 and 7.77, respectively, for Cases 1 and 2. The inelastic energy absorption factor evaluated in accordance with Equation 3-4 is 1.30 for Case 1 and 2.30 for Case 2. The median inelastic energy absorption factor is evaluated to be 1.68 in a manner consistent with assumptions described above.

Utilizing Equation 3-5 of Reference 1, β_R is about 0.06. Uncertainty exists in the story drift value used to evaluate system ductility and in the assumptions used to evaluate system ductility and inelastic energy absorption factor by Cases 1 and 2. Using 0.4 percent story drift, inelastic energy absorption factors of 1.26 and 2.14 are computed by Case 1 and 2 assumptions, respectively. Since, 0.4 percent story drift is a 10% probability value, β_U of 0.04 may be computed as the average value from Case 1 and 2 assumptions. Since inelastic energy absorption factors of 1.30 and 2.30 are 5 and 98 percent probability of non-exceedance values, an additional β_U of 0.15 associated with assumption of the two cases may be computed. Combining these two sources of uncertainty results in a total β_U of 0.16.

$$F_\mu = 1.68$$

$$\beta_R = 0.06$$

$$\beta_U = 0.16$$

$$HCLP = 1.17$$

As presented in Reference 1, median structure capacity can be approximated by the median response factor (Section 3.1.6 of Reference 1) times the median strength factor times the median inelastic energy absorption factor times the design free-field ground acceleration (0.2g). These median factors along with their randomness and uncertainty are summarized below:

Attribute	Factor	β_R	β_U
Strength	1.70	0.00	0.22
Inelastic Energy Absorption	1.68	0.06	0.16
Response	1.55	0.18	0.31

Using the values given above and the method of combination described in Reference 1, the fragility of the structure as represented by the median capacity, the logarithmic standard deviation associated with randomness, β_R , the logarithmic standard deviation associated with uncertainty, β_U , and the 95 percent confidence of 5 percent probability of failure (HCLPF) level are given by:

$$\hat{A} = 0.89g$$

$$\beta_R = 0.18$$

$$\beta_U = 0.40$$

$$\text{HCLPF} = 0.34g$$

4. PLANT DAMAGE STATE FRAGILITIES

Plant damage state fragilities for seismic-induced indirect RCL pipe are developed from the individual component fragilities described in the previous section for the P-Reactor building and in Reference 1 for other components. Plant damage state fragility curves, like a component fragility curve, represent the frequency with which the occurrence of the plant damage state (failure) is expected to occur, given the occurrence of an earthquake of a particular peak ground acceleration. As previously noted, both laminated and solid (block) shims were observed in the heat exchanger bracing. The capacity of this component is different depending on which condition exists for a given heat exchanger. Consequently, plant fragilities were developed for both heat exchangers cases.

Tables 4-6P through 4-11P show the plant level fragilities for several cases including the P-Reactor building fragility. Table 4-6P is for the condition of heat exchangers with thin

laminated shims, the tank, and the building with independent randomness and uncertainty for all components. A median acceleration capacity of about 0.59 g with a high confidence, low probability of seismic failure of about 0.27 g is indicated.

If solid block shims are assumed, the median capacity is seen in Table 4-7P to increase to about 0.67 g with a HCLPF of about 0.29 g. If the heat exchangers are strengthened to the extent they do not influence the plant fragility, the plant fragility is seen in Table 4-8P to increase to about 0.75 g with a HCLPF of 0.29 g, again for both the randomness and uncertainty assumed independent (conservative).

Tables 4-6P through 4-8P assume both the randomness and uncertainty are independent while Tables 4-9P through 4-11P show the plant level fragilities for the cases where the randomness is assumed independent and the uncertainty is assumed to be dependent. Comparison of these assumptions show that the assumption to independency for both randomness and uncertainty leads to conservative values. The median capacity for the heat exchanger with laminated shims, the tank, and the building is 0.68 g for dependent uncertainty. The median capacity for the heat exchanger with solid shims, the tank, and the building is 0.81 g for dependent uncertainty. The median capacity for the main tank and the building is 0.85 g for dependent uncertainty.

The effects of including the building for a number of cases can be seen from the comparisons in Table 4-12P. For instance, for independent randomness and uncertainty for the case of the heat exchangers with laminated shims and the tank indicates including the building reduces the median capacity from about 0.65 g to 0.59 g (about 9%), while the HCLPF is reduced from about 0.28 g to 0.27 g (about 4%). If the heat exchangers are assumed to be further strengthened so that they do not influence the plant fragility and only the tank and building are considered, the addition of the building compared to the tank alone results in a decrease in the median acceleration from 1.04 g to

about 0.75 g (28% reduction) and the HCLPF from 0.36 g to 0.29 g (19% reduction). For the P-Reactor, the relatively low building capacity has a greater influence than the influence of the L-Reactor building.

5. SEISMIC RISK

The seismic risk of RCL pipe failure indirectly-induced by earthquakes is developed by a convolution of the seismic hazard curves with fragility curves representing the plant damage states developed in the previous section. In this manner, a probabilistic distribution on the frequency of plant damage can be obtained. Tables 5-6P through 5-12P summarize these results for the plant damage states at the P-Reactor for various cases of laminated shims and solid shims for the heat exchanger bracing with the main tank with and the building. The tables show the median, mean, 90% and 95% upper confidence bounds and 10% lower confidence bound on the annual occurrence frequency.

Including the risk from the building in the overall plant seismic risk is very important for the P-Reactor. For example, the mean frequency of failure for the case of heat exchangers with laminated shims and main tank (with independent randomness) is seen to increase to about 7.6×10^{-6} or an increase of about 29% compared to the value not considering the building. The median risk is about 1.2×10^{-6} or two times greater and the 90% and 10% confidence bounds are 1.9×10^{-5} and 4.9×10^{-8} , respectively.

Comparisons of the seismic risk of RCL Pipe Failure for several cases including and excluding the contribution of the building are shown in Table 5-13P. This table indicates that, for the P-Reactor, the building capacity dominates the seismic risk of the plant. The table also indicates that the expected gain from further strengthening the heat exchanger bracing or attempting to strengthen the tank would result in only a relatively small decrease in risk and is likely unwarranted.

