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Handbook of Nuclear Power Plant Seismic Fragilities

Seismic Safety Margins Research Program

L. E. Cover, M. P. Bohn, R. D. Campbell, and D. A. Wesley

Prepared for
U.S. Nuclear Regulatory Commission

Lawrence
Livermore
National
Laboratory

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ABSTRACT

The Seismic Safety Margins Research Program (SSMRP) is an NRC-funded, multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete and fully-coupled analysis procedure, including methods and computer codes, for estimating the risk of earthquake-induced radioactive release from a commercial nuclear power plant. As part of this program, calculations of the seismic risk from a typical commercial nuclear reactor were made. These calculations required a knowledge of the probability of failure (fragility) of safety-related components in the reactor system that actively participate in the hypothesized accident scenarios. This report describes the development of the required fragility relations and the data sources and data reduction techniques upon which they are based. Both building and component fragilities are covered. The building fragilities are for the Zion Unit 1 reactor, the specific plant used for development of methodology in the program. Some of the component fragilities are site-specific, but most would be usable for other sites as well.

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FOREWORD

The Seismic Safety Margins Research Program (SSMRP) is an NRC-funded, multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete and fully-coupled analysis procedure, including methods and computer codes, for estimating the risk of earthquake-caused radioactive release from a commercial nuclear power plant. The analysis procedure is based upon a state-of-the-art evaluation of the current seismic analysis and design process and explicitly includes the uncertainties inherent in such a process. The results will be used to improve seismic licensing requirements for nuclear power plants.

The SSMRP was begun in 1978 when it became evident that an accurate seismic risk analysis must simultaneously consider all interrelated factors that affect the final probability of radioactive release. In the traditional design procedure, by contrast, each factor is usually analyzed separately. These closely coupled factors are:

- The likelihood and magnitude of an earthquake.
- The transfer of earthquake energy from a fault source to a power plant, a phenomenon that varies greatly with the magnitude of an earthquake.
- Interaction between the soil underlying the power plant and the structural response, a phenomenon that depends on the soil composition under the plant and the location of the fault source relative to the plant.
- Coupled responses of a power plant's buildings and the massive reactor vessels, piping systems, and emergency safety systems within.
- Numerous accident scenarios, which vary according to types of failures assumed and the success or failure of the engineered safety features intended to mitigate the consequences of an accident.

A nuclear power plant is designed to ensure the survival of all buildings and emergency safety systems in a worst-case ("safe shutdown") earthquake. The assumptions underlying this design process are deterministic. In practice, however, these assumptions are clouded by considerable uncertainty. It is not possible, for example, to accurately predict the worst earthquake that will occur at a given site. Soil properties, mechanical properties of buildings, and damping in building and internal structures also vary significantly among plants.

To model and analyze the coupled phenomena that contribute to the total risk of radioactive release, it is therefore necessary to consider all significant sources of uncertainty as well as all significant interactions. Total risk is then obtained by considering the entire spectrum of possible earthquakes and integrating their calculated consequences. In the SSMRP this approach to risk analysis is embodied in the seismic methodology chain, which comprise five steps: determining seismic input characteristics for a site, calculating the effects of soil-structure interaction, calculating major structure response, calculating subsystem response, and calculating probability of failure.

The seismic input consists of the earthquake hazard in the vicinity of a nuclear power station, defined by an estimate of the seismic hazard function (i.e., the relationship between the probability of occurrence and a measure of

the size of an earthquake) and a description of the free-field motion. The soil-structure interaction link in the chain transforms the free-field ground motion into basemat or in-structure response, accounting for the interaction of the soil with the massive, stiff structures present at a nuclear power plant. Determination of the major structure response follows the soil-structure interaction step, where "major structure" commonly denotes a building, but may also include very large components. The final step in the traditional seismic analysis and design process is predicting subsystem structural response. An additional step in the SSMRP is the prediction of failure and subsequent risk of radioactive release.

The goals of the SSMRP were to be achieved in two phases. In Phase I, the overall seismic risk assessment methodology was developed and assembled. The methodology is embodied in three computer codes: HAZARD, SMACS and SEISIM. In addition, extensive data bases on earthquake occurrence models and failure data for nuclear power components were assembled. A pressurized water reactor was selected for demonstration calculations, and fault trees were developed for its essential safety and auxiliary systems. The plant chosen was the Zion nuclear power plant, located on Lake Michigan just east of the town of Zion, Illinois, and about 40 miles north of Chicago. This plant was chosen on the basis of being reasonably typical (in terms of power, systems design, and site conditions) of pressurized water reactors designed and constructed during the 1960s.

The limited-demonstration calculations (and Phase I) were completed in February 1981. The goals of Phase II of the SSMRP were to complete the seismic risk methodology development and perform a complete seismic risk assessment of the Zion plant. This risk assessment was not limited to computing the frequency of core melt and radioactive release; it also included an uncertainty analysis on the entire risk assessment process so that confidence bounds on the core melt frequencies could be determined. This report addresses the fragilities development done by the SSMRP and includes the final results of the efforts of both phases of the Program.

This work reflects one of the first major attempts to quantify fragility. The sources of data and the methods used are the best sources available at the time this work was done. In many instances, where data were inadequate or absent, decisions were made to construct fragility curves based upon the best professional judgment of LLNL and its contractors. Progress and change have occurred very quickly in this very important area. Current practices and methods, especially in the area of building fragilities, may have changed as investigators refine their techniques and knowledge. However, the work presented here represents a significant step forward in the quantification of component and building fragilities for nuclear reactors.

The NRC technical monitors have been J. J. Burns, followed by C. W. Burger, and presently D. J. Guzy. The authors wish to acknowledge the contributions of the members of the Fragility Panel, S. H. Bush, R. P. Kennedy, E. C. Rodabaugh, G. D. Shipway, J. D. Stevenson, J. M. Thomas, and P. P. Zemanick who have reviewed and monitored the Fragilities Development Project since its early stages. The contributions of data and helpful recommendations given by the many persons who participated in the expert opinion survey are also acknowledged.

GLOSSARY OF TERMS

A_F	Acceleration at failure.
A_D	Design peak acceleration.
$\check{A}$	Median value of the random variable A.
$\hat{A}$	An estimate of the random variable A.
$\hat{\hat{A}}$	A second estimate of the random variable A.
F_c	Capacity factor (the product of F_s F_μ).
F_s	Factor relating the actual strength capability to the design load.
F_μ	Factor accounting for inelastic energy absorption capability of the structure or structural element.
F_R	Factor accounting for conservatism in the method of analysis used to obtain the reference value of the fragility parameter.
V	Shear load in building walls. It is used as a fragility parameter for buildings with shear walls.
v	Shear stress in building walls. It is used as a fragility parameter for buildings with shear walls.
V_F	Shear load in building walls at failure. It is used as a fragility parameter for shear wall failure.
V_{ult}	Ultimate shear load.
v_{ult}	Ultimate shear stress.
$V_{seismic}$	Seismic shear load.
V_{normal}	Normal shear load assumed to act simultaneoulsy with siesmic shear loads. This is sometimes referred to as dead load.
σ_{normal}	Normal stress. This is the stress or load due to normal operating loads or "dead" loads.
$\sigma_{seismic}$	Peak stress induced by seismic excitation.
σ_{lim}	Limiting stress at failure. It could be yield, ultimate, or code allowable depending upon the component or structure and the mode of failure.
M_A	Median of acceleration at failure.
M_S	Median value of F_S.
M_μ	Median value of F_μ.
m	Median of a lognormal random variable.

β	Standard deviation of the logarithm of a normal random variable.
β^2	Variance of the logarithm of a normal random variable.
β^T	Standard deviation of the logarithm of the variable representing total uncertainty.
$(\beta^T)^2$	Variance of the logarithm of the random uncertainty.
β^R	Standard deviation of the logarithm of the random uncertainty.
$(\beta^R)^2$	Variance of the logarithm of the total uncertainty.
β^U	Standard deviation of the logarithm of the modeling uncertainty.
$(\beta^U)^2$	Variance of the logarithm of the modeling uncertainty.
β^{TEO}	Standard deviation of the logarithm of the total variability from expert opinion or a combination of expert opinion and Type A data.
β^{TS}	Standard deviation of the logarithm of the total variability from Type A data.
β^{RS}	Standard deviation of the logarithm of the variability due to randomness only of Type A data.
β^{US}	Standard deviation of the logarithm of the variability due to uncertainty only of Type A data.
β_A	Standard deviation of the logarithm of the acceleration at failure.
ϵ	Lognormal random variable with unit median and a standard deviation of β.
ϵ_U	Lognormally distributed variable with unit median variance of $(\beta^U)^2$ representing modeling uncertainty.
ϵ_R	Lognormally distributed variable with unit median variance of $(B^R)^2$, representing random uncertainty.
β_F^2	Variance of the lognormally distributed variable representing fragility.
β_S^2	Variance of the lognormally distributed variable, F_S.
β_μ^2	Variance of the lognormally distributed variable, F_μ.
β_R^2	Variance of the lognormally distributed variable, F_R.
β_C^2	Variance of the lognormally distributed variable, F_C.

$(\beta_{\mu}^{R})^2$	Variance of the lognormally distributed variable, F_{μ}, representing only random uncertainty of F_{μ}.
$(\beta_{S}^{R})^2$	Variance of the lognormally distributed variable, F_S, representing only random uncertainty of F_S.
$(\beta_{\mu}^{U})^2$	Variance of the lognormally distributed variable, F_{μ}, representing only modeling uncertainty of F_{μ}.
$(\beta_{S}^{U})^2$	Variance of the lognormally distributed variable, F_S, representing only modeling uncertainty of F_S.
f_c'	Compressive strength of concrete.
f_y	Yield strength of steel.
V_{cu}	Shear load taken by concrete in a shear wall.
V_{su}	Shear load taken by reinforcing steel in a concrete shear all.
P_C	Median collapse load or stress used as the limit load.
P_N	Normal operating load or stress.
P_T	Total normal plus seismic load or stress.
P_D	Code allowable design load or stress.
σ_E	Standard deviation of a normally distributed random variable.
H_V	Variable computed to determine the 97.7% probability of survival of components tested under the safeguards program. A value greater than unity indicates survival.

HANDBOOK OF NUCLEAR POWER PLANT SEISMIC FRAGILITIES DEVELOPED FOR THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM

EXECUTIVE SUMMARY

This report summarizes the fragility curves and methodology developed under the Seismic Safety Margins Research Program (SSMRP). This methodology was used to evaluate the seismic risk at the Zion nuclear power plant. Key to the evaluation of seismic risk is the concept and use of component and building fragility. Fragility is represented by a cumulative probability density function that is referenced to a key parameter such as spectral acceleration level, displacement, or other significant factor that is related to failure.

We used test data from the SAFEGUARD Program, design reports, an expert panel, and an expert-opinion survey to construct lognormally distributed fragility curves for 37 major categories of components. One was piping fragility, which was constructed from a "master" piping fragility curve for 6-in. pipe and then scaled for pipes of different sizes. Fragility curves for electrical components, while also lognormally distributed, are significantly different in shape and reflect a higher probability of failure for a given acceleration than do mechanical components.

Although developed for the SSMRP study of the Zion plant, the components in the 37 categories could be used for similar studies at other plants. Appendix A contains enough information about Zion safety-related equipment that it can be compared to equipment at other plants to evaluate their similarity.

Fragility curves were also developed for the buildings at the Zion plant. All were derived by identifying failure modes and then calculating the median capacity and fitting lognormal curves to account for variability. Variability for both buildings and mechanical components were attributed to both modeling uncertainty and the inherent randomness of failure for actual structures and components. Determination of building fragilities required a great deal of judgment and are of necessity plant specific.

Chapter 3 describes the reasoning used to determine failure modes and building fragility curves. This process is required for every plant where construction and layout are unique. Building fragility was referenced to key acceleration values that were determined by comprehensive finite element analyses of the buildings. The only exception is the crib house, for which design calculations were used to determine its fragility.

Chapter 4 summarizes the details of the calculational procedure used to determine mechanical component fragilities. A nested analysis of variance technique was used to combine data from different sources. Experimental data were assigned the highest weight because they were assumed to be the most accurate. Data from expert-opinion surveys or from vendors were assigned a variety of weights depending on the source and reliability of the data. A summary of the specific information about the values and sources of component fragilities is summarized in Appendix F.

Stand-alone appendices have been included for completeness and added detail. Each has been included for a specific reason.

Appendix A describes all the safety-related equipment at Zion. Enough information is included for the reader to judge whether equipment at other plants is the same or similar.

Appendix B summarizes the reports from the SAFEGUARD Program used to construct fragility curves. Also listed next to each report are the corresponding component categories.

Appendix C summarizes the results of our expert-opinion survey for all the component categories.

Appendix D gives updated information on SSMRP fragilities.

Appendix E reproduces a previous report (UCRL-53038). It is a description of the data base used to organize and keep track of all the fragility data collected for this study. It is a relational data base that was essential for data organization, storage, and retrieval. As an example of the power of using such a data base, the last section of Appendix E shows a summary of the component fragility for all the component categories. This table was constructed directly from the data base.

Finally, Appendix F summarizes the component fragilities in a different form. It includes details about the source of the data used to construct the fragility curves, and it also references the information to its location in the relational data base explained in Appendix E.

HANDBOOK OF NUCLEAR POWER PLANT SEISMIC FRAGILITIES DEVELOPED FOR THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM

SECTION 1: INTRODUCTION

The Seismic Safety Margins Research Program (SSMRP) is an NRC-funded, multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete and fully-coupled analysis procedure, including methods and computer codes, for estimating the risk of earthquake-induced radioactive release from a commercial nuclear power plant. As part of this program, calculations of the seismic risk from a typical commercial nuclear reactor were made (Ref. 1). These calculations require a knowledge of the probability of failure (fragility) of safety-related components in the reactor system which actively participate in the hypothesized accident scenarios. This report describes the development of the required fragility relations and the data sources and data reduction techniques upon which they are based.

Failure of components is defined as either loss of functional operability or loss of pressure boundary integrity, as appropriate. Structures are considered to fail functionally when inelastic deformations under seismic load are sufficient to interfere with the operability of safety-related equipment attached to the structure. Failure (fragility) is characterized by a cumulative distribution function which describes the probability that failure has occurred, given a value of loading. In the context of the SSMRP, the loading may be spectral acceleration, zero-period acceleration (ZPA), or internal force resultant (such as moment or shear), depending on the component and failure mode under consideration.

This report is organized as follows. Section 2 presents an overview of the fragilities development and includes a summary of component fragilities. Section 3 describes the critical structures and the development of fragility relations for them. Section 4 describes the data sources from which the component fragilities were constructed and the types of data available from each source; it also describes the statistical data reduction techniques used to reduce and combine the data from the various sources and the weighting scheme used to rank the data. Section 5 lists the references cited in the report. Finally, several appendices are included to document the various contributors to the data used in component fragilities development.

The data and techniques presented in this report have relied to a large extent on information given in NUREG/CR-2320 (reference 11) and NUREG/CR-2405 (reference 9). It should be noted that this information has since been updated and corrected as discussed in this report, in UCID-20164, and in Chapter 5 of NUREG/CR-3428.

SECTION 2: OVERVIEW OF THE FRAGILITIES DEVELOPMENT

Fragility relations are required both for the buildings and for the piping and components. Building and major component fragilities are necessarily specific to the plant being analyzed. For the Zion Unit 1 reactor being studied in the SSMRP, fragilities were developed for the reactor containment, turbine, auxiliary, fuel handling, and crib house buildings. Development of these fragilities is described in Sec. 3.

The components for which fragility curves must be developed are determined by the depth of detail in the event and fault tree analyses of the reactor system under consideration. For Zion, 7 event trees and 11 fault trees (Ref. 2) have been devised to cover all hypothesized reactor transients and potential modes of release of radioactivity. Taken together, these event and fault trees require determination of the probability of failure (from seismic loading) of more than 2300 basic events. (A basic event could be failure of a certain valve, for example.)

Since it was clearly not feasible to generate fragility curves for thousands of specific components, the first step in the development of the fragility data base was to group all the components identified on the event and fault trees into categories. For example, all motor-operated valves with piping diameters between 2-1/2 and 8 inches were placed in a single category; similarly, all electrical motor control centers were placed in another category. Then a single fragility curve was derived for each category. A detailed review of the components showed that a set of 37 different categories would suffice to cover all the required fragilities. These categories were selected on the basis of equipment functions governing design criteria, method of seismic qualification, and response characteristics. These criteria and other pertinent information for the components that were reviewed are presented in Appendix A. The 37 categories are shown in Table 1 and are described in Sec. 2.2.

2.1 Data Sources for Components

Actual experimental data on failure of components as a function of local base acceleration are scarce. The type of data most commonly available results from qualification tests in which the component is experimentally shown to function as designed for a prescribed acceleration spectrum input. While such data do provide a lower limit to the fragility level, it is difficult to extrapolate from them to higher response levels. One notable exception to the lack of actual fragility data was the data obtained in the U.S. Army Corps of Engineers SAFEGUARD Program. This 11-year program, conducted as part of a missile-site hardening effort, included tests of both mechanical and electrical components. The items tested were off-the-shelf and were typical of components used in commercial reactors in the late 1960s. Some of the results are thus directly applicable to the Zion power plant.

Sixty-four test programs involving shaker-table tests of approximately 300 items were conducted. Excitation consisted of sine beat pulse tests, selected to fit a prescribed acceleration spectrum. Equipment function was monitored during the test. Thus, these were truly tests of fragility with respect to both functional and structural failure. Typically, components were tested to peak accelerations of more than 15 g. From nearly 300 reports generated in

Table 1. Component items and categories for fragility development.

Site Specific Components

- Reactor core assembly
- Reactor pressure vessel
- Pressurizer
- Steam generator
- Reactor coolant pump

Component Categories

Mechanical

- Large horizontal vessel
- Small to medium vessels and heat exchangers
- Piping
- Large vertical storage vessels with formed heads
- Large vertical flat bottom storage tank
- Miscellaneous small valves
- Large vertical centrifugal pumps with motor drive
- Motor-driven pumps and compressors
- Large motor-operated valves
- Small motor-operated valves
- Large hydraulic- and air-actuated valves
- Large relief, manual, and check valves

Electrical

- Horizontal motors
- Generators
- Battery racks
- Switchgear
- Dry transformers
- Control panels and racks
- Auxiliary relay cabinets
- Local instruments
- Motor control centers
- Communications equipment
- Light fixtures
- Inverters
- Cable trays
- Circuit breakers
- Relays
- Ceramic insulators

Miscellaneous

- Air handling units
- Instrument racks and panels
- Duct work
- Hydraulic snubbers and pipe supports

the SAFEGUARD program, 63 were found to be directly applicable to components needed in the SSMRP. In particular, these data were the only data available for electrical components; thus, all our electrical component fragilities are derived from this source. The reports from the SAFEGUARD Program utilized for fragilities development are listed in Appendix B.

A second source of information was the design analyses performed by Westinghouse and various component manufacturers for components used in the Zion plant. In these analyses, the component was assumed to be excited by a

base acceleration corresponding to a prescribed design spectrum. Then an analytical solution for the stresses or loads in the component was obtained. From these analytical solutions we obtained the acceleration at failure by extrapolating the stresses to our estimate of the ultimate stress capacity using a procedure due to Newmark (Ref. 3). In this procedure, the acceleration at failure, A_F, is determined from the relation:

$$A_F = A_D \cdot F_S \cdot F_\mu \cdot F_R \qquad (1)$$

where

A_D = design peak acceleration

F_S = factor accounting for ultimate load capacity

F_μ = factor accounting for the inelastic energy absorption

F_R = factor accounting for conservatisms in the method of analysis from which the acceleration and stress resultants were obtained.

The factor F_S, accounting for the ultimate load capacity, is computed from:

$$F_S = \frac{\sigma_{lim} - \sigma_{normal}}{\sigma_{seismic}}$$

where σ_{normal} is the static stress due to weight, pressure, thermal, etc.; $\sigma_{seismic}$ is the peak stress induced by the seismic excitation; and σ_{lim} is the effective failure stress, which depends on the equipment and mode of failure. Typically, for ductile failure, σ_{lim} is the code-allowable yield stress, but for more brittle failure it is the ultimate stress or the average of yield and ultimate. Thus, F_S scales the design acceleration to the failure acceleration, assuming all loads (or stresses) are calculated by a linear elastic analysis, since the peak load (or stress) is proportional to peak acceleration.

Before failure occurs, however, a significant amount of inelastic deformation (hence, energy absorption) takes place. In this inelastic response range, the stress increases much more slowly than does the peak acceleration. Hence, the actual acceleration at failure is much higher than that predicted by the product $A_D \cdot F_S$ alone. This additional acceleration capacity is accounted for by the ductility factor, F_μ. This ductility factor was introduced by Newmark (Ref. 4) and is a function of both the ductility of the component and the component damping. The ductility, μ, is usually estimated on the basis of engineering judgment and a knowledge of component construction details.

The statistical distribution of the acceleration at failure (the fragility relation) is obtained by assuming that factors F_S and F_μ are lognormally distributed random variables. This choice of distributional form has been found to be appropriate in several studies (Refs. 5-7); it also results in considerable computational convenience. If M_S and M_μ denote the median values of F_S and F_μ, and if β_S and β_μ denote the standard deviations of the natural logarithms of the variables F_S and F_μ, then the multiplicative property of lognormal random variables gives the median (M_A) and log-standard deviation (β_A)of the acceleration at failure as:

$$M_A = A_D M_S M_\mu \qquad \beta_A = \sqrt{\beta_S^2 + \beta_\mu^2}$$

These two parameters completely define the distribution of acceleration at failure. Values of the uncertainty in the factors F_S and F_μ are estimated from data, analysis, or engineering judgment, depending on the component. While this method of estimating fragility of components is not based directly on failure tests, it does allow an estimate of failure incorporating experimental determination of ultimate strength, weld and connector ductilities, etc. The choice of the uncertainty factors, β_S and β_μ, may be made so as to reflect our confidence (or lack thereof) in the analysis. This measure of confidence can then be propagated through the entire SSMRP calculational scheme, and its effect on the final prediction of radioactive release probability can be determined.

The final source of information on fragility of components was an expert opinion survey performed in the spring of 1980. In this survey, a carefully worded questionnaire was mailed to several hundred acknowledged specialists in the nuclear industry. These individuals were selected from the Nuclear Steam Supply System (NSSS) vendors, architect/engineering firms, consultants to the nuclear industry, and colleges and universities. In each case, the individual was asked to respond only for those components for which he felt a high degree of expertise. For each component, the respondent was asked to provide:

- The three lowest (weakest) failure modes.
- The appropriate response quantity for each mode (e.g., peak acceleration, spectral acceleration at some frequency, damping or force resultant).
- The response values at 10, 50, and 90% probability of failure.
- The primary source of his information (experience, test data, etc.).

The expert-opinion responses covered every category of component needed for Phase I of the SSMRP, with 147 detailed responses being returned. Comparison of responses from different experts for the same component showed, in general, good agreement. Inasmuch as the expert opinion responses were provided for different failure modes and three probability levels, it was necessary to develop a method of statistically combining them into a single fragility relation.

The procedure adopted was based on a combined least-squares analysis and nested analysis of variance approach. The equations used are developed in Appendix B and the approach is described in detail by George (Ref. 8). In this approach, each failure mode (for each component) is treated as independent, and a single fragility curve is developed for each mode based on the responses of all experts who identified that particular failure mode. The statistical model used was

$$A_{ijq} = A_q + T_j + E_{ijq} \tag{2}$$

where i refers to the i^{th} expert, q denotes the fractile level (10, 50, or 90%), and j denotes the group number. Based on our subjective evaluation of the expert opinion responses, we combined different experts' responses into a common group if we had reason to believe that these experts were all referring to the same type of component within the broad category being considered. Thus in Eq. (2), A_{ijq} is the estimate of the fragility for the q^{th} percentile provided by the i^{th} expert in the j^{th} group, T_j is the deviation of the q^{th} percentile (A_q), and E_{ijq} is the variation in the estimate of the q^{th} percentile by the i^{th} expert in the j^{th} group. The use of the

nested analysis of variance procedure then allowed us to identify the total variance, σ^2, from

$$\sigma^2 = \hat{\sigma}^2 + \hat{\sigma}_T^2 + \hat{\sigma}_E^2$$

where

$\hat{\sigma}^2$ = inherent uncertainty in each individual expert's fragility estimate,

$\hat{\sigma}_T^2$ = uncertainty resulting from the different groups of components within the category,

$\hat{\sigma}_E^2$ = uncertainty between experts whose data were combined in the same group.

By this procedure, we can identify whether or not the categories selected (as shown in Table 1) are too broad, for if $\hat{\sigma}_T^2$ is the major contributor to the total variance, then this is an indication that the category should be further subdivided into two or more separate categories.

In the analysis of Eq. (2), a weighted least-squares approach was used in estimating σ^2. The weights were assigned as a product of two factors: a factor for presumed expertise of the specialist providing the opinion and a factor for source of his opinion. In assigning weights, a differentiation between pressure boundary failure and functional failure was made to reflect a lesser degree of confidence in analytical methods for predicting functional failure.

It is at this point that data from the other sources (the SAFEGUARD fragility data and the component design analyses previously described) were incorporated. These additional data were treated as independent expert opinions, with weight factors assigned based on our subjective evaluation of the quality of the data.

The final step in the development of a single fragility curve for a given category was to combine, for each independent failure mode, the fragility estimates obtained from Eq. (2). This combination of modes was performed using the relation

$$F(r) = 1 - \prod^{n} [1 - F_i(r)]$$

where $F(r)$ is the single combined-mode fragility curve and $F_i(r)$ are the fragility curves derived for the n failure modes identified for the category. This is the statistical union of failure modes; in effect, it produces an effective fragility curve which is nearly a lower bound.

2.2 Description of Categories

All components are considered to include their supports to the point of interface with the building structure. Electro- or active-mechanical devices such as motor-operated valves, pneumatic- and hydraulic-operated valves, and motor-, turbine-, and diesel-driven pumps, include the complete assemblies normally furnished by the component suppliers. Thus, valve operators, pumpmotors, and ancillary equipment for cooling and lubrication are included

as part of the component category. External control systems, power supplies, and connecting electrical cables are not included as part of the component and are considered in separate categories. The categories are described below, based on Ref. 9.

Reactor Core Assembly. This category includes the fuel rods, core support structure, and control rod assemblies, and spacer grids. Crushing of grid spacers or deformation of control rod assemblies might prevent re-insertion of control rods following scram.

Reactor Coolant System Vessels. These categories include the reactor pressure vessel, steam generators, and the pressurizer. The vessels are of heavy wall construction to contain the high pressure in the primary system. A failure of one of the nozzle-to-pipe weld joints could occur in the presence of a large flaw in the weld joint and result in a loss-of-coolant accident (LOCA). Another failure mode during an extreme seismic event would be failure of the vessel supports. Steam generator support failure could be especially significant because gross failure of the steam generator supports could cause a LOCA in both the primary and secondary system.

Note that steam generator tube failure is not considered a failure mode since no external loss of coolant results and only partial loss of function could result.

Reactor Coolant Pumps. Pumps are rugged and have performed well in nonnuclear applications in major earthquakes. The main coolant pumps have ancillary equipment for lubricating and cooling bearings and seals. Due to its complexity, failure of ancillary equipment is a likely failure mode. Failure of pump supports is the most important failure mode since it leads to loss of pressure boundary integrity.

Piping. This category includes piping of all sizes, as well as elbows, tees, butt welds, reducer sections, etc. Both stainless steel and carbon steel are considered. A single master fragility curve was developed for this category, and scale factors (dependent on size, material, and temperature) are used to relate the different pipe elements to the master fragility curve.

Large Vertical Storage Vessels with Formed Heads. This category includes the accumulator tanks and the volume control tanks. These vessels are typically low pressure, with thin wall construction supported by skirts. They may have nonintegrally reinforced nozzles or nonreinforced fabricated nozzles. Temperatures are usually quite low and loading on the tank supports and nozzles is predominantly from seismic events. Fluid sloshing and fluid-structure interaction, including the effects of the thin wall flexibility, are very important in determining the dynamic response. Critical failure modes are usually tank support failure caused by either buckling or anchor bolt failure. Such failure could result in sufficient tank movement to fail the pressure boundary at tank nozzles or at the support to tank interface.

Large Vertical Flat Bottom Storage Tanks. These large flat-bottomed storage tanks are used for holding unpressurized fluids, and include the borated water storage tanks and the condensate storage tanks. They are typically anchored to the foundation. Fluid sloshing effects are of prime importance in this category also. The most predominant failure mode in such tanks is failure of the anchor bolts, allowing uplift of the tank. The uplift would then result

in buckling of the tank wall on the compression side and possible rupture of the wall-to-bottom joint on the tensile side.

Large Horizontal Vessels and Heat Exchangers. This category includes large storage tanks, heat exchangers such as the residual heat exchangers, component cooling water heat exchangers, the pressurizer relief tank, and often diesel oil storage tanks. The designs are characterized by large volume, relatively low pressure, thin wall cylindrical tanks mounted with the cylinder axis in the horizontal position. These tanks are usually supported by two saddles mounted to the floor. The relationship between asymmetric loading from dead weight and seismic acceleration results in a different dynamic response and a different design problem than for large, thin wall, vertical tanks. The effect of fluid sloshing is quite different for horizontal tanks than for vertical tanks.

These vessels are similar in construction to vertical vessels except for the tank support design. The failure modes are the same as for vertical tanks with formed heads. However, the mechanism of a support failure can be quite different. The critical stresses due to a seismic event are usually at the support-to-tank interface. The failure mode depends much on the details of the interface and could be cracking of the tank wall from excessive local deformation, or it could be failure at a nozzle which is induced by tank movement caused by support bolt failure.

Small to Medium Vessel and Heat Exchangers. There are numerous small- and medium-sized vessels and heat exhangers in the reactor system, for example, the boron injection tank. They are typically cylindrical in shape, although spherical vessels are occasionally used. Cylindrical vessels may be mounted horizontally or vertically. Supports are typically legs or saddles welded directly to the pressure boundary and bolted to the floor of a building. The least ductile, and hence, most likely points for failure are in the supports at either the support/tank interface or support/building interface. The next most likely failure point is at a nonintegral reinforced or nonreinforced nozzle followed by the butt weld joint at a nozzle to the connecting piping.

Large Vertical Centrifugal Pumps with Motor Drives. These types of pumps are found in the crib house and are used as service water pumps and fire pumps, and in some plants, are used as the condenser coolant pumps located in the intake structure. They typically are supported at a flange at the motor-pump interface and have lengths several times the pump diameter such that they respond to seismic excitation as a flexible cantilever beam. Rupture of support strut connections is a likely failure mode, and since they are quite flexible, vibration-induced distortion could ultimately result in bearing failure and seizure.

Motor-Driven Pumps and Compressors. These medium to small pumps and compressors include the auxiliary feedwater system pumps, residual heat removal pumps, safety injection pumps, centrifugal charging pumps, containment spray and recirculation pumps, and lube oil pumps for the diesels. These pumps are generally mounted separately from their drive motors and the pump and drive motors are skid mounted or mounted directly to the floor. Drive motors are generally in line with the pump shaft. The size of these pumps is generally much less than the large vertical pumps described above.

These pump-motor combinations are usually horizontal, floor mounted, compact,

and quite rigid assemblies. Consequently, vibration-induced distortion is not expected to be a principal failure mode. The likely failure mode would be support failure due to a combination of inertia loading and pipe reaction loading. Support failure or partial failure could then cause misalignment between the pump and motor drive. A less likely failure mode would be a structural failure of a pump nozzle/pipe interface.

Large Motor-Operated Valves. These remotely actuated valves are used on all the plant piping systems for isolation and flow control, and they appear on the fault trees for all safety systems. They are characterized by a rugged body with an extended yoke structure that supports a motor-gearbox operator assembly. The valves are line mounted and can undergo significant seismic acceleration and displacement such that the motor operator and its connecting electrical leads experience quite high seismic excitation. The principal mode of failure would be binding due to permanent deformation of the yoke-neck-stem assemblies, resulting in full or partial failure to actuate. The next most likely failure mode would be an electrical failure of the operator assembly. A third and much less likely failure mode would be fracture of the pipe-to-valve nozzle joint.

Large Relief and Check Valves. These types of valves are compact, rugged assemblies that should not be as susceptible to seismic loading as the extended motor-operated valves. Binding of check or relief valve mechanical parts could occur during a severe seismic event; however, because of the compactness of the designs, the mechanical parts are relatively immune to seismic damage. Another possible failure mode would be an electrical failure of the power actuator if it is present. Degradation of insulation coupled with severe seismic excitation could cause a breakdown in electrical continuity. Pipe-to-valve nozzle joint fracture is a lower probability failure mode and would only occur in the presence of large undetected flaws.

Large Hydraulic- and Air-Actuated Valves. This category includes the main steam-isolation valves and the power-operated relief valve on the pressurizer, both of which play prominent roles on the event/fault trees. These large valves do not have the massive extended operators found in the large motor-operated valves, and are thus less susceptible to seismic damage. Modes of failure include failure of electrical signal, binding of stem or actuator, or failure of air or hydraulic lines.

Small Motor-Operated Valves. These are similar to large motor-operated valves but are for piping of less than 4-in. diam. They have a rugged body with an extended yoke structure that supports a motor-gearbox operator assembly. Because they are line mounted, they are subjected to piping accelerations. The principal mode of failure would be binding due to permanent deformation of the yoke-neck-stem assembly. Electrical failure of the operator is also a possibility.

Miscellaneous Small Valves. This small valve category includes all types of small valves (manual, air, or hydraulic) except small motor-operated valves. Although some testing laboratories do have the capability to test complete large valve assemblies, it is common to test complete assemblies only for the smaller valves and to test only the electrical operators on the larger valves. The valve itself is then qualified for seismic service by analysis.

Since these valves are compact and rugged, the potential failure modes are

failure of the actuators or failure of the air/hydraulic lines.

Horizontal Motors. This category includes the large-capacity electric-drive motors used for cooling fans and equipment drives and motor-generator sets. They are characterized as rigid, compact, rotating electrical machinery. The most likely failure mode during a severe seismic event would be distortion in the motor casing or shaft to the extent that resulting vibration from misalignment would ultimately damage the bearings or windings. A secondary failure mode is considered to be the motor supports at the motor/structure interface. Support damage or failure would result in misalignment with the driven component and severe vibration and bearing damage. A third mode of failure would be bearing failure and immediate seizure. Immediate bearing seizure is a much less probable event, though, than slower bearing deterioration caused by distortion and misalignment.

Generators. These are the large diesel-powered generators used to provide emergency ac power (4160 V) following loss of off-site power. As such, they play a prominent role in the event and fault trees for the electrical power system.

Diesel generator units are complex systems having many potential failure modes. The diesel engines and alternators are of rugged construction and are not considered to be very susceptible to seismic damage. The most probable failure mode in the event of a severe earthquake would be failure of some of the ancillary equipment necessary for the diesel generator to operate. Items such as air supply, fuel and oil lines, filter brackets, local controls, and instrumentation would be the predominant candidates for failure.

Batteries and Battery Racks. These batteries provide emergency dc power and are kept charged by a static charger system. The batteries themselves are mounted on large metal racks. The batteries and chargers are compact units that in themselves are quite rugged. Batteries have proven very reliable when subjected to severe shock loading. The most likely initial failure point would be the battens or the rack-to-building interface. The resulting uplift or shifting could sever the electrical connections.

Switchgear. Switchgear are complex electrical systems consisting of active and passive electrical devices housed in a structural assembly. Included are transformers, relays, breakers, capacitors, and buses. Most of the components are compact rigid elements with most of the flexibility being in the supporting structural elements. The functional electrical devices are qualified for seismic service by test, while the support structure is often qualified by analysis. Some of the electrical devices, such as transformers, may be qualified by analysis only, especially if they are large and testing is impractical.

As in any complex subsystem that consists of a number of components of differing response and fragility characteristics, there will be a weak link or links depending upon the combination of response and fragility factors for each of the subsystem elements. The probability model must necessarily group complex subsystems by functions, hence, the choice of the generic classification for switchgear.

The switchgear of main concern is that associated with the emergency ac power supply (4160 V and 480 V) and not that for distribution of off-site power.

These units tend to be smaller than the main power plant switchgear units.

Switchgear that handles emergency ac power are complex electrical assemblies that possess many failure modes. The electrical components are housed in structural cabinets bolted to the building floor or welded to steel channels embedded in the floor. The most likely failure mode is a failure to function for active electrical components of the switchgear, i.e., relays and breakers. The second mode of failure is considered to be equipment supports, either at the switchgear-to-building interface or the switchgear transformer supports.

Dry Transformers. The transformers of main interest are the 4160/480 V auxiliary transformers and the 480/120 V transformers to the instrument buses on the electric power fault tree. These transformers are compact and rugged. Structural/mounting failures are the failure modes of interest.