Figure 5-2P illustrates what ranges of acceleration contribute most significantly to the overall frequency of occurrence of the damage state. About 20.5% of the mean risk results from earthquakes less than 0.25 g for the P-Reactor as compared to 2.3% for the L-Reactor. Even so, most of the contribution comes from acceleration ranges above the design basis (SSE) earthquake of 0.2 g as would be expected. Seismic ground motions in excess of the 0.2 g design level are required to produce substantial risk due to indirect pipe failure since earthquakes accelerations of from about 0.25 g to 0.55 g contribute the greatest to the seismic risk for P-Reactor. This indicates that large earthquakes must occur before any significant probability of pipe failure is expected as a result of indirectly-induced failure due to earthquakes.

6. CONCLUSIONS

An evaluation of the probability of main coolant (process water) pipe failure at the Savannah River P-Reactor indirectly-induced by earthquakes was conducted. Pipe break failure in the main coolant piping resulting from potential failure of the main tank, heat exchangers, main pumps, forest support frame and control rods, and the building structure above Elev. 0 was included. Seismic inertia loads on the piping itself were not considered in this evaluation.

The probability of main coolant pipe break in the P-Reactor was developed by determining the expected seismic fragilities of the P-Reactor building and from the seismic fragility of other individual components listed above as determined for the L-Reactor (Reference 1). Plant damage state fragilities were then developed from several combinations of the individual components.

If the most conservative assumptions regarding independency of the randomness and uncertainty are used, the mean conditional

frequency of indirect seismically-induced failure of the RCL piping is approximately 7.6×10^{-6} per year and the median frequency is about 1.25×10^{-6} per year for the P-Reactor with thin laminated shims installed in the heat exchanger supports. If solid block shims are installed in all locations, the risk is decreased somewhat to a mean of about 4.7×10^{-6} per year and a median of about 6.4×10^{-7} per year. Neglecting the contribution of the building to the seismic risk, the mean value is about 6×10^{-6} per year and the median about 6×10^{-7} per year, again for the case of the laminated shims and independent randomness and uncertainty. Comparison of building and no building values indicates that, for the P-Reactor, building structure fragility, while important, does not dominate the plant seismic risk. The risk values described above are all quite low and are not substantially out-of-line with estimates for commercial nuclear power plants. Therefore, for seismic indirectly-induced pipe failure, no plant modifications appear warranted.

Table 6-1 provides a comparison of building fragility, plant fragility and seismic risk between the L and P reactors. These comparisons are for the controlling case including the building, the main tank, and the heat exchangers with laminated shims. The P-Reactor building fragility is about 63% of that for the L-Reactor. The P-Reactor plant fragility is about 92% of that for the L-Reactor. These differences in fragility result in the P-Reactor mean risk being about 27% greater than that for the L-Reactor and the P-Reactor median risk being about 1.6 times that for the L-Reactor.

REFERENCES

1. Kennedy, R.P., S.A. Short, and D.A. Wesley, "Probability of Main Coolant (Process Water) Pipe Failure at the Savannah River 'L' Reactor Indirectly-Induced by Earthquakes," RPK Structural Mechanics Consulting, Santa Ana, California, February 1988.
2. Letter from D.A. Wesley to Bill Awadalla on "Walkdown of the 'P' Reactor for Probability of Main Coolant Pipe Failure Indirectly-Induced by Earthquakes", Impell Corporation, Santa Ana, California, February 12, 1988.
3. Tang, C.C., "Seismic Analysis of 'L' Reactor Buildings at the Savannah River Site," QUAD-1-85-016, Vol. IV, prepared for E.I. du Pont de Nemours and Company, November 1985.

TABLE 3-2P
EVALUATION OF INELASTIC ENERGY ABSORPTION FACTOR

CASE 1						
Elevation (feet)	Weight, W (kips)	$\Delta_{Quadrax}$ (inches)	Δ_u (inches)	$W^*\Delta_u$	Δ_u (inches)	$W^*\Delta_u$
148.67	530	1.153	1.960	1039	3.079	1632
125.00	894	0.991	1.685	1506	2.803	2506
107.50	1121	0.870	1.479	1658	2.597	2912
91.25	3885	0.760	1.292	5019	2.410	9364
75.00	4957	0.628	1.068	5292	2.186	10836
66.00	9390	0.585	0.994	9338	2.113	19840
48.00	18852	0.472	0.802	15127	1.921	36211
34.00	24011	0.364	0.619	14858	0.619	14858
15.00	26059	0.249	0.423	11031	0.423	11031
0.00	49548	0.179	0.304	15077	0.304	15077
-20.00	51446	0.088	0.150	7696	0.150	7696
				87642		131963

CASE 2						
Elevation (feet)	Weight, W (kips)	$\Delta_{Quadrax}$ (inches)	Δ_u (inches)	$W^*\Delta_u$	Δ_u (inches)	$W^*\Delta_u$
148.67	530	0.309	0.525	278	1.643	871
125.00	894	0.253	0.429	384	1.548	1384
107.50	1121	0.210	0.357	400	1.475	1654
91.25	3885	0.173	0.294	1140	1.412	5485
75.00	4957	0.113	0.193	955	1.311	6499
66.00	9390	0.111	0.188	1766	1.307	12268
48.00	18852	0.078	0.133	2506	1.358	25598
34.00	24011	0.033	0.056	1341	0.056	1341
15.00	26059	0.003	0.005	127	0.005	127
				8899		55228

CASE 1	CASE 2
$\mu = \frac{131,963}{87,642} = 1.62$	$\mu = \frac{55,228}{8,899} = 6.21$
$\mu^* = 1.80$	$\mu^* = 7.77$
Eq. 3-6	Eq. 3-6
$F_\mu = 1.30$	$F_\mu = 2.30$
Eq. 3-4	Eq. 3-4

a. Cross Section from EL. 125' to EL. 149.5'

b. Cross Section from EL. 91.25' to EL. 107.5'

FIGURE 3-5P.

LATERAL FORCE RESISTING ELEMENTS OF "P" REACTOR BUILDING

c. Cross Section from EL. 75 to EL. 91.25'

d. Cross Section from EL. 66' to EL. 75'

FIGURE 3-5P.

LATERAL FORCE RESISTING ELEMENTS OF P REACTOR BUILDING (CONT'D)

e. Cross Section from EL. 48' to EL. 66'

FIGURE 3-5P.