Control and Instrument Panels and Racks. These categories of electrical instrumentation and control equipment are characterized as lightweight electrical equipment mounted in panels and racks. Due to the large number of individual items within a rack or panel, the most likely failure mode would be failure to function of an electrical control device or instrument. A second failure mode would be a structural failure of the supporting rack or panel itself. The failure could be at the holddown bolts at the interface of the rack and building structure, or it could be local failure in which a critical instrument or control device would not be properly supported. A third failure mode could be the electrical leads at the interface point with the racks.

Auxiliary Relay Cabinets. Auxiliary relay cabinets were given a separate category inasmuch as they occur specifically on the fault trees. They are cabinets housing electrical relay and switching gear, including some transformers, and their lowest failure modes are functional. Structural failure of the cabinet or supports is another potential failure mode.

Local Instruments. A specific category was assigned to local instruments. This category is intended to cover process instrumentation (especially pressure and temperature) from sensor, through wiring to gage or dial indicator. The most likely seismic failure mode would be loosening of fasteners. Another potential failure mode is seismic excitation of the pickup leads, which is anticipated to occur at frequencies characteristic of typical earthquake spectra.

Motor Control Centers. Like the auxiliary relay cabinets, motor control centers occur specifically and frequently on the fault trees, as potential failure paths for all the emergency safety system pumps and valves. They are included as a separate category so that more refined fragilities may be used in future work should this be required. Failure modes are expected to be similar to those of auxiliary relay cabinets.

Light Fixtures. This category includes the emergency lighting provided in the event of failure of normal lighting systems. Structural or component breakage is considered a likely failure mode.

Communication Equipment. For the fault trees developed, this category is primarily used for annunciators. Failure would most likely result from components dislodged by seismic excitation.

Inverters. Inverters are passive electrical devices that convert dc power to 125 V ac. They are fairly rugged units and not particularly sensitive to seismic loading. However, with sufficient excitation, electrical component malfunction could occur. Structural failure of internal supports and failure of external supports at the inverter-building interface are also possible failure modes.

Cable Trays. Cable trays are used throughout the plant to support electrical power and instrumentation and control wiring. For purposes of the SSMRP, failure of the cable trays was taken to be equivalent to failure of the wires themselves, although this is certainly a conservative assessment.

Cable trays are usually supported for seismic loading by means of struts and threaded rods. The first mode of failure is considered to be a structural failure of a tray support at a threaded connection. At Zion, however, all safety-related systems were designed with bracing to resist seismic loading. Therefore, the most likely mode of failure for Zion safety-related trays would be in the miscellaneous steel (unistruts) which serves as an interface between the building structure and the cable tray supports. A second mode of failure is considered to be cable damage at termination points due to excessive motion of the cable trays relative to electrical equipment or junction boxes.

Circuit Breakers. Circuit breakers occur throughout the plant electrical system in a wide range of sizes and capacities. Inadvertent opening of these breakers is possible under seismic accelerations. All sizes and types of breakers are included in this category.

Relays. Like circuit breakers, relays occur in virtually every electrical control cabinet in the plant. Relay chatter during seismic excitation is a common occurrence. All sizes and types of relays are included in this category.

Ceramic Insulators. This category covers the ceramic insulators which are used in many applications at the point where off-site power is brought to the switchyard. Their failure is the probable cause of loss of off-site power during an earthquake.

Air Handling Units. This category covers the containment cooler system fans. Functional failure of these fans can be caused by rubbing of the fan blades on the fan housing or rubbing of the motor rotor on the motor housing.

Ductwork. Ducting for critical cooling air, exhaust, etc., is considered to possess much lower susceptibility to seismic damage than other more massive passive structural elements. Ducting is light in weight and inertial loading from a seismic event is consequently small. Relative motion between the ducting supports and the equipment with which the ducting interfaces could cause joint leakage. Such leakage might be introduced due to buckling of the thin wall ducts or pulling apart of the joints. The second failure mode to be postulated is local support failure due to excessive motion of the building stucture. A third failure mode would be total severance of a ducting joint. This would require considerable motion of the ducting system.

Hydraulic Snubbers and Pipe Supports. Two types of seismic supports are considered: (1) rigid-rod-type supports that carry deadweight of the piping plus vertical seismic response, and (2) lateral supports, either rigid or

snubbers, that carry seismic load only. Failure would be most likely to occur at a welded connection.

2.3 Summary of Component Fragilities

For Phase I demonstration computations, fragility descriptions consisted of the lognormal parameters of median (m) and beta (β), where β was a single value representing all variability, i.e., including contribution from both randomness and uncertainty. For the final Zion computations, the contributions to variability from randomness and uncertainty had to be separated. For most categories of equipment, multiple sets of fragilities were available to represent different failure modes or different sources of data. In some cases, the choice of which to use was obvious, but in others the data were combined to result in one set of values to be used for a category. Table 2 summarizes the component fragility estimates developed by the SSMRP. Tables 3 and 4 present strucutral fragilities for Zion.

2.3.1 Separation of Uncertainty

In order to construct confidence intervals of release probabilities, component fragilities with separate values of variability of randomness and modeling uncertainty (β^R and β^U) are needed. This separation had been determined for the fragilities based either on SAFEGUARD test data or on design reports (i.e., from NUREG/CR-2405 - hereafter called Type A data). However, the expert opinion data which were used to develop fragilities were not separated, and there was insufficient information from the expert-opinion survey to make such a separation. In many cases Type A data and expert-opinion data were folded together to yield one resulting fragility with only the total Beta (β_T), the combination of random and modeling uncertainty.

In order to provide the required separation of variability, we essentially applied the Type A separation for the various categories of equipment but modified the values to accommodate the uncertainty introduced by the expert-opinion data.

The following procedure was used for each category of components.

Given: β^{TEO} = Total variability from expert opinion or a combination of expert opinion and Type A data.

β^{TS} = Total variability from Type A data.

β^{RS} = Variability due to randomness only from Type A data.

β^{US} = Variability due to uncertainty only from Type A data.

$\left.\begin{array}{l}\beta^{T}\\ \beta^{R}\\ \beta^{U}\end{array}\right\}$ Total, random, and modeling uncertainty values to be used for result.

1. If $\beta^{TS} < \beta^{TEO}$, then assume

$$\beta^R = \beta^{RS}$$

$$\beta^U = \sqrt{(\beta^{TEO})^2 - (\beta^{RS})^2}$$

$$\beta^T = \sqrt{(\beta^R)^2 + (\beta^U)^2}$$

2. If $\beta^{TS} > \beta^{TEO}$ and $\beta^{TEO} > \beta^{RS}$, then assume

$$\beta^R = \beta^{RS}$$

$$\beta^U = \beta^{US}$$

$$\beta^T = \sqrt{(\beta^R)^2 + (\beta^U)^2}$$

(i.e., for this case the results are the same as the Type A data.)

3. If $\beta^{TS} > \beta^{TEO}$ and $\beta^{TEO} < \beta^{RS}$, then assume

$$\beta^R = \beta^{TEO}$$

$$\beta^U = \beta^{US}$$

$$\beta^T = \sqrt{(\beta^R)^2 + (\beta^U)^2}$$

Table 4 shows the resulting lognormal parameters of the component fragilities. The other data shown in Table 2 are applicable to these results as well as to the fragilities used for demonstration calculations.

All of the fragilities used in SSMRP are developed for local responses.

Table 2. Component Fragilities Developed by the SSMRP [a]

Component Category	Fragility Parameters[b] Median	β_R	β_U	β_T
Reactor core assembly	2.06	0.24	0.32	0.40
Reactor pressure vessel*	3.83	0.23	0.39	0.45
Pressurizer*	2.00	0.21	0.34	0.40
Steam generator*	2.45	0.24	0.37	0.44
Piping (master fragility-moment (in.-lb))*	2.44×10^6	0.18	0.33	0.38
Large vertical vessels with formed heads*	1.46	0.20	0.35	0.40
Large vertical tanks with flat bottoms	2.01	0.25	0.29	0.38
Large horizontal vessels	3.91	0.30	0.53	0.61
Small to medium vessels & heat exchangers*	1.84	0.25	0.45	0.51
Reactor coolant pump*	2.64	0.24	0.37	0.44
Large vertical pumps*	2.21	0.22	0.32	0.39
Motor driven pumps and compressors	3.19	0.21	0.27	0.34
Large motor-operated valves (>4 in.)				
1. Distortion of extended operator*	4.83	0.26	0.60	0.65
2. Rupture*	14.40	0.28	0.56	0.63
Large Hydraulic and Air Actuated Valves	7.61	0.31	0.34	0.46
Large relief, manual, and check valves*	8.90	0.20	0.35	0.40
Miscellaneous small valves	12.50	0.33	0.43	0.54
Small motor-operated valves	9.84	0.26	0.60	0.65
Horizontal motors*	12.10	0.27	0.31	0.41
Generators*	0.65	0.25	0.31	0.40
Battery Racks*	2.29	0.31	0.39	0.50
Switchgear*	2.33	0.47	0.66	0.81
Dry transformers*	2.78	0.28	0.30	0.41
Air handling units**	2.24	0.27	0.31	0.41
Instrument racks and panels	1.15	0.48	0.66	0.82
Control panels and racks	11.50	0.48	0.74	0.88
Auxiliary relay cabinets	7.63	0.48	0.66	0.82
Local instruments*	7.68	0.20	0.35	0.40
Motor control centers	7.63	0.48	0.74	0.88
Light fixtures	9.20	0.14	0.14	0.20
Communications equipment	5.00	0.33	0.35	0.48
Inverters*	15.60	0.26	0.35	0.44
Cable trays*	2.23	0.34	0.19	0.39
Ducting	3.97	0.29	0.46	0.54
Hydraulic snubbers and pipe supports	1.46	0.22	0.49	0.54
Relays (chatter)	1.66	0.57	1.40	1.51
Circuit breakers*	7.63	0.48	0.74	0.88
Ceramic insulators*	0.20	0.25	0.25	0.35

Notes:

a. Appendix F of NUREG/CR 3558 presents more detailed information.

b. Except for piping, median values are for local acceleration and are in units of gravity (g's).
 β_T = single value representing total variability.
 β_R = variability due to random uncertainty.
 β_U = variability due to systematic or modeling uncertainty.

*Used in final accident sequences of SSMRP Zion analysis (NUREG/CR-3428)

**Used only in initial accident sequences (culled out)

Table 3. Zion Structural Fragilities Developed by the SSMRP[a]

Structure Category	Fragility Parameters[b] Median	β^R	β^U	β^T
Reactor Building				
o Collapse of pressurizer enclosure	1.40	0.14	0.15	0.25
o Shear failure of containment wall	4.00	0.13	0.25	0.28
o Vertical shear failure at buttress plates	4.20	0.11	0.20	0.23
o Flexural failure of containment wall	9.00	0.13	0.24	0.27
o Shear failure of base mat	13.00	0.15	0.18	0.23
o Failure of internal shear anchors	5.00	0.11	0.19	0.22
Soil Failure Beneath Base Mat (Base Overturning moment in 10^7K-ft)[c]	1.29	0.20	0.20	0.28
Impact between reactor and auxiliary building (deflection at El.642' - in inches)[c]	0.99	0.11	0.22	0.25
Auxiliary building shear walls				
o Due to North-South ground motion	1.1C	0.12	0.20	0.23
o Due to East-West ground motion	2.70	0.11	0.26	0.28
Auxiliary building roof diaphragm	3.00	0.07	0.22	0.23
Diesel generator building walls	1.10	0.07	0.18	0.23
Control room masonry walls	1.70	0.23	0.24	0.33
Crib house pump enclosure roof	0.86	0.24	0.27	0.36
Crib house intake walls				
o Due to North-South ground motion	2.50	0.23	0.27	0.35
o Due to East-West ground motion	5.40	0.27	0.27	0.38
Crib house guide walls (due to North-South ground motion)	3.90	0.22	0.27	0.35
Condensate storage tank	0.81	0.28	0.30	0.41
Service water piping (underground)	1.70	0.20	0.57	0.60

Notes:

a. Reference NUREG/CR-2320.

b. Unless indicated otherwise, median values are for local acceleration and are in units of gravity (g's).

β^T = single value representing total variability.

β^R = variability due to random uncertainty.

β^U = variability due to systematic or modeling uncertainty.

c. Updated by "Base Slab Uplift" category discussed in NUREG/CR-3558 and NUREG/CR-3428. (That is, these fragility values have been replaced by:

median = 0.70 g's; β^R = 0.4, β^T = 0.57.)

Table 4. Structural Fragilities Used in the Accident Sequences of the SSMRP Zion Analysis[a]

Structure Category	Fragility Parameters[b]			
	Median	β^R	β^U	β^T
Base slab uplift	0.70	0.40	0.40	0.57
Crib house pump enclosure roof	0.86	0.24	0.27	0.36
Diesel generator building walls[c]	1.10	0.07	0.18	0.23
Condensate storage tank	0.81	0.28	0.30	0.41
Containment base mat	13.00	0.15	0.18	0.23
Auxiliary building roof diaphragm	3.00	0.07	0.27[d]	0.28

Notes:

a. NUREG/CR-3428 discusses the SSMRP Zion Analysis. Errors in Table 5.1 of NUREG/CR-3428 have been corrected in NUREG/CR-3558. Except for "Base slab uplift", the source for the Zion structural fragility values is NUREG/CR-2320.

b. Median values are for local acceleration and are in units of gravity (g's).

β^T = single value representing total variability.
β^R = variability due to random uncertainty.
β^U = variability due to systematic or modeling uncertainty.

c. This category was used instead of "Auxiliary Building N-S Shear Wall" to represent the shear wall between the Zion Auxiliary and Turbine buildings. The median fragilities are the same for the two categories and a judgment was made that the diesel generator building fragility was appropriate for this particular analysis.

d. NUREG/CR-2320 gives a value of 0.22 for this.

SECTION 3: ZION BUILDING FRAGILITIES

As part of determining the risk of radioactive release, it is necessary to determine failure criteria for all critical components in the safety systems. Besides functional failure of these critical components, one must consider the possibility that the buildings enclosing the critical components may fail and secondarily cause component failure. If a floor slab or wall collapses onto a pump or valve, the latter has some probability of failure. More likely is the possibility that the walls or floor slabs will be so cracked and spalled that bolts anchoring critical equipment will pull out, and components will then fail by excessive motion. Thus an essential part of developing fragility relations for the Zion plant was the development of failure criteria for those buildings housing critical components.

3.1 Scope

The five structures selected for detailed failure analysis were the reactor containment building shell, the reactor containment building internal structure, the turbine building, the auxiliary building, and the crib house (intake structure).

Consideration of failure of the containment shell is essential because of its role as the final barrier to radioactive release to the atmosphere. Vapor-tightness is maintained by a 0.25-in.-thick steel liner which is attached to the inside of the containment shell. Functional failure of the containment shell was defined as failure of this steel liner. In addition, pipe restraints for a number of critical piping systems are tied to the containment walls.

The reactor containment building internal structures consist of a 3-ft-thick base slab poured over the foundation slab (which is separated from the containment shell by a cork-filled 1.0-in. gap), the circular ring wall, the fuel handling pool and its supporting walls, the operating floor slab, the biological shield walls surrounding the reactor vessel, and the missile shield walls surrounding the pressurizer. The reactor coolant system (reactor vessel, steam generators, pressurizer, reactor coolant pumps, and primary piping) is located within the ring wall, which provides lateral support for its components.

The turbine building and the auxiliary building share an extensive common wall, and their structural responses are closely coupled, even though the auxiliary building is a Seismic Class I structure while the turbine building is not. The auxiliary building houses the majority of the safety system components, the control room, the diesel generators, and all components of the on-site emergency power system. In particular, it houses the auxiliary feedwater pumps, the charging pumps, the safety injection pumps, the RHR pumps, the containment spray pumps, and all the associated heat exchangers. Oil storage tanks for all pumps and the diesel generators are in the auxiliary building, as are the vast majority of the stepdown transformers, inverters, electrical buses, motor control centers, and instrument panels. In addition, the refueling water storage tanks (RWST), which are the major source of emergency cooling water, share a common wall with the auxiliary building; failure of the auxiliary building walls could thus cause a failure of the RWST.

All the above-mentioned components play important roles in the accident sequences developed for Zion. The turbine building contains the turbines, main feedwater pumps (both turbine and motor driven), and the condensers.

The crib house is an open boxlike structure which acts as a reservoir for the circulating water system and which houses the circulating water pumps, the service water pumps, and the fire pumps.

These five structures were identified in a preliminary investigation of the potential structural failure modes of the Zion plant (Ref. 10). As part of this preliminary investigation, possible failure modes for these structures were identified. Subsequent to this preliminary evaluation, detailed analyses were performed of the failure modes of these structures, and fragility relations were generated for the most probable failure modes of each building. Reference 11 provides specific details of the building designs and configurations and of the detailed analysis.

In the following sections, an overview of the method of generating the building fragilities is presented. The most probable failure modes and their corresponding fragility curves are then presented and discussed. Note that selected information in Ref. 11 has been updated or corrected, e.g., Eq. 3-6 of Ref. 11 is corrected to Eq. 9 in this report.

3.2 General Approach

Inasmuch as no actual tests to failure of typical nuclear power plant buildings exist, it is necessary to base the development of the building fragilities on a comparison of analytically calculated loads with experimentally determined wall, slab, and beam capacities. The starting point for this comparison is to have available a dynamic structural analysis of the building under consideration, which provides estimates of dynamic response (in-structure accelerations; forces in walls, slabs, and beams; etc.) for a specified free-field ground motion. This analysis can be based on a design calculation or on a best-estimate basis. In terms of building fragilities, the important results are the amplitude and distribution of the forces and moments in structural members conditional on the specified free-field ground motion. From this preliminary response information and an assessment of the capacities of the members, their fragility functions are developed.

Fragility functions relate probability of failure to one or more fragility parameters. In the SSMRP, fragility functions were expressed in terms of a single parameter. Examples are support or response accelerations of a component and moment in a piping system. The parameter is typically a measure of the excitation or response of the item of interest. For building fragilities, one first considers structural elements, e.g., shear walls. The failure of the structural element is described by loads in the member (e.g., shear force in a shear wall), with consideration given to other simultaneously acting loads. This fragility parameter coincides with a response parameter which describes response conditional on the occurrence of an earthquake described by the seismic hazard curve. Convolution of the two yields the probability of failure of the item of interest.

In the SSMRP, fragility functions were developed for structural elements of importance, first, in terms of forces in the members, e.g., shear force in a shear wall. Subsequently, the fragility parameter was transformed to an in-structure floor acceleration for computational convenience. Structural member forces were correlated with floor accelerations, and the acceleration

at a node point in the structure was selected as the fragility and response parameter.

Failure of a structural element or building is described by a fragility parameter. For example, this parameter may be the acceleration, the internal stress, or the applied loads.

Fragility functions for a structural element or building take the form:

$$V_F = V \cdot F_S \cdot F_\mu \cdot F_R \qquad (3)$$

where,

- V_F = fragility parameter at failure (e.g., shear force in wall)
- V = reference value of fragility parameter at a known earthquake level (e.g., the SSE)
- F_S = factor relating the actual strength capacity to the design load
- F_μ = factor accounting for inelastic energy absorption capability of the structure or structural element
- F_R = factor accounting for conservatisms in the method of analysis by which the reference value of V was determined; in the SSMRP, best estimate probabilistic response calculations were performed on most structures and $F_R = 1$; in subsequent discussions here, F_R will not be included.

The strength factor, F_S, is computed by

$$F_S = \frac{V_{ult} - V_{normal}}{V_{seismic}}$$

where V_{ult} is the capacity of the member in terms of load, V_{normal} is the load due to normal conditions assumed to act simultaneously with the earthquake (dead weight, thermal, pressure, etc.), and $V_{seismic}$ is the load at the reference level earthquake. The factor F_S ratios up the load or response in Eq. (3) to the actual ultimate load capacity. Figure 1 shows a typical nonlinear load-deflection curve. The linearly extrapolated V_{ult} is shown schematically.

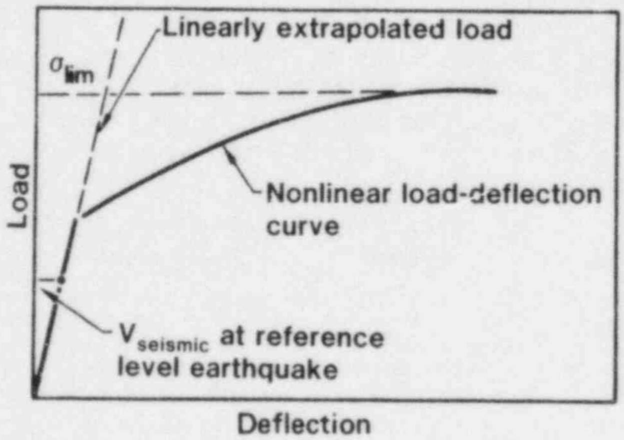


Figure 1. Typical stress-deflection curve

For members that behave in a brittle fashion, V_{ult} is the load at failure. However, many members behave in a ductile manner, and a significant degree of nonlinearity occurs before failure. Figure 1 shows this schematically. To accocunt for this nonlinear behavior before failure, a ductility factor or inelastic energy absorption factor, F_μ, is developed and aplied. F_μ is applied to reduce the linearly calculated response or, alternatively, to increase the capacity as described by the fragility parameter. Development of F_μ is based on parameter studies involving a large number of nonlinear analyses of relatively simple systems of varying frequency characteristics, damping, and available ductility.

Because failure is not deterministic, additional factors in Eq. (3) are also subject to uncertainty. These factors are treated as random variables, and uncertainties are explicitly included. Lognormal distributions were assumed for F_S, F_μ, and F_R, which are independent variables. Consequently, V_F is lognormally distributed and

$$\check{V}_F = V \cdot \check{F}_S \cdot \check{F}_\mu \cdot \check{F}_R \tag{4}$$

$$\beta_F^2 = \beta_S^2 + \beta_\mu^2 + \beta_R^2 \tag{5}$$

where the symbol $^\vee$ indicates the median and β denotes the log-standard deviation. The two variables V_F and β_F define the distribution of the fragility parameter, V_F, and

$$V_F = \check{V}_F\ \epsilon \tag{6}$$

where ϵ is a random variable with median of unity and log-standard deviation, β_F, given by Eq. (5). In our subsequent discussion, F_R is not included since, in the SSMRP, best-estimate response calculations were performed, and F_R was unity; uncertainty associated with the response parameters was determined explicitly in the response calculations. In general, however, F_R can be treated in the same manner as F_μ and F_S since it is an additional independent random variable.

3.2.1 Modeling and Random Uncertainties

Uncertainty in the calculation of the fragility can be separated into two categories, random uncertainty and modeling uncertainty. Random uncertainty is that part of the total variance which results from inherent randomness in the system, which cannot be reduced by additional data or analysis. Random uncertainty is variability induced by the earthquake motion. By contrast, modeling uncertainty is that part of the total variance which results from our model or representation of the phenomenon. Modeling uncertainties can be reduced by use of improved models, additional tests, etc.

It is possible to separate the effects of random and modeling uncertainties by estimating the variances in the terms F_S and F_μ separately. Thus we estimate

$$\beta_S^2 = (\beta_S^R)^2 + (\beta_S^U)^2$$

$$\beta_\mu^2 = (\beta_\mu^R)^2 + (\beta_\mu^U)^2$$

in which each β^R is the variance due to random uncertainty and each β^U

is the variance due to modeling uncertainty. Thus, Eq. (6) can be generalized to

$$V_F = \check{V}_F \, \epsilon_U \, \epsilon_R \tag{7}$$

where ϵ_U is a lognormal random variable with unit median and log-standard deviation

$$(\beta^U)^2 = (\beta_S^U)^2 + (\beta_\mu^U)^2$$

which accounts for all the modeling uncertainty, and ϵ_R is a lognormal random variable with unit median and log-standard deviation

$$(\beta^R)^2 = (\beta_S^R)^2 + (\beta_\mu^R)^2$$

which accounts for all the inherent random uncertainty.

The formulation in Eq. (7) allows us to put upper and lower bounds on the location of the median $\check{V}_F$ by thinking of it as a random variable with variance which is the variance caused by modeling uncertainties alone. Hence, using the lognormal distribution for ϵ_U, we can get upper and lower values of the median corresponding to prescribed probabilities of nonexceedance.

For example, it can be shown that the 5% and 95% probability values of the median are given by

$$(\check{V}_F)_{5\%} = \check{V}_F \, e^{-1.65\beta_U}$$

$$(\check{V}_F)_{95\%} = \check{V}_F \, e^{+1.65\beta_U}$$

These are points m and n shown on Fig. 2. The distribution of ϵ_U from

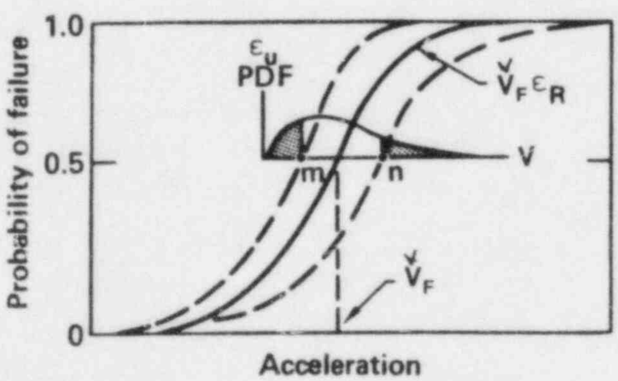


Figure 2. Construction of upper and lower bounds on fragility curve.

which they were derived is superimposed on the figure. The shaded areas each represent 5% of the area under the curve. The solid curve is the cumulative distribution function (cdf) of the capacity with no modeling uncertainty. The dashed bounding curves are the curves which pass through the 5% upper and lower values of the median as computed above. All three curves have the same

variance (due to the random uncertainty alone).

Snown in Fig. 3 is a comparison between the three curves in Fig. 2 and the cumulative distribution function of the V_F based on the total uncertainty which includes both random and modeling uncertainty. The latter curve is flatter than the other three since its variance is larger.

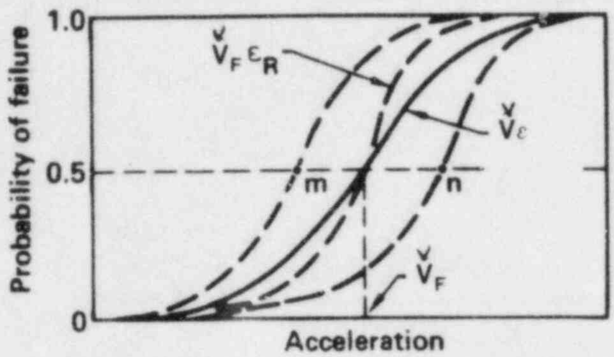


Figure 3. Fragility curve with combined random and modeling uncertainty.

Either Eq. (6) or Eq. (7) can be used, depending on the application. In Phase I of the SSMRP, only the total variance formulation (random plus modeling) was utilized. For the final Zion analysis, however, the random and modeling uncertainties will be propagated through the calculational sequence separately, and thus in developing the fragilities, the two types of uncertainty were considered separately.

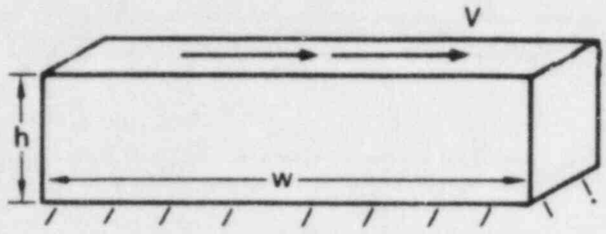
3.2.2 The Strength Factor F_S

As outlined in the last section, the strength factor is given by

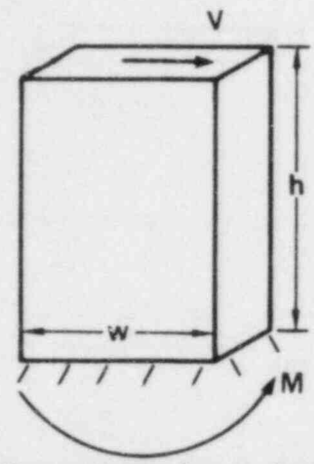
$$F_S = \frac{V_{ult} - V_{normal}}{V_{seismic}} \qquad (8)$$

in which V_{ult} is the capacity of the member in terms of load, and the terms V_{normal} and $V_{seismic}$ are the calculated loads due to normal operating conditions and the reference level earthquake, respectively.

Shear wall construction is used for typical nuclear power plant buildings. With such construction, lateral loads due to ground shaking are resisted by reinforced concrete walls. This results in a strong and very stiff structure. The ultimate capacities of such shear walls depend on the relative ratios of height to width. The two main failure modes (failure due to in-plane shear and failure due to in-plane moments) are shown in Fig. 4. The failure criteria for these two modes are presented below. In evaluating the fragility of the Zion buildings, the shear walls were assumed to resist in-plane loading only. Also, failure of the walls due to direct bearing stresses was never a governing factor. Hence no failure criteria for out-of-plane bending or bearing were needed for these two modes of failure.



(a) Shear loading on wall



(b) Bending moment due to shear loading

Figure 4. Shear and bending loadings on walls.

The ultimate shear capacity was taken as

$$v_{ult} = 8.3\sqrt{f_c'} - 3.4\sqrt{f_c'}\left(\frac{h}{w} - \frac{1}{2}\right) + \frac{N}{4\ wt} + \rho_{se}f_y \quad \text{(psi)} \tag{9}$$

in which

f_c' = compressive concrete strength, psi

h = wall height

w = wall length

N = normal (bearing) load, lb

f_y = yield strength of reinforcing steel, psi

t = wall thickness

$\rho_{se} = A\rho_h + B\rho_u$

ρ_h = horizontal steel reinforcement ratio

ρ_u = vertical steel reinforcement ratio

A, B = constants depending on h/w

This expression is based on the experiments of Barda (Ref. 12) modified to reflect the data of Refs. 12-15 which show the decreasing effect of vertical reinforcing steel with increasing h/w ratios. From the data of Refs. 12-15, the constants A and B were taken as

$A = 1$	$B = 0$	for $h/w \leq 0.5$
$A = 2(1 - h/w)$	$B = 2\,h/w - 1$	for $0.5 < h/w \leq 1.0$
$A = 0$	$B = 1$	for $1.0 < h/w$

The ultimate moment capacity of shear walls due to in-plane forces, M_{ult}, was taken as

$$M_{ult} = \frac{A_s f_y W}{2}\left(1 + \frac{N}{A_s f_y}\right)\left(1 - \frac{\beta_1 c}{w}\right) + A_{ch} f_y \left(d - \frac{\beta_1 c}{2}\right) \tag{10}$$

in which

c = depth to neutral axis from extreme compression fiber

A_s = total distributed steel

A_{ch} = area of chord steel

w = wall length

f_y = steel yield strength

N = axial (bearing) load

d = distance from the extreme compressive fiber to the centroid of tensile chord steel

β_1 = ratio of depth of equivalent rectangular concrete stress block to depth to neutral axis (c)

This equation follows that presented in Ref. 13 modified to account for the presence of chord steel.

The equations for V_{ult} and M_{ult} presented above give the median ultimate capacities. Based on comparing these two equations against data (Refs. 12-14), an estimate was made of their agreement with the data. A log-standard deviation of 0.15 was found for V_{ult}, and a corresponding value of 0.10 was found for M_{ult}.

Both equations involve the reinforcing steel yield strength, f_y, and the ultimate shear capacity depends on the concrete compressive strength, f_c. Throughout the Zion structures, Grade 60 reinforcing steel was used, and data on yield strength were taken. The resulting median and log-standard deviations were:

No. 3 to No. 11 bars	Median f_y = 66 ksi	$\beta_{f_y} = 0.09$
No. 14 and No. 18	Median f_y = 71 ksi	$\beta_{f_y} = 0.11$

Different concrete design strengths were specified for the Zion buildings, and 90-day concrete compression test data were taken, with the results shown in

Table 5. Based on these test data and a correction factor to account for the increase of concrete strength with aging, it was found that the ratio of the median compressive strength (including aging effects) to the design compressive strength is 1.3 to 1.4 in the reactor building base mats and 1.31 to 1.35 in the containment shells. Corresponding log-standard deviations are approximately 0.10 to 0.11. For the auxiliary building, the ratio of median to design compressive strength is approximately 1.65 with log-standard deviation of 0.13 for the walls and slabs. The crib house was designed with 2500-psi concrete so that the ratio of median to design compressive strength for this building is approximately 1.74, again with a log-standard deviation of 0.12. These increased values of f'_c are used in the equation for V_{ult} when computing the median shear strength capacities of walls.

Table 5. Zion concrete compression test results (90-day test).

	Design strength (psi)	Average strength (psi)	Standard deviation (psi)	Number of samples
Reactor building base mats (Unit 1)	5000	5948	570	76
Reactor building base mats (Unit 2)	5000	6521	661	92
Reactor containment building (Unit 1)	5500	6812	585	415
Reactor containment building (Unit 2)	5500	6664	617	404
Auxiliary building foundations	4000	6072	427	22
Auxiliary building walls and slabs	4000	6136	704	500
Crib house	3500	5603	606	200

3.2.3 The Ductility Factor F_μ

The ductility factor or inelastic energy absorption factor, F_μ, approximately accounts for nonlinear behavior before failure. The factor F_μ is a measure of the capacity of the structural element (or structure) to absorb energy inelastically and hence withstand larger earthquakes than would be predicted by using a linear analysis.

The factor F_μ is applied to reduce the linearly calculated response or, alternatively, increase the capacity as described by the fragility parameter. Thus,

$$F_\mu = \frac{V_F}{V F_S} \tag{11}$$

In the SSMRP, no nonlinear analyses were performed. Hence calculations of F_μ were based on the work of Newmark on "ductility modified response spectra" as documented in Refs. (4, 16-18). In this work, it was shown that the ductility factor was primarily a function of the ductility ratio, defined as the ratio between the maximum displacement of an elastic-plastic element to the elastic displacement. By analyzing simple one-degree-of-freedom systems with base excitation corresponding to a number of different recorded earthquake time histories, it was shown that the ductility factor could be approximated by

$$F_\mu = \sqrt{2\mu - 1} \tag{12}$$

where μ is the ductility as defined in Fig. 5. Later studies (Ref. 19)

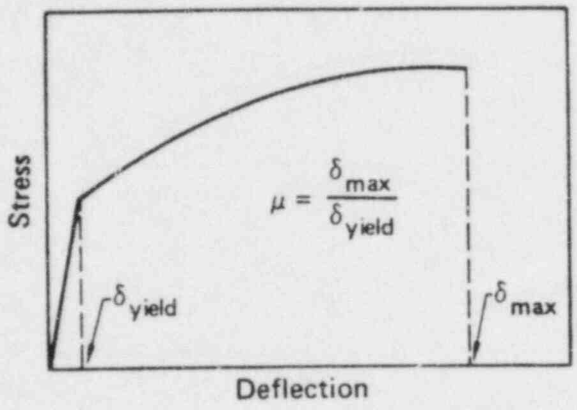


Figure 5. Definition of ductility ratio.

showed that the ductility factor was not sensitive to the particular form of the elastic-plastic constitutive law assumed, but did depend on the assumed degree of damping. These studies gave the results shown in Fig. 6.

The relation between F_μ and the ductility ratio and damping imposes no limitations on the maximum displacement, but only relates the maximum nonlinear displacement to the linearly calculated value. Actual values of maximum displacement at failure are determined by experiment. Thus, the value of the ductility ratio at failure was taken from data on reinforced concrete walls failing in shear under reversal loading given in Ref. 15. From this data, the median value of ductility at failure was found to be approximately 4, with a log-standard deviation of 0.18. Thus, from Fig. 6, values of the ductility factor F_μ can be computed for $\mu = 4$, for any assumed value of structural damping.

3.2.4 The Response Factor F_R

The factor F_R accounts for conservatisms in the method of analysis by which the reference values were calculated, e.g., V in Eq. (3). For the reactor containment building, and the auxiliary/fuel handling/turbine (AFT) building complex, detailed dynamic analyses were performed as part of the SSMRP, and hence for these buildings the factor F_R is unity. Uncertainties in response, as characterized by β^R and β^U, were calculated explicitly in the SSMRP analysis. However, for the crib house, the original design analysis performed by Sargent and Lundy was used, so for the crib house a response factor F_R was computed.

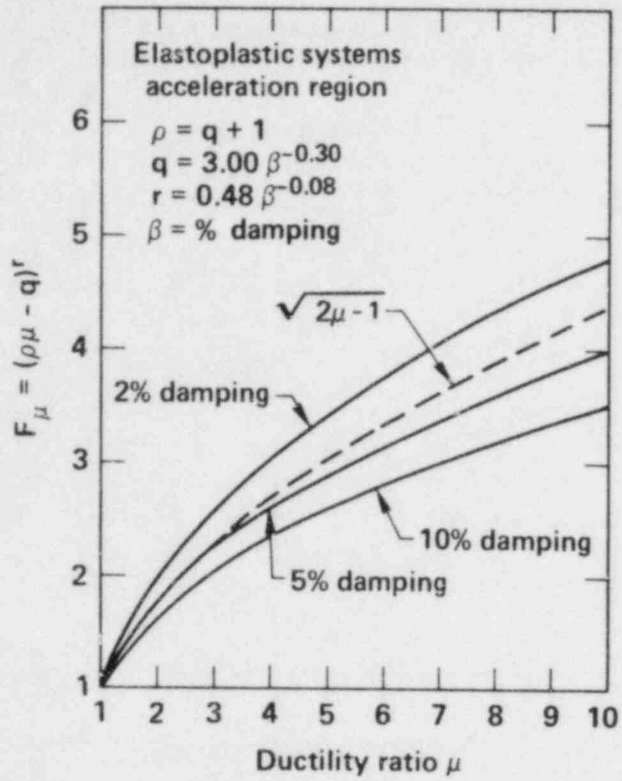


Figure 6. Relationship of ductility ratio and damping factor on ductility factor (from Ref. 19).

The variables that typically affect the calculated response of structures to a given seismic event with a given free-field acceleration can be grouped into three categories given by

- Free-field ground motion
- Soil-structure interaction (SSI) effects
- Structure response aspects such as method of modal and directional response combination

For example, no SSI effects were included in the original design analyses of the crib house. The analytical model for this structure assumed fixed base conditions and did not consider kinematic or inertial interaction effects. Spatial variation of the ground motion over the embedded extent of the foundation was not considered. Radiation damping was not treated and only soil material damping (corresponding to 5% equivalent viscous damping) was included. Both of these factors are considered to result in some overestimation of structural response. The combined estimated factor of safety due to SSI effects only for the crib house was judged to have median and log-standard deviations (F_R and β_R, respectively) of:

$F_R = 1.2$ $\beta_R = 0.15$

Similarly, contributions to F_R from the other categories above were estimated. In summary, the values were:

• Free-field ground motion	$F_R = 0.88$	$\beta_R = 0.05$
• Soil-structure interaction effects	$F_R = 1.2$	$\beta_R = 0.15$
• Structure response aspects	$F_R = 1.0$	$\beta_R = 0.23$
• Composite	$F_R = 1.05$	$\beta_R = 0.28$

Note, the beta values are for total uncertainty, which includes random and modeling.

3.2.5 Example of Fragility Development

To illustrate the process of developing fragility curves using the strength and ductility factors just described, the calculations for the fragility curve of the diesel generator room walls in the auxiliary building will be presented.

The loads (shear forces and moments) in all the walls and slabs in the auxiliary building were computed from time history analyses using SMACS for a set of earthquakes all scaled to have peak accelerations in the range 0.17 to 0.30 g. Ten different earthquake time histories were used. The most highly stressed walls in the diesel generator rooms were the end walls, having a median shear force of 1430 kips. For computational convenience, the in-structure acceleration of the control room floor slab was used as the fragility parameter. The median floor slab east-west acceleration for the 10 time histories was 0.15 g. The factors F_S and F_μ are used to, first, scale up the shear load to its failure level and, second, to scale up the control room floor slab acceleration for computational purposes.

The location of the two walls is shown in Fig. 7. The walls are 25 ft high, 42 ft long, and 2 ft thick, with No. 6 high strength steel reinforcement on both sides, spaced 1 ft apart along the wall and in both directions..

The Strength Factor. The median strength factor, F_S (as discussed in Sec. 3.2.2), is given by

$$F_S = \frac{V_{ult} - V_{normal}}{V_{seismic}}$$

which was approximated as

$$F_S = \frac{V_{ult}}{V_{seismic}}$$

since the static loading on shear walls is very small compared to the dynamic seismic loading. The ultimate shear load capacity for a reinforced concrete wall is given by Eq. (9) as

$$v_{ult} = 8.3 \sqrt{f_c'} - 3.4 \sqrt{f_c'}\left(\frac{h}{w} - \frac{1}{2}\right) + \frac{N}{4wt} + \rho_{se} f_y \qquad (13)$$

There is no significant normal load on these walls, so N = 0. The vertical reinforcement ratio is

$$\rho_u = \frac{2(0.44 \text{ sq in.})}{(12 \text{ in.})\ (24 \text{ in.})} = 0.00306$$

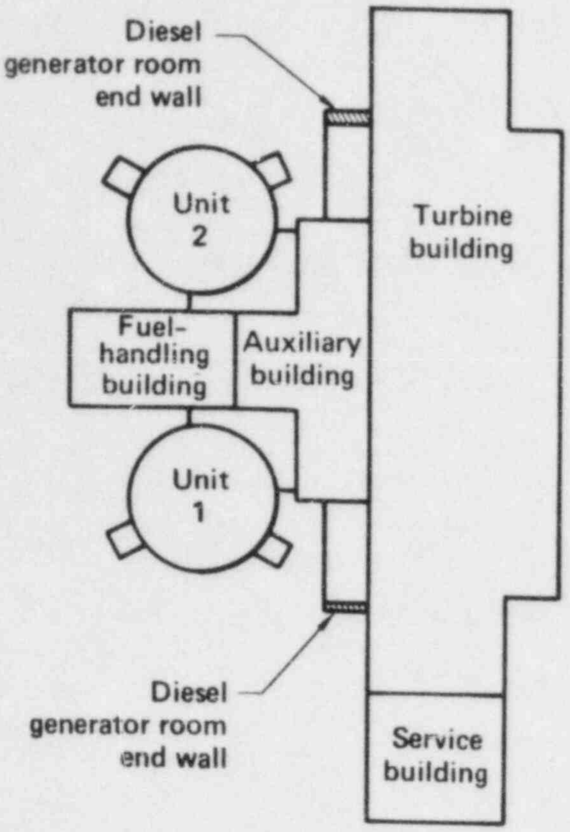
Note that in this case $\rho_u = \rho_h$ and the effective steel reinforcement ratio (ρ_{se}) equals either the vertical steel reinforcement ratio or the horizontal steel reinforcement ratio. Equation (13) can be written

$$v_{ult} = v_{cu} + v_{su} \qquad (14)$$

where

$$v_{cu} = 8.3 \sqrt{f_c'} - 3.4 \sqrt{f_c'}\left(\frac{h}{w} - \frac{1}{2}\right) + \frac{N}{4wt}$$

$$v_{su} = \rho_{se} f_y$$



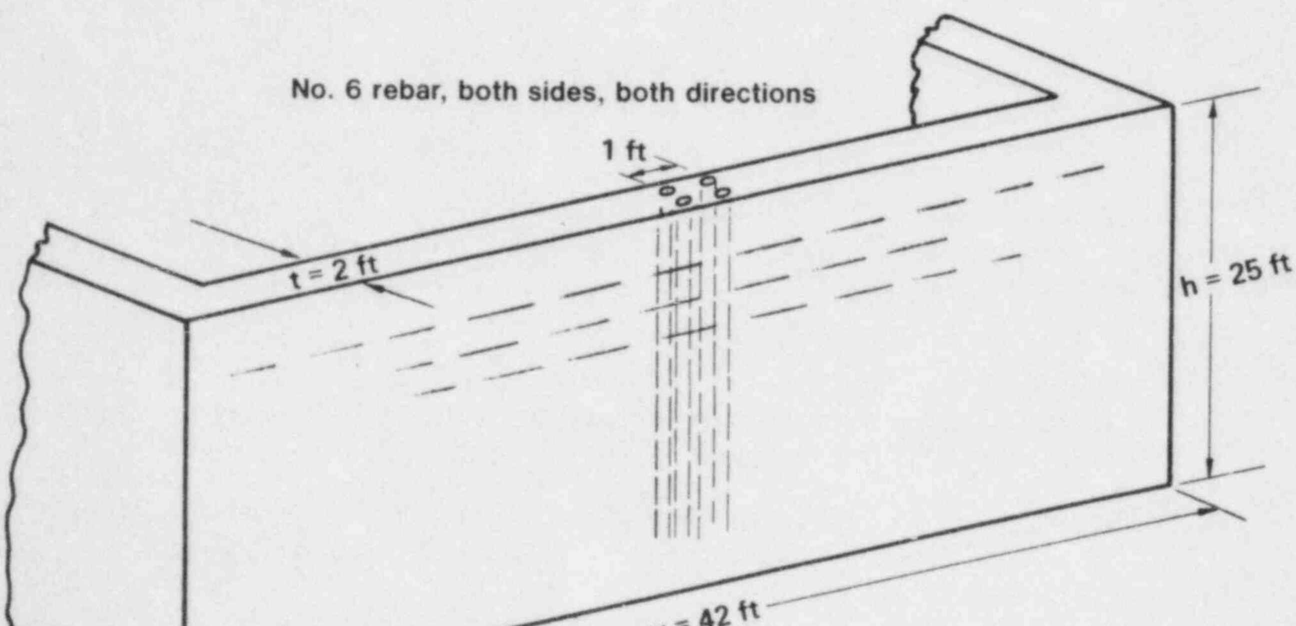


Figure 7. Diesel generator room end walls.

From test data, the median concrete strength for the diesel room walls (taken as 1.65 times the 4000 psi design concrete strength as explained in Sec. 3.2.2) is

$$f_c' = 6600 \text{ psi}$$

and the log-standard deviation

$$\beta_{f_c'} = 0.13$$

The median and log-standard deviation steel strength are

$$f_y = 66{,}000 \text{ psi}$$

$$\beta_{f_y} = 0.09$$

Thus the median concrete shear strength is

$$v_{cu} \approx 8.3\sqrt{6600} - 3.4\sqrt{6600}\,[(\frac{25}{42}) - (\frac{1}{2})] = 647 \text{ psi}$$

and the median steel shear strength is

$$v_{su} = (0.00306)\,(66{,}000) = 202 \text{ psi}$$

Hence the median wall shear strength is

$$v_{ult} = v_{cu} + v_{su} = 849 \text{ psi}$$

and the median wall shear force capacity becomes

$$V_{ult} = v_{ult}\,(t)\,(0.8w) \qquad (15)$$

$$= 849\,(2)(12)(0.8)(42)(12)$$

$$= 8216 \text{ kips}$$

in which 0.8w is the effective wall length as specified in the ACI code, a best-estimate value. Thus the median strength factor of safety, F_s, is

$$F_s = \frac{V_{ult}}{V_{seismic}} = \frac{8216}{1430} = 5.75$$

The value of $V_{seismic}$ = 1430 kips corresponds to an ensemble of earthquakes with median peak free-field acceleration of 0.17g.

The uncertainty in the ultimate shear load results from the random uncertainty in the test data for the concrete and steel shear strengths (having log-standard deviations

$$\beta^R_{f_c'} = 0.13 \text{ and } \beta^R_{f_y} = 0.09,$$

respectively), and from the fact that the equation for the ultimate strength

of shear walls is an approximate model fit to data (i.e., modeling uncertainty of $\beta^U = 0.15$). Thus we model the ultimate load of the wall as having the form

$$V_{ult} = V_u \, \epsilon_R \, \epsilon_U$$

in which ϵ_R, ϵ_U are lognormal random variables with medians equal to unity and log-standard deviations β_R, β_U, respectively. From Eq. (14),

$$v_{ult} = v_{cu} + v_{su}$$

and, using the approximation $\beta \cong \sigma/\mu$ and assuming V_{ult} is log normal, it can easily be shown that

$$\beta_{v_{ult}} = \sqrt{\frac{\left(\check{v}_{cu} \, \beta_{V_{cu}}\right)^2 + \left(\check{v}_{su} \, \beta_{V_{su}}\right)^2}{v_{ult}^2}}$$

in which $(\check{v})$ denotes the median value. Further, since v_{cu} is proportional to $\sqrt{f_c}$ it can be shown that

$$\beta_{V_{cu}} = 0.5 \, \beta_{f_c}' = 0.065 \quad ,$$

$$\beta_{V_{ult}} = \sqrt{\frac{[0.065(647)]^2 + [0.09(202)]^2}{(850)^2}} = 0.05 \quad ,$$

$$\beta^R = \beta_{V_{ult}}$$

Thus we have characterized the safety factor, F_s, in lognormal form as having a median value of 5.8, and random and modeling uncertainties of $\beta^R = 0.05$ and $\beta^U = 0.15$, respectively. In Phase I of the SSMRP, the relative effects of random and modeling uncertainties were not considered separately, but were combined to give a total uncertainty

$$\beta_{F_S} = \sqrt{(\beta^R)^2 + (\beta^U)^2} = 0.16$$

The Ductility Factor. The ductility factor, F_μ, is taken from Fig. 6 for specified values of the ductility ratio and structural damping. Damping in cracking reinforced concrete walls near failure is expected to be large, so a value of 10% damping is assumed which is consistent with limited available test data.

The system ductility ratio for shear wall failure is normally estimated to be about 2. However, failure of this shear wall is primarily localized because of load redistribution, and nonlinear response of the wall will not significantly deamplify the response of the structure as a whole. Accordingly, a reduced system ductility ratio of 1.2 is estimated.

For $\mu = 1.2$ and 10% damping, the value of F_μ from Fig. 6 is 1.18. The modeling uncertainty inherent in Fig. 6 is estimated to be 0.10 while the random uncertainty is estimated to be 0.05. Hence

$F_\mu = 1.18$

$\beta_\mu^R = 0.05$

$\beta_\mu^U = 0.10$

$$\beta_{F_\mu} = \sqrt{(\beta_\mu^R)^2 + (\beta_\mu^U)^2} = 0.11$$

Fragility Parameter. First let us consider the linearly calculated median load at failure:

$$\check{V}_F = \check{V} \cdot \check{F}_S \cdot F_\mu = (1430 \text{ kips})(5.8)(118) = 9787 \text{ kips}$$

Second, in an identical manner, consider acceleration of the control room floor slab

$$\check{A}_F = (0.15g)(5.8)(1.18) = 1.1g$$

This latter quantity was used as our fragility parameter.

The random uncertainty is

$$\beta^R = \sqrt{(0.05)^2 + (0.05)^2} = 0.07$$

and the modeling uncertainty is

$$\beta^U = \sqrt{(0.15)^2 + (0.1)^2} = 0.18$$

The corresponding fragility curve is plotted in Fig. 8.

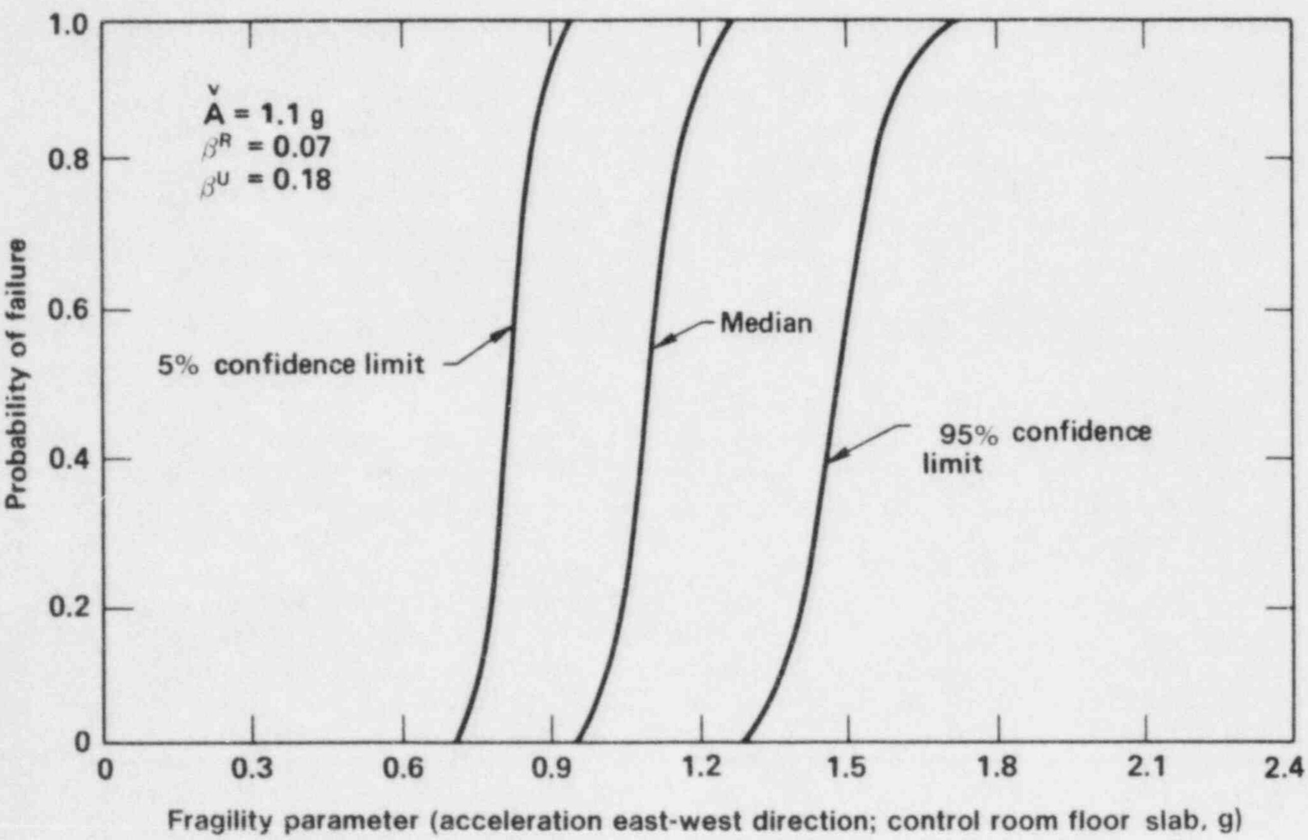


Figure 8. Failure of diesel generator room walls.

This completes the example of the methods used in the development of structural fragilities. These methods were applied to the reactor containment building, auxiliary/fuel handling/turbine building complex, and the crib house. Descriptions of these structures and their resulting fragilities follow.

3.3 Reactor Containment Building Fragilities

The reactor containment buildings for Zion Units 1 and 2 consist of the prestressed containment shell and a reinforced concrete internal structure which supports the NSSS. The containment shells are vertical circular cylinders with shallow domed roofs. They enclose the concrete internal structures, the reactor vessels, and reactor coolant systems. The containment buildings are supported by independent flat circular foundation slabs with a sump near the center which acts as a shear key.

3.3.1 Description

The cylindrical portion of the containment building is prestressed by a posttensioning system that consists of horizontal and vertical unbonded tendons. The horizontal hoop tendons terminate in one of the six equally spaced vertical buttresses that extend from the base slab to above the spring line of the vessel. The dome is prestressed by a three-way posttensioning system. Vertical and circumferential reinforcing steel is placed in the cylinder, and the dome contains radial and circumferential reinforcing steel toward the outside diameter and reinforcing steel in a rectangular grid near the center. The foundation slab is conventionally reinforced with high-strength steel. Other than the vertical containment vessel tendons that extend through the base slab, no prestressing is used for the base slab. The entire structure is lined with 1/4-in. welded steel plate to provide vapor tightness. A vertical section through the containment is shown in Fig. 9. Located within the containment buildings are the concrete internal structures. These structures are conventionally reinforced and support the reactor vessel, the nuclear steam supply system, the fuel handling pool, and the polar crane. The concrete internal structure consists of a ring wall, operating floor, fuel handling pool, and the reactor biological shield wall. The ring wall is 3 ft, 9 in. thick with an outside diameter of 106 ft and extends upward from the floor slab (elevation 568 ft) to the operating floor (elevation 617 ft). On the operating floor immediately above the ring wall is located the polar crane.

Figure 10 shows a vertical section through the internals and containment vessel. Figure 11 shows the location of the major items of equipment, including the reactor vessel, the steam generators, the reactor coolant pumps, and the polar crane.

The only location where the concrete internals are structurally connected to the containment vessel is at the base of the internal structure. One-foot-square by 2-in.-deep shear keys connect the ring wall to the 3-ft-thick slab above the liner, and 1-3/8-in.-diam anchor bolts tie the wall into the 9-ft-thick foundation slab. This detail is designed to transmit loads from the internals to the foundation directly without affecting the liner.

3.3.2 Failure Modes and Fragilities

Under seismic excitation, the containment building responds like a cantilever

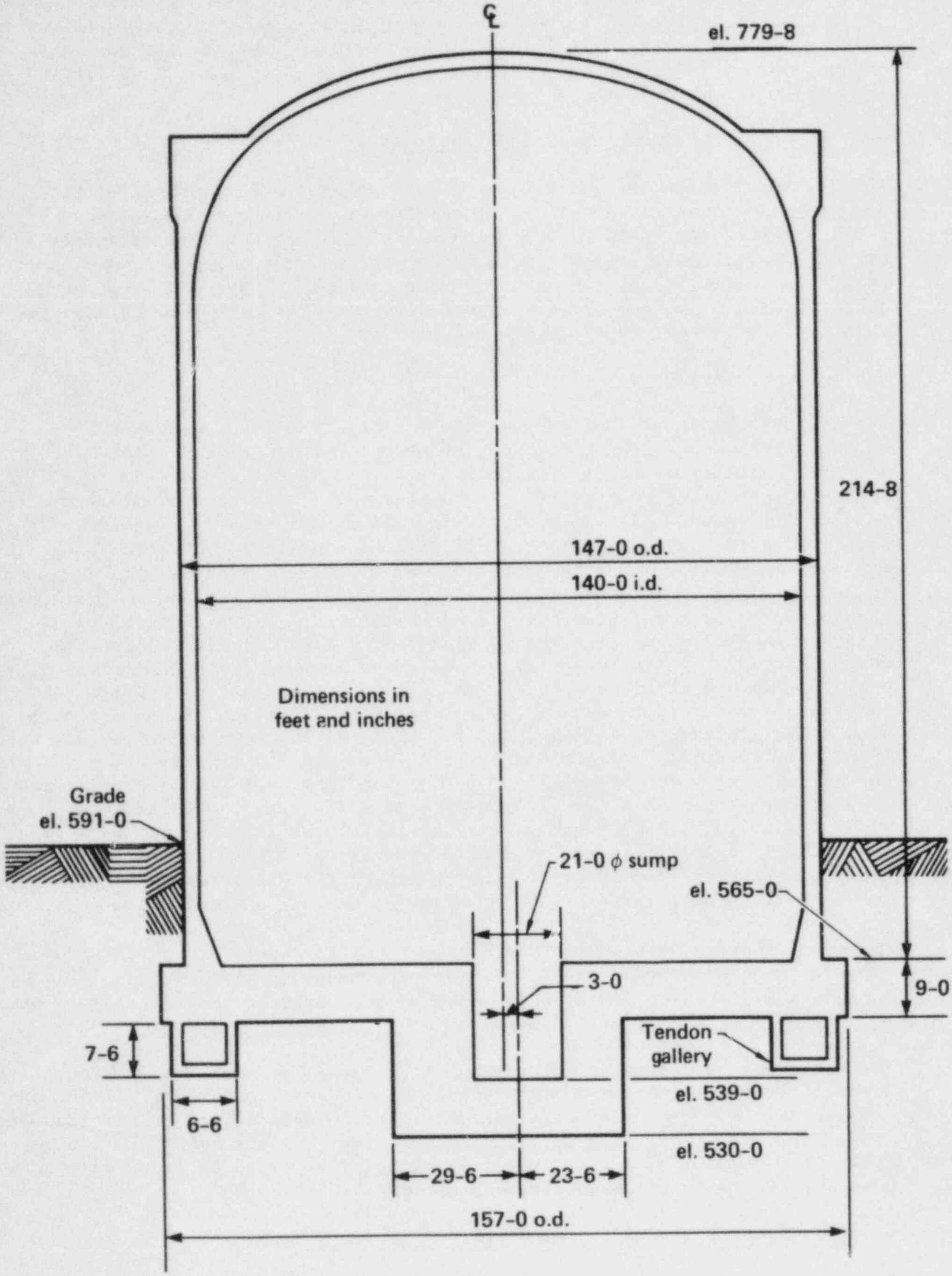


Figure 9. Section of reactor containment building.

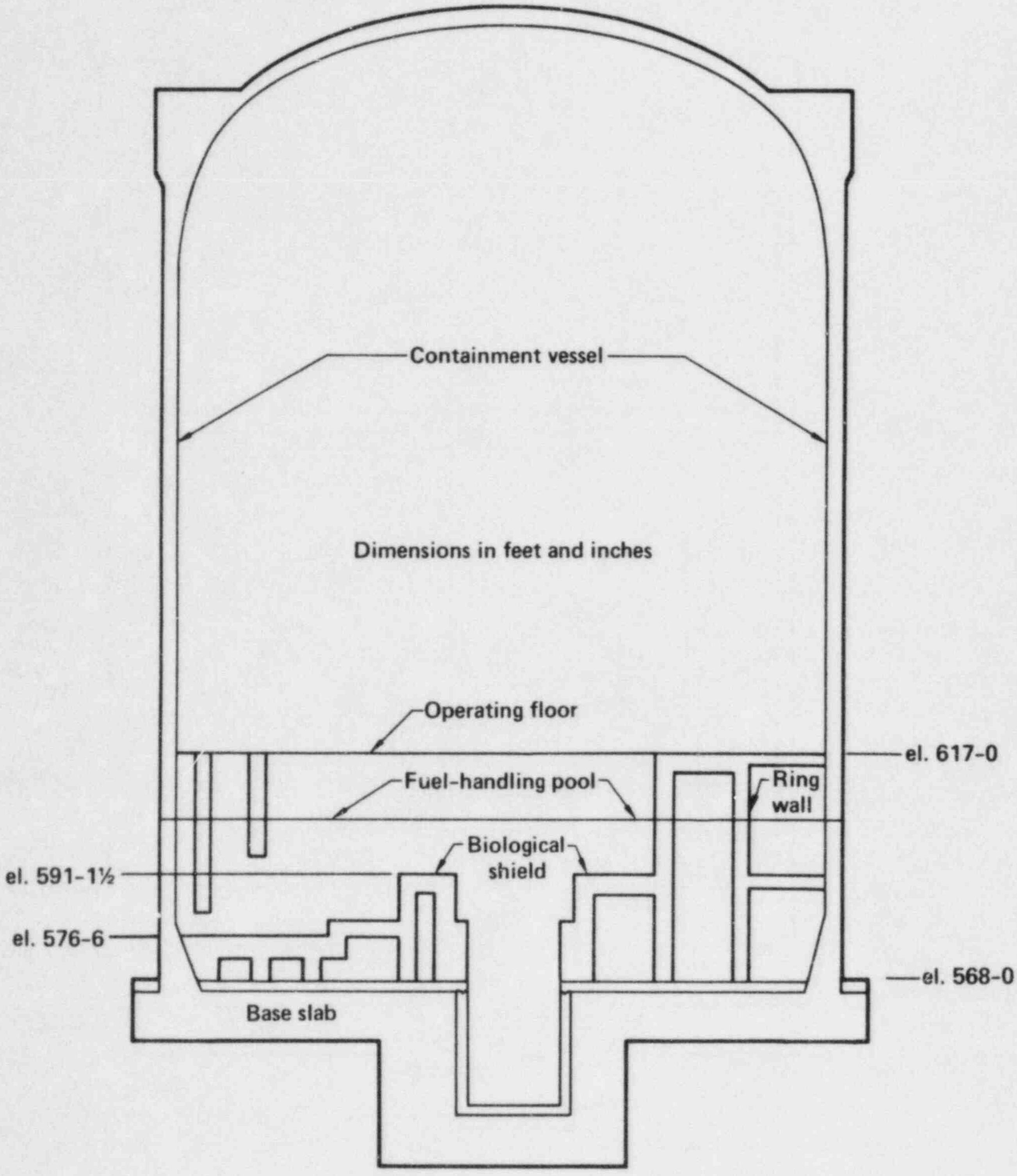


Figure 10. Zion reactor building and internal structure.

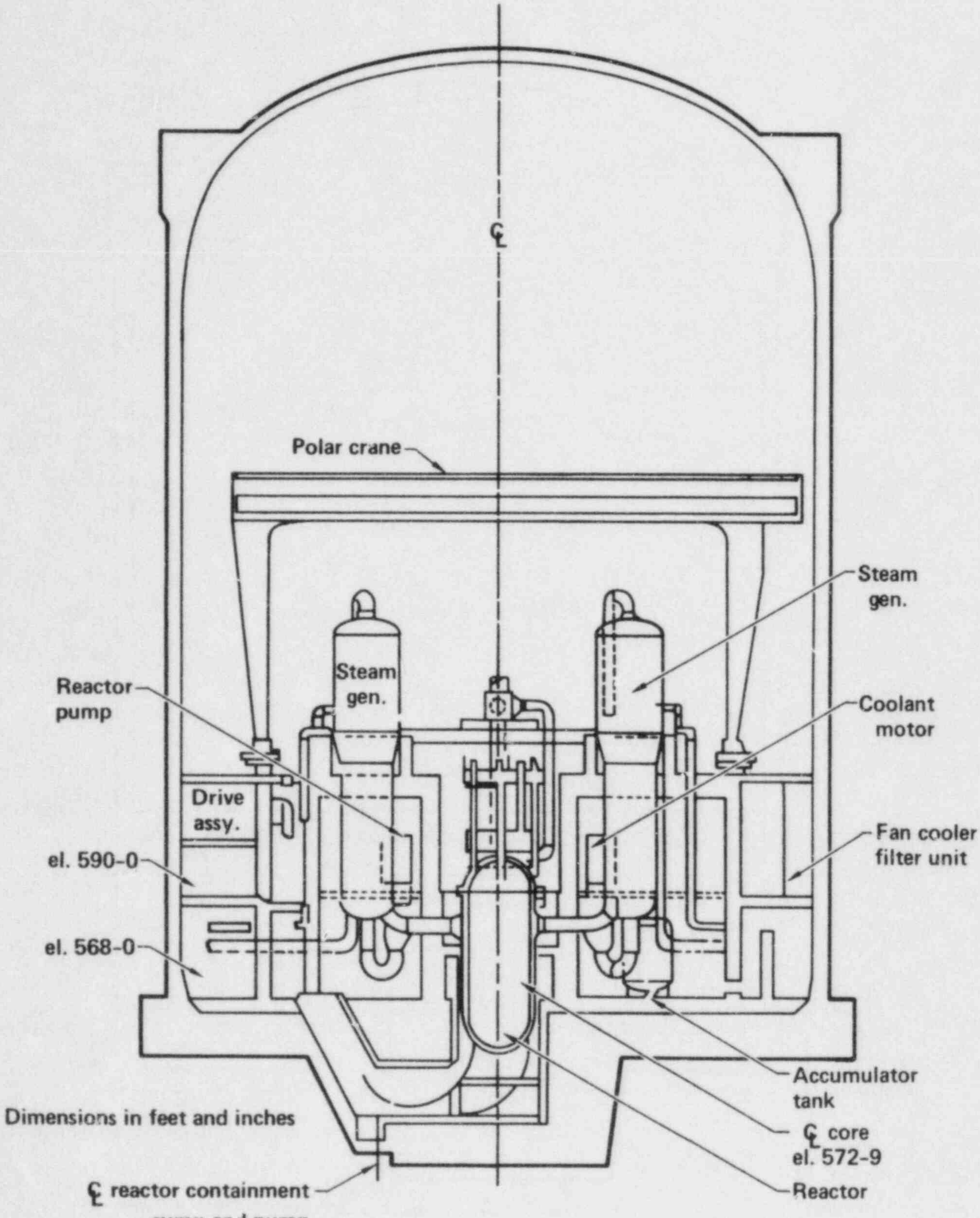


Figure 11. E-W section of containment building.

beam with a circular cross section, somewhat modified by rocking of the foundations. The spherical dome and ring girder act to stiffen the circular cross-section and also add mass to the system. Because of the large radius-to-wall thickness ratio (approximately 25) the shear stresses in the wall are predominately tangential and axial, as shown in Fig. 12.

The stress distributions due to ground motion (in one direction) are shown schematically in Fig. 13. The axial bending stress, σ_{ZZ}, varies linearly across the cross section as long as the response of the structure stays in the elastic range and local discontinuities are neglected. Due to the lateral inertia loading, both axial and tangential shear stresses are present. The point of maximum shearing stresses is 90° away from the location of the maximum axial bending stress. Figure 13(b) shows the typical shear stress distribution due to bending of a thin tubular beam.

The axial bending stresses are reacted by the concrete in compression, and by the vertical prestressing tendons and vertical steel reinforcement in tension. In the Zion containment structures, the tendons are stressed to approximately 60 to 65% of their ultimate strength over the life of the structure. For low levels of seismic excitation, the wall will behave essentially elastically. The concrete is effective in resisting shear and flexural tensile stress in this case. Only after the flexural tensile stress exceeds the prestress and the concrete cracks will the bonded reinforcing steel experience any load. The increase in load in the tendons will be small due to the very small increase in strain compared to the preload strain. This occurs because the strain resulting from a crack width is distributed over the length of the unbonded tendon. As the load is increased and the cracks widen, yielding will occur in the reinforcing steel and liner. When the inertia loads are reversed, buckling of the reinforcing steel and liner can occur and failure of the liner integrity can result since the steel alone must resist the compressive forces. Local spalling of the concrete outside of the reinforcing steel will result in loss of confinement for the steel and accentuate the failure. Based on dynamic loads computed using a beam element finite-element analysis, the median acceleration of the ring girder which induces failure is 9.0 g. Failure occurs at the intersection of the shell and foundation. The associated fragility curve is shown in Fig. 14. Note, as before, an in-structure acceleration was selected as the fragility parameter for computational convenience. The log-standard deviations representing random and modeling uncertainties were developed based on the specific material characteristics of the shell and its failure modes.

As inelastic response levels are reached, the tangential shear distribution changes. This shear "yielding" occurs due to reduction in dowel stiffness and loss of aggregate interlock as the cracks widen. Any loss of prestress will result in a significant reduction of shear resistance capacity, since only the gravity and vertical response loads are available for aggregate "friction." The <u>tangential shear</u> must then be resisted to a larger extent by the bonded reinforcing steel. The dowel action of the reinforcing steel depends on whether the concrete can confine the steel bars. Failure of dowel action can result from either crushing of the concrete or bond splitting along the bar. Initial consequences of shear type failure will be potential failure of the liner and possibly some pipes. This level of failure is expected to occur when the equivalent elastic response at the location of the containment vessel ring girder reaches a median value of approximately 4 g. The fragility curve for this mode of failure is shown in Fig. 15.

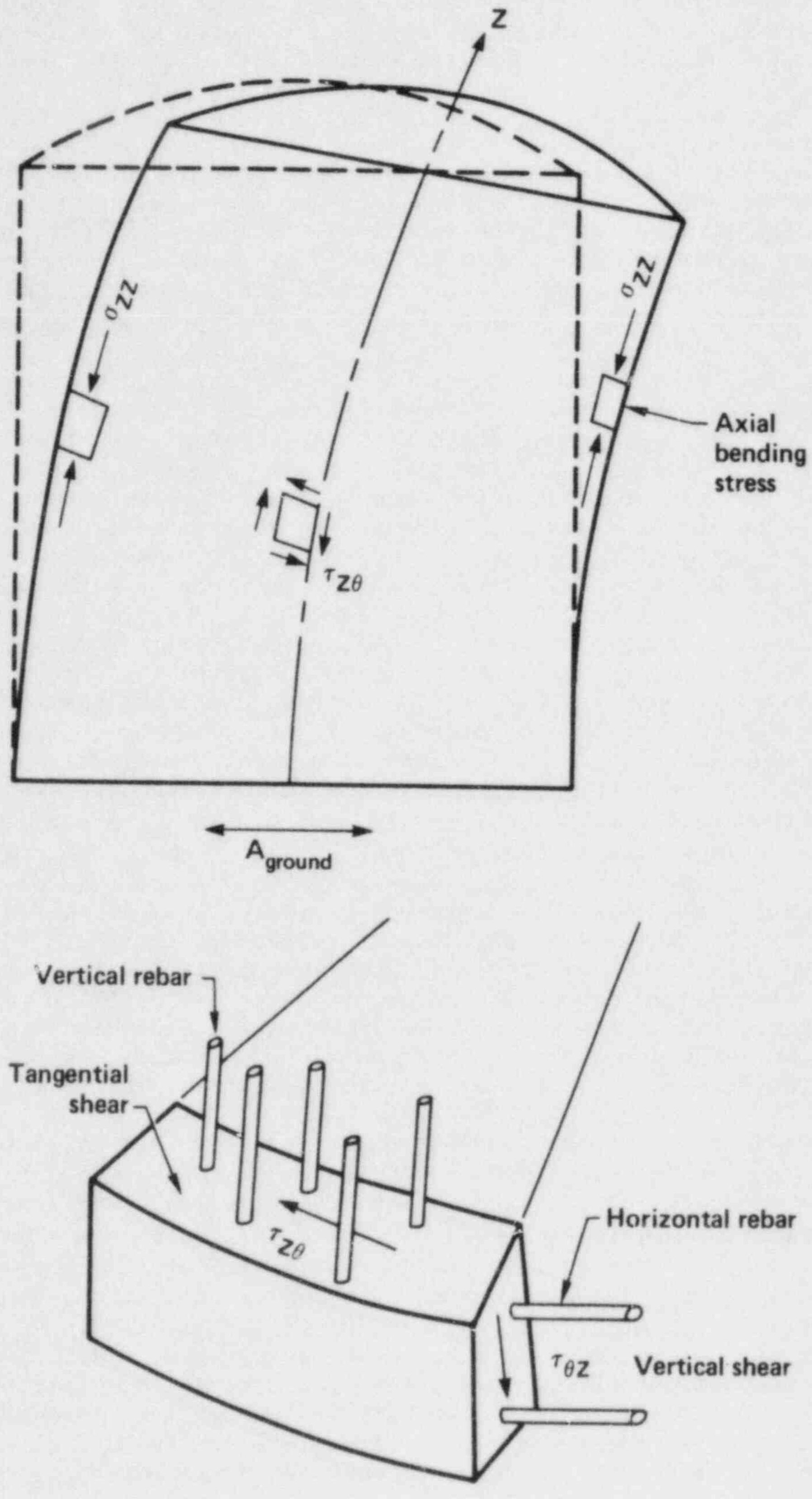


Figure 12. Shear stresses in containment building wall.