LATERAL FORCE RESISTING ELEMENTS OF P-REACTOR BUILDING (CONT'D)

f. Cross Section from EL. 34' to EL. 48'

FIGURE 3-5P.

LATERAL FORCE RESISTING ELEMENTS OF "P" REACTOR BUILDING (CONT'D)

g. Cross Section from EL. 15' to EL. 34'

FIGURE 3-5P.

LATERAL FORCE RESISTING ELEMENTS OF "P" REACTOR BUILDING (CONT'D)

h. Cross Section from EL. 0' to EL. 15'

LATERAL FORCE RESISTING ELEMENTS OF "P" REACTOR BUILDING (CONT'D)

FIGURE 3-7P.

DEEEECTED SHAPES AT YIELD AND AT FAILURE FOR P-REACTOR BUILDING

TABLE 4-6P. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/LAMINATED SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	3.308E-07	1.131E-06	8.666E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	5.029E-09
	2.928E-07	4.423E-06	1.423E-04	6.408E-04	3.499E-03	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.248E-07	3.340E-06
	6.549E-05	5.115E-04	4.738E-03	2.065E-02	7.316E-02	
.300	1.000E-20	1.000E-20	9.537E-09	6.376E-07	1.494E-05	1.891E-04
	1.764E-03	9.806E-03	4.194E-02	1.406E-01	3.328E-01	
.350	1.000E-20	6.437E-08	1.353E-06	3.155E-05	3.979E-04	2.842E-03
	1.606E-02	6.412E-02	1.646E-01	3.964E-01	6.676E-01	
.400	1.824E-07	2.387E-06	3.659E-05	5.315E-04	4.066E-03	1.852E-02
	7.267E-02	2.085E-01	3.823E-01	6.724E-01	8.829E-01	
.450	3.201E-06	4.282E-05	4.508E-04	4.247E-03	2.123E-02	6.916E-02
	2.024E-01	4.307E-01	6.254E-01	8.600E-01	9.687E-01	
.500	3.293E-05	4.049E-04	3.113E-03	1.985E-02	6.932E-02	1.756E-01
	3.983E-01	6.569E-01	8.170E-01	9.514E-01	9.932E-01	
.550	2.239E-04	2.376E-03	1.379E-02	6.256E-02	1.628E-01	3.374E-01
	6.095E-01	8.285E-01	9.261E-01	9.864E-01	9.988E-01	
.600	1.092E-03	9.649E-03	4.336E-02	1.455E-01	3.014E-01	5.260E-01
	7.829E-01	9.288E-01	9.757E-01	9.967E-01	9.998E-01	
.650	4.064E-03	2.939E-02	1.048E-01	2.702E-01	4.689E-01	7.008E-01
	8.966E-01	9.748E-01	9.935E-01	9.993E-01	1.000E+00	
.700	1.209E-02	7.121E-02	2.063E-01	4.227E-01	6.367E-01	8.333E-01
	9.574E-01	9.924E-01	9.985E-01	9.999E-01	1.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-6P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	2.982E-02 9.847E-01	1.433E-01 9.980E-01	3.431E-01 9.997E-01	5.806E-01 1.000E+00	7.770E-01 1.000E+00	9.178E-01
.800	6.289E-02 9.953E-01	2.476E-01 9.995E-01	4.974E-01 1.000E+00	7.212E-01 1.000E+00	8.769E-01 1.000E+00	9.639E-01
.850	1.161E-01 9.987E-01	3.769E-01 9.999E-01	6.458E-01 1.000E+00	8.302E-01 1.000E+00	9.387E-01 1.000E+00	9.858E-01
.900	1.913E-01 9.997E-01	5.166E-01 1.000E+00	7.699E-01 1.000E+00	9.048E-01 1.000E+00	9.722E-01 1.000E+00	9.949E-01
.950	2.860E-01 9.999E-01	6.497E-01 1.000E+00	8.609E-01 1.000E+00	9.511E-01 1.000E+00	9.885E-01 1.000E+00	9.984E-01
1.000	3.936E-01 1.000E+00	7.625E-01 1.000E+00	9.213E-01 1.000E+00	9.770E-01 1.000E+00	9.956E-01 1.000E+00	9.995E-01
1.050	5.050E-01 1.000E+00	8.491E-01 1.000E+00	9.579E-01 1.000E+00	9.902E-01 1.000E+00	9.984E-01 1.000E+00	9.999E-01
1.100	6.112E-01 1.000E+00	9.096E-01 1.000E+00	9.789E-01 1.000E+00	9.961E-01 1.000E+00	9.995E-01 1.000E+00	1.000E+00
1.150	7.054E-01 1.000E+00	9.487E-01 1.000E+00	9.901E-01 1.000E+00	9.985E-01 1.000E+00	9.998E-01 1.000E+00	1.000E+00
1.200	7.838E-01 1.000E+00	9.722E-01 1.000E+00	9.957E-01 1.000E+00	9.995E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.250	8.454E-01 1.000E+00	9.858E-01 1.000E+00	9.982E-01 1.000E+00	9.998E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.300	8.922E-01 1.000E+00	9.930E-01 1.000E+00	9.993E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.350	9.263E-01 1.000E+00	9.967E-01 1.000E+00	9.997E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.400	9.505E-01 1.000E+00	9.985E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.450	9.672E-01 1.000E+00	9.993E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00 1.000E+00	1.000E+00 1.000E+00	1.000E+00

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-6P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
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1.500	9.785E-01	9.997E-01	1.000E+00	1.000E+00	1.000E+00	1.000E+00
	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-7P. PLANT LEVEL FRAGILITY
HEAT EXCHANGER (W/SOLID SHIMS), MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	5.230E-07	2.292E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	4.218E-07	2.763E-06	4.051E-04	8.633E-04	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	5.364E-08
	2.877E-06	5.565E-05	4.325E-04	1.065E-02	2.919E-02	
.300	1.000E-20	1.000E-20	1.000E-20	2.123E-08	2.193E-07	7.157E-06
	1.609E-04	1.379E-03	9.628E-03	7.106E-02	1.905E-01	
.350	1.000E-20	1.000E-20	7.947E-08	1.467E-06	1.161E-05	2.105E-04
	2.523E-03	1.281E-02	6.602E-02	2.213E-01	4.946E-01	
.400	1.000E-20	2.468E-07	3.434E-06	3.178E-05	2.173E-04	2.372E-03
	1.722E-02	6.114E-02	2.156E-01	4.412E-01	7.692E-01	
.450	9.934E-08	4.548E-06	5.868E-05	3.345E-04	1.926E-03	1.378E-02
	6.673E-02	1.798E-01	4.373E-01	7.76E-01	9.193E-01	
.500	1.612E-06	4.549E-05	5.305E-04	2.099E-03	9.957E-03	5.004E-02
	1.735E-01	3.696E-01	6.590E-01	8.375E-01	9.773E-01	
.550	1.611E-05	2.992E-04	2.977E-03	8.570E-03	3.494E-02	1.290E-01
	3.373E-01	5.836E-01	8.237E-01	9.342E-01	9.946E-01	
.600	1.064E-04	1.414E-03	1.123E-02	2.651E-02	9.038E-02	2.571E-01
	5.275E-01	7.636E-01	9.216E-01	9.780E-01	9.989E-01	
.650	5.077E-04	5.118E-03	3.121E-02	6.654E-02	1.860E-01	4.206E-01
	7.022E-01	8.837E-01	9.694E-01	9.938E-01	9.998E-01	
.700	1.867E-03	1.489E-02	6.980E-02	1.391E-01	3.172E-01	5.918E-01
	8.333E-01	9.499E-01	9.893E-01	9.985E-01	1.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-7P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	5.557E-03 9.161E-01	3.610E-02 9.809E-01	1.337E-01 9.967E-01	2.476E-01 9.997E-01	4.693E-01 1.000E+00	7.409E-01
.800	1.390E-02 9.621E-01	7.506E-02 9.934E-01	2.249E-01 9.992E-01	3.847E-01 9.999E-01	6.202E-01 1.000E+00	8.510E-01
.850	3.011E-02 9.851E-01	1.368E-01 9.979E-01	3.392E-01 9.998E-01	5.330E-01 1.000E+00	7.498E-01 1.000E+00	9.214E-01
.900	5.778E-02 9.947E-01	2.228E-01 9.994E-01	4.666E-01 1.000E+00	6.724E-01 1.000E+00	8.478E-01 1.000E+00	9.619E-01
.950	1.000E-01 9.983E-01	3.294E-01 9.998E-01	5.941E-01 1.000E+00	7.872E-01 1.000E+00	9.142E-01 1.000E+00	9.829E-01
1.000	1.584E-01 9.995E-01	4.479E-01 1.000E+00	7.093E-01 1.000E+00	8.698E-01 1.000E+00	9.561E-01 1.000E+00	9.930E-01
1.050	2.324E-01 9.999E-01	5.677E-01 1.000E+00	8.041E-01 1.000E+00	9.257E-01 1.000E+00	9.792E-01 1.000E+00	9.973E-01
1.100	3.184E-01 1.000E+00	6.781E-01 1.000E+00	8.758E-01 1.000E+00	9.604E-01 1.000E+00	9.908E-01 1.000E+00	9.990E-01
1.150	4.118E-01 1.000E+00	7.716E-01 1.000E+00	9.260E-01 1.000E+00	9.803E-01 1.000E+00	9.962E-01 1.000E+00	9.997E-01
1.200	5.073E-01 1.000E+00	8.457E-01 1.000E+00	9.585E-01 1.000E+00	9.908E-01 1.000E+00	9.985E-01 1.000E+00	9.999E-01
1.250	5.991E-01 1.000E+00	9.007E-01 1.000E+00	9.779E-01 1.000E+00	9.959E-01 1.000E+00	9.994E-01 1.000E+00	1.000E+00
1.300	6.829E-01 1.000E+00	9.390E-01 1.000E+00	9.888E-01 1.000E+00	9.983E-01 1.000E+00	9.998E-01 1.000E+00	1.000E+00
1.350	7.535E-01 1.000E+00	9.642E-01 1.000E+00	9.946E-01 1.000E+00	9.993E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00
1.400	8.158E-01 1.000E+00	9.798E-01 1.000E+00	9.975E-01 1.000E+00	9.997E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00
1.450	8.640E-01 1.000E+00	9.890E-01 1.000E+00	9.989E-01 1.000E+00	9.999E-01 1.000E+00	1.000E+00 1.000E+00	1.000E+00