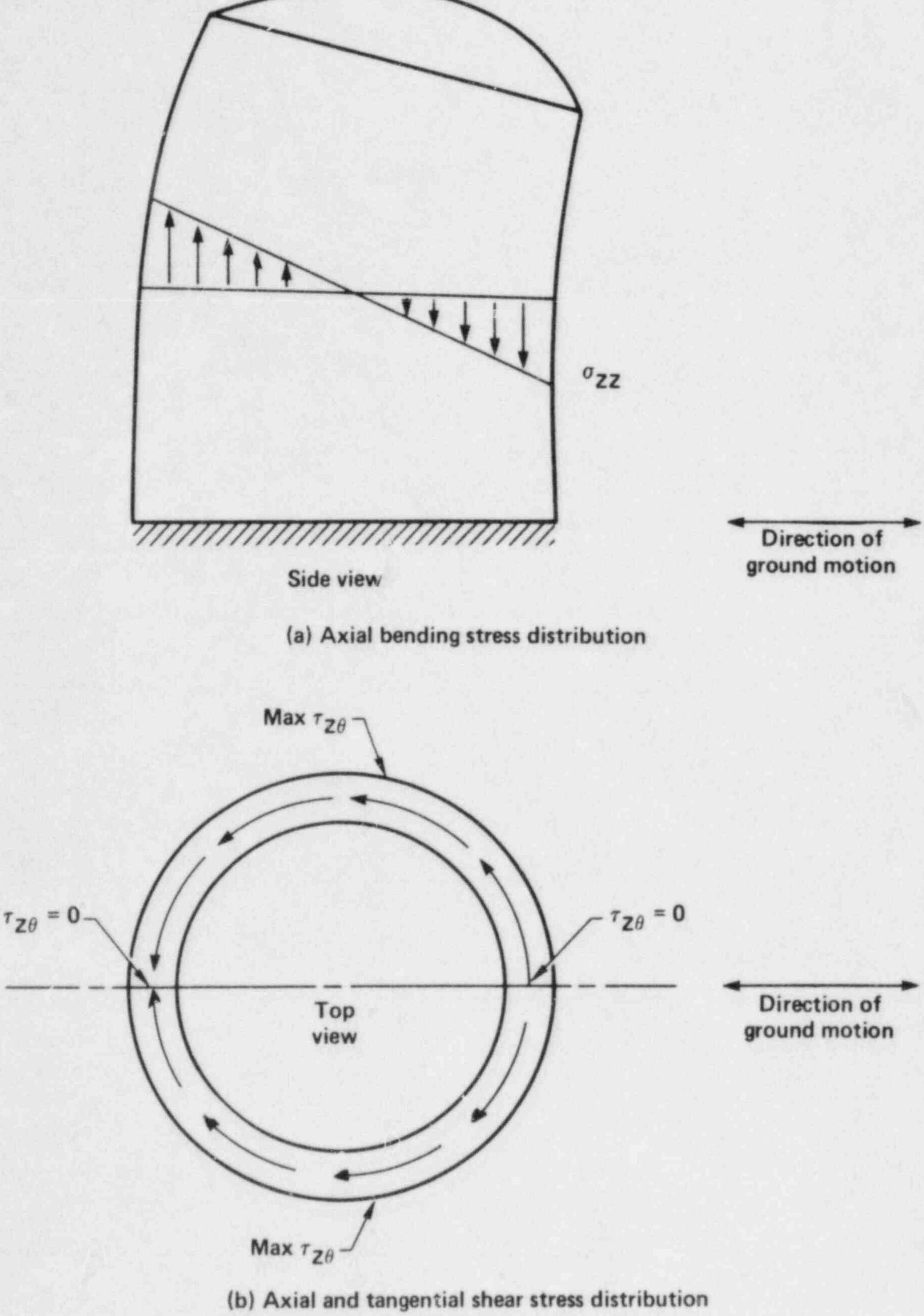


Figure 13. Stress distributions in containment building wall.

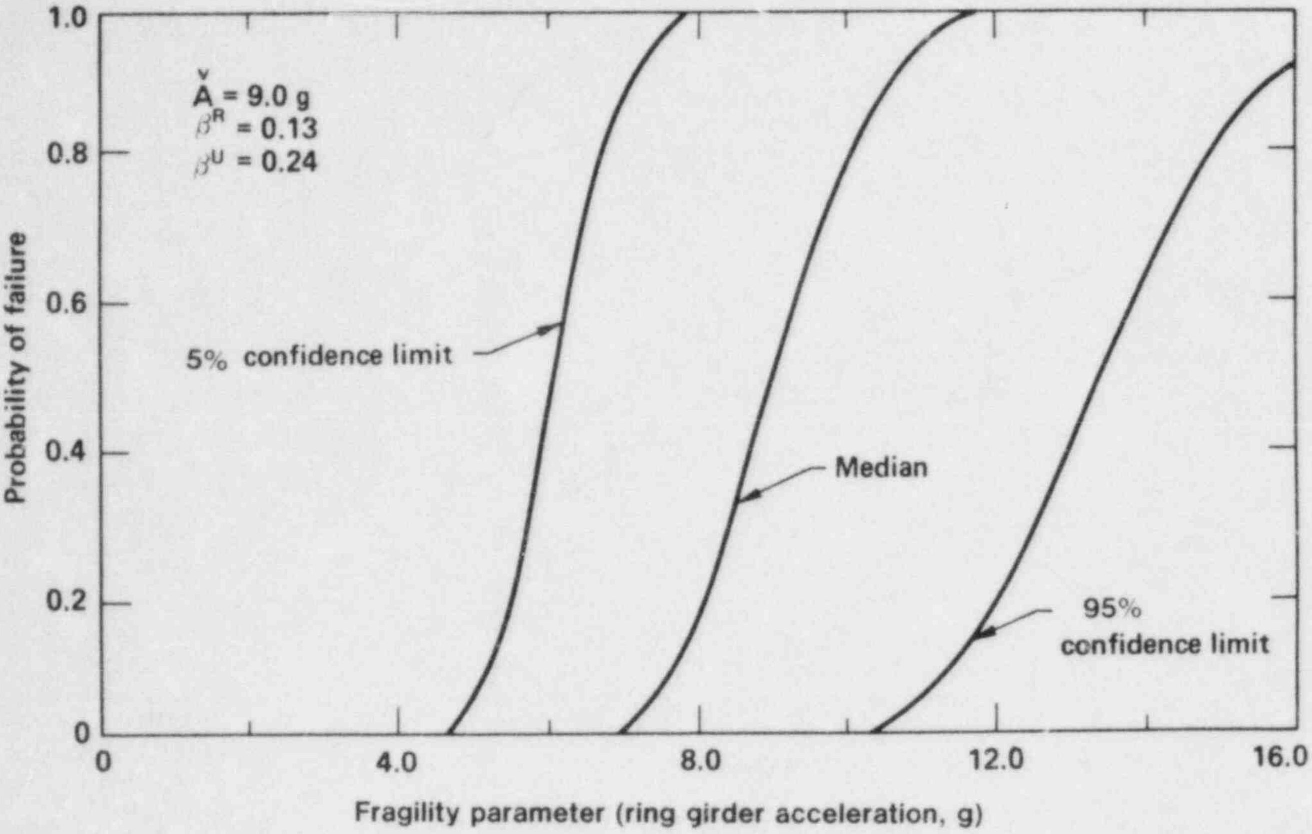


Figure 14. Flexural failure of reactor building containment wall.

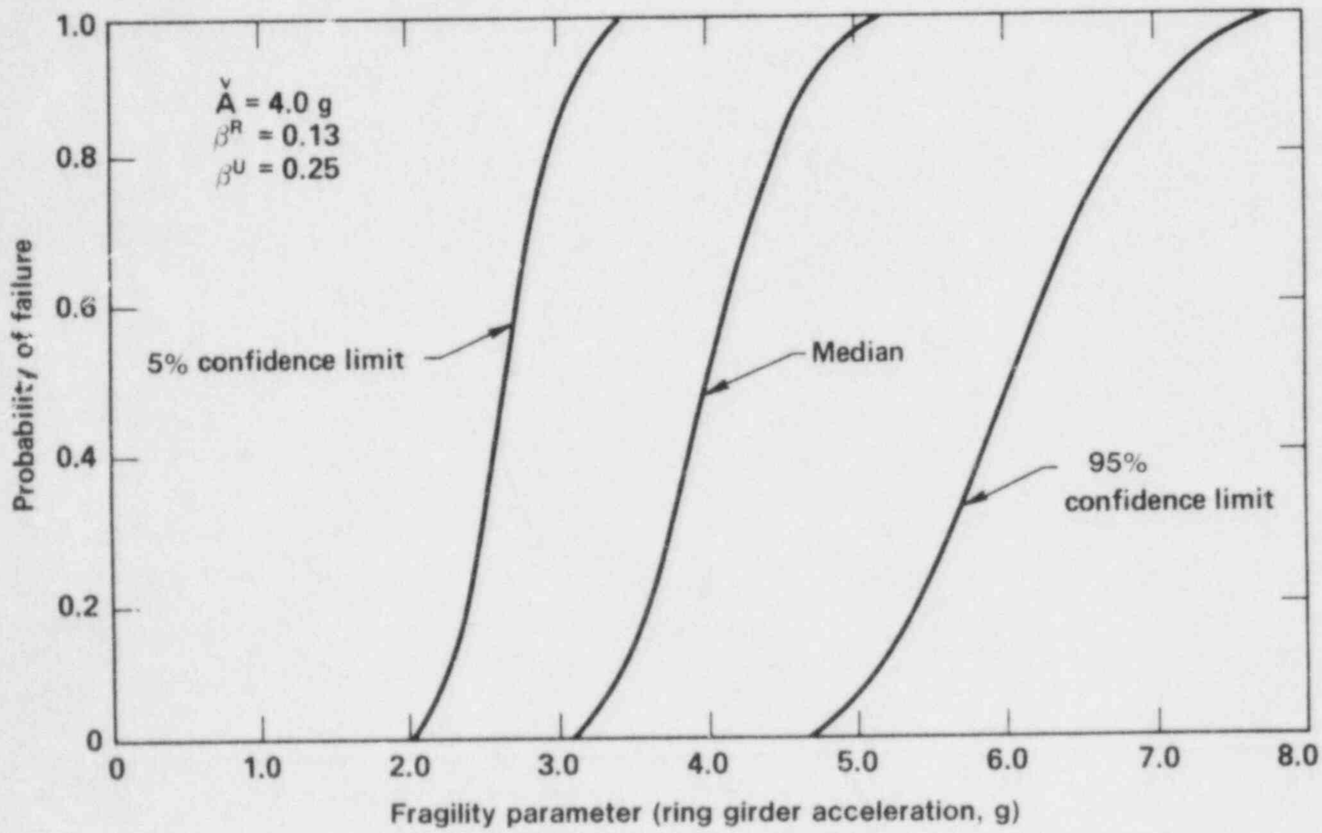


Figure 15. Shear failure of reactor building containment wall.

The vertical shear stresses are carried by the horizontal steel reinforcing and by concrete aggregate interlock. The horizontal steel reinforcement, however, does not extend continuously across the buttresses. Here, the concrete segments of the containment wall are separated by steel buttress plates. Shear anchors are provided to transfer the vertical shear across the buttress plates, and frictional forces also serve to transfer the shear across the plates. The friction forces are high because the circumferential prestress tendons overlap at the buttress, thus doubling the compressive preload stress on the buttress plate. However, shear anchors were provided only on one side of the buttress plate as shown in Fig. 16. Thus the buttresses are a site of

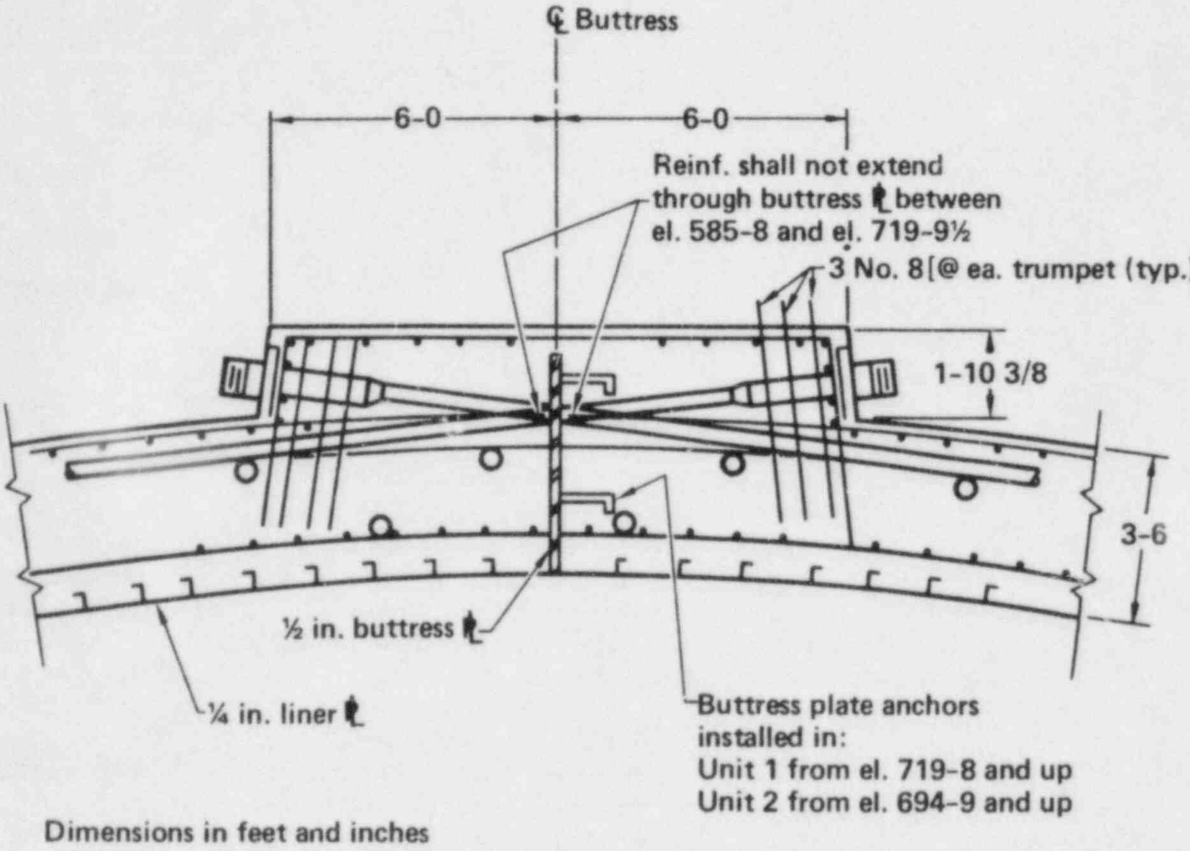


Figure 16. Section of containment wall buttress.

potential vertical shear failure. Their failure, with corresponding loss of liner integrity is expected to occur at a median acceleration at the ring girder of approximately 4.2 g. The fragility curve for vertical shear failure is shown in Fig. 17.

It should be noted, however, that the addition of other dynamic loads can significantly influence the seismic capacity of the containment vessel. If loss-of-coolant accident (LOCA) internal pressure is present during the earthquake (or aftershocks), a very substantial amount of the prestress capacity will be required to withstand the pressure loads. Consequently, a much lower strength capacity will be available to withstand the seismic loads. This is true not only for the capacity of the vertical system required to resist flexure and transverse shear but also the horizontal system. Typically, the horizontal preload system does not need to resist large increases in load

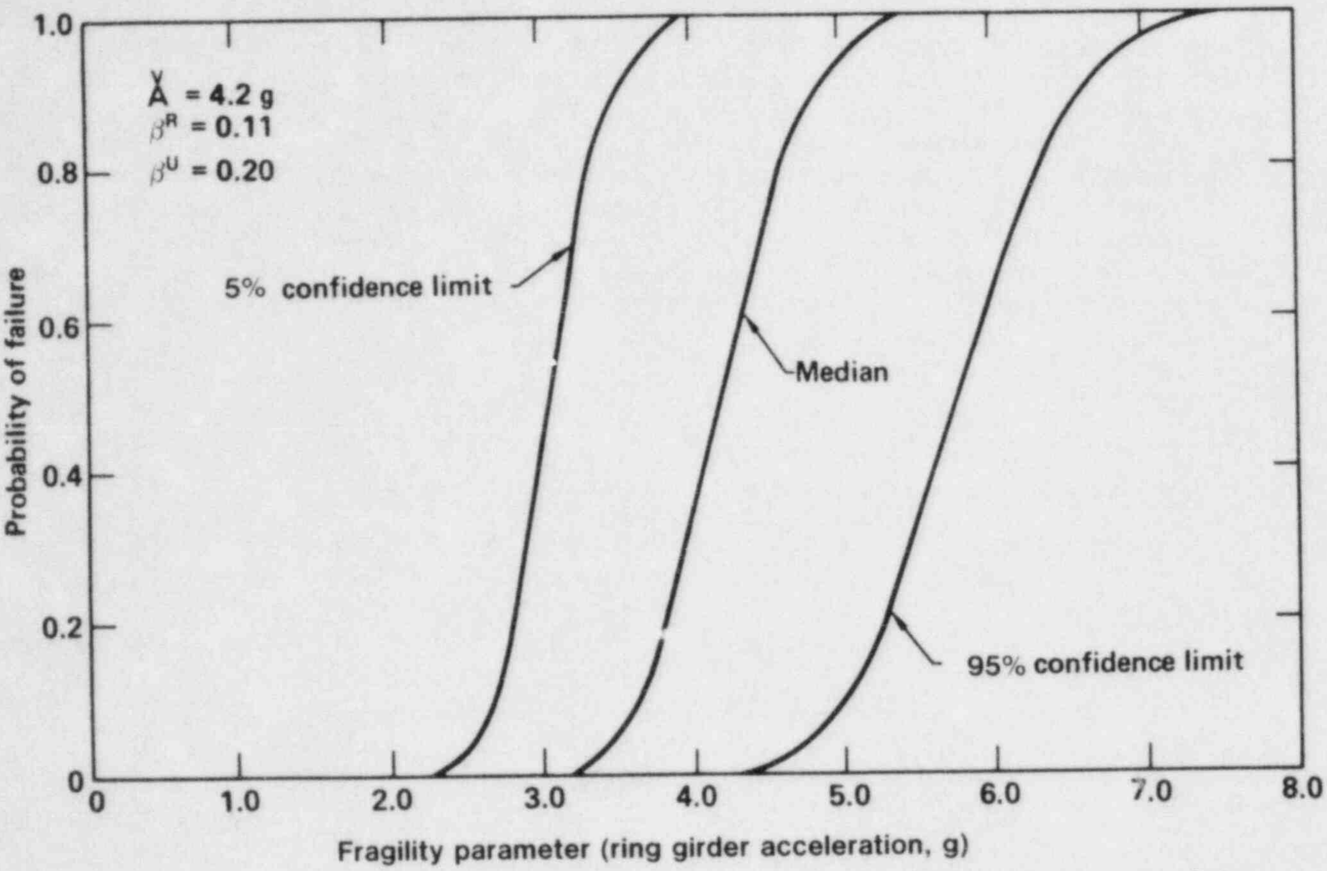


Figure 17. Vertical shear failure at reactor building buttress plates.

as the result of flexural loads. However, in the Zion reactor buildings the circumferential preload is required to transfer the VQ/I shear across the vertical buttress plates. In view of the low probability of a concurrent LOCA, however, these effects were not investigated as part of the current study.

The concrete internal walls and supporting structures were also examined for potential failure modes. These concrete structures consist of a ring wall, the reactor biological shield wall, the fuel-handling pool, and the operating floor. The reactor coolant system (which consists of the reactor vessel, the steam generators, the pressurizers, and the reactor coolant pumps) is located within the ring wall and laterally supported by the ring wall and the shield wall. The polar crane is also supported by the ring wall.

A major failure of the concrete internal structure could lead to a total failure of the reactor coolant system due to loss of support for major components or impact on the coolant system with consequent failure of the pressure boundary. Thus, attention was focused on the failure of any structural elements of the concrete internal structures that could lead to such an event.

The controlling seismic failure mode for the internal structures is shear failure. The lowest capacity failure mode for the internal walls is the shear failure of the weld for the 1-3/8-in.-diam dowels at the interface of the 3-ft and 9-ft slabs and simultaneous shear failure of the vertical portion of the 3-ft-thick slab in the sump. This will result in loss of liner integrity and

possibly pipe and conduit failure. The median expected acceleration for shear failure of the concrete internals is approximately 5.0 g at the operating floor elevation.

One of the internal structures was found to have a significantly low failure mode. This was the possible failure of the pressurizer enclosure, a reinforced concrete structure at the operating floor which encloses the portion of the pressurizer above the operating floor (Fig. 18). The pressurizer enclosure has 1-ft-thick poured-in-place concrete walls on three sides. The walls are approximately 39 ft tall. The fourth wall consists of several pieces of removable concrete panels. The roof is constructed of a 1-ft-thick removable concrete slab bolted down to the two walls which are perpendicular to the roof slab span (Fig. 19).

No diaphragm action is provided by the roof slab due to lack of roof connection to the other two walls and the discontinuity at the center of the roof slab. Because of the open section, considerable torsional response results. The failure mode of the wall results mainly from yielding and failure of the wall reinforcing and eventual collapse of the roof and removable panels. This mode of failure is not expected to cause liner damage or to result in damage of any of the remainder of the building structure. However, damage to the pressurizer and its associated piping, including possible rupture of the reactor coolant pressure boundary, should be expected following collapse of the enclosure. The median effective capacity for this structure is approximately 1.2 g at the reactor building operating floor. Figure 20 shows the fragility curve for this failure mode.

3.3.3 Summary of Zion Reactor Building Fragilities

In summary, the three lowest failure modes for the containment shell, internal walls, and internal structures were found to be:

1. Collapse of pressurizer roof enclosures, at 1.2-g acceleration of operating floor slab.
2. Tangential shear failure at base of containment shell, at 4.0-g acceleration at ring girder.
3. Axial shear failure along buttress plates, at 4.2-g acceleration at the ring girder.

No examination was made of possible failure modes associated with soil liquefaction, surface faulting, or sliding. A preliminary investigation of the effect of base slab uplift was conducted, however, and a summary discussion follows.

When one considers the range of earthquakes for the seismic risk analysis, it is essential to include consideration of phenomenon which may not be of major consequence in the design process. One such consideration is soil-foundation separation or uplift. For structures such as the Zion reactor building (i.e., of large height-to-diameter ratio), overturning moments due to its seismic response lead to a prediction of uplift. Soil-foundation separation, per se, is not critical. The consequences of uplift on structure response are usually a reduction in member load and introduction of additional high frequency response. These effects are generally considered to be of second order, particularly for a seismic risk analysis, and were not explicitly included in our analysis. In addition, the potential exists for large soil pressures to

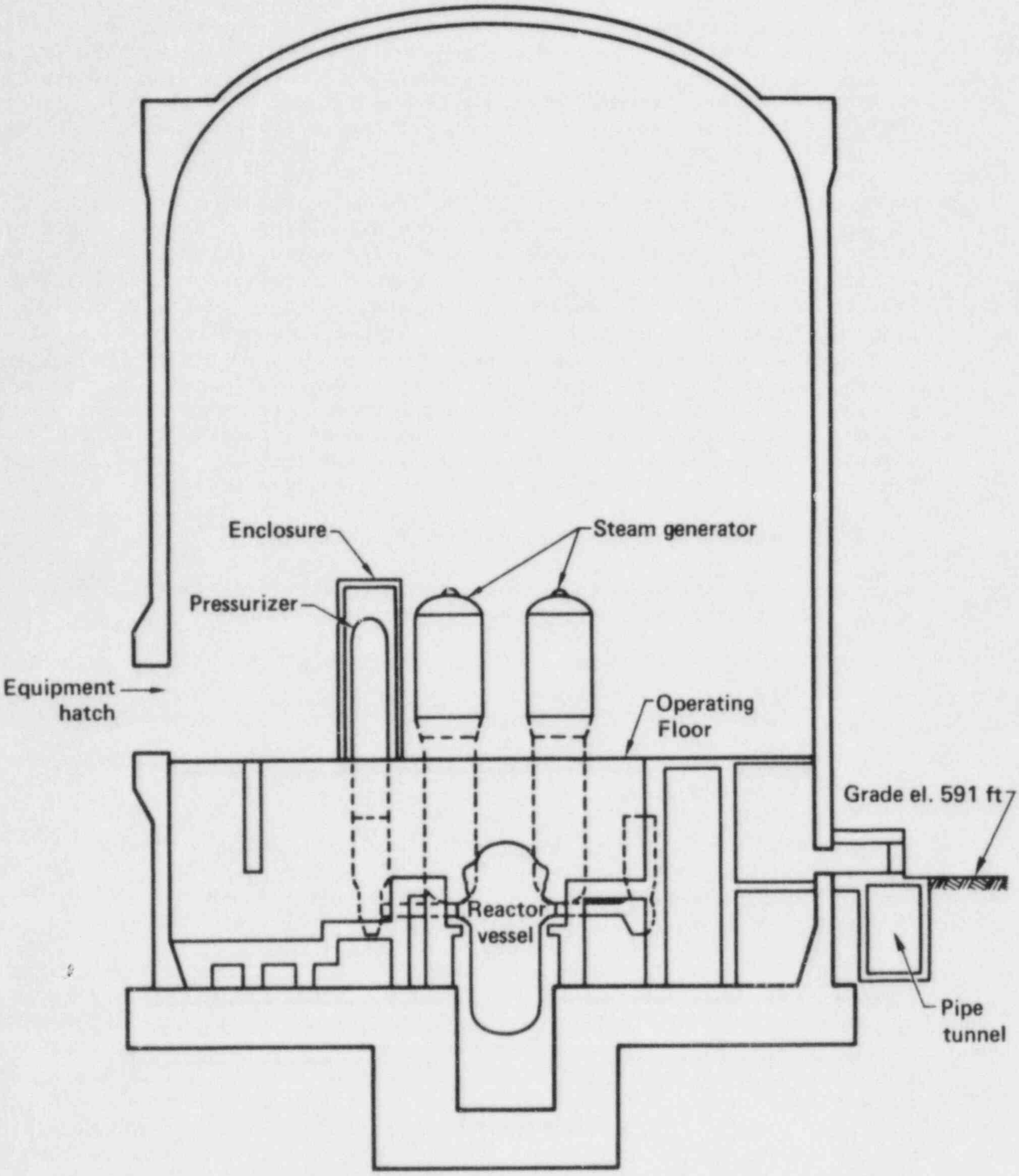


Figure 18. N-S section of containment building.

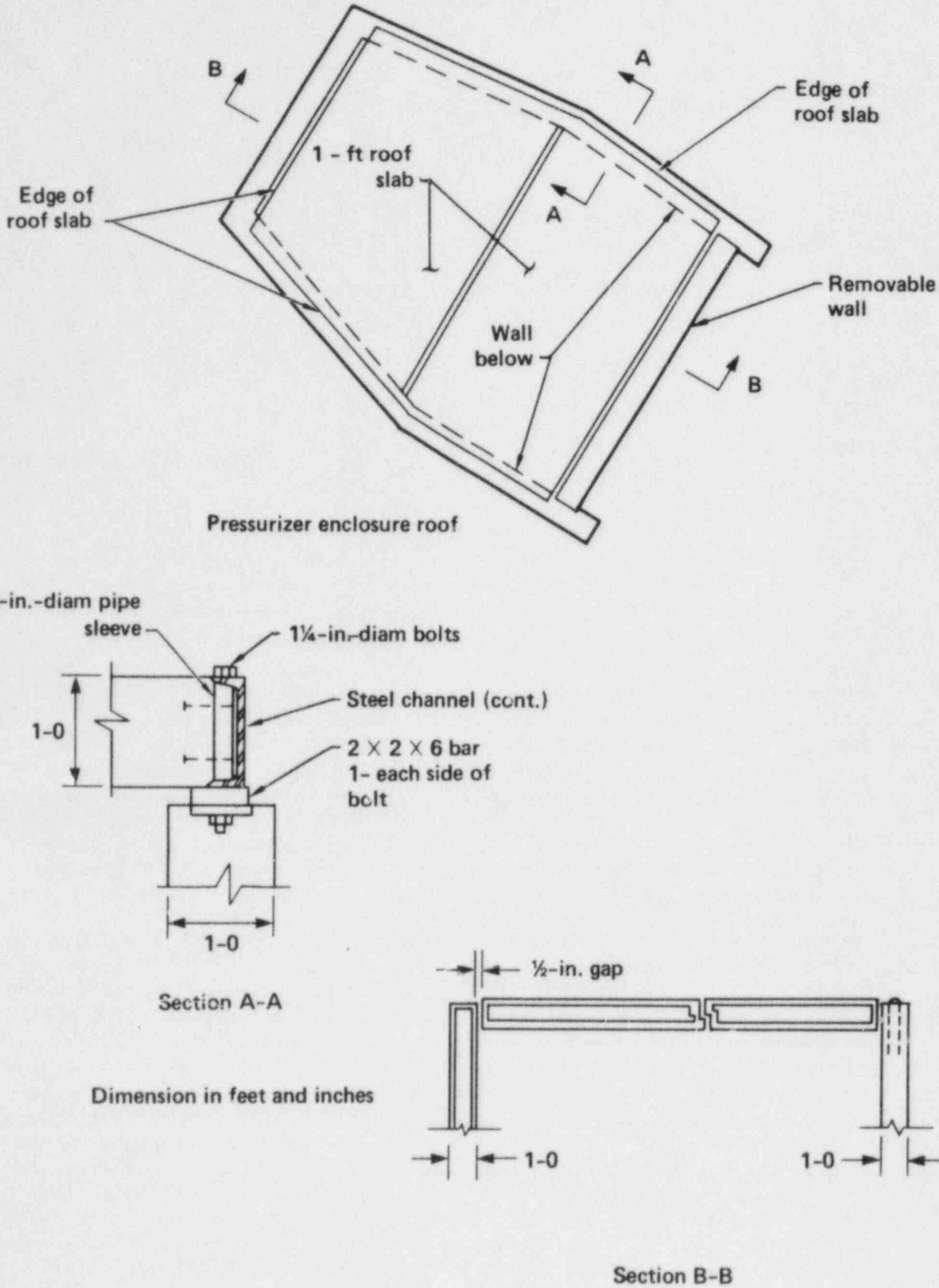


Figure 19. Plan and sections of pressurizer enclosure.

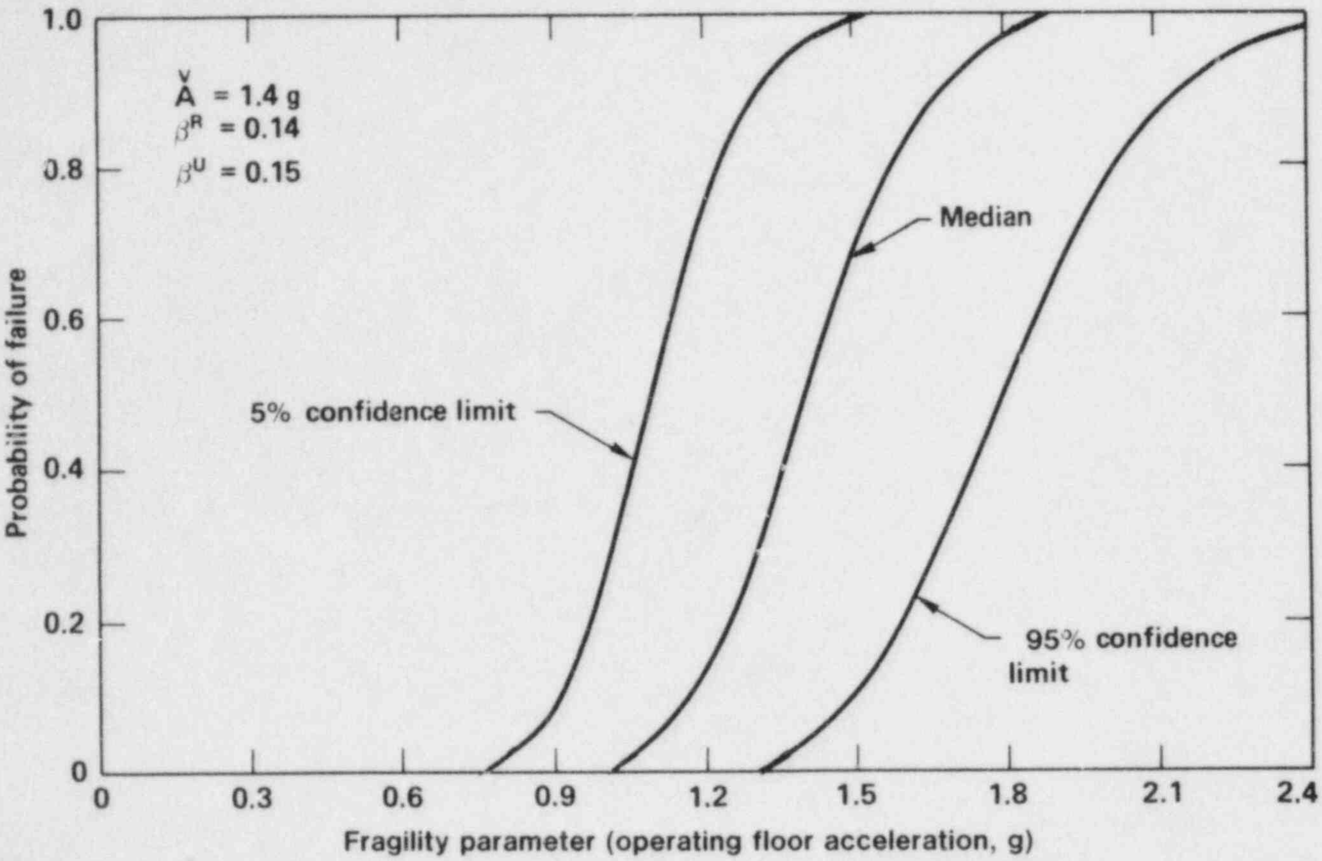


Figure 20. Collapse of reactor building pressurizer enclosure.

occur due to a redistribution of stress once tension in the soil is predicted. Peak toe pressures may, in fact, increase to the point of exceeding the soil bearing capacity causing failure. A further consequence of uplift itself and potential soil failure is increase in relative displacements between adjacent structures which then causes failure of interconnecting pipes due to the large relative motions. At Zion, large relative displacements would be predicted to occur between the reactor building and the AFT complex. In the SSMRP final Zion analyses, we included basemat uplift as a potential failure mode of interconnecting pipes.

To estimate the excitation levels at which uplift and soil failure occurred, a series of linear analyses was performed using SMACS for the range of earthquakes. A post-processing of results combined each horizontal response with the vertical response to determine overturning moments and peak toe pressures. In the SMACS analyses, ensembles of earthquakes represented the seismic input, and variations in soil and structure input parameters were included. In the post-processing, the effects of dead weight, buoyancy, and an estimate of the position of response distributed to the side soil were taken into account. The results were estimates of overturning moments, peak toe pressures, and vertical displacements based on our linear response calculations. Such an analysis greatly overpredicts peak soil pressure. Several studies (Refs. 20,21) have made comparisons between peak toe pressures calculated by linear and nonlinear analyses. Using these data as a basis, the linearly calculated toe pressures were adjusted by nonlinear effects. These scaled values of toe pressures were compared with the ultimate soil capacity of 45 KSF. A median toe pressure of 45 KSF was estimated at a peak horizontal

acceleration of the reactor building foundation of 0.70 g.

Although soil failure is not expected to result in failure of the structure directly, the resulting increased relative displacement of the reactor building can lead to impact between the reactor and auxiliary building. In the Zion reactor containment vessels, no tangential (or hoop) reinforcing steel was included on the inside surfaces of the containment shell. Consequently, concrete spalling and subsequent liner damage is expected at relatively low levels of additional displacement once the circumferential prestress is overcome. No impact is expected to occur for reactor building displacements less than approximately 0.8 in. at elevation 642 ft, regardless of phasing. The fragility curves associated with impact between the reactor buildings and auxiliary buildings are shown in Fig. 21.

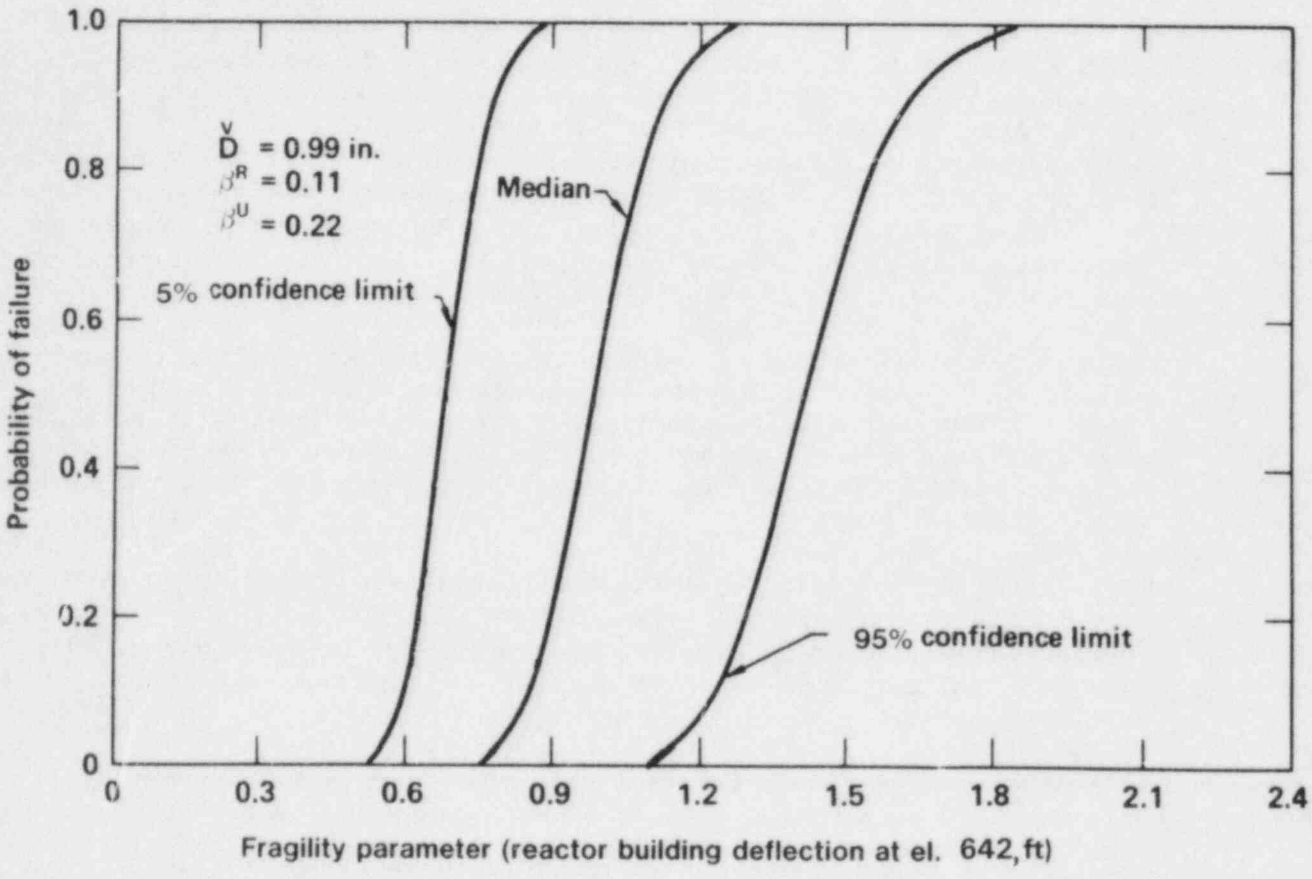


Figure 21. Impact between reactor and auxiliary buildings.

3.4 Auxiliary/Fuel Handling/Turbine (AFT) Building

The AFT complex of the Zion nuclear power plant consists of the following buildings: turbine building, auxiliary building, fuel handling building, and the diesel generator rooms. All four buildings are structurally interconnected at different levels through walls, roofs, and floor slabs. The general layout of the complex is given in Fig. 7.

3.4.1 Description

The turbine building, a 678-ft by 130-ft structure, is symmetrical about an

approximate east-west centerline. Most of the turbine building (i.e., turbine and condenser supporting structures) is founded on a reinforced concrete foundation mat with varying thickness. The remainder of the turbine building, which is not located over the foundation mat, is supported by concrete columns which extend downward to the spread footings.

The turbine foundations are massive reinforced concrete space frames that are continuous with the piers of the condenser walls and rise from elevation 592 ft to the main floor of the turbine building at elevation 642 ft. The turbine foundations are isolated from the major turbine building floors at elevations 617 ft and 642 ft by a 1-in. gap.

The ground floor, a 3-ft-thick reinforced concrete slab, is continuous with the floor slab at the same elevation in the auxiliary building. At elevations 617 ft and 642 ft, the floors were constructed of poured-in-place concrete slabs supported by vertical and horizontal braced steel framing. The slabs are continuous, through the steel floor framings and concrete slabs, with the floor slabs at the same elevations in the auxiliary building. The west side vertical braced frame, located between the turbine building and the auxiliary building and diesel generator rooms, is encased in reinforced concrete walls from ground level up to the auxiliary building roof level at elevation 668 ft. The other walls above ground, including the wall above the auxiliary building roof level, are constructed of fluted metal sidings.

The roof was constructed of 3-1/2-in.-thick precast concrete channel slabs covered with 1-in. rigid insulation and is supported by braced steel roof framing. The roof framing consists of steel roof girders, wide flange roof beams, and double-angle diagonal bracings. A minimum of three 7/8-in.-diameter bolts and 3/8-in.-thick gusset plates were used for the connections of the diagonal bracings.

The lateral force resisting systems of the turbine building are the steel braced frames along all four sides of the building. Schedule 40 pipes were used as diagonal bracing elements for the braced frames. Fluted metal sidings were attached to the girt system of each vertical braced frame to enclose the turbine building.

The tee-shaped auxiliary and fuel handling building is structurally continuous with the turbine building. A common wall joins the two structures as shown in Fig. 7. Structural connectivity between the two buildings is further provided by continuous floor slabs at various levels. The diesel generator rooms are an integral part of the structural complex. The auxiliary building, the fuel handling building, and the diesel generator rooms were all designed as Class I structures.

Above grade, the lateral force resisting system is a combination of braced structural steel frames and concrete slabs and walls. Vertical braced steel frames were erected on foundaton walls around the periphery of the auxiliary-fuel handling building and diesel generator rooms. Various diameter steel pipe was used for the diagonal bracing. The entire vertical braced frames were then encased in reinforced concrete walls which form the shear wall system. The floors are reinforced concrete slabs supported by horizontal braced steel framing. At places where heavy floor loads were expected, shear studs were used at the top flange of the steel floor beams to achieve a composite action. The roofs of the auxiliary building and diesel generator

rooms were constructed of a poured concrete slab supported by braced steel roof framing at elevations 668 ft and 658 ft.

3.4.2 Turbine Building Failure

The turbine, auxiliary, fuel handling, and diesel generator buildings form a single combined structure. Failure of one part of the structure, while not necessarily resulting in failure of the entire complex, will at least influence the dynamic response characteristics of the overall building. Since no Seismic Category I equipment is located in the turbine building with the exception of the 48-in.-diameter service water pipes that are embedded in the turbine building base slab, turbine building failure modes were investigated only to the extent they could directly cause damage or failure to Category I structures or equipment.

The lowest potential mode of failure consists of failure of the turbine building roof system. There are two horizontal lateral force resisting systems in the turbine building roof which are effective in collecting and transmitting lateral inertia forces to the vertical shear resisting systems. The first system consists of the precast concrete channel slabs. The second system is the braced steel roof truss. No positive connection of the roof channel slabs to the braced steel roof truss is provided. The roof inertia force is transferred to the vertical resisting systems by the roof channel slabs only through the friction forces developed between the channel slabs and supporting steel members. The channel slabs span in the east-west direction. Thus, under the east-west direction ground excitations, only half of a channel slab weight is effective in producing friction forces and resulting couples to transfer the roof inertia force to the end vertical braced frames. Therefore, the diaphragm capacity of the first horizontal force resisting system is very low, and sliding between adjacent concrete channel slabs and between the slabs and roof beams will occur at low acceleration level. However, sufficient restraint will be provided by the parapet walls to limit motions of the roof slabs and prevent them falling, provided the horizontal roof braced frame remains effective.

The roof braced frame will resist the roof inertia force as soon as sliding begins to occur in the roof channel slabs. The steel roof framing system consists of roof girders, roof beams, and double angle diagonal bracing members. Due to the high aspect ratio (approximately 5) of the turbine building, the roof frame is quite flexible. For north-south response, sliding of the roof slabs is restrained by a parapet wall. Loss of this restraint capacity can be expected at a median acceleration response of the roof of approximately 0.7 g.

For both north-south and east-west excitation, it is expected that virtually all the roof slabs will fall inside the turbine building. This may be expected to result in loss of the turbine units as well as possible loss of equipment which is located under any open hatches or those with light steel gratings under the operating floor. It is not considered possible that falling roof slabs could damage the service water pipes. Although the steel framing in both the roof frame and the vertical braced frames may be expected to be damaged, it is expected to remain standing after loss of the concrete roof slabs. This relatively lightweight structure is then expected to withstand substantially higher excitation levels.

Other modes of failure involving impact between the turbine pedestal and the turbine building floor slabs or shear wall failures at the lower elevations of the turbine building, while resulting in structural damage to the turbine building and equipment within this structure, are not expected to result in damage to any safety-related equipment. Therefore, no fragility curves are provided for any of the turbine building failure modes.

3.4.3 Auxiliary Building Failure

The lowest significant structural failure mode for the auxiliary building consists of failure of the common shear wall between the auxiliary building and the turbine building. At elevations above ground level, structural steel braced frames are encased in the concrete shear walls and floor and roof slabs. With one or two exceptions, no shear connectors or reliable bond between the steel members and concrete exists. Thus, the concrete and steel tend to behave as a redundant system. Due to its relative flexibility, the steel frame structure carries little load as long as the concrete wall and floor system remains intact. Once failure of the concrete occurs, load is transferred to the braced frame system. However, the capacity of the steel framing is significantly less than that of the concrete so that once failure of the concrete occurs, failure of that part of the structure will rapidly follow provided there is no redundant structure available to carry the redistributed seismic loads.

This failure is expected to initiate at elevation 592 ft where the composite wall construction consisting of braced steel framing with in-fill reinforced concrete panels begins. In this wall, shear studs are welded to the steel column webs to ensure a composite action between the concrete panels and the braced steel frame and to provide the continuity of the concrete shear wall across the columns. After the common shear wall-braced frame fails, the shear load will be redistributed to the remaining shear walls at this story. However, because this wall resists a major portion of the load and contributes significantly to the story shear capacity, it is expected that failure of the remaining shear walls will immediately follow failure of the common wall. The median response acceleration capacity for the common turbine/auxiliary building shear wall is approximately 1.1 g at the control room floor slab in the north-south direction (Fig. 22). Note, as before, the capacity of the wall was first developed in terms of load in the wall and then related to control room floor acceleration for computational convenience.

At very slightly above the same median capacity, failures of the outermost east-west shear walls (column lines 5 and 35) are expected. Failure of these walls is expected to be initiated at elevation 592 ft from north-south excitation. Due to the torsional response in the structure, the east-west shear walls are highly loaded from north-south excitation. There are a number of redundant east-west shear walls between the diesel generator rooms as well as the auxiliary building at column lines 10 and 20 and other locations that can be expected to carry additional loads once the maximum capacity of the outermost walls is reached. Thus, although the outermost walls may be expected to reach their ultimate capacity and experience substantial cracking, the load will be transferred to adjacent walls and collapse of a significant part of the diesel generator rooms is not expected until higher levels of response are reached. There will then be a sequential failure of the shear walls from the extremities of the combined auxiliary building and diesel rooms propagating towards the center of the structure. The fragility curve for the

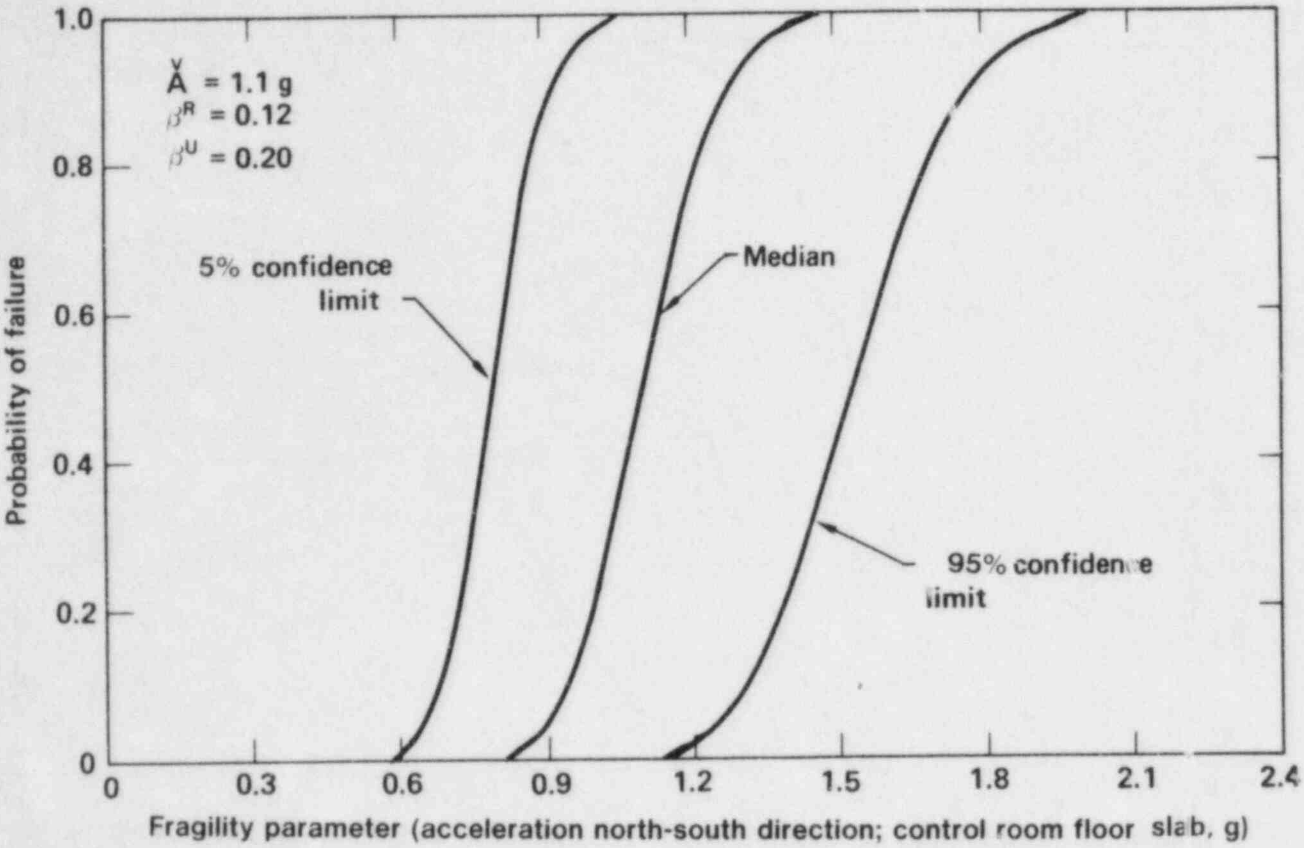


Figure 22. Failure of auxiliary shear walls due to N-S ground motion.

diesel generator building shear walls from north-south excitation is shown in Fig. 8. The median fragility parameter for this mode of failure is expected to be an east-west acceleration of the control room floor slab of approximately 1.1 g. The details of the analysis of this failure mode were presented in Sec. 2.2.3.

A number of concrete block masonry walls are located throughout the auxiliary building. For the most part, these walls are not load-bearing; they may support an unloaded concrete slab. The walls are typically constructed of 1-ft-thick concrete blocks, vertically reinforced and grouted. The evaluation of these walls was conducted using in-structure response spectra generated in the original design analysis scaled up to the response acceleration level required to cause failure. Failure of these walls may be expected to result in loss of function of any attached conduit or equipment but will be quite localized and will not affect any other structural member. The fragility curves associated with masonry walls at elevation 592 ft are shown in Fig. 23. The median fragility parameter associated with failure of the walls is approximately 1.7 g at the control room floor slab. Walls at lower elevations may be expected to have higher equivalent capacity.

3.4.4 Shear Wall Failure for East-West Excitation

The auxiliary building, including the diesel generator rooms and the fuel storage building, has higher seismic capacity to withstand east-west excitations than excitations in the north-south direction. This is because the structure is essentially symmetric about the east-west axis and very little torsional response results for east-west excitations.

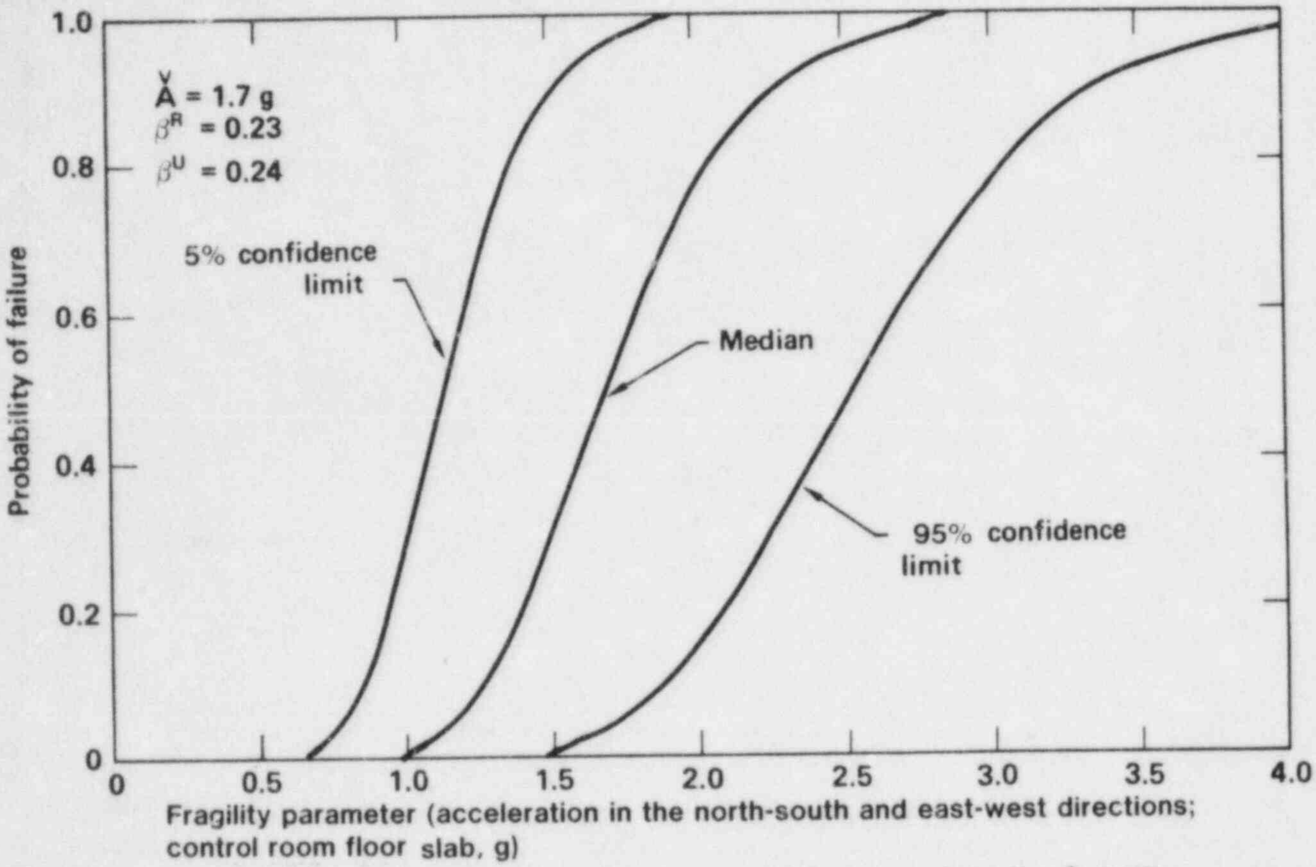


Figure 23. Collapse of masonry walls around control room.

Failure from east-west excitations is expected to be initiated in the shear walls along column lines 17 and 23 at elevation 592 ft. Failure of the walls along column lines 17 and 23 may be expected to result in failure of the two 400,000-gal refueling water storage vaults, which may result in flooding of some components in addition to other damage. The fragility curve for failure of the auxiliary building shear wall system for east-west excitation is shown in Fig. 24. The median fragility parameter for failure due to east-west excitation is control floor slab acceleration in the east-west direction of approximately 2.7 g.

The roof of the auxiliary building is a 21-in.-thick reinforced concrete slab. The lowest capacity failure mode consists of a shear failure of this slab along column line P due to north-south excitation. The roof slab is supported on a shelf angle so that only the upper reinforcing steel in the slab is effective. Loss of the roof diaphragm results in the requirement that the concrete walls resist the lateral inertia force in transverse bending. The capacity to this loading is relatively low. Failure of the reinforced concrete walls in bending about the weak axis then leads to collapse of the roof. The control room equipment at the floor immediately below (elevation 642 ft) will be severely damaged by the collapsed roof. The fragility curve corresponding to this mode of failure is shown in Fig. 25. The median fragility parameter is control room floor slab acceleration of approximately 3.0 g in the north-sourth direction (assuming no failures associated with the previous failure modes have occurred).

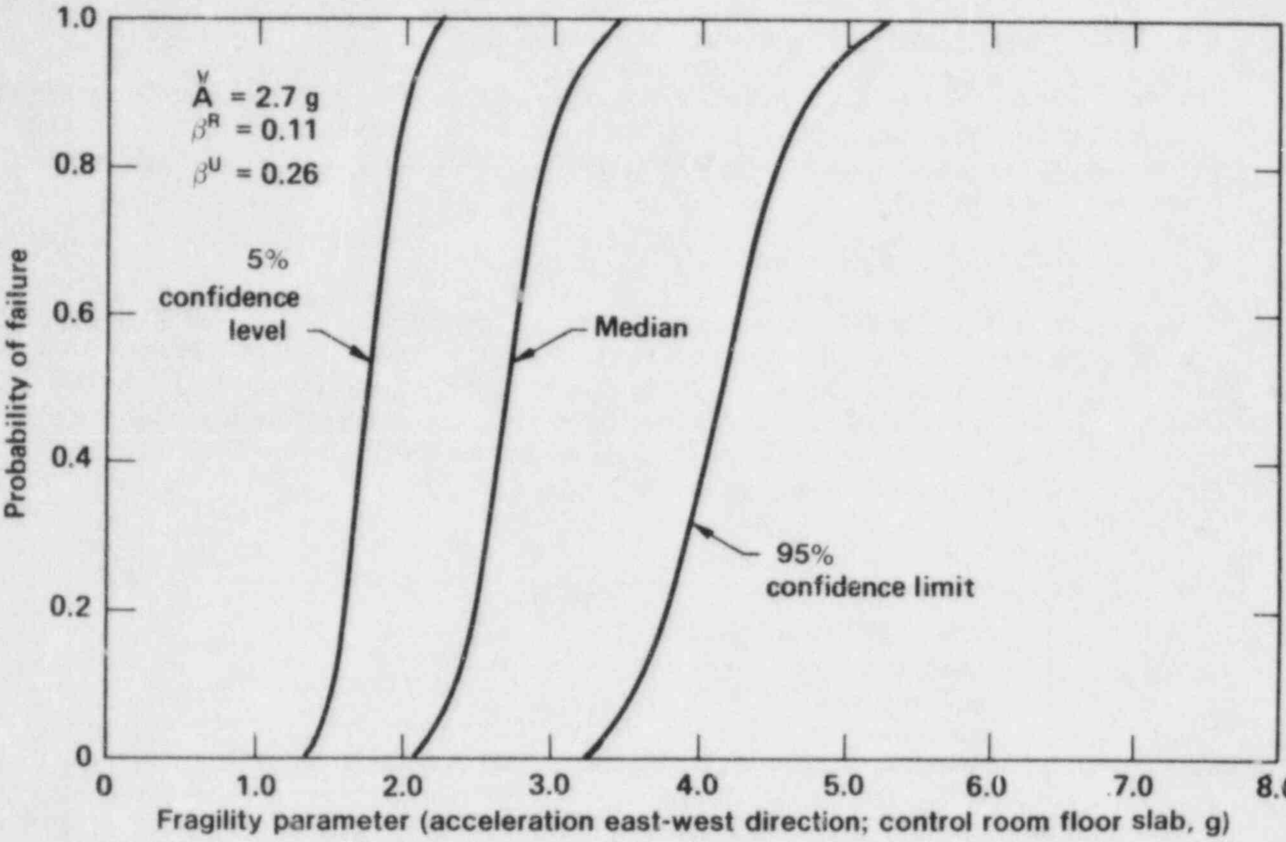


Figure 24. Failure of auxiliary building shear walls due to E-W ground motion.

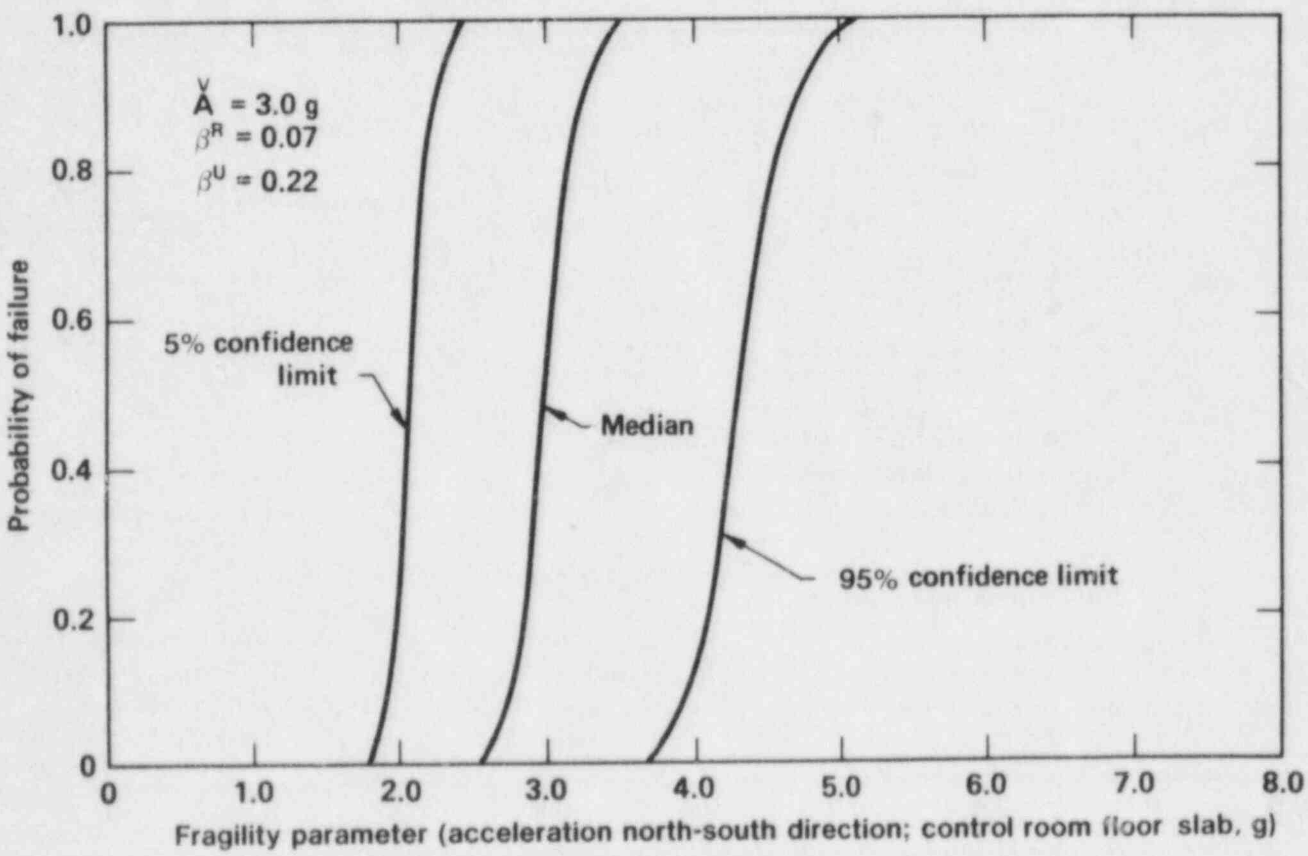


Figure 25. Failure of auxiliary building roof diaphragm.

3.5 Crib House (Intake Structure)

The crib house of the Zion Nuclear Power Plant is a partially open, box-like reinforced concrete structure which acts as a reservoir for the circulating water pumps and also houses the circulating water pumps, the service water pumps, and the fire pumps.

3.5.1 Crib House Description

The structure is founded on a rectangular reinforced concrete slab 6 ft thick, 170 ft long in the east-west direction and 179 ft wide in the north-south direction. The foundation slab is horizontal at elevation 545 ft on the intake end of the structure and slopes gently downward to another horizontal slab at elevation 537 ft under the pump suction area. A vertical section through the crib house is shown in Fig. 26.

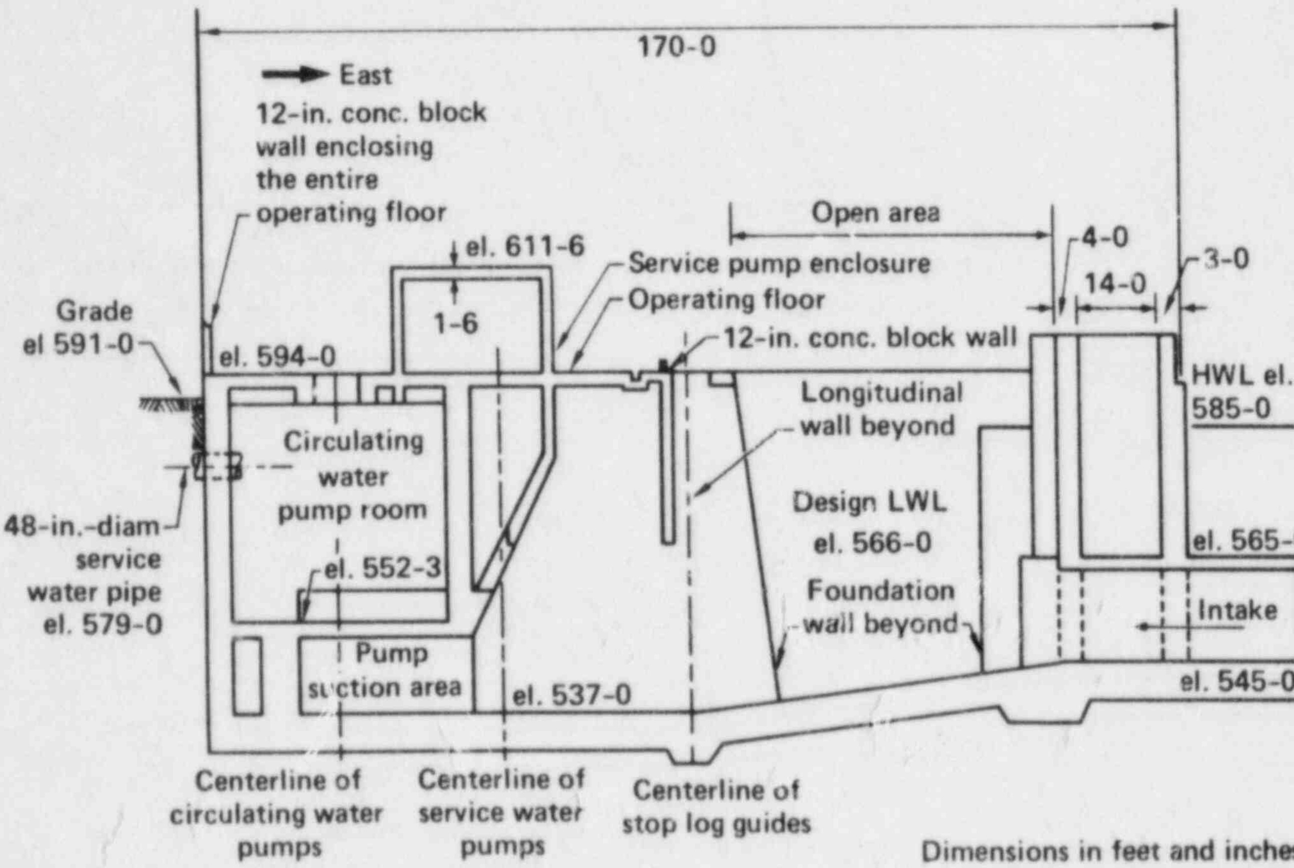


Figure 26. East-west section of the crib house.

The circulating water supply flows into the crib house through three 16-ft-diam circular intake pipes which extend approximately 2600 ft out into Lake Michigan. At the back or west end of the crib house, longitudinal walls (Fig. 27) form six cells that channel the flow of water into the pump suction areas. The longitudinal walls span from the foundation slab to the operating floor at elevation 594 ft. Except for one 7-ft-thick wall at the center of the crib house, all the longitudinal walls are 3 ft thick.

The operating floor is a 2-ft-thick reinforced concrete slab that covers the

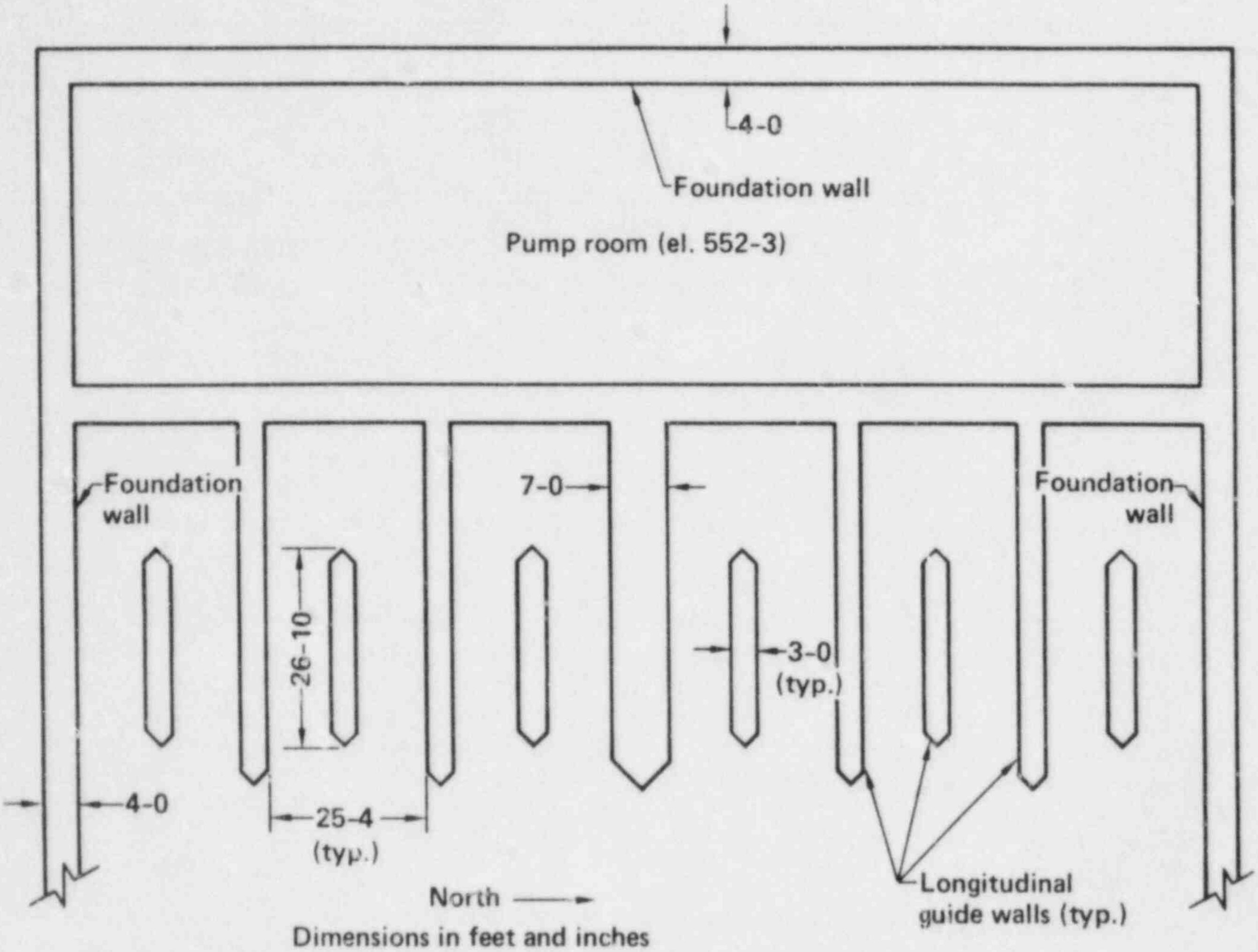


Figure 27. Section (plan view) at the pump suction area of the crib house.

total width and approximately one-half the length of the crib house. The operating floor supports six vertical service water pumps spaced equally across its width, the two fire pumps, and the reinforced concrete pump enclosure. The enclosure was constructed of 18-in.-thick reinforced concrete roof slab and walls. The roof plan of the pump enclosure at elevation 616 ft 6 in. is shown in Fig. 28. Several large openings in the roof slab are shown in the figure.