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-7P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
1.500	9.013E-01	9.943E-01	9.995E-01	1.000E+00	1.000E+00	1.000E+00
	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-8P. PLANT LEVEL FRAGILITY
MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.100	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	
.150	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.000E-20	5.230E-07	2.292E-06	
.200	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20
	1.000E-20	1.000E-20	1.911E-06	4.038E-04	8.631E-04	
.250	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.000E-20	1.118E-08
	8.732E-07	5.939E-06	2.731E-04	1.052E-02	2.917E-02	
.300	1.000E-20	1.000E-20	1.000E-20	1.000E-20	3.179E-08	1.373E-06
	4.765E-05	3.461E-04	6.084E-03	6.933E-02	1.901E-01	
.350	1.000E-20	1.000E-20	1.000E-20	1.192E-08	1.232E-06	4.036E-05
	8.319E-04	5.271E-03	4.403E-02	2.148E-01	4.930E-01	
.400	1.000E-20	1.000E-20	1.000E-20	1.156E-06	2.423E-05	5.161E-04
	6.717E-03	3.326E-02	1.556E-01	4.289E-01	7.668E-01	
.450	1.000E-20	2.980E-08	5.762E-07	1.899E-05	2.469E-04	3.606E-03
	3.099E-02	1.155E-01	3.443E-01	6.487E-01	9.173E-01	
.500	1.000E-20	4.619E-07	8.688E-06	1.720E-04	1.554E-03	1.596E-02
	9.420E-02	2.654E-01	5.597E-01	8.174E-01	9.761E-01	
.550	5.066E-08	4.722E-06	7.978E-05	9.937E-04	6.747E-03	4.967E-02
	2.091E-01	4.570E-01	7.428E-01	9.187E-01	9.941E-01	
.600	4.053E-07	3.305E-05	4.824E-04	4.062E-03	2.182E-02	1.174E-01
	3.654E-01	6.450E-01	8.664E-01	9.692E-01	9.987E-01	
.650	3.093E-06	1.715E-04	2.093E-03	1.268E-02	5.554E-02	2.237E-01
	5.341E-01	7.958E-01	9.373E-01	9.898E-01	9.997E-01	
.700	1.782E-05	6.916E-04	6.953E-03	3.198E-02	1.163E-01	3.599E-01
	6.883E-01	8.951E-01	9.729E-01	9.969E-01	9.999E-01	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-8P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	8.037E-05 8.095E-01	2.260E-03 9.509E-01	1.861E-02 9.895E-01	6.788E-02 9.991E-01	2.073E-01 1.000E+00	5.075E-01
.800	2.953E-04 8.931E-01	6.179E-03 9.789E-01	4.176E-02 9.962E-01	1.251E-01 9.998E-01	3.238E-01 1.000E+00	6.466E-01
.850	9.097E-04 9.450E-01	1.453E-02 9.917E-01	8.102E-02 9.988E-01	2.050E-01 9.999E-01	4.540E-01 1.000E+00	7.627E-01
.900	2.410E-03 9.736E-01	3.004E-02 9.969E-01	1.393E-01 9.996E-01	3.043E-01 1.000E+00	5.831E-01 1.000E+00	8.506E-01
.950	5.609E-03 9.881E-01	5.564E-02 9.989E-01	2.165E-01 9.999E-01	4.156E-01 1.000E+00	6.987E-01 1.000E+00	9.115E-01
1.000	1.160E-02 9.949E-01	9.383E-02 9.996E-01	3.085E-01 1.000E+00	5.299E-01 1.000E+00	7.931E-01 1.000E+00	9.503E-01
1.050	2.150E-02 9.979E-01	1.460E-01 9.999E-01	4.067E-01 1.000E+00	6.490E-01 1.000E+00	8.646E-01 1.000E+00	9.734E-01
1.100	3.688E-02 9.992E-01	2.116E-01 1.000E+00	5.079E-01 1.000E+00	7.364E-01 1.000E+00	9.151E-01 1.000E+00	9.864E-01
1.150	5.909E-02 9.997E-01	2.881E-01 1.000E+00	6.060E-01 1.000E+00	8.152E-01 1.000E+00	9.488E-01 1.000E+00	9.933E-01
1.200	8.919E-02 9.999E-01	3.730E-01 1.000E+00	6.951E-01 1.000E+00	8.756E-01 1.000E+00	9.702E-01 1.000E+00	9.968E-01
1.250	1.277E-01 1.000E+00	4.617E-01 1.000E+00	7.718E-01 1.000E+00	9.196E-01 1.000E+00	9.831E-01 1.000E+00	9.985E-01
1.300	1.746E-01 1.000E+00	5.500E-01 1.000E+00	8.347E-01 1.000E+00	9.499E-01 1.000E+00	9.907E-01 1.000E+00	9.993E-01
1.350	2.289E-01 1.000E+00	6.336E-01 1.000E+00	8.840E-01 1.000E+00	9.697E-01 1.000E+00	9.951E-01 1.000E+00	9.997E-01
1.400	2.894E-01 1.000E+00	7.093E-01 1.000E+00	9.210E-01 1.000E+00	9.821E-01 1.000E+00	9.976E-01 1.000E+00	9.999E-01
1.450	3.541E-01 1.000E+00	7.752E-01 1.000E+00	9.477E-01 1.000E+00	9.897E-01 1.000E+00	9.988E-01 1.000E+00	9.999E-01

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-8P (CONTINUED)

Acceleration (g)		Conditional Frequency of Occurrence*				
1.500	4.208E-01	8.304E-01	9.663E-01	9.943E-01	9.994E-01	1.000E+00
	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-9P. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/LAMINATED SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.150	1.192E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.200	5.119E-03	4.905E-05	1.132E-06	5.960E-08	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.250	1.176E-01	4.340E-03	2.549E-04	1.490E-05	4.768E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.300	5.249E-01	6.167E-02	7.291E-03	7.976E-04	5.335E-05	1.252E-06
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.350	8.886E-01	2.892E-01	6.170E-02	1.110E-02	1.282E-03	5.960E-05
	1.311E-06	5.960E-08	0.000E+00	0.000E+00	0.000E+00	
.400	9.888E-01	6.447E-01	2.376E-01	6.496E-02	1.172E-02	9.520E-04
	3.856E-05	1.490E-06	5.960E-08	0.000E+00	0.000E+00	
.450	9.994E-01	8.939E-01	5.272E-01	2.111E-01	5.540E-02	7.189E-03
	4.864E-04	2.986E-05	1.311E-06	0.000E+00	0.000E+00	
.500	1.000E+00	9.809E-01	7.928E-01	4.492E-01	1.646E-01	3.174E-02
	3.342E-03	3.033E-04	1.931E-05	4.172E-07	0.000E+00	
.550	1.000E+00	9.978E-01	9.371E-01	6.989E-01	3.479E-01	9.462E-02
	1.460E-02	1.872E-03	1.680E-04	5.603E-06	0.000E+00	
.600	1.000E+00	9.998E-01	9.865E-01	8.743E-01	5.678E-01	2.104E-01
	4.521E-02	7.870E-03	9.595E-04	4.625E-05	1.192E-07	
.650	1.000E+00	1.000E+00	9.979E-01	9.598E-01	7.628E-01	3.737E-01
	1.074E-01	2.449E-02	3.935E-03	2.654E-04	1.371E-06	
.700	1.000E+00	1.000E+00	9.997E-01	9.900E-01	8.931E-01	5.572E-01
	2.077E-01	6.008E-02	1.237E-02	1.133E-03	9.298E-06	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-9P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	1.000E+00 3.415E-01	1.000E+00 1.219E-01	1.000E+00 3.136E-02	9.980E-01 3.797E-03	9.603E-01 4.864E-05	7.246E-01
.800	1.000E+00 4.930E-01	1.000E+00 2.125E-01	1.000E+00 6.669E-02	9.997E-01 1.042E-02	9.877E-01 2.011E-04	8.504E-01
.850	1.000E+00 6.415E-01	1.000E+00 3.275E-01	1.000E+00 1.228E-01	1.000E+00 2.421E-02	9.968E-01 6.827E-04	9.291E-01
.900	1.000E+00 7.683E-01	1.000E+00 4.568E-01	1.000E+00 2.010E-01	1.000E+00 4.891E-02	9.993E-01 1.961E-03	9.705E-01
.950	1.000E+00 8.635E-01	1.000E+00 5.869E-01	1.000E+00 2.983E-01	1.000E+00 8.787E-02	9.999E-01 4.884E-03	9.892E-01
1.000	1.000E+00 9.268E-01	1.000E+00 7.053E-01	1.000E+00 4.082E-01	1.000E+00 1.430E-01	1.000E+00 1.075E-02	9.965E-01
1.050	1.000E+00 9.641E-01	1.000E+00 8.032E-01	1.000E+00 5.222E-01	1.000E+00 2.140E-01	1.000E+00 2.129E-02	9.990E-01
1.100	1.000E+00 9.839E-01	1.000E+00 8.772E-01	1.000E+00 6.315E-01	1.000E+00 2.982E-01	1.000E+00 3.843E-02	9.997E-01
1.150	1.000E+00 9.933E-01	1.000E+00 9.283E-01	1.000E+00 7.290E-01	1.000E+00 3.914E-01	1.000E+00 6.401E-02	9.999E-01
1.200	1.000E+00 9.974E-01	1.000E+00 9.608E-01	1.000E+00 8.101E-01	1.000E+00 4.882E-01	1.000E+00 9.938E-02	1.000E+00
1.250	1.000E+00 9.991E-01	1.000E+00 9.799E-01	1.000E+00 8.734E-01	1.000E+00 5.831E-01	1.000E+00 1.451E-01	1.000E+00
1.300	1.000E+00 9.997E-01	1.000E+00 9.903E-01	1.000E+00 9.196E-01	1.000E+00 6.713E-01	1.000E+00 2.008E-01	1.000E+00
1.350	1.000E+00 9.999E-01	1.000E+00 9.956E-01	1.000E+00 9.514E-01	1.000E+00 7.494E-01	1.000E+00 2.652E-01	1.000E+00
1.400	1.000E+00 1.000E+00	1.000E+00 9.981E-01	1.000E+00 9.720E-01	1.000E+00 8.153E-01	1.000E+00 3.362E-01	1.000E+00
1.450	1.000E+00 1.000E+00	1.000E+00 9.992E-01	1.000E+00 9.846E-01	1.000E+00 8.684E-01	1.000E+00 4.111E-01	1.000E+00