The circulating water pump room, located under the operating floor and behind the service water pumps, houses six vertical circulating water pumps. The room is enclosed by three foundation walls (4 ft thick), one 4-ft-thick vertical wall, the operating floor, and the floor slab at elevation 552 ft, 3 in. The pump floor slab (2 ft, 9 in. thick) is supported by short vertical walls below which is located the pump suction area. The circulating water pump drives are located on the operating floor directly over the circulating water pumps.

3.5.2 Crib House Failure

The primary safety-related function of the crib house is to provide a reservoir and to house the service water pumps. Thus, only failures that

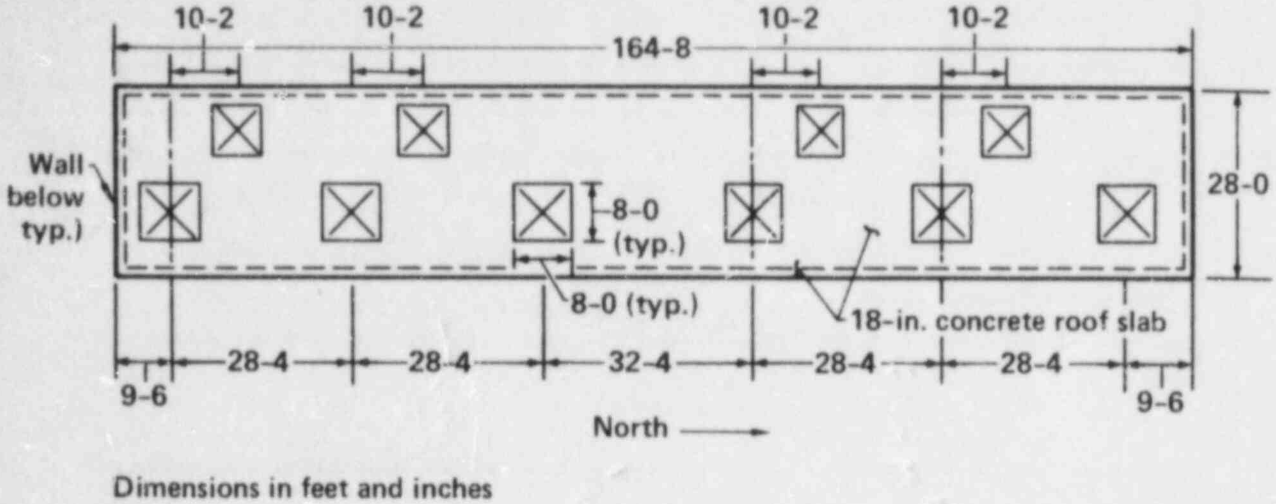


Figure 28. Pump enclosure roof plan (el. 616 ft 6 in.).

would interrupt intake and flow of water or cause failure of the service water pumps were considered.

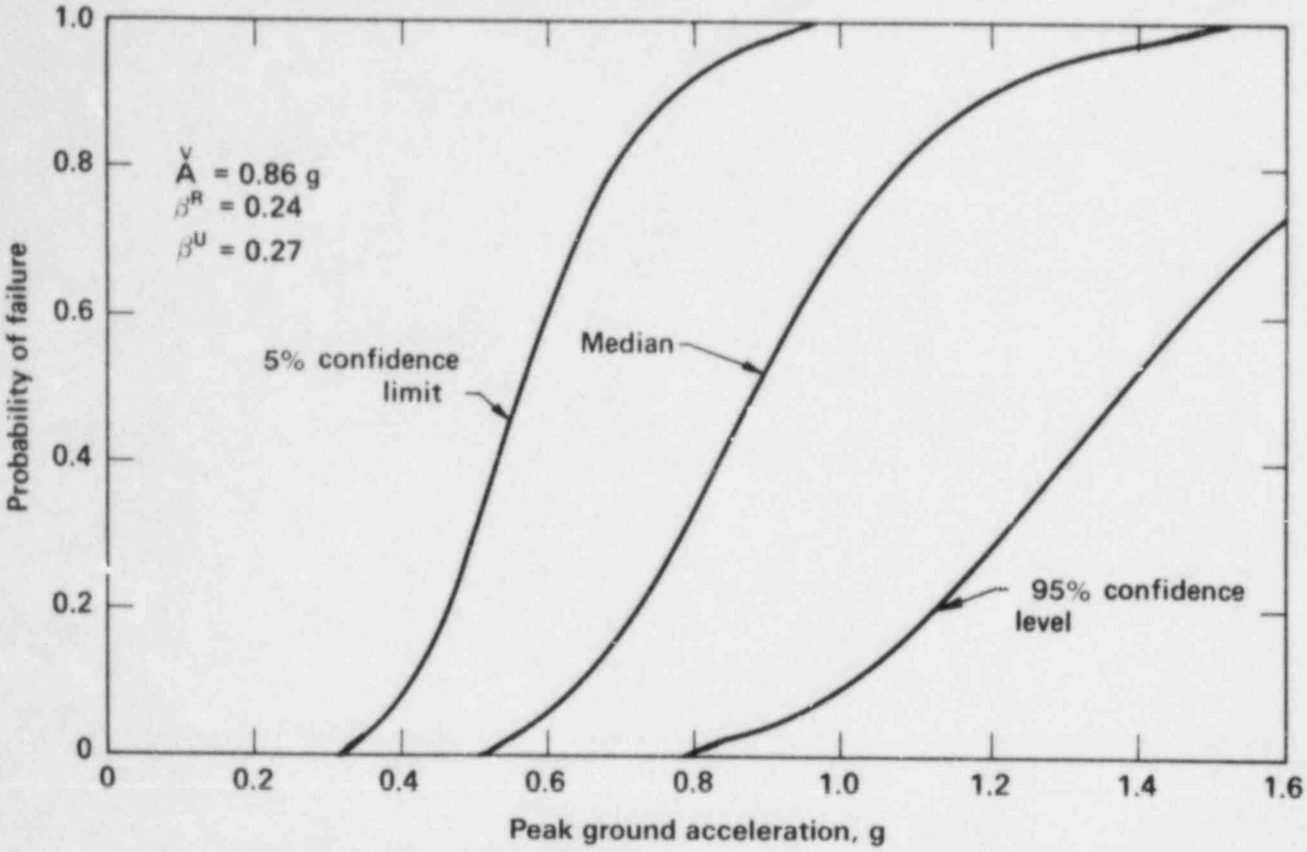
No reanalysis of the crib house was conducted as part of of the SSMRP. The evaluation of the structure fragility levels was based on seismic loads developed by Sargent & Lundy as part of the original design analyses (Ref. 22). In addition to a consideration of the strength and ductility capacities for the structure, the design loads were modified as discussed in Sec. 3.3 to account for expected structure response. The assumption was made that the loads developed from the Sargent & Lundy model were conservative by a median response factor of $F_R = 1.05$ and $\beta_R^R = .19$, $\beta_R^U = .21$, and $\beta_R^T = .28$.

The pump enclosure is a 165-ft-long by 28-ft-wide reinforced concrete box-type structure. The enclosure structure is essentially symmetric about the two orthogonal directions. Thus, no torsion occurs except that resulting from the response of the remaining part of the structure that supports the pump enclosure room. Because of the unusually high aspect ratio of the roof slab, some horizontal response amplification of the roof slab results.

The lowest capacity failure mode results from loss of the roof diaphragm due to east-west response. The roof is somewhat lower in capacity than the north and south shear walls of the pump enclosure room due to the large hatches provided (Fig. 28). Although hatch covers are provided, the shear capacity is reduced. Once the diaphragm capacity is lost, loads are transferred to the north and south walls which must resist the east-west roof inertia loads by out-of-plane bending. The out-of-plane capacity of these walls is substantially less than the roof diaphragm capacity. Consequently, diaphragm failure is expected to be followed essentially at the same time by flexural failure of the north and south walls with rigid body rocking and vertical collapse of the roof structure. Collapse of the roof could result in loss of all the service water pumps.

The fragility curves for the crib house are referenced to free field peak ground acceleration. Figure 29 shows the fragility curve for failure of the pump enclosure room roof.

At ground acceleration levels above that required for failure of the pump



Failure 29. Failure of crib house pump enclosure roof.

enclosure roof, failure of various shear walls within the crib house may be expected. Failure of these walls can result from north-south and east-west response depending on the specific shear walls under consideration. Under north-south response, the north-south intake walls are expected to fail at a median ground acceleration capacity of approximately 2.5 g. Failure of the east-west intake walls is expected at a median ground acceleration of approximately 5.4 g. Failure of the intake end of the structure is expected to result in at least partial flow blockage. It is considered unlikely that the blockage would completely prevent flow to the service water pumps. However, the flow could be partially restricted.

Failure of the guide walls under the pump room (Fig. 27) from north-south response is expected at a median ground acceleration level of approximately 3.9 g. Failure of these walls may be expected to result in loss of the service water pumps and service water pipes located within the structure. It should be noted, however, that the median ground acceleration levels discussed in this section for shear wall failure are considered extremely improbable.

SECTION 4: COMPONENT FRAGILITIES

The 37 categories for reactor system components were described in Sec. 2. Data for computing estimates of fragility for these categories were obtained from a variety of sources including actual fragility data, qualification test data, design calculations, and expert opinion. These data were statistically combined for each category to obtain a single final fragility curve. Section 4.1 describes the fragilities of plant-specific components determined from design reports, Final Safety Analysis Report data, and qualification tests. Section 4.2 describes the fragilities developed from the U.S. Army Corps of Engineers SAFEGUARD Program data base. Section 4.3 describes the development of fragilities of piping components using both data and analysis. Section 4.4 contains an extensive expert opinion survey that covered all the categories of equipment. Section 4.5 describes the statistical methods used to combine the data of different types and for different modes of the same piece of equipment and the weighting scheme used to rank the data.

Virtually all of the data used for component fragility development have been stored in a relational data base on the LLNL computer system. This data base and its contents are documented in UCRL-53038, Rev. 1 which, with modifications, is included in this report as Appendix E.

4.1 Plant-Specific Component Data Sources

A number of different sources of information were used in deriving fragilities for plant-specific components:

- Design reports for specific equipment
- Zion Final Safety Analysis Report
- High Seismic Zone Qualification reports
- Specifications for seismic design of equipment
- Westinghouse topical reports

Several reports were made available to the Lawrence Livermore National Laboratory for plant-specific equipment through Commonwealth Edison and their architect/engineer and NSSS supplier. For the most part, the design reports for major NSSS items were based on reference design spectra more severe than the Zion spectra and were complete engineering reports that both summarized and provided details of analyses for seismic qualification. Most design reports for non-NSSS items were based on Zion-specific seismic conditions. The Final Safety Analysis Report (Ref. 23) provided general seismic design criteria, and in some instances, summaries of critical stresses, qualification results, etc.

In the case of the reactor protection system electrical and electronic equipment, Westinghouse provided a series of WCAP reports (Refs. 24,25) that documented high seismic zone qualification tests on similar or identical equipment to that in the Zion nuclear power plant. The high seismic zone qualification test environment exceeded the Zion seismic environment by a large margin.

Specifications for seismic qualification of equipment were provided to the SSMRP by Sargent & Lundy, the architect/engineer of the Zion plant. In cases where plant-specific qualification reports were not readily available,

knowledge of the vendor requirements plus fragility and qualification test data were combined to develop fragility descriptions.

Several reports summarizing equipment damage during major earthquakes were reviewed (Refs. 26-37). Most reports do not provide sufficient information to determine the extent of the loading experienced by equipment during the seismic event. Reference 35 does, however, provide such information and indicates that only insignificant failures were present for equipment that experienced from 0.5- to 1.8-g spectral acceleration, although most equipment was rigid and experienced less than 1.0-g spectral acceleration. This information is comforting in that steam plant power mechanical, electrical, and control equipment have been demonstrated to withstand an earthquake of 2 to 3 times the Zion design basis earthquake, but, since no significant damage was observed on equipment typical of nuclear power plant equipment, fragility descriptions cannot be concluded from the information.

Equipment whose fragilities were derived from the Zion-specific data sources described above can be conveniently discussed under four separate headings.

1. Plant specific equipment whose fragility is based on structural failure and for which design reports were available.
2. Plant specific equipment whose fragility is based on functional limits and for which design report data design reports were available.
3. Structural capacities of equipment derived from knowledge of the design specifications and the strength factors of safety inherent in the governing codes and standards.
4. Structural and functional capacities of equipment derived from high seismic zone qualification test data.

In the following, each of these headings is discussed separately, with a brief description of the method and a listing of the components whose fragilities were derived by that method.

4.1.1 Plant-Specific Structural Fragilities Derived from Analysis or Design Reports

Major safety-related equipment items that fail in a structural mode are derived in this section:

- Reactor vessel
- Reactor vessel internals
- Control rod drives
- Steam generator
- Pressurizer
- Reactor coolant pump
- Safety injection pump
- Residual heat exchanger
- Component cooling water heat exchanger
- Accumulator tank
- Boron injection tank
- Main steam isolation valve
- Large motor-operated valves
- Small motor-operated valves
- Condensate storage tank
- Diesel oil storage tank

- Buried service water pipe from crib house
- Buried auxiliary feedwater pipe from condensate storage tank
- Service water pumps
- Battery racks

In development of fragility relationships for these components, the concept of capacity factors and response factors is used. These factors represent factors of conservatism or unconservatism in the design codes, design loading, and subsystem response calculations; in other words, they are factors of safety above the original seismic design bases of the equipment. Once the factors of safety are established, the fragility can be derived as the product of these factors times the original seismic design basis acceleration or load.

In deriving response factors and their variabilities the following parameters were considered:

- Qualification method
- Modeling error (frequency and mode shape)
- Damping
- Modal response combinations
- Earthquake component combination

A detailed presentation of the derivations of these factors and the results used by the SSMRP is presented in Ref. 9, Ch. 5.

Since the equipment fails in a structural mode, both a strength factor, F_S (based on static strength), and a ductility factor, F_μ (based on inelastic energy absorption), must be considered. The capacity factor, F_C, is then the product of the strength and ductility factors:

$$F_C = F_S F_\mu \tag{16}$$

In the case of metal structures, the ultimate load or stress is defined as the ultimate load capacity under static loading, i.e., that load or stress at which the displacement increases without bound for a small additional increase in load. In deriving median capacities, a concerted effort was made to be realistic about capacities and, as such, average material properties were used and larger deformation capability and strain hardening, where feasible, were considered in order to get a best estimate of the median structural capacity.

The strength factor, F_S, is derived from the equation:

$$F_S = \frac{\dfrac{P_C}{P_D} - \dfrac{P_N}{P_D}}{\dfrac{P_T}{P_D} - \dfrac{P_N}{P_D}} \tag{17}$$

where P_C is the median collapse load or stress and is taken as the limit load, P_N is the normal operating load or stress, P_T is the total normal plus seismic load or stress, and P_D is the code design allowable load or stress. This is the same as the equation used in developing the building fragilities except that all terms on the right hand side are divided by P_D because, in many instances, design reports provided the exact values for use in Eq. (17). Some variability is assigned to each term in this equation to

account for the range of material properties and the uncertainty in actual loading.

For structures that respond in the amplified response region of the design spectrum, the ductility factor, F_μ, introduced in Sec. 3.2.3, is applied. The value is taken from the simplified relation

$$F_\mu = \sqrt{2\mu - 1} \tag{18}$$

For equipment that is considered rigid (i.e., fails without yielding), the ductility factor is taken as 1.0; that is, the earthquake loading behaves the same as a static load and no credit can be taken for inelastic energy absorption.

Due to the large number of components whose fragility was derived by this approach, not all derivations are reported in detail. The steam generator capacity calculation presented below is typical of this method of generating fragility descriptions.

Steam Generator. Review of Ref. 38 indicates that for a conservative response spectrum the seismic stresses are less than yield for all components of the steam generator. The steam generator tubes, per Ref. 38, are the most critical item of the steam generator assembly. Based upon the design analysis, the tubes would not yield until the spectral acceleration at the system fundamental frequency was about 5 g.

Item Q 4.17-1 from Ref. 23 indicates that the NSSS component supports were limited to yield for normal plus DBE loads. Information from Westinghouse indicated that for Zion the steam generator support columns are the most critically stressed item, with the normal and DBE loads consuming 32% and 38%, respectively, of the faulted condition allowable.

The construction material is ASTM A-588 with a 50 ksi minimum yield. Considering the median yield strength to be about 1.25 times the specified minimum, and assuming this to be the limit load, then applying Eq. (17) with the above stated stress levels, the median of the strength factor is computed to be

$$F_S = 2.45$$

The variability in this strength factor is due to variability in the yield strength. The yield strength for austenitic stainless steel, specified in the ASME Code, is, per Ref. 39, about 1.65 standard deviations below the average value, corresponding to the 95% nonexceedance value, i.e., 95% of the data fall above the code specified value. Material strengths tend to be more lognormal than normal; thus, it was assumed that the coefficient of variation, from Ref. 39, for yield strength is applicable to a lognormal distribution. Reference 39 indicates that the average yield strength of austenitic stainless steel is about 25% above the code specified value. Considering the average yield strength to be an approximate median value, the log-standard deviation on material strength is computed to be 0.14. The randomness of the strength and the uncertainty of the median are assigned values of 0.1 and are treated as equal contributors to the variability in strength. Therefore,

$\beta_S = 0.14$ $\beta^R = 0.1$ $\beta^U = 0.1$

Reference 4 recommends that, for design of members loaded primarily in compression, the ductility should range from about 1.5 to 3.0. Since these are design values, 3.0 is used as a median value and 1.5 is used as a minus 2 log-standard deviation value.

Applying Eq. (18), the median factor for ductility is

$$F_\mu = 2.24$$

Considering the range of ductility from 1.5 to 3 as representing 2 log-standard deviations and considering the uncertainty in the application of Eq. (18), the variability can be defined as

$\beta_\mu = 0.31$ $\beta^R = 0.10$ $\beta^U = 0.29$

Combining factors and log-standard deviations, the overall capacity factor, including strength and ductility factors, is

$F_C = 5.5$ $\beta_C = 0.34$ $\beta^R = 0.14$ $\beta^U = 0.31$

Multiplying the computed factor, F_C, times the original acceleration design spectra value of 0.6 g for the Zion Plant for the DBE gives a median capacity of 3.3 g S_a at the 5-Hz fundamental NSSS system frequency. The resulting fragility parameter is spectral acceleration at 5 Hz at the steam generator support at elevation 590 ft of the reactor building. β_C above was combined with a response factor $\beta_R = 0.28$ (Reference: NUREG/CR-2405, page 5-35) to yield a $\beta_{TOTAL} = 0.44$.

These "design data" fragility parameters were further combined with values from expert opinion (detailed in Appendix F) to derive the final fragility parameters shown in Tables 2 and 4 of this report.

4.1.2 Plant-Specific Functional Capacities Derived from Design Reports

Major equipment items whose failure modes are functional rather than structural, are addressed in this section. Equipment whose fragility was derived based on functional failure derived from design reports are:

- Containment fan coolers
- Residual heat removal pumps
- Centrifugal changing pumps

In addressing functional failure modes, ductility (i.e., inelastic energy absorption) is not a consideration since the functional limits may be within the realm of subsystem elastic response. As an example, the calculation of the fragility of the residual heat removal (RHR) pumps is presented.

Residual Heat Removal Pumps (RHR)   The RHR pumps in Zion were analyzed for seismic loading as part of a system dynamic model that included attached piping. A generic response spectrum was used. The two most critical areas were identified as the pump holddown bolts and the impeller deflection. The minimum factor of safety was associated with impeller deflection.

The calculated deflection was 0.0099 in., and the stated allowable was 0.0105 in. Tolerances are not known; thus, it was assumed that the worst case tolerance stack-up, equivalent to a -3β value, resulted in the minimum allowable deflection of 0.0105 in. Considering the size of the impeller, the method of fabrication of the impeller and pump housing, and normal machine shop tolerances, the median clearance is estimated to be 0.0145 in. The resulting median factor on capacity is 1.46 with a log-standard deviation, β_C, approximately equal to 0.11. The resulting variability is primarily uncertainty in the actual clearance in each unit with a small contribution due to randomness inherent in the clearance under operating conditions. The estimated variabilities due to randomness and uncertainty, respectively, are

$$\beta^R = 0.05 \quad , \qquad \beta^U = 0.10$$

Multiplying the safety factor times the design spectral acceleration, at the equipment fundamental frequency of 7 Hz, results in a median spectral acceleration capacity of 3.2 g. The mounting bolt capacity is much greater, with a median value of 11.7 g spectral acceleration at 7 Hz. Thus, the RHR pump fragility is determined by the deflection of the impeller.

4.1.3 Fragilities Based on Generic Code Specifications

For several components, detailed information on stresses, deflections, bearing loads, etc., was not readily available, and fragility relations had to be derived from a knowledge of design criteria. In this section, the method of developing fragility relations solely from design criteria for equipment whose failure modes are structural is described. This method was used for:

- Large vertical vessels with formed heads
- Large horizontal vessels and heat exchangers
- Small-to-medium vessels and heat exchangers
- Ducting.

This method of deriving fragilities is based on the fact that, during the era in which the Zion plant was designed, the seismic design of passive equipment (i.e., equipment for which structural rather than functional failure is of concern) was based on loads in the equipment support. The ASME code working stress level for carbon steel is the lesser of 5/8 of the yield strength or 1/4 of the ultimate strength. Assuming a common carbon steel such as SA 516-GR 60, an allowable stress of 1/4 of the ultimate stress at operating base earthquake (OBE) accelerations (which for Zion was 0.085-g peak ground acceleration) would be 15 ksi. The median acceleration at failure is computed using the general approach and equations presented in Sec. 3.2.

The equation for computing the strength factor is modified slightly for convenience, as follows:

$$F_S = \frac{\dfrac{\sigma_{lim}}{\sigma_{design}} - \dfrac{\sigma_{normal}}{\sigma_{design}}}{\dfrac{\sigma_{seismic}}{\sigma_{design}}} \tag{19}$$

The typical steel that was assumed (SA 516-GR 60) has a median yield strength of approximately 40 ksi.

The normal stress range used in this analysis, from 5 to 35% of the allowable design stress, and the seismic stress may range on the order of 20 to 80% of the allowable stress. These are assigned as 2/3 values on a lognormal distribution. Median values of these ranges are then about 13% for normal stress and 40% for seismic stress. Using Eq. (19), the median strength factor is:

$$(F_S) = \frac{\frac{40}{15} - 0.13}{0.4} = 6.33$$

The log-standard deviations of each of the variables can be combined by the second-moment method (Ref. 40) to develop an approximate variance on the strength factor. The mean and variance of a function of lognormal variables can be derived utilizing the moments (i.e., the mean and variance) of the basic lognormal variables. The resulting equation for the standard deviation of the strength factor is:

$$\beta = \frac{[(\sigma_{lim}^2 \ \beta_{lim}^2) + (\sigma_{lim} - \sigma_{normal}) \ (\beta_{seismic})^2 + (\sigma_{normal}^2 \quad \beta_{normal}^2)]^{1/2}}{\sigma_{lim} - \sigma_{normal}}$$

The log-standard deviation of the yield strength is known to be about 0.14. The seismic load range used is plus or minus 2β (i.e., a range of 4β), the log-standard deviation is computed by:

$$4\beta = \ln 0.8 - \ln 0.2$$

$$\beta = \frac{\ln 0.8 - \ln 0.2}{4} = 0.35$$

Using the same assumptions, the β on the normal load is computed to be approximately 0.5. Applying the second-moment theorem to the median values of the variables and their respective uncertainties, the log-standard deviation on strength is computed to be

$$\beta_s = \frac{\sqrt{(40)^2(0.14)^2 + (40 - 1.95)^2(0.35)^2 + (1.95)^2(0.5)^2}}{40 - 1.95}$$

$$= 0.38$$

It remains to consider median and β values for the ductility factor F_μ. Values for this factor were taken from Newmark (Ref. 4), who recommended:

$$F_\mu = 1.41$$

$$\beta_\mu = 0.26$$

for light equipment and

$$F_\mu = 1.73$$

$$\beta_\mu = 0.28$$

for heavy equipment.

The median acceleration at failure can now be computed for any given design acceleration. Since the specified design acceleration varies from building to building and floor to floor, the acceleration capacities would likewise vary. Since the fundamental frequency is not known for the equipment, capacities can be referenced to the ZPA of the applicable floor spectra. Most of the equipment is sufficiently rigid that the fundamental frequency would not coincide with high amplification regions of the response spectra and using the ZPA as the fragility parameter is justified. Table 6 lists the ZPA capacities and variabilities of equipment that fail in a structural mode.

Table 6. Fragility description for vessels and heat exchangers.

Building and floor elevation (ft)	Design ZPA (g)	Failure acceleration (g) Light equipment	Heavy equipment
Crib house			
552	0.11	0.98	1.20
594	0.21	1.88	2.30
Auxiliary/turbine building			
642	0.25	2.24	2.74
630	0.20	1.79	2.19
617	0.17	1.52	1.86
592	0.12	1.07	1.32
580	0.10	0.90	1.10
560	0.08	0.72	0.88
542	0.08	0.72	0.88
Containment building			
617	0.13	1.16	1.42
590	0.13	1.16	1.42
582	0.08	0.72	0.88
568	0.08	0.72	0.88
Outdoor equipment	0.08	0.72	0.88

4.2 Fragilities Derived from Test Data

Actual testing to failure data (fragility data) are rare. The bulk of the testing performed on nuclear components is for the purpose of qualifying the component to a specified seismic loading level. Four sets of data were utilized in constructing fragility curves for the following items:

1. Westinghouse high seismic zone qualification test data were used to develop fragilities for the reactor protection system electrical and electronic equipment and for the static inverters.
2. A series of dynamic tests on cable tray systems of various

configurations was used to generate a generic cable tray fragility relation.

3. Data from the U.S. Army SAFEGUARD Missile Site Hardening Program were used to generate fragilities for the following generic categories:
   - Pumps and compressors
   - Large hydraulic and air-operated valves
   - Large check, spring, and manual valves
   - Miscellaneous small valves
   - Switchgear
   - Batteries and racks
   - Transformers
   - Local instruments
   - Instrument panels and racks
   - Auxiliary relay cabinets
   - Motor control centers
   - Breakers
   - Relays
   - Air handling units

   In these tests, the acceleration levels were increased in steps, and equipment function was monitored. Hence, these were actual fragility tests.
4. Although not test data per se, the fragility of the ceramic insulators was determined from a review of insulator failures in six major earthquakes.

Following is a description of each of these tests and the methods used to develop fragility relations from the data. Analysis of these tests was performed by Structural Mechanics Associates, Inc., and complete details are presented in Ref. 9.

4.2.1 Fragilities Derived from Tests for Higher Seismic Zones

Reactor protection system electrical and electronic equipment, plus the static inverters, have been qualified by Westinghouse for high seismic zone environments significantly greater than the Zion seismic environment specified for the auxiliary building at elevation 642 ft. References 22 and 23 document the high seismic zone tests.

Here, a factor of safety need not be derived since the fragility description was derived directly. The fragility parameter is spectral acceleration for a frequency range of 5 to 10 Hz and at a median damping value of 5%.

Testing was conducted using the sine beat method to excite a single axis at a time. The input level varied with frequency, but in the predominant frequency range of the electrical equipment cabinets (5 to 10 Hz), the input acceleration was 1.5 g. Ten sine waves per beat were typically used in the sine beat testing, wherein the sine waves would increase in amplitude for 5 cycles then decrease for the remaining 5 cycles. Median damping, as suggested by Ref. 38, is about 5%. This is further verified by examining response to similar equipment tested in the SAFEGUARD Program (Ref. 41). At 5% damping, the 10-cycle input has an amplification factor of about 7.6, resulting in an approximately 11.4-g response, i.e., the response spectrum from 5 to 10 Hz has a spectral acceleration of 11.4 g.

No failures were observed at this test level. In the case of the static

inverter, when the input acceleration was increased by a factor of $\sqrt{2}$, a minor malfunction was observed. Other equipment was not tested at higher levels so that a fragility level was not experimentally determined.

A single qualification test does not provide much insight into fragility levels; however, when a number of different items of the same generic type survive a qualification level, then there is reason to believe that the qualification level is in the lower tail of the fragility curve, but the exact fragility level is still indeterminate. Engineering judgments as to the median fragility and its variability must, therefore, be made.

Since a $\sqrt{2}$ increase in one test article caused minor malfunctions, where several test articles functioned without incident at the specified test level, it was assumed that the specified spectral acceleration of 11.4 g was about minus one log-standard deviation below the median and that the median is approximately $\sqrt{2}$ above the specified test level of 11.4-g spectral acceleration. The fragility level was then established at 16.1-g spectral acceleration with a log-standard deviation of 0.35. The contribution to the variability due to randomness, β^R, is estimated to be about 0.2 with the uncertainty, β^U, equal to about 0.29.

4.2.2 Cable Tray Qualification Tests

Reference 42 reports results of extensive dynamic testing conducted on cable tray systems. Some general conclusions regarding cable tray capacities are reached in the paper that indicate large seismic capacities. The large capacities result, in a significant part, from the large amount of damping measured in cable tray systems.

The cable tray tests were conducted on a biaxial shake table. Regulatory Guide 1.60 spectral shapes were used in synthesizing the time history inputs. In some 2,000 tests at ZPA input levels of 1 to 3 g, no functional failures or complete structural failures occurred in strut-supported cable tray systems. Rod-supported systems had significantly lower capacity; however, in accordance with Zion specifications for cable tray systems, all safety-related systems were designed with bracing to resist seismic loading, such that the rod-supported cable tray system tests are not considered applicable to Zion safety-related systems. Rod-supported trays do exist in the plant but, as previously stated, they are not safety related and are not considered in this analysis.

Assuming conservatively that 3-g ZPA is the approximate median capacity and the 1-g lower test level to be about a -2β value, the computed log-standard deviation on capacity is about 0.55, which is about what would be expected for such a generic treatment of capacity. Most of the critical cable systems are in the cable spreading room which is located fairly high in the auxiliary building at elevation 630 ft. The ZPA for the DBE at elevation 630 ft is about 0.36 g, resulting in a capacity factor of about 8.33. The log-standard deviation on that factor is about 0.55, of which β^R is estimated to be 0.3, with $\beta^U \approx 0.46$. The fragility parameter specified for cable trays will be the ZPA at the floor level under consideration.

4.2.3 Fragilities Derived from SAFEGUARD Program Test Data

In the SAFEGUARD Program, a comprehensive series of tests was undertaken to demonstrate reliability of power and process equipment used in hardened radar

installations. Reference 41 summarizes the results of this program. References 43 and 44 portray the methodology utilized to assure reliability of the equipment when subjected to severe ground shocks due to nuclear weapons effects.

In the SAFEGUARD Program, off-the-shelf equipment was procured rather than specially engineered equipment qualified for shock and vibration environments. The equipment was very similar to that installed in nuclear power plants and was procured in the same time frame as the Zion equipment. Consequently, the test performance of SAFEGUARD equipment should be indicative of the balance of nuclear power plant equipment purchased then. Some 400 component and system tests were conducted in support of the qualification of some 30,000 critical items in the SAFEGUARD installation. The program plan and methodology for assuring reliability of untested equipment are contained in Ref. 45.

Initially, in the SAFEGUARD Program, fragility testing was conducted for selected equipment items. This proved to be very costly and further testing was restricted to GO/NO-GO qualification testing. Thus, the resulting data base consists predominantly of shock test results of equipment for which no permanent functional failure occurred. In many of the tests, electrical malfunctions occurred that were only temporary or intermittent. In many cases, at the shock test levels applied, structural damage or functional anomalies noted would appear to be near the fragility level. In other cases, however, no evidence of damage or functional anomalies was present.

In the SAFEGUARD test program, items were excited on a shaker table to a prescribed spectrum corresponding to in-structure response spectra at various equipment locations. The tests were single-directional, and the maximum acceleration level was approached in (typically) four steps. The prescribed spectra were not typical of earthquake spectra in that the test spectra emphasized the high frequency, high-spectral acceleration response typical of blast loading. Maximum acceleration levels were typically up to 15 or 20 g. Figure 30 illustrates a typical test spectrum. Note that it contains very little input below 5 Hz. Thus, the resulting shock test data are not applicable to (nor were they used for) equipment whose lowest natural frequency is near or below 5 Hz.

After examination of the data base, it was concluded that two separate methodologies should be applied to develop fragility relationships for generic classes of equipment. For equipment that is not complex, and for which the generic test data generally indicated no functional anomalies, a pseudo-probabilistic methodology developed by the U.S. Corps of Engineers was applied. This methodology requires detailed comparisons between construction details of the items tested and the item whose fragility level is being sought. This approach could be used for a number of items of interest to the SSMRP.

For complex electrical and control equipment, such detailed comparisons of Zion equipment construction features to the tested equipment were not feasible within the resources of the SSMRP. Thus, a different methodology was devised to utilize the test data to develop fragility descriptions. The tests of electrical instrumentation and control equipment often resulted in functional anomalies, such as relay chatter and breaker trip, which were common to many generic classes of equipment. The data were, consequently, used to develop

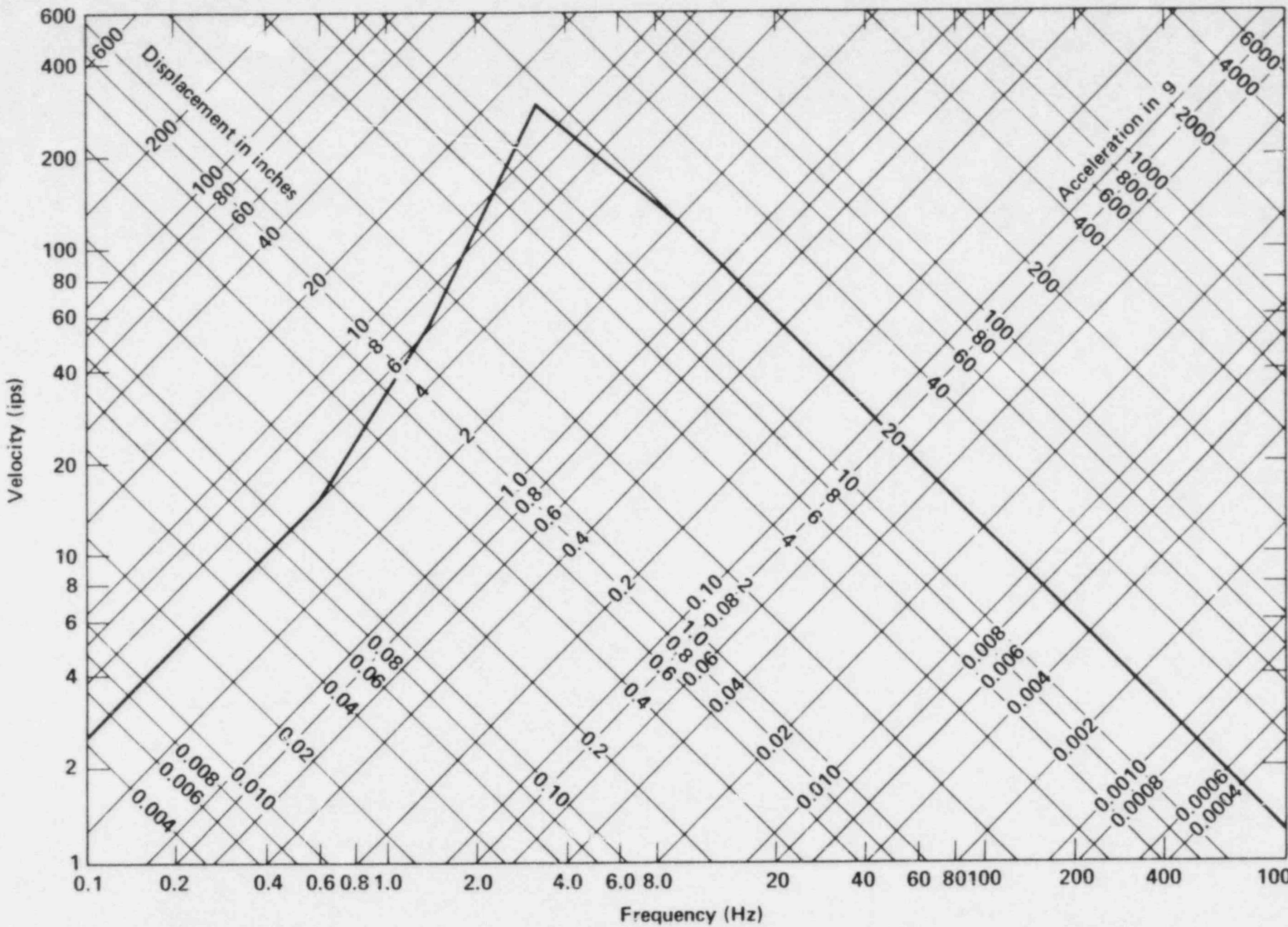


Figure 30. Typical hard mounted spectrum for mechanical equipment--horizontal spectrum.

fragility descriptions by failure mode, which can be combined for several generic classes of equipment. For purposes of abbreviated reference to the applicable methodology, the application of the Corps of Engineers methodology is referred to as Method A and the development of fragility descriptions by failure mode is referred to as Method B.