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-9P (CONTINUED)

Acceleration Conditional Frequency of Occurrence*

1.500	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
	1.000E+00	9.997E-01	9.919E-01	9.094E-01	4.872E-01	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-10P. PLANT LEVEL FRAGILITY

HEAT EXCHANGER (W/SOLID SHIMS), MAIN TANK, AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.150	3.338E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.200	1.675E-03	4.172E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.250	5.009E-02	6.383E-04	1.127E-05	1.788E-07	0.000E+00	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.300	3.071E-01	1.481E-02	6.469E-04	2.229E-05	3.576E-07	0.000E+00
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.350	7.094E-01	1.073E-01	9.953E-03	6.609E-04	2.056E-05	1.192E-07
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.400	9.385E-01	3.548E-01	6.393E-02	7.418E-03	4.170E-04	6.378E-06
	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.450	9.932E-01	6.746E-01	2.210E-01	4.214E-02	3.950E-03	1.110E-04
	1.311E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
.500	9.996E-01	8.921E-01	4.802E-01	1.448E-01	2.143E-02	1.031E-03
	2.015E-05	3.576E-07	0.000E+00	0.000E+00	0.000E+00	
.550	1.000E+00	9.763E-01	7.390E-01	3.369E-01	7.619E-02	5.916E-03
	1.885E-04	5.603E-06	1.192E-07	0.000E+00	0.000E+00	
.600	1.000E+00	9.964E-01	9.033E-01	5.767E-01	1.938E-01	2.339E-02
	1.158E-03	4.959E-05	1.550E-06	0.000E+00	0.000E+00	
.650	1.000E+00	9.996E-01	9.732E-01	7.839E-01	3.757E-01	6.866E-02
	5.086E-03	3.044E-04	1.287E-05	1.788E-07	0.000E+00	
.700	1.000E+00	1.000E+00	9.943E-01	9.122E-01	5.841E-01	1.578E-01
	1.702E-02	1.384E-03	7.772E-05	1.609E-06	0.000E+00	

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-10P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	1.000E+00 4.551E-02	1.000E+00 4.916E-03	9.990E-01 3.588E-04	9.713E-01 9.954E-06	7.655E-01 0.000E+00	2.958E-01
.800	1.000E+00 1.009E-01	1.000E+00 1.423E-02	9.999E-01 1.326E-03	9.923E-01 4.828E-05	8.885E-01 1.192E-07	4.667E-01
.850	1.000E+00 1.904E-01	1.000E+00 3.466E-02	1.000E+00 4.062E-03	9.983E-01 1.911E-04	9.550E-01 6.557E-07	6.393E-01
.900	1.000E+00 3.130E-01	1.000E+00 7.282E-02	1.000E+00 1.061E-02	9.997E-01 6.343E-04	9.844E-01 3.159E-06	7.835E-01
.950	1.000E+00 4.570E-01	1.000E+00 1.346E-01	1.000E+00 2.414E-02	9.999E-01 1.812E-03	9.953E-01 1.276E-05	8.848E-01
1.000	1.000E+00 6.033E-01	1.000E+00 2.224E-01	1.000E+00 4.879E-02	1.000E+00 4.547E-03	9.987E-01 4.399E-05	9.454E-01
1.050	1.000E+00 7.333E-01	1.000E+00 3.330E-01	1.000E+00 8.883E-02	1.000E+00 1.019E-02	9.997E-01 1.326E-04	9.768E-01
1.100	1.000E+00 8.352E-01	1.000E+00 4.576E-01	1.000E+00 1.475E-01	1.000E+00 2.067E-02	9.999E-01 3.569E-04	9.911E-01
1.150	1.000E+00 9.062E-01	1.000E+00 5.838E-01	1.000E+00 2.255E-01	1.000E+00 3.841E-02	1.000E+00 8.680E-04	9.969E-01
1.200	1.000E+00 9.508E-01	1.000E+00 6.995E-01	1.000E+00 3.204E-01	1.000E+00 6.601E-02	1.000E+00 1.930E-03	9.990E-01
1.250	1.000E+00 9.760E-01	1.000E+00 7.961E-01	1.000E+00 4.267E-01	1.000E+00 1.058E-01	1.000E+00 3.962E-03	9.997E-01
1.300	1.000E+00 9.891E-01	1.000E+00 8.699E-01	1.000E+00 5.364E-01	1.000E+00 1.591E-01	1.000E+00 7.575E-03	9.999E-01
1.350	1.000E+00 9.954E-01	1.000E+00 9.219E-01	1.000E+00 6.415E-01	1.000E+00 2.261E-01	1.000E+00 1.358E-02	1.000E+00
1.400	1.000E+00 9.982E-01	1.000E+00 9.557E-01	1.000E+00 7.352E-01	1.000E+00 3.049E-01	1.000E+00 2.300E-02	1.000E+00
1.450	1.000E+00 9.993E-01	1.000E+00 9.762E-01	1.000E+00 8.132E-01	1.000E+00 3.925E-01	1.000E+00 3.695E-02	1.000E+00