Fragility descriptions for the following generic categories of equipment were developed by the methods indicated.

Method A	Method B
Large hydraulic- and air-operated valves	Switchgear
Large check and spring relief valves	Instrument panels and racks
Small miscellaneous valves	Control panel and racks
Batteries	Relay cabinets
Transformers	Motor control centers
Local instruments	Breaker panels
Air conditioning and air handling units	
Pumps and compressors	

4.2.3.1 Methodology A

The objective of the SAFEGUARD Program was to assure a 97.7% or greater probability of survival for the anticipated blast shock environment. This was quantitatively evaluated by computing the ratio

$$H_v = \frac{f_1 \cdot f_2 \cdot f_3 \cdot f_4}{\check{E} + 3\sigma_E}$$

in which $(\check{E} + 3\sigma_E)$ is the 3σ upper limit to the anticipated blast shock environment and the achieved lower test level is the lowest level of acceleration at which failure was found in the tested piece of equipment. The scaling factors based on engineering judgment are defined as

f_1 = achieved lower acceleration level of test

f_2 = similarity of component to be qualified to tested component

f_3 = similarity of test conditions to actual expected conditions of component to be qualified

f_4 = performance of tested component

Based on unpublished data, it was concluded that if the H_v ratio was greater than 1, the desired probability of survival requirement was met. Detailed procedures were presented for quantifying the scaling factors and their upper 3σ limits (Ref. 45).

The numerator in the H_v ratio is thus a measure of fragility, and this was used for Phase I of the SSMRP and for Phase II, which includes the Zion analysis. The results for the equipment whose fragility was defined by this method are presented in Table 7. For more details, the reader is referred to Ref. 9, pages 4-53 through 4-56.

Table 7. Summary of f factors.

Generic category	$f_{1_{Upper}}$	$f_{2_{Upper}}$	$f_{3_{Upper}}$	$f_{4_{Upper}}$	Upper bound of fragility $f_{1_U} \cdot f_{2_U} \cdot f_{3_U} \cdot f_{4_U}$	$f_{1_{Lower}}$	$f_{2_{Lower}}$	$f_{3_{Lower}}$	$f_{4_{Lower}}$	Lower bound of fragility $f_{1_L} \cdot f_{2_L} \cdot f_{3_L} \cdot f_{4_L}$
1. Large hydraulic and air-operated valves	26.8	1.1	2.0	1.15	67.8	6.4	0.85	0.7	1.0	3.8
2. Large check and spring relief valves	30.0	1.1	2.0	1.15	75.9	6.0	0.85	0.7	1.0	3.6
3. Small miscellaneous valves	30.0	1.1	2.0	1.15	75.9	6.0	0.85	0.7	1.0	3.6
4. Batteries	5.36	1.15	1.0	1.0	6.2	5.36	0.85	1.0	0.5	2.3
5. Transformers	13.34	1.10	1.2	1.0	17.6	6.63	0.85	0.8	0.9	4.1
6. Local instruments	32.8	1.15	2.0	1.0	75.4	4.7	0.85	0.7	1.0	2.8
7. Air conditioning and air handling units (structural failure)	10.66	1.3	1.2	1.0	16.6	6.7	0.75	0.8	0.71	2.9
8. Air conditioning and air handling units (fan failure)	28.8	1.1	1.2	1.0	38.0	13.4	0.9	0.8	0.7	6.8
9. Pumps and compressors	30.0	1.2	1.2	1.0	43.2	17.4	0.8	0.8	0.9	10.0

Note 1: f_1 = achieved test level (acceleration, g).
Note 2: The upper and lower bounds on fragility are taken at $\pm 3\sigma$ limits based on unpublished SAFEGUARD program data.

4.2.3.2 Methodology B

This methodology was utilized to analyze the test results for electrical equipment: relays, circuit breakers, switchgear, etc. This was necessitated because failure of these components was observed to be predominantly functional, and for some components, failure was intermittent. That is, the unit might fail to function at one acceleration level, but then function properly at the next higher acceleration level.

The predominant failure modes observed in all electrical and control equipment were relay chatter and breaker trip. Neither of these failure modes results, in all cases, in failure of the equipment to perform its intended function. Relay chatter is a functional failure mode that is self-correcting after the vibratory earthquake motion ceases. In this case, the function of the system is interrupted for a few seconds. Relay or breaker trip is a functional failure mode that requires manual or remote electrical reset and can potentially interrupt function for minutes or hours.

The general trend of the shock test results on electrical and control equipment was to experience relay chatter at the lower test levels on some equipment but not all. There was an order of magnitude in the relay chatter threshold over the range of equipment tested. Breaker trip resulted in many tests but usually at higher acceleration levels than relay chatter.

The relay chatter and breaker trip test results were, unfortunately, not completely logical. Frequently, functional failures would occur at one test level but not at twice that level. This behavior prevents direct calculations of cumulative failure distributions. Since the failure modes of relay chatter and breaker trip were common to several generic categories of equipment, it was decided to combine all test data to increase the data base and result in more representative cumulative distribution functions for failure modes common to several generic categories of equipment.

In addition, fragility relationships for permanent structural damage failure modes were developed for individual generic categories of equipment. Thus, three failure modes were then available for each generic category of electrical and control equipment: relay chatter, breaker trip, and structural failure.

In applying the Corps of Engineers test results to develop generic fragility relationships for electrical and control equipment by failure modes, it must be kept in mind that the equipment was subjected to predetermined levels of shock spectra, and the percentage of component failures for different failure modes was observed for each shock spectrum level. It should also be borne in mind that, in most cases, permanent damage did not occur and that higher test levels could be achieved on the same equipment. Finally, the test shock spectra were usually flat over a wide frequency range so that spectral acceleration at the estimated fundamental frequency of the equipment is the fragility parameter of interest.

The unconditional probabilities of failure may be computed by introducing the idea of a "hazard" or "risk" function. If f(x) is the probability density function (pdf) of failure at acceleration level x, and

$$F(x) = \int_0^x f(\xi)d\xi$$

is the cumulative distribution function (cdf) of failure, then the risk (hazard) function, $\lambda(x)$, is defined as

$$\lambda(x) = \frac{f(x)}{1 - F(x)} \tag{20}$$

and inversely

$$F(x) = 1 - \exp\left[- \int_0^x \lambda(\xi) d\xi \right] \tag{21}$$

By definition, $\lambda(x)dx$ is the probability of failure in the interval x to x + dx, given that the equipment is operable up to level x.

Because of the intermittent nature of the failures observed, the percentage of units failing at each test level cannot strictly be identified with $\lambda(x)$. However, as an engineering approximation, it was assumed that $\lambda(x)$ could be derived from the percentage of failure data and that the two were proportional to one another for all acceleration levels. The unknown constant of proportionality is found using the fact that, at the lowest test level at which a failure occurs, F(x) equals the observed percentage of failure at that level.

To illustrate this process, consider the data from a four-level test of a single piece of equipment:

Level	Acceleration, g	Ratio of failures, $\phi(x)$
1	1.65	0.33
2	3.32	0.00
3	4.97	0.00
4	6.63	0.30

These data are plotted in Fig. 31, and are assumed to vary linearly between

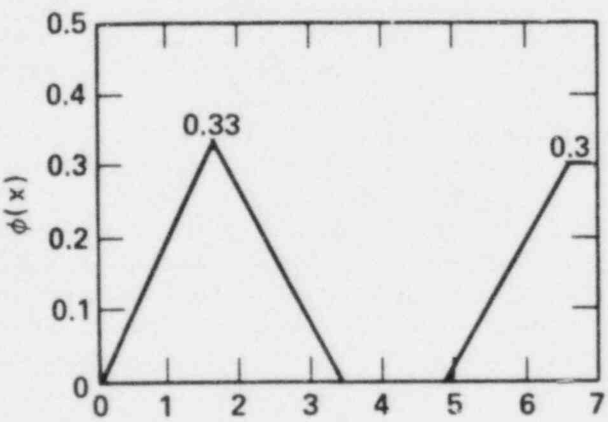


Figure 31. Observed failures.

the data points. Since $\lambda(x)$ is assumed proportional to the percentage of failure, we can write

$$\lambda(x) = C\phi(x)$$

where $\phi(x)$ is the observed ratio of failures (percentage of items failing) and C is an unknown constant of proportionality. In the first interval then,

$$\lambda(x) = C\left(\frac{0.33}{1.65}\right)x$$

where x is the acceleration. Substituting this into Eq. (21) gives

$$F(x) = 1 - \exp\left[-C\left(\frac{0.33}{1.65}\right)\frac{x^2}{2}\right] \tag{22}$$

which is only valid in the first acceleration interval. Then, within the resolution of the data,

$$F(1.65) = \phi(1.65)$$

and hence one can solve Eq. (22) directly for C giving C = 1.47. This constant of proportionality is assumed to hold for all acceleration levels, so $\lambda(x)$ is as shown in Fig. 32.

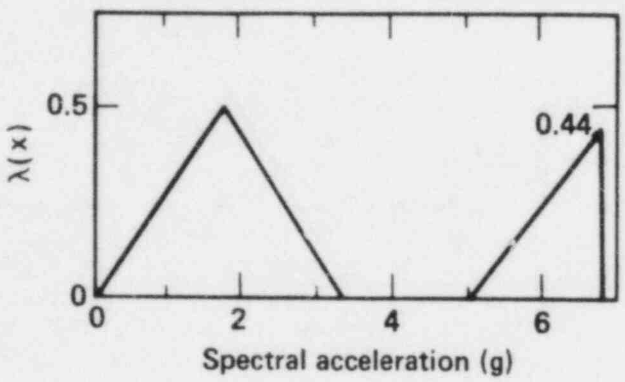


Figure 32. Risk function.

Finally, using $\lambda(x)$ and Eq. (21), one can directly compute F(x) for all higher test accelerations. F(x) is then the desired fragility curve, and for this case is as shown in Fig. 33.

This process was repeated for 16 sets of data on relay chatter, and for 17 sets of data on breaker trip; the resulting cdf's were then averaged and put in lognormal distributional form to obtain final fragility functions for relay chatter and breaker trip, respectively. These two fragility curves are shown in Fig. 34. The structural failure fragility curve (which could be derived by standard methods) is also shown on this figure.

4.3 Piping

The generic category for piping includes not only straight pipe but also elbows, miters, butt welds, and both reinforced and unreinforced branches. Carbon steel and stainless steel are typically used, so both of these materials were considered. Pipe operating temperatures vary from ambient to 600°F in normal operation. Because of these widely varying conditions, sizes, and configurations, it was decided not to develop separate fragility curves

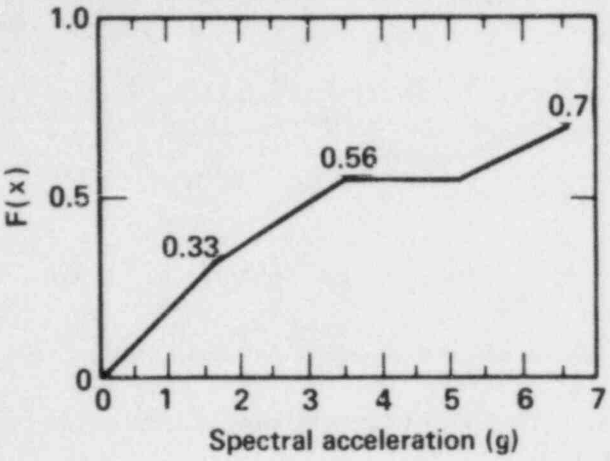


Figure 33. Cumulative distribution function.

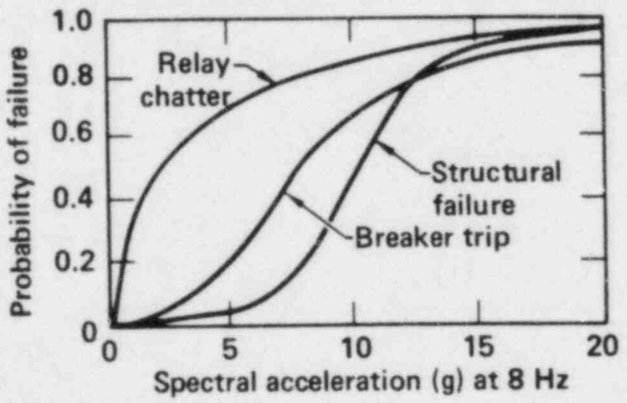


Figure 34. Fragility comparison for electrical and control equipment.

for each possible combination, but instead to develop a single master fragility curve for one piping component, and then relate the fragility of all other piping components to the master curve by means of scaling factors dependent on size, configuration, material, and temperature. The independent variable is taken as the moment in the pipe. Thus

$$\left(M_{Fail}\right)_{i^{th}\ \text{Component}} = \frac{1}{\beta_i}\left(M_{Fail}\right)_{\text{Reference Component}} \qquad (23)$$

where β_i is the scale factor. Thus, in application it is only necessary to multiply the computed moment for any component by its scale factor, and then use the master fragility curve to compute the probability of failure using the scaled moment.

Development of these fragility curves was based on available data and use of scaling relations (based on theoretical considerations) to relate piping configurations of different sizes to those for which data are available. For straight pipe and butt welds, scaling was based on the equation for plastic collapse moment, derived from limit analysis:

$$M = K\,Z\sigma_y$$

where K is the shape factor, Z is the section modulus, and σ_y is the yield stress. The shape factor, K, is determined from experiment or can be estimated analytically from the cross-section geometry and material constitutive relations. From test data (Refs. 46-52) covering a wide range of diameter to thickness ratios, a median value of K = 1.5 was determined. Values for K ranged from 1.4 to greater than 2.8, depending upon the diameter-to-thickness ratio, material, strain hardening exponent, and definition of collapse, with 1.5 being a representative value. The median value of σ_y was estimated as 1.25 times the code specified yield stress. Thus, scaling was performed using

$$M_A = M_B \frac{Z_A}{Z_B} \frac{\sigma_y(A)}{\sigma_y(B)} \tag{24}$$

where A and B refer to two different sizes of the same configuration. This relationship assumes elastic, perfectly plastic behavior and does not consider buckling and dynamic effects.

For elbows, branches, tees, and miters, scaling was performed using ASME Section III Code stress intensification factors. For these factors,

$$M = \frac{Z\sigma_y}{i}$$

where i is the stress intensification factor. Rewriting this as a scaling relation yields

$$M_A = M_B \left(\frac{i_B}{i_A}\right)\left(\frac{Z_A}{Z_B}\right)\left(\frac{\sigma_y(A)}{\sigma_y(B)}\right) \tag{25}$$

In this case, the reference moment, M_B, was experimentally determined. Stress intensification factors were taken directly from ASME Section III tables.

Once static collapse moments are obtained from data or analysis and by use of Eqs. (24) and (25), the dynamic collapse moment is obtained by multiplying the static moments by the previously defined ductility factor, F_μ [see Eq. (12)]. Based on a review of data reported in Refs. 53 and 54, a ductility factor of 3 was found to be appropriate for straight pipe and elbows, while a factor of 2 was determined for butt welds, tees, and miters.

Finally, the dynamic collapse moments were related to the collapse moment of one single component to determine the β_i factors using Eq. (23). The reference component was taken to be a butt weld in a 6-in. Schedule 160 carbon steel pipe. A listing of all the derived β factors is presented in Table 8. More details can be found in section 4.2 of Ref. 9.

Capacity of Reference Pipe Element

A 6-in. Schedule 160 carbon steel butt weld pipe joint was selected as the basis for the master fragility relationship. Base material was considered to be A-106 B at room temperature with a code specified yield strength of 35 ksi and a specified ultimate strength of 60 ksi. The specified strengths are considered to be 95% nonexceedance values corresponding to 1.65 standard

Table 8. Pipe fittings and load scale (β) factors.

Size (in.)	Schedule	Material	Temperature (°F)	Unreinforced[a] branches		Elbows	Miters	Straight pipe	Butt welds	Reinforced branches	
				F_{PR}	F_{PB}					F_{PR}	F_{PB}
1/2	160	Stainless steel	300	NA	NA	492	NA	298	480	NA	NA
3/4	160	Stainless steel	300	NA	NA	259	NA	157	254	NA	NA
1	160	Stainless steel	300	NA	NA	138	NA	83.5	135	NA	NA
2	160	Stainless steel	300	NA	NA	27.7	NA	43.5	27.0	NA	NA
2	40	Stainless steel	500	NA	NA	107	NA	37.5	60.4	NA	NA
3	160	Carbon steel	Ambient	NA	NA	4.8	NA	3.83	6.19	NA	NA
3	160	Carbon steel	140	NA	NA	4.93	NA	3.96	6.39	NA	NA
3	160	Stainless steel	300	NA	NA	9.85	NA	5.95	9.62	NA	NA
3	160	Carbon steel	556	NA	NA	6.24	NA	4.99	8.05	NA	NA
3x3x1/2	160	Stainless steel	300	9.62	480	NA	NA	NA	NA	9.62	480
3x3x3/4	160	Stainless steel	300	9.62	254	NA	NA	NA	NA	9.62	254
3x3x2	160	Stainless steel	300	10.0	27.0	NA	NA	NA	NA	9.62	27.0
3x3x3	160	Stainless steel	300	10.0	10.0	NA	NA	NA	NA	9.62	9.62
4	40s	Stainless steel	200	NA	NA	15.81	NA	5.12	8.25	NA	NA
4	40s	Stainless steel	300	NA	NA	17.65	NA	5.69	9.19	NA	NA
4	40s	Stainless steel	500	NA	NA	20.54	NA	6.60	10.63	NA	NA
4	120	Carbon steel	140	NA	NA	3.35	NA	2.26	3.63	NA	NA
4	120	Stainless steel	300	NA	NA	6.47	NA	3.27	5.27	NA	NA
4	120	Stainless steel	535	NA	NA	7.72	NA	3.90	6.31	NA	NA
4	160	Stainless steel	300	NA	NA	4.87	NA	2.83	4.57	NA	NA
4	160	Stainless steel	535	NA	NA	5.97	NA	3.47	5.60	NA	NA
4x4x3/4	160	Stainless steel	300	4.57	254	NA	NA	NA	NA	4.57	254
4x4x1	160	Stainless steel	300	4.57	135	NA	NA	NA	NA	4.57	135
4x4x2	160	Stainless steel	300	5.15	27.0	NA	NA	NA	NA	4.57	27.0
4x4x3	160	Stainless steel	300	5.15	9.64	NA	NA	NA	NA	4.57	9.62
4x4x4	40s	Stainless steel	500	21.0	21.0	NA	NA	NA	NA	10.63	10.63
4x4x4	120	Carbon steel	140	4.74	4.74	NA	NA	NA	NA	3.63	3.63
4x4x4	120	Stainless steel	300	6.72	6.72	NA	NA	NA	NA	5.27	5.27
4x4x4	120	Stainless steel	535	8.21	8.21	NA	NA	NA	NA	6.31	6.31

Table 8. (Continued).

Size (in.)	Schedule	Material	Temperature (°F)	Unreinforced branches[a] F_{PR}	Unreinforced branches[a] F_{PB}	Elbows	Miters	Straight pipe	Butt welds	Reinforced branches F_{PR}	Reinforced branches F_{PB}
6	120	Carbon steel	Ambient	NA	NA	1.27	NA	0.76	1.24	NA	NA
6	40	Carbon steel	Ambient	NA	NA	3.77	NA	1.40	2.26	NA	NA
6	120	Carbon steel	140	NA	NA	1.30	NA	0.791	1.27	NA	NA
6	160	Carbon steel	Ambient	NA	NA	0.86	NA	0.63	1.0	NA	NA
6x6x3	160	Carbon steel	Ambient	1.22	6.19	NA	NA	NA	NA	1.0	6.19
6x6x4	120	Carbon steel	140	1.85	8.21	NA	NA	NA	NA	1.27	3.63
6x6x6	120	Carbon steel	Ambient	1.28	1.28	NA	NA	NA	NA	1.0	1.0
8	40	Carbon steel	Ambient	NA	NA	2.09	NA	0.71	1.15	NA	NA
8	40s	Stainless steel	200	NA	NA	3.92	NA	0.993	1.60	NA	NA
8	40s	Stainless steel	300	NA	NA	4.36	NA	1.11	1.78	NA	NA
8	40s	Stainless steel	350	NA	NA	4.47	NA	1.13	1.73	NA	NA
8	40s	Stainless steel	400	NA	NA	4.58	NA	1.16	1.87	NA	NA
8	40s	Stainless steel	500	NA	NA	5.04	NA	1.28	2.05	NA	NA
8	140	Stainless steel	535	NA	NA	1.16	NA	0.571	0.919	NA	NA
8	160	Stainless steel	535	NA	NA	0.99	NA	0.54	0.87	NA	NA
8	160	Stainless steel	595	NA	NA	1.03	NA	0.56	0.91	NA	NA
8x8x2	40s	Stainless steel	500	2.05	72.4	NA	NA	NA	NA	2.05	60.4
8x8x4	40s	Stainless steel	500	5.2	19.7	NA	NA	NA	NA	2.05	10.63
8x8x8	40s	Stainless steel	400	4.84	4.84	NA	NA	NA	NA	1.87	1.87
8x8x8	40s	Stainless steel	500	5.2	5.2	NA	NA	NA	NA	2.05	2.05
10	40	Carbon steel	Ambient	NA	NA	1.26	2.21	0.401	0.647	NA	NA
10	40s	Stainless steel	400	NA	NA	2.74	NA	0.654	1.05	NA	NA
10	160	Stainless steel	535	NA	NA	0.510	NA	0.272	0.438	NA	NA
10x10x8	40s	Stainless steel	400	2.89	4.54	NA	NA	NA	NA	1.05	1.87
10x10x10	40s	Stainless steel	400	2.89	2.89	NA	NA	NA	NA	1.05	1.05
12	SW	Carbon steel	Ambient	NA	NA	0.951	NA	0.274	0.441	NA	NA
12	40s	Stainless steel	200	NA	NA	1.78	NA	0.384	0.620	NA	NA
12	40s	Stainless steel	300	NA	NA	1.98	NA	0.426	0.688	NA	NA
12	40s	Stainless steel	500	NA	NA	2.30	NA	0.495	0.799	NA	NA
12	40	Stainless steel	400	NA	NA	1.83	NA	0.416	0.671	NA	NA

Table 8. (Continued).

Size (in.)	Schedule	Material	Temperature (°F)	Unreinforced branches[a] F_{PR}	Unreinforced branches[a] F_{PB}	Elbows	Miters	Straight pipe	Butt welds	Reinforced branches F_{PR}	Reinforced branches F_{PB}
12x12x8	40	Stainless steel	400	1.92	4.27	NA	NA	NA	NA	0.67	1.87
12x12x12x12	40	Stainless steel	400	1.92	1.92	NA	NA	NA	NA	0.67	0.67
14	tn=0.375	Carbon steel	Ambient	NA	NA	0.837	1.47	0.226	0.365	NA	NA
14	40	Carbon steel	Ambient	NA	NA	0.64	NA	0.197	0.31	NA	NA
14	40	Stainless steel	400	NA	NA	1.42	NA	0.319	0.515	NA	NA
14	160	Stainless steel	400	NA	NA	0.226	NA	0.115	0.186	NA	NA
14	160	Stainless steel	595	NA	NA	0.255	NA	0.131	0.211	NA	NA
14x14x12	40	Stainless steel	400	1.51	1.81	NA	NA	NA	NA	0.515	0.671
14x14x14	tn=0.375	Carbon steel	Ambient	1.18	1.18	NA	NA	NA	NA	0.365	0.365
14x14x14	40	Carbon steel	Ambient	1.02	1.02	NA	NA	NA	NA	0.31	0.31
14x14x14	160	Stainless steel	400	0.237	0.237	NA	NA	NA	NA	0.186	0.186
16	120	Carbon steel	140	NA	NA	0.109	NA	0.061	0.099	NA	NA
16	120	Carbon steel	556	NA	NA	0.137	NA	0.077	0.124	NA	NA
16x16x3	Run=120 Branch=160	Carbon steel	556	0.124	8.05	NA	NA	NA	NA	0.124	8.05
18	SW	Carbon steel	Ambient	NA	NA	0.593	NA	0.135	0.217	NA	NA
18	SW	Stainless steel	200	NA	NA	1.11	NA	0.189	0.304	NA	NA
18	SW	Stainless steel	300	NA	NA	1.24	NA	0.209	0.339	NA	NA
18	SW	Stainless steel	500	NA	NA	1.43	NA	0.244	0.394	NA	NA
18	40	Stainless steel	400	NA	NA	0.671	NA	0.151	0.244	NA	NA
18x18x14	40	Stainless steel	400	0.711	1.17	NA	NA	NA	NA	0.244	0.515
20	SW	Carbon steel	Ambient	NA	NA	0.517	NA	0.110	0.176	NA	NA
20	SW	Stainless steel	200	NA	NA	0.966	NA	0.153	0.247	NA	NA
20	SW	Stainless steel	300	NA	NA	1.07	NA	0.170	0.274	NA	NA
20	SW	Stainless steel	500	NA	NA	1.24	NA	0.198	0.318	NA	NA
20	tn=0.500	Carbon steel	Ambient	NA	NA	0.317	NA	0.083	0.134	NA	NA
24	SW	Carbon steel	Ambient	NA	NA	0.403	NA	0.075	0.122	NA	NA
27-1/2	tn=2.38 in.	Stainless steel	535	NA	NA	0.032	NA	0.013	0.021	NA	NA

Table 8. (Continued).

Size (in.)	Schedule	Material	Temperature (°F)	Unreinforced[a] branches		Elbows	Miters	Straight pipe	Butt welds	Reinforced branches	
				F_{PR}	F_{PB}					F_{PR}	F_{PB}
27-1/2x27-1/2x4	tr=2.38 in. tb=0.438 in.	Stainless steel	535	0.021	6.32	NA	NA	NA	NA	0.021	5.60
27-1/2x27-1/2x8	tr=2.38 in. tb=0.812 in.	Stainless steel	535	0.021	0.92	NA	NA	NA	NA	0.021	0.87
27-1/2x27-1/2x10	tr=2.38 in.	Stainless steel	535	0.034	0.438	NA	NA	NA	NA	0.021	0.438
29	tn=2.50 in.	Stainless steel	595	NA	NA	0.029	NA	0.012	0.019	NA	NA
29x29x8	tr=2.50 in. tb=0.812 in.	Stainless steel	595	0.0199	0.949	NA	NA	NA	NA	0.019	0.91
29x29x14	tr=2.50 in. tb=1.406 in.	Stainless steel	595	0.0302	0.212	NA	NA	NA	NA	0.019	0.212
30	tn=0.500 in.	Carbon steel	Ambient	NA	NA	0.184	NA	0.036	0.058	NA	NA
30x30x20	tr=0.500 in. tb=0.375 in.	Carbon steel	Ambient	0.261	0.589	NA	NA	NA	NA	0.058	0.176
31	tn=2.66 in.	Stainless steel	530	NA	NA	0.023	NA	0.0093	0.015	NA	NA
36	tn=0.500 in.	Carbon steel	Ambient	NA	NA	NA	0.255	0.023	0.040	NA	NA
36x36x36	tn=0.500 in.	Carbon steel	Ambient	0.203	0.203	NA	NA	NA	NA	NA	NA
48	tn=0.625 in.	Carbon steel	Ambient	NA	NA	NA	0.12	0.014	0.023	NA	NA
48x48x20	t=0.625 in.	Carbon steel	Ambient	0.0957	0.557	NA	NA	NA	NA	NA	NA
48x48x30	tr=0.625 in. tb=0.500 in.	Carbon steel	Ambient	0.0957	0.247	NA	NA	NA	NA	NA	NA
48x48x48	tr=0.625 in. tb=0.500 in.	Carbon steel	Ambient	0.0957	0.0957	NA	NA	NA	NA	NA	NA

a. F_{PR} = scale factor for run; F_{PB} = scale factor for branch.

deviations below the average strengths. Average strength is not specified in the ASME code but is typically about 25% above the specified value (Ref. 39).

A lognormal representation of material strength was assumed. If the median yield strength is approximately 25% above the code specified strength and the code specified strength is a 95% nonexceedance value, the log-standard deviation is about 0.14.

In developing the range of strength for the reference pipe element, an analytical limit type analysis procedure was utilized to develop upper and lower values of moment capacity accounting for strain-hardening effects and accounting for a low probability that a large flaw could exist.

The upper value of moment capacity was developed based upon a procedure in the Zion FSAR amendments, Q 4-45-3, wherein the limit moment capacity is derived from integration of the stress field over the pipe cross section, assuming the outer fibers to be at the material ultimate strength with the neutral axis at the material yield strength. The derived upper value limit moment capacity is 1.65×10^6 in.-lb. This value is considered to be approximately one log-standard deviation above the median.

A lower bound capacity was derived by a limit analysis procedure documented in Appendix B of Ref. 55. A through-wall elliptical flaw of length equal to six times the wall thickness was assumed. A new neutral axis was derived for the flawed pipe and the limit moment was calculated assuming an elastic-perfectly plastic model with a flow stress equal to a specified fraction of the sum of the yield and ultimate strengths. The derived lower bound moment capacity was 9.5×10^5 in.-lb. Since the existence of a flaw of the size assumed has a very low probability of occurrence, the lower value is considered to be a minus 3 log-standard deviation value, which corresponds to about a 10^{-3} probability of occurrence.

With the establishment of the upper and lower bound values, and assuming the properties of the lognormal distribution, the median moment capacity for static loading was computed to be 1.41×10^6 in.-lb. Combining the variance of the strength due to the failure model with the variance of the material properties, the log-standard deviation on strength is computed to be 0.22. The random portion of this is due to random variations in material properties and is considered to be approximately 0.1 with the uncertainty equal to 0.20.

The static capacity was then modified for ductility. For heavy wall steel piping elements loaded primarily in bending, ductility is considered to range from 1.0 to 5, where the low value of 1.0 represents reduced ductility for the flawed condition. A ductility of 5 corresponds to about 1% primary strain observed at instability in limit moment tests of some piping fittings (Ref. 56). The associated ductility factors from Eq. (12) are 1.0 and 3.0. Assuming these factors to represent approximately a plus or minus two log-standard deviation range, the median ductility factor was computed to be 1.73 with the log-standard deviation equal to 0.27. The random portion is due to the randomness of the material and weld joint ductility and is considered to be approximately 0.15 with the uncertainty portion equal to 0.22. In addition, there is a dispersion on this ductility factor due to the uncertainty in the use of Eq. (12). The coefficient of variation, which is approximately the same as the log-standard deviation, is estimated to be approximately 0.15, which is considered to be all uncertainty.

The median capacity of the reference pipe element, modified for ductility, is the ductility factor times the median static capacity or

$$M = 2.44 \times 10^6 \text{ in.-lb}$$

The overall variabilities, expressed as log-standard deviations representing randomness and uncertainty, are obtained from the square root of the sum of the squares of the variabilities on individual variables contributing to the overall capacity:

$$\beta^R = 0.18$$
$$\beta^U = 0.33$$

The total uncertainty is thus

$$\beta = \sqrt{(\beta^R)^2 + (\beta^U)^2} = 0.376$$

A plot of the resulting fragility curve is shown in Fig. 35. This was used as the master fragility curve from which all other piping fragilities could be determined by use of the β factors in Table 6.

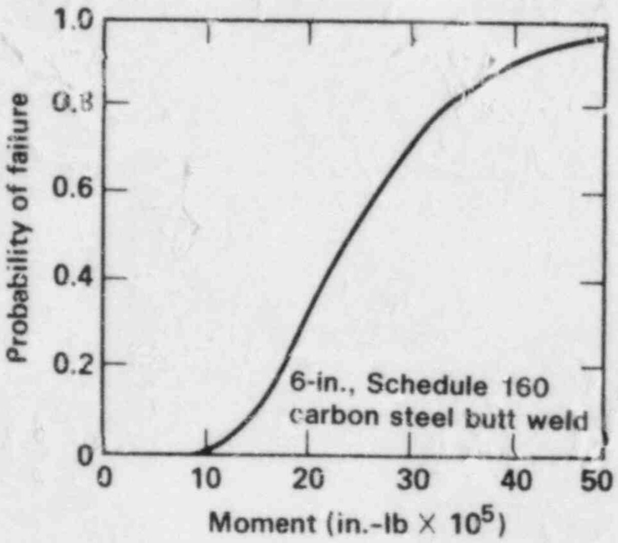


Figure 35. Master piping fragility curve.

4.4 Expert-Opinion Survey

Data for use in determining the strengths at failure of nuclear power plant components exposed to seismic excitations are very scarce. To date, no nuclear plant has been exposed to a major seismic disturbance. Non-nuclear plants have experienced earthquakes and some data, useful mainly for fragility verification purposes, have been gathered (Ref. 57), but for in situ performance of nuclear components there are no data at all. Also, seismic qualification of nuclear power plant components was not emphasized in the nuclear industry until about 1973. Components are still only qualified to a given excitation level by testing or by analytical methods. Determining the excitation that will cause failure of the component is not normally done.

Because of the lack of data, the SSMRP resorted to solicitation of expert opinion. It was recognized that many firms had tested their components to failure, but held the resulting information as proprietary and therefore not available directly. However, it was believed that individuals would respond to a questionnaire provided that their anonymity was protected and the response to the questionnaire was to be treated as opinion.

Of 40 manufacturers who had supplied components to the Zion plant, 38 were still in business and were asked to participate in the survey. All but two Zion component suppliers agreed to participate. In addition, all organizations possessing an ASME nuclear N stamp were contacted. The solicitation included both domestic and foreign suppliers of nuclear equipment; however, the bulk of the contacts were made with domestic organizations. Companies involved in the construction of nuclear plants and in the design of plant-related systems were also contacted. Altogether, over 600 individuals considered to be experts in the fragility of electrical and mechanical nuclear components were identified and categorized as follows:

1. Zion-specific component manufacturers
2. Component manufacturers
3. Test laboratories
4. Consulting firms
5. Architect/engineer firms
6. Reactor designers
7. Military experts
8. University professors

Approximately 400 of these individuals were contacted by telephone and their participation solicited. Of the 400 individuals contacted, 253 agreed to participate.

The questionnaire that was mailed to each individual who agreed to participate asked for specific details regarding the following general categories of information:

1. Identification and description of specific (or generic) component to which the answers were directed
2. Normal operating environment
3. Seismic qualification details
4. Failure modes (the three most likely were requested)
5. Fragility parameters, seismic capacities (10th, 50th, and 90th percentiles), confidence levels, and sources of information for each failure mode
6. Similarity of non-nuclear equipment
7. Equipment design era
8. Expertise of respondent

From the solicitation, 147 questionnaires were returned. A number of these contained only qualitative information which could not be used to construct a fragility description. These questionnaires described the environment to which components could be expected to be subjected or, in some cases, described the modes of component failure without giving a quantitative description. A total of 88 questionnaires were used to construct the analytical fragility descriptions. The results of the survey are contained in tables in Appendix C.

The tables show the estimates of seismic capacity, the appropriate parameter of response, and other pertinent information for each failure mode within each generic equipment category. The weighting factor assigned to each set of estimates for purposes of combining data is also indicated.

4.5 Combination of Data

It was assumed in the development of the SSMRP methodology that a single fragility curve of normal or lognormal distribution can appropriately represent each generic category of components for a particular failure mode. In general, however, there were multiple opinions and/or data for each failure mode, and since the various sets of opinion or data could be based on quite different components (because of size, manufacturing processes, design, etc.) within a single generic category, it was necessary to provide for subgrouping of similar components within a category for each mode. The procedure adopted, as discussed briefly in Sec. 2.1, was based on a combined least-squares and nested analysis of variance approach. The equations used are developed in Appendix E and the approach is described in detail in Ref. 8.

In the analysis, a weight was applied to the expert-opinion responses as a product of two factors: a factor for presumed expertise of the specialist providing the opinion, and a factor for the source of his opinion. The factors for expertise are listed in the following table.

Factor for source of expertise

Source	Weight
Zion manufacturers Component manufacturers Test laboratories Consulting firms Architect/engineers Reactor designers	3
Military experts	2
University professors	1

The second factor relates to the basis of response. Thus, if a respondent was in possession of test data and used it as the basis for his response it was considered better than an analytical method or pure opinion. Analytical methods were considered superior to pure opinion. Additionally, a different weighting was applied for pressure boundary failures and for functional failures. The factors for source of opinion are shown on the following table.

Factors for source of data

Source	Pressure boundary fragility weight	Functional fragility weight
Test	4.0	4.0
Analysis	3.0	2.0
Expert opinion	1.0	1.0

Analysis was weighted more heavily in the case of pressure boundary failure than for functional failure because it is believed that analysis more accurately predicts pressure boundary failures than functional failures.

The factors were combined multiplicatively and normalized to a maximum value of 3.0. When data from other sources were combined with expert opinion, they were treated as independent expert opinions, with weights assigned based on subjective evaluation of the quality of the data. When site-specific data was used it was assigned a weight of 3.0. The specific combinations of data used for each component category are documented in Appendix F.

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APPENDIX A
SUMMARY OF ZION SAFETY-RELATED COMPONENTS

This appendix summarizes all the safety-related components used in our study of the seismic safety of the Zion Nuclear Power Plant. Although used for the Zion study, the information on component fragility could be used for similar studies at other plants. The purpose of this appendix is to identify the components and provide sufficient information to determine if the components at Zion are sufficiently similar to components at other plants that the fragility data could be used for safety studies at other plants.

The data are organized in tabular form with the following headings:

P&I I.D. Number - This identifies the part.

Component - The name of the component. It may be a valve, a feedwater pump, or any safety component.

Description - A brief description which may be the type of pump and its capacity or a size of valve.

Location - This is the location of the component in the power plant.

Pipe Run - If appropriate, the pipe run with a component is identified.

Manufacturer - Company that manufactured the component.

Function - A component is identified as either active or passive.

Seismic Qualification Method - This may be a static analysis, a dynamic analysis, or some form of a test.

Acceptance Criteria - The ASME boiler and pressure vessel code, the Uniform Building Code (UBC), or other standard such as the American National Standards Institute (ANSI).

Dynamic Response Determination - A component's response to dynamic loads may be determined by the original design analysis or extrapolated. This identifies which method is used.

Frequencies - If dynamic analysis was performed, it lists the cutoff frequency; if not, then a component was treated as rigid or only responding in rigid-body modes.

Fragility Mode - The failure mechanism is identified as functional or stress- and load-related.

Fragility Parameter - Spectral acceleration is usually used and is in g.

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Fu
FW0037	Valve, gate	4", manual	Aux. bldg. (22-23, G-H) elev. 584		W. M. Powell Co.	Ac
FW0033	Valve, check	4" manual	Aux. bldg. (23-24, G-H) elev. 581		Chapman Valve	Ac
FW0036	Valve, globe	4", manual	Aux. bldg. (23-24, G-H) elev. 581		W. M. Powell Co.	Ac
FW0038	Valve, gate	4", manual	Aux. bldg. (23-24, G-H) elev. 581		W. M. Powell Co.	Ac
FW85H	Valve, globe	6", pneumatic/ Diaphragm	Aux. bldg. (23, P-R) elev. 600			Ac

nction	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
tive	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
tive	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
tive	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
tive	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
tive	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

n	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
FW0050	Valve, globe	6", MOV	Aux. bldg. (23, P-R) elev. 500		W. M. Powell Co.	Active
FW85G	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23-24, P-R) elev. 600			Active
FW0051	Valve, globe	6", MOV	Aux. bldg. (23-24, P-R) elev. 600		W. M. Powell Co.	Active
FW85F	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23, P-R) elev. 583			Active
FW0052	Valve, globe	3", MOV	Aux. bldg. (23-24, P-R) elev. 583		W.M. Powell Co.	Active
FW85E	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23-24, P-R) elev. 583			Active
FW0053	Valve, globe	3", MOV	Aux. bldg. 23-24, P-R) elev. 583		W. M. Powell Co.	Active
FW85D	Valve	3", pneumatic/ diaphragm operator	Aux. bldg. (23, P-R) elev. 576			Active
FW0054	Valve, globe	3", MOV	Aux. bldg. (23, P-R) elev. 576		W. M. Powell Co.	Active
FW85C	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23-24, P-R) elev. 581			Active
FW0055	Valve	3", MOV	Aux. bldg. (23-24, P-R) elev. 581		W. M. Powell Co.	Active
FW0068	Valve, check	3"	Containment bldg. (30-31, M-N) elev. 581		Chapman Valve	Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	F
FW85B	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23, P-R) elev. 596			Ac
FW0056	Valve, globe	3", MOV	Aux. bldg. (23, P-R) elev. 596		W. M. Powell Co.	Ac
FW85A	Valve, globe	3", pneumatic/ diaphragm operator	Aux. bldg. (23-24, P-R) elev. 596			Ac
FW0057	Valve, globe	3", MOV	Aux. bldg. (23-24, P-R) elev. 596		W. M. Powell Co.	Ac

nction	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
tive	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
tive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
tive	Static analysis	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration
tive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis	Rigid	Functional	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis	ASME boiler and pressure vessel code	Design analysis extrapolation	4.3 Hz	Tensile & shear in pump column walls	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code	Design analysis extrapolation	4.3 Hz	Tensile & shear in pump column walls	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code	Design analysis extrapolation	4.3 Hz	Tensile & shear in pump column walls	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code	Design analysis extrapolation	Rigid	Support structure	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code	Design analysis extrapolation	Rigid	Support structure	Spectral acceleration
Static analysis	1968 ASME draft code for nuclear components	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
Static analysis	1968 ASME draft code for nuclear components	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
Static analysis	1968 ASME draft code for nuclear components	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	1968 ASME draft pump and valve code	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
Static analysis	1968 ASME draft pump and valve code	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1SW001	Service water pump	24", vane 22,000 GPM	Crib house elev. 590 (108, BB-CC)	1SW138-24" X1-N	Layne-Bowler Inc.	Active
1SW002	Service water pump	24", vane 22,000 GPM	Crib house elev. 590 (110, BB-CC)	1SW127-24" X1-N	Layne-Bowler Inc.	Active
1SW033	Service water pump	24", vane 22,000 GPM	Crib house elev. 590 (112, BB-CC)	1SW136- [illegible]" X1-N	Layne-Bowler Inc.	Active
1SW004	Strainer	36", mech. restriction	Crib house elev. 590 (109-110, BB-CC)	1SW140-36" X1-N	Layne-Bowler Inc.	Passive
1SW005	Strainer	36", mech. restriction	Crib house elev. 590 (111-112, BB-CC)	1SW139-36" X1-N	Layne-Bowler Inc.	Passive
1SW0002	Butterfly valve	24", manual	Crib house elev. 603 (112, BB-CC)	1SW136-24" X1-N	Henry Pratt Co.	Active
1SW0005	Butterfly valve	24", manual	Crib house elev. 603 (110, BB-CC)	1SW137-24" X1-N	Henry Pratt Co.	Active
1SW0008	Butterfly valve	24", manual	Crib house elev. 603 (108, BB-CC)	1SW138-24" X1-N	Henry Pratt Co.	Active
1SW0001	Valve, check	24"	Crib house elev. 600 (112, BB-CC)	1SW136-24" X1-N	Mission Man. Corp.	Active
1SW0004	Valve, check	24"	Crib house elev. 600 (110, BB-CC)	1SW137-24" X1-N	Mission Man. Corp.	Active
1SW0007	Valve, check	24"	Crib house elev. 600 (108, BB-CC)	1SW138-24" X1-N	Mission Man. Corp.	Active
1SW0003	Butterfly valve	36", manual	Crib house elev. 603 (110-111, BB-CC)	1SW139-36" X1-N	Henry Pratt Co.	Active
1SW0006	Butterfly valve	36", manual	Crib house elev. 603 108-109, BB-CC)	1SW140-36" X1-N	Henry Pratt Co.	Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Fun
1S.'0017	Butterfly valve	36", manual	Crib house elev. 596 (112, BB-CC)	1SW139-36" X1-N	Henry Pratt Co.	Act
1SW0018	Butterfly valve	36" manual	Crib house elev. 596 (110, BB-CC)	1SW140-36" X1-N	Henry Pratt Co.	Act
OMOVSW0003	Butterfly valve	48", elec. motor	Crib house elev. 579 (107-108, BB-CC)	OSW012-48" X1-N	Henry Pratt Co.	Act
OSW0670	Valve, gate	8"		OSW098-8" X1-N	Henry Pratt Co.	Act
1MOVSW0107	Valve, gate	8", elec. motor operated	Aux. bldg. elev. 585 (22-23, G-H)	1SW154-8" X1-N	W. M. Powell Co.	Act
1MOVSW0106	Valve, gate	8", elec. motor operated	Aux. bldg. elev. 585 (22-23, G-H)	1SW154-8" X1-N	W. M. Powell Co.	Act

tion	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
ve	Static analysis	1968 ASME draft pump and valve code	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
ve	Static analysis	1968 ASME draft pump and valve code	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
ve	Static analysis (test operator)	1968 ASME draft code for nuclear components	Design analysis extrapolation	33 Hz	Functional: bending in disc or shaft	Spectral acceleration
ve	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ve	Static analysis (test operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ve	Static analysis (test operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	30.3 Hz	Bending at base of yoke arms	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	30.3 Hz	Bending at base of yoke arms	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static an[illegible]	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft + pump + valve code	Design analysis extrapolation		Functional	Spectral acceleration
Static analysis	ASME draft + pump + valve code	Design analysis extrapolation		Functional	Spectral acceleration
Static analysis	ASME Sect. VIII	Design analysis extrapolation		Support structure	Spectral acceleration
Static analysis	ASME Sect. VIII	Design analysis extrapolation		Support structure	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
2MOV5W0001	Gate valve	20", Electric motor operator	Aux. bldg.	25W003-20" X1-N	W. M. Powell Co.	Active
1MOVSW0002	Gate valve	20", Electric motor operator	Aux. bldg. elev. 572 (20-22, G-H)	1SW003-20" X1-N	W. M. Powell Co.	Active
1SW0179	Gate valve	8", manual	Aux. bldg.	1SW205-8" X1-N		Active
1MOVSW0102	Gate valve	8", electric motor operator	Aux. bldg.	1SW205-8" X1-N		Active
1MOVSW0101	Gate valve	8", electric motor operator	Aux. bldg.	1SW102-8" X1-N		Active
1MOVSW0104	Gate valve	8", electric motor operator	Aux. bldg.	1SW102-8" X1-N		Active
1MOVSW0103	Gate valve	8", electric motor operator	Aux. bldg.	1SW145-8" X1-N		Active
1MOVSW0105	Gate valve	8", electric motor operator	Aux. bldg.	1SW145-8" X1-N		Active
1SW0439	Gate valve	10", manual	Aux. bldg.	1SW100-10" X1-N		Active
1RH001	Pump	Centrifugal, 3000 GPM	Aux. bldg. elev. 542 (22, L-M)	1RH013-14" L-R 1RH001-10" L-R	Ingersoll-Rand Company	Active
1RH002	Pump	Centrifugal, 3000 GPM	Aux. bldg. elev. 542 (22, L-M)	1RH014-14" L-R 1RH002-10" L-R	Ingersoll-Rand Company	Active
1RH003	Heat exchanger	Vertical shell and tube	Aux. bldg. elev. 563 (20-21, L-M)	1RH007-10" L-R 1RH001-10" L-R	Engineers and Fabricators	Passive
1RH004	Heat exchanger	Vertical shell and tube	Aux. bldg. elev. 563 (20-21, L-M)	1RH008-10" L-R 1RH002-10" L-R	Engineers and Fabricators	Passive
1RH8749A	Check valve	8"	Containment elev. 586 (Z8-Z9)	1R0007-8" E-R		Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer
1MOVRH9000	Gate valve	12", electric motor operator	Aux. bldg. elev. 580 (23-23, P-R)	1RH006-12" L-R	
1MOVRH8702	Gate valve	14", Electric motor operator	Containment elev. 579 (Z-7)	1RH015-14" E-R	Copes-Vulcan, Inc.
1MOVRH8701	Gate valve	14", electric motor operator	Containment elev. 579 (Z-5, Z-6)	1RH015-14" E-R	Copes-Vulcan, Inc.
1MOVRH8700A	Gate valve	14", electric motor operator	Aux. bldg. elev. 546 (21-23, L-M)	1RH015-14" E-R	Darling Valve Company

unction	Seismic qual. method	Dynamic Acceptance criteria	response determination	Frequencies	Fragility mode	Fragility parameter
ctive	Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code: Sect. VIII	Design analysis extrapolation	33 Hz	Bolt failure yoke to bonnet	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code: Sect. VIII	Design analysis extrapolation	33 Hz	Bolt failure yoke to bonnet	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code: Sect. VIII	Design analysis extrapolation	33 Hz	Bolt failure yoke to bonnet	Spectral acceleration
Static analysis	ASME boiler and pressure vessel code: Sect. VIII	Design analysis extrapolation	33 Hz	Bolt failure yoke to bonnet	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1RH8730A	Check valve	10"	Aux. bldg. elev. 548 (21-23, K-L)	1RH001-10" L-R	Aloyco, Inc.	Active
1RH8728A	Gate valve	10", manual	Aux. bldg. elev. 553 (20-21, L-M)	1RH001-10" L-R	Darling Valve Company	Active
1RH8724A	Gate valve	10", manual	Aux. bldg. elev. 553 (20-21, L-M)	1RH001-10" L-R	Darling Valve Company	Active
1RHHOV606	Butterfly control valve	10", pneumatic, diaphragm operator	Aux. bldg. elev. 554 (20-21, L-M)	1RH007-10" L-R	Continental Equipment Co.	Active
1MOVRH8716A	Gate valve	8", electric motor operator	Aux. bldg. elev. 557 (20-21, L-M)	1RH009-8" L-R	Darling Valve Company	Active
1RHHCV618	Butterfly control valve	8", pneumatic, diaphragm operator	Aux. bldg. elev. 555 (20-21, L-M)	1RH005-8" L-R	Continental Equipment Co.	Active
1MOVRH8716C	Gate valve	8", electric motor operator	Aux. bldg. elev. 557 (20-21, L-M)	1RH010-8" L-R	Darling Valve Company	Active
1MOVRH8716B	Gate valve	8", electric motor operator	Aux. bldg. elev. 557 (20-21, L-M)	1RH010-8" L-R	Darling Valve Company	Active
1RHHCV607	Butterfly control valve	10", pneumatic, diaphragm operator	Aux. bldg. elev. 554 (20-21, L-M)	1RH008-10" L-R	Continental Equipment Co.	Active
1RH8724B	Gate valve	10", manual	Aux. bldg. elev. 554 (20-21, L-M)	1RH002-10" L-R	Darling Valve Company	Active
1RH8728B	Gate valve	10", manual	Aux. bldg. elev. 553 (20-21, L-M)	1RH002-10" L-R	Darling Valve Company	Active
1RH8730B	Check valve	10"	Aux. bldg. elev. 546 (21-23, M-N)	1RH002-10" L-R	Aloyco, Inc.	Active
1RH8726B	Gate valve	8", manual	Aux. bldg. elev. 553 (20-21, L-M)	1RH004-8" L-R	Darling Valve Company	Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer
1MOVRH8700B	Gate valve	14", electric motor operated	Aux. bldg. elev. 546 (21-23, L-M)	1RH014-14" L-R	Darling Valve Company
S1002	Boron injection tank	Vertical, skirt mounted	Outside containment (23-24, R) elev. 592	1SI078-4" E-R 1SI083-4" E-R	
1S1005	Accumulator tank 1A	Liquid pressurized	Containment bldg. (Z5-Z6) elev. 568	1SI036-10" L-N	Delta Southern Company
1SI8949D	Check valve	8"	Containment bldg. (Z1-Z2) elev. 585	1SI125-8" E1-R	Copes-Vulcan, Inc.
1SI8924	Diaphragm valve	4", manual	Aux. bldg. elev. 569 (23-25, L-M)	1SI120-4" AA-R	Gulf Energy & Environmental Systems
1SI8735	Gate valve	8", manual		1SI003-8" L-R	
1MOVSI8804A	Gate valve	8", motor operator	Aux. bldg. elev. 556 (23-25, L-M)	1SI001-8" L-R	Darling Valve Company

Function	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Active	Static analysis (valve) test (operator)	ASME draft/ASNI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Passive	Dynamic analysis	ASME Sect. VIII	Design analysis extrapolation	Rigid	Support structure	Spectral acceleration
Passive	Dynamic analysis	ASME Sect. VIII	Design analysis extrapolation		Support structure	Spectral acceleration
Active	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Active	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Active	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Active	Static analysis	ASME boiler and pressure vessel code: Sect. VIII	Design analysis extrapolation	Rigid	Bolt failure yoke to bonnet	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1SI8948A	Check valve	10"	Containment bldg. (Z5-Z6) elev. 587	1SI036-10" E-R	Darling Valve Company	Active
1SI8956A	Check valve	10"		1SI036-10" E-R	Darling Valve Company	Active
1MOVSI8406A	Gate valve	10", electric motor operated	Containment bldg. (Z6-Z7) elev. 576	1SI036-10" E-R		Active
1MOVSI8809A	Needle valve, motor operator	10", electric motor operator	Aux. bldg. elev. 593 (23-25, P-R)	1SI004-10" L-R	Velan Engineering	Active
1MOVSI8809B	Needle valve, motor operator	10", electric motor operator	Aux. bldg. elev. 592 (23-25, P-R)	1SI005-10" L-R	Velan Engineering	Active
1SI8957B	Check valve	10"	Containment elev. 591 (Z4-Z5)	1SI005-10" L-R	Darling Valve Company	Active
SI9002C	Check valve	8"	Containment elev. 572 (Z4-Z5)	1SI123-8" E-R	Darling Valve Company	Active
SI9002D	Check valve	8"	Containment elev. 574	1SI124-8" E-R	Darling Valve Company	Active
1SI9001C	Check valve	8"	Containment elev. 581 (Z14-Z15)	1SI123-8" E-R	Darling Valve Company	Active
1SI9001D	Check valve	8"	Containment elev. 582 (Z5-Z6)	1SI124-8" E-R	Darling Valve Company	Active
1MOVSI8811B	Gate valve	18", electric motor operator	Aux. bldg. elev. 557 (25-27, M-N)	1SI008-18" AA-R		Active
1MOVSI8811A	Gate valve	18", electric motor operator	Aux. bldg. elev. 557 (25-27, M-N)	1SI007-18" AA-R		Active
1MOVSI8812B	Gate valve	12", electric motor operator	Aux. bldg. elev. 568 (23-24, M-N)	1SI006-12" AA-R	Darling Valve Company	Active
1MOVSI8812A	Gate valve	12", electric motor operator	Aux. bldg. elev. 559 (23-24, M-MN)	1SI006-12" AA-R	Darling Valve Company	Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer
1SI8958	Check valve	12"	Aux. bldg. elev. 556 (21-23, M-N)	1SI006-12" AA-R	
1MOVSI9010A	Gate valve, motor operator	4", electric motor operator	Aux. bldg. elev. 568 (23-24, K-L)	1SI075-4" E-R	Darling Valve Company
1MOVSI9010B	Gate valve, motor operator	4", electric motor operator	Aux. bldg. elev. 568 (24-26, K-L)	1SI007-4" E-R	Darling Valve Company
1MOVSI8601A	Gate valve, motor operator	4", electric motor operator		1SI089-4" E-R	
1MOVSI8601B	Gate valve, motor operator	4", electric motor operator		1SI087-4" E-R	
1MOVSI8807A	Gate valve, motor operator	4", electric motor operator	Aux. bldg. elev. 511 (23-25, L-M)	1SI121-4" AA-R	Darling Valve Company
1MOVSI8807A	Gate valve, motor operator	4", electric motor operator	Aux. bldg. elev. 569 (23-25, L-M)	1SI120-4" AA-R	Darling Valve Company

unction	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
assive	Static analysis	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
ctive	Static analysis (valve) test (operator)	ASME draft, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis (valve) test (operator)	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1MOVCS0050	Gate valve	8", motor operator		1SI002-8" L-R		Active
1MOVCS0049	Gate valve	8", motor operator		1SI001-8" L-R		Active
1VC8546	Check valve	8"		1VC122-8" AA-R		Active
1MOV-VC-LCV 112-E	Gate valve	8", motor operator		1VC121-8" AA-R		Active
1MOV-VC-LCV 112-D	Gate valve	8", motor operator		1VC121-8" AA-R		Active
VC8481B	Check valve	4"		1VO77-4" E-R		Active
VC8481A	Check valve	4"		1VC078-4" E-R		Active
1VC8387B	Globe valve	3"		1VC256-3" E-R		Active
1VC8485B	Gate valve	4"		1VC073-4" E-R		Active
1VC8485A	Gate valve	4"		1VC078-4" E-R		Active
1VC8483B	Globe valve	4"		1VC073-4" E-R		Active
WCFCV0121	Globe valve	4"		1VC073-4" E-R		Active
1VC8483A	Globe valve	4"		1VC073-4" E-R		Active
1VC8387A	Globe valve	3"		1VC255-3" E-R		Active
1VC8365	Globe valve	3"		1VC079-3" E-R		Active

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer
1VC8401	Check valve	3"		1VC079-3" E-R	
1MOV-VC 8106	Gate valve	3", motor operator		1VC073-3" E-R	
1MOV-VC 8105	Gate valve	3", motor operator		1VC073-3" E-R	

Function	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Active	Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Active	Static analysis (valve) test (operator)	ASME boiler and pressure vessel code Sect. VIII and App. II	Design analysis extrapolation	Rigid	Yoke bolting	Spectral acceleration
Active	Static analysis (valve) test (operator)	ASME boiler and pressure vessel code Sect. VIII and App. II	Design analysis extrapolation	Rigid	Yoke bolting	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
Static analysis	ASME code Section VIII	Design analysis extrapolation	33 Hz	Functional	Spectral acceleration
Static analysis	ASME code Section VIII	Design analysis extrapolation	33 Hz	Functional	Spectral acceleration
Static analysis	ASME code Section VIII	Design analysis extrapolation	33 Hz	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Static analysis	ASME draft/ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
Dynamic analysis	ASME code Section III	Reanalysis	8 Hz	Structural at outlet nozzle	Bending moment at outlet nozzles
Dynamic analysis	ASME code Section III	Reanalysis	low 4 Hz	Structural	Spectral acceleration
Dynamic analysis	ASME code Section III	Reanalysis	low 4 Hz	Structural	Spectral acceleration
Dynamic analysis	ASME code Section III	Reanalysis	low 4 Hz	Structural	Spectral acceleration
Dynamic analysis	ASME code Section III	Reanalysis	low 4 Hz	Structural	Spectral acceleration
Dynamic response spectrum analysis	ASME boiler and pressure vessel code, Sect. III	Reanalysis	10 Hz tubes	Bending stress in the tubes	Spectral acceleration
Dynamic response spectrum analysis	ASME boiler and pressure vessel code, Sect. III	Reanalysis	10 Hz tubes	Bending stress in the tubes	Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1VC006	Charging pump 1A	Centrifugal	Aux. bldg. (23-24, K-1) elev. 579	1VC091-6" AA-R 1VC077-4" E-R		Active
1VC007	Charging pump 1B	Centrifugal	Aux. bldg. (24-25, K-1) elev. 579	1VC092-6" AA-R 1VC078-4" E-R		Active
1VC008	Charging pump 1C	Reciprocating	Aux. bldg. (25-26, K-1) elev. 579	1VC093-4" AA-R 1VC079-3" E-R		Active
1VC8402B	Globe valve	3", manual		1VC091-3E-R		Active
1VCHCV-182	Globe valve	3", hydraulic operator		1VC091-3E-R		Active
1VC8402A	Globe valve	3", manual		1VC091-3E-R		Active
1VC011-3E-R	Globe valve	3", manual		1VC091-3E-R		Active
			Nuclear Steam Supply System			
1RC001	Reactor vessel		Containment bldg. 560-600		Combustion Engineering	Passive
1RC110	Reactor coolant pump	1A	Containment bldg. Z6 elev. 580-600	1RC002-31" E-1R 1R003-27.5" E-1R	Westinghouse	Passive
1RC210	Reactor coolant pump	1C	Containment bldg. Z11 elev. 580-600	1RC034-31" E-1R 1RC035-27" E-1R	Westinghouse	Passive
1RC310	Reactor coolant pump	1D	Containment bldg. Z15 elev. 580-600	1RC069-31" E-1R 1RC070-27.5" E-1R	Westinghouse	Passive
1RC410	Reactor coolant pump	1B	Containment bldg. Z3 elev. 580-600	1RC121-31" E-1R 1RC122-27.5" E-1R	Westinghouse	Passive
1RC100	Steam generator	1A	Containment bldg. Z8 elev. 584-655	1RC001-29" E-1R 1RC002-31" E-1R	Westinghouse	Passive
1RC200	Steam generator	1C	Containment bldg. Z10 elev. 584-655	1RC033-29" E-1R 1RC034-31" E-1R	Westinghouse	Passive

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Functi
1RC300	Steam generator	1D	Containment bldg. Z16 elev. 584-655	1RC068-29" E-1R 1RC069-31" E-1R	Westinghouse	Passiv
1RC400	Steam generator	1B	Containment bldg. Z1 elev. 584-655	1RC110-29" E-1R 1RC121-31" E-1R	Westinghouse	Passiv
1RC002	Pressurizer	1800 ft^3	Containment bldg. Z2 elev. 580-647	1RC140-14" E-1R 1RC142-4" E-1R	Westinghouse	Passiv
1MPVRC-8001C	Gate valve	29", motor operator	Containment bldg.	1RC068-29" E-1R		Active
1MOVR-8001B	Gate valve	29", motor operator	Containment bldg.	1RC033-29" E-1R		Active
1MOVRC-8001A	Gate valve	29", motor operator	Containment bldg.	1RC001-29" E-1R		Active
1MOVRC-8001D	Gate valve	29", motor operator	Containment bldg.	1RC110-29" E-1R		Active

n	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
e	Dynamic response spectrum analysis	ASME boiler and pressure vessel code, Sect. III	Reanalysis	10 Hz tubes	Bending stress in the tubes	Spectral acceleration
e	Dynamic response spectrum analysis	ASME boiler and pressure vessel code, Sect. III	Reanalysis	10 Hz tubes	Bending stress in the tubes	Spectral acceleration
e	Dynamic response spectrum analysis	1971 ASME boiler and pressure vessel code, Section III	Reanalysis	.7 Hz (sloshing) 27 Hz (heater) Rigid (vessel)	Support skirt structure	Bending moment at base of support skirt
	Static analysis (valve) test (operator)	Draft ASME code/ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	Draft ASME code/ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	Draft ASME code/ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
	Static analysis (valve) test (operator)	Draft ASME code/ANSI	Reanalysis	Rigid	Functional	Spectral acceleration

Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
tatic analysis valve) test operator)	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis valve) test operator)	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis valve) test operator)	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis valve) test operator)	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Reanalysis	Rigid	Functional	Spectral acceleration
tatic analysis	Draft ASME Code, ANSI	Design analysis extrapolation	Rigid	Functional	Spectral acceleration
est and static nalysis	Functional & 90% of yield for structural failure modes	Design analysis extrapolation	5 Hz (control panel)	Tripping of relays	Spectral acceleration
nalysis	API code	Design analysis extrapolation			Spectral acceleration

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Function
1MOVRC-8002A	Gate valve	27.5", motor operator	Containment bldg.	1RC003-27.5" E-1R		Active
1MOVRC-8002B	Gate valve	27.5", motor operator	Containment bldg.	1RC035-27.5" E-1R		Active
1MOVRC-8002C	Gate valve	27.5", motor operator	Containment bldg.	1RC070-27.5" E-1R		Active
1MOVRC-8002D	Gate valve	27.5", motor operator	Containment bldg.	1RC122-27.5" E-1R		Active
1RC0022	Gate valve	4", manual	Containment	1RC142-4" E-1R		Active
1PVC-RC07	Globe control valve	4"	Containment bldg.	1RC142-4" E-1R		Active
1RC0023	Gate valve	4", manual	Containment bldg	1RC142-4" E-1R		Active
1RC0020	Gate valve	4", manual	Containment bldg.	1RC141-4" E-1R		Active
1PCV-RC06	Globe control valve	4"	Containment bldg.	1RC141-4" E-1R		Active
1RC0021	Gate valve	4", manual	Containment bldg.	1R141-4" E-1R		Active
1RC0021	Gate valve	4", manual	Containment bldg.	1RC141-4" E-1R		Active
1RC8010A 1RC8010B 1RC8010C	Pressurizer relief valve	6"	Containment bldg. at top of pressurizer	1RC157-6" E-1R 1RC156-6" E-1R 1RC155-6" E-1R		
			Miscellaneous Electrical Components			
	Diesel generator system		Diesel, Generator bldg. (29-35, G-J) elev. 592	NA	Cooper-Bessemer	Active
	Diesel generator oil storage tank	50,000 gal	Diesel, Generator bldg. (31-35, G-J) elev. 560	NA		Passive

Summary of Zion safety-related components (continued).

P&I ID number	Component	Description	Location	Pipe run	Manufacturer	Func
	Motor control centers & I&C panels		Aux. bldg. (17-23, G-J) elev. 642	NA		Ac
	Switchgear	4160	Aux. bldg. (31-34, G-H) elev. 617 (31-34, G-J) elev. 642	NA		Ac
	Switchgear	480	Aux. bldg. (31-34, H) elev. 617	NA		Ac
	Battery racks		Aux. bldg. (25-29, K-L) elev. 642	NA		Pa
	Battery chargers (static)		Aux. bldg. (25-29, K-L) elev. 642	NA		Pa
	Cable tray		Throughout plant	NA		Pa
	Aux. relay cabinets		Aux. bldg. elev. 642	NA		Ac
	Breaker panels		Aux. bldg. elev. 642	NA		Ac
	Local instruments		All locations	NA		Ac

...tion	Seismic qual. method	Acceptance criteria	Dynamic response determination	Frequencies	Fragility mode	Fragility parameter
...ive	Test	Function	Design analysis extrapolation		Functional	Spectral acceleration
...ive	Test	Function	Design analysis extrapolation		Functional	Spectral acceleration
...ive	Test	Function	Design analysis extrapolation		Functional	Spectral acceleration
...ssive	Static analysis (rocks) test (chargers)	AISC code	Design analysis extrapolation	15 to 20	Anchor bolting	Spectral acceleration
...ssive	Test		Design analysis extrapolation	33 Hz	Functional failure	Spectral acceleration
...ssive	No qualification specified	AISC code	Design analysis extrapolation	Low frequencies 4 to 10 Hz	Structural	Spectral acceleration
...ive	Test	Functionability	Design analysis extrapolation	5 - 15 Hz	Function	Spectral acceleration
...ive	Test	Functionability	Design analysis extrapolation	5 - 15 Hz	Function	Spectral acceleration
...ive	Test	Functionability	Design analysis extrapolation	5 - 15 Hz	Function	Spectral acceleration

APPENDIX B

REPORTS FROM THE U.S. ARMY CORPS OF ENGINEERS SAFEGUARD PROGRAM USED BY THE SSMRP IN FRAGILITY DEVELOPMENT

This appendix establishes the source of most experimental data used to establish the fragility for mechanical components used in the Seismic Safety Margins Research Program (SSMRP). When appropriate, these data were used in conjunction with other fragility data, such as expert opinion, analysis, or design data, to construct fragility curves.

Actual test data are the most reliable way to establish fragility or failure data. Conventional practice for nuclear components is to test to a qualification level and not to failure. Consequently, most tests of nuclear power plant components cannot be used to establish a fragility data base.

The data sources documented in this appendix are an exception. The major source of data on fragility came from the SAFEGUARD Program conducted by the U.S. Army Corps of Engineers. It was an 11-year effort in support of missile-site hardening. Tests were done on off-the-shelf components representative of those used in nuclear power plants in the late 1960s. It included electrical and mechanical components.

Sixty-four test programs were conducted on a shake table excited by sine beat pulse tests that were selected to fit prescribed acceleration spectra. Components were excited to levels of more than 15 g while their functions were monitored. Consequently, the tests were true measures of fragility. Approximately 300 test reports were issued; 63 were directly applicable to components used in the SSMRP.

The table appearing in this appendix lists the 63 applicable test reports and the component categories for each report. These test reports can be used by the reader to trace the source of the experimental fragility data.

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development.

Report No.	Huntsville subsystem hardness report	Applicable* categories
1	"A Quasi-Probabilistic Method for Evaluation Conservatism in the Design of Protective Facilities," Document Nos. SAF-102, SAF-103, SAF-105, Prepared by RMP, issued date 3-1-75	NA
2	"Screening of M/C Subsystem Equipment for Hardness Testing," Document Nos. PAR-CRI-A&W-94, (Vol. II) Prepared by A&W, issued date 6-72	NA
3	"Screening of M/C Subsystem Equipment for Hardness Testing," Document Nos. PAR-CRI-A&W-94, (Vol. III Part 1) Prepared by A&W, issued date 6-72	NA
4	"Screening of M/C Subsystem equipment for Hardness Testing," Document Nos. PAR-CRI-A&W-94, (Vol. III Part 2) Prepared by A&W, issued date 6-72	NA
5	"Shock Test Program, Air Handling Unit (H06AU), For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-325-ED-R, Prepared by CERL, issued date 12-31-74	#29
6	"Shock Test Program, Piping Segment (P02PC), For Safeguard TSE Systems Equipment." Chilled Water Segment Digital Rock Coding Segment Compressed Air Segment, Document Nos. HNDSP-74-326-ED-R, Prepared by CERL, issued date 12-31-74	#12, 17, 25
7	Shock Test Program, Piping Segment (P39PC), For Safeguard TSE Systems and Equipment." Chilled Water Circulating System, Document Nos. HNDSP-74-327-ED-R, Prepared by CERL, issued data 12-31-74	#12, 17, 25
8	"Shock Test Program, Piping Segment (P30PC) For Safeguard TSE Systems and Equipment." Cooled Water Circulating System, Document Nos. HNDSP-74-328-ED-R Prepared by CERL, issued date 12-31-74	#12, 17, 25
9	"Shock Test Program Gas Turbo-Generator Assembly (E01GT), For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-329-ED-R, Prepared by CERL, issued date 12-31-74	NA
10	"Unit Substation (E05SS), (A), Motor Control Center," Document Nos. HNDSP-74-331-ED-R, Prepared by CERL, issued date 12-31-74	#26

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
11	"Unit Substation (E05SS) (B), Voltage Regulator, Circuit Breaker," Document Nos. HNDSP-74-332-ED-R, Prepared by CERL, issued data 12-31-74	#22, 28
12	"Unit Substation (E12SS) Motor Control Center," Westinghouse, 2 Cabinets with motor starters, Document Nos. HNDSP-74-333-ED-R, Prepared by CERL, issued date 12-31-74	#26
13	"Unit Substation (E16SS) Transformers," Document Nos. HNDSP-74-334-ED-R, Prepared by CERl, issued date 12-31-74	#21
14	"Unit Substation (E27SS), Circuit Breaker," Document Nos. HNDSP-74-335-ED-R, Prepared by CERL, issued date 12-31-74	#29
15	"Unit Substation (E29SS), Circuit Breaker," Document Nos. HNDSP-74-336-ED-R, Prepared by CERL, issued date 12-31-74	#29
16	"Shock Test Program, Motor Generator Set (E03GM), For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-337-ED-R, Prepared by CERL, issued date 12-31-74	#18, 23
17	"Shock Test Program, Motor Generator Set (E12GM), For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-338-ED-R, Prepared by CERL, issued date 12-31-74	#18, 23, 26
18	"Shock Test Program, Air Conditioner Test For Safeguard TSE Systems and Equipment," Document Nos. HNDDSP-71-58-Ed-R, Prepared by Wyle, issued date 5-15-72	#30
19	"Shock Test Program, Station Battery System For Safeguard TSE Systems and Equipment," AC Switchboard Document Nos. HNDDSP-72-69-ED-R, Prepared by Wyle, issued date 8-18-72	#19
20	"Shock Test Program - Electrical Panelboards Test - For Safeguard TSE Systems and Equipment," Document Nos. HNDDSP-72-64-ED-R, Prepared by Wyle, issued date 9-30-72	#24, 29

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
21	"Shock Test Program - Water Purification Units - For Safeguard TSE Systems and Equipment," Document Nos. HNDDSP-72-70-ED-R, Prepared by Wyle, issued date 4-73	NA
22	"Shock Test Program, Water Chiller For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-73-95-ED-R, Prepared by Wyle, issued data 4-1-73	NA
23	"Shock Test Program - Heat Exchanger - For Safeguard TSE systems and Equipment," Document Nos. HNDSP-73-85-ED-R, Prepared by Wyle, issued data 4-30-73	#9
24	"Shock Test Program - Centrifugal Axial Fans - For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-73-87-Ed-R, Prepared by Wyle, issued date 4-30-73	#30
25	"Shock Test Program - Waste Disposal Pumps - For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-73-88-ED-R, Prepared by Wyle, issued date 4-30-73	#12, 23
26	"Shock Test Program, Monitoring and Control Components For Safeguard TSE Systems and Equipment," Valves & Transmitting Devices, Document Nos. HNDDSP-73-302-ED-R, Prepared by Wyle, issued data 12-31-73	#14, 17
27	"Shock Test Program, Metal-Clad Switchgear For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-73-305-ED-R, Book 1 & 2, Prepared by Wyle