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-10P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
	1.500	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
	9.997E-01	9.879E-01	8.741E-01	4.843E-01	5.661E-02	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-11P. PLANT LEVEL FRAGILITY

MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Acceleration (g)	Conditional Frequency of Occurrence*					
.050	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.100	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.150	3.338E-06 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.200	1.667E-03 0.000E+00	4.172E-06 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.250	4.916E-02 0.000E+00	6.303E-04 0.000E+00	1.115E-05 0.000E+00	1.788E-07 0.000E+00	0.000E+00 0.000E+00	0.000E+00
.300	2.941E-01 0.000E+00	1.434E-02 0.000E+00	6.273E-04 0.000E+00	2.152E-05 0.000E+00	3.576E-07 0.000E+00	0.000E+00
.350	6.738E-01 0.000E+00	1.008E-01 0.000E+00	9.393E-03 0.000E+00	6.211E-04 0.000E+00	1.895E-05 0.000E+00	1.192E-07
.400	9.105E-01 0.000E+00	3.250E-01 0.000E+00	5.832E-02 0.000E+00	6.746E-03 0.000E+00	3.720E-04 0.000E+00	5.305E-06
.450	9.843E-01 8.941E-07	6.185E-01 0.000E+00	1.957E-01 0.000E+00	3.695E-02 0.000E+00	3.398E-03 0.000E+00	8.947E-05
.500	9.981E-01 1.335E-05	8.411E-01 1.788E-07	4.217E-01 0.000E+00	1.231E-01 0.000E+00	1.778E-02 0.000E+00	8.020E-04
.550	9.998E-01 1.222E-04	9.499E-01 2.742E-06	6.618E-01 5.960E-08	2.826E-01 0.000E+00	6.127E-02 0.000E+00	4.458E-03
.600	1.000E+00 7.371E-04	9.876E-01 2.438E-05	8.397E-01 4.768E-07	4.896E-01 0.000E+00	1.531E-01 0.000E+00	1.714E-02
.650	1.000E+00 3.188E-03	9.975E-01 1.507E-04	9.374E-01 4.172E-06	6.886E-01 0.000E+00	2.974E-01 0.000E+00	4.933E-02
.700	1.000E+00 1.055E-02	9.996E-01 6.904E-04	9.794E-01 2.635E-05	8.369E-01 2.384E-07	4.736E-01 0.000E+00	1.126E-01

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-11P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
.750	1.000E+00 2.809E-02	9.999E-01 2.476E-03	9.941E-01 1.269E-04	9.259E-01 1.669E-06	6.470E-01 0.000E+00	2.129E-01
.800	1.000E+00 6.251E-02	1.000E+00 7.249E-03	9.985E-01 4.881E-04	9.703E-01 9.060E-06	7.881E-01 0.000E+00	3.450E-01
.850	1.000E+00 1.198E-01	1.000E+00 1.791E-02	9.997E-01 1.553E-03	9.894E-01 3.928E-05	8.856E-01 0.000E+00	4.928E-01
.900	1.000E+00 2.023E-01	1.000E+00 3.835E-02	9.999E-01 4.207E-03	9.965E-01 1.417E-04	9.440E-01 1.192E-07	6.359E-01
.950	1.000E+00 3.073E-01	1.000E+00 7.273E-02	1.000E+00 9.931E-03	9.990E-01 4.375E-04	9.749E-01 6.557E-07	7.577E-01
1.000	1.000E+00 4.264E-01	1.000E+00 1.243E-01	1.000E+00 2.083E-02	9.997E-01 1.180E-03	9.896E-01 2.682E-06	8.502E-01
1.050	1.000E+00 5.485E-01	1.000E+00 1.941E-01	1.000E+00 3.946E-02	9.999E-01 2.830E-03	9.960E-01 9.298E-06	9.136E-01
1.100	1.000E+00 6.625E-01	1.000E+00 2.804E-01	1.000E+00 6.839E-02	1.000E+00 6.124E-03	9.985E-01 2.885E-05	9.533E-01
1.150	1.000E+00 7.603E-01	1.000E+00 3.787E-01	1.000E+00 1.097E-01	1.000E+00 1.211E-02	9.995E-01 8.011E-05	9.762E-01
1.200	1.000E+00 8.381E-01	1.000E+00 4.823E-01	1.000E+00 1.643E-01	1.000E+00 2.211E-02	9.998E-01 2.020E-04	9.885E-01
1.250	1.000E+00 8.957E-01	1.000E+00 5.843E-01	1.000E+00 2.317E-01	1.000E+00 3.762E-02	9.999E-01 4.669E-04	9.947E-01
1.300	1.000E+00 9.357E-01	1.000E+00 6.784E-01	1.000E+00 3.099E-01	1.000E+00 6.013E-02	1.000E+00 9.984E-04	9.977E-01
1.350	1.000E+00 9.620E-01	1.000E+00 7.602E-01	1.000E+00 3.954E-01	1.000E+00 9.089E-02	1.000E+00 1.990E-03	9.990E-01
1.400	1.000E+00 9.784E-01	1.000E+00 8.275E-01	1.000E+00 4.840E-01	1.000E+00 1.307E-01	1.000E+00 3.725E-03	9.996E-01
1.450	1.000E+00 9.882E-01	1.000E+00 8.801E-01	1.000E+00 5.713E-01	1.000E+00 1.797E-01	1.000E+00 6.585E-03	9.998E-01

* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-11P (CONTINUED)

Acceleration (g)	Conditional Frequency of Occurrence*					
1.500	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	9.999E-01
	9.937E-01	9.194E-01	8.533E-01	2.373E-01	1.105E-02	

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* Eleven conditional frequencies are given with respective probabilities (weights) of 0.025, 0.05, 0.075, 0.1, 0.15, 0.2, 0.15, 0.1, 0.075, 0.05 and 0.025

TABLE 4-12P

COMPARISON OF PLANT LEVEL FRAGILITIES WITH AND WITHOUT THE BUILDING
(INDEPENDENT RANDOMNESS AND UNCERTAINTY)

	Heat exchanger (with laminated shims) and Main Tank		Heat exchanger (with solid shims) and Main Tank		Main Tank		Bldg. Only
	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	
Median Capacity (g)	0.59	0.65	0.67	0.78	0.75	1.04	0.89
HCLPF (g)	0.27	0.28	0.29	0.33	0.29	0.36	0.34

TABLE 5-6P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - HEAT EXCHANGERS (WITH LAMINATED SHIMS)
MAIN TANK AND BUILDING,
INDEPENDENT RAMDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.76 E - 05
Median Frequency of Failure	0.125 E - 05
90% Confidence Bound	0.19 E - 04
95% Confidence Bound	0.41 E - 04
10% Confidence Bound	0.49 E - 07

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TABLE 5-7P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - HEAT EXCHANGERS (WITH SOLID SHIMS)
MAIN TANK AND BUILDING,
INDEPENDENT RAMDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.47 E - 05
Median Frequency of Failure	0.64 E - 06
90% Confidence Bound	0.11 E - 04
95% Confidence Bound	0.28 E - 04
10% Confidence Bound	< E - 08

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TABLE 5-8P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND UNCERTAINTY

Mean Frequency of Failure	0.39 E - 05
Median Frequency of Failure	0.23 E - 06
90% Confidence Bound	0.80 E - 05
95% Confidence Bound	0.23 E - 04
10% Confidence Bound	< E - 08

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TABLE 5-9P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY EARTH-
QUAKES

- HEAT EXCHANGERS (WITH LAMINATED SHIMS)

MAIN TANK AND BUILDING

INDEPENDENT RAMDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.56 E - 05
Median Frequency of Failure	0.48 E - 06
90% Confidence Bound	0.13 E - 04
95% Confidence Bound	0.30 E - 04
10% Confidence Bound	< E - 08

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TABLE 5-10P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - HEAT EXCHANGERS (WITH SOLID SHIMS)
MAIN TANK AND BUILDING
INDEPENDENT RANDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.34 E - 05
Median Frequency of Failure	0.12 E - 06
90% Confidence Bound	0.76 E - 05
95% Confidence Bound	0.17 E - 04
10% Confidence Bound	< E - 08

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TABLE 5-11P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - MAIN TANK AND BUILDING
INDEPENDENT RAMDOMNESS AND DEPENDENT UNCERTAINTY

Mean Frequency of Failure	0.31 E - 05
Median Frequency of Failure	0.65 E - 07
90% Confidence Bound	0.72 E - 05
95% Confidence Bound	0.16 E - 04
10% Confidence Bound	< E - 08

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TABLE 5-12P

RISK OF MAIN COOLANT PIPE FAILURE INDIRECTLY-INDUCED BY
EARTHQUAKES - BUILDING ONLY -

Mean Frequency of Failure	0.25 E - 05
Median Frequency of Failure	0.57 E - 07
90% Confidence Bound	0.56 E - 05
95% Confidence Bound	0.13 E - 04
10% Confidence Bound	< E - 08

1

TABLE 5-13P

'P' REACTOR SEISMIC RISK OF RCL PIPE FAILURE
(INDEPENDENT RANDOMNESS AND UNCERTAINTY)

	Heat exchanger (with laminated shims) and Main Tank		Heat exchanger (with solid shims) and Main Tank		Main Tank		Bldg. Only
	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	W/Bldg.	W/O Bldg.	
Mean Frequency of Failure	7.6×10^{-6}	5.9×10^{-6}	4.7×10^{-6}	2.8×10^{-6}	3.9×10^{-6}	1.8×10^{-6}	2.5×10^{-6}
Median Frequency of Failure	1.25×10^{-6}	6.2×10^{-7}	6.4×10^{-7}	2.0×10^{-7}	2.3×10^{-7}	2.0×10^{-8}	5.7×10^{-8}
95% Upper Confidence Bound*	4.1×10^{-5}	3.3×10^{-5}	2.8×10^{-5}	1.6×10^{-5}	2.3×10^{-5}	8.5×10^{-6}	1.3×10^{-5}

* 5% lower confidence bounds are all less than 10^{-8}

FIGURE 5-2P.

PERCENT CONTRIBUTION OF DIFFERENT ACCELERATION RANGES - HEAT EXCHANGER (W/LAMINATED SHIMS), MAIN TANK, AND BUILDING - INDEPENDENT RANDOMNESS AND UNCERTAINTY

TABLE 6-1

**COMPARISON OF BUILDING FRAGILITY, PLANT FRAGILITY
AND SEISMIC RISK BETWEEN THE SRP L AND P REACTORS
(Independent Randomness and Uncertainty)**

	L-Reactor	P-Reactor
Building Fragility		
Median Capacity (g)	1.42	0.89
HCLPF (g)	0.55	0.34
Plant Fragility (Building, Main Tank, Heat Exchangers with Laminated Shims)		
Median Capacity (g)	0.64	0.59
HCLPF (g)	0.28	0.27
Seismic Risk (Building, Main Tank, Heat Exchangers with Laminated Shims)		
Mean Frequency of Failure	6.0×10^{-6}	7.6×10^{-6}
Median Frequency of Failure	7.8×10^{-7}	1.25×10^{-6}
95% Upper Confidence Bound	3.3×10^{-5}	4.1×10^{-5}

END

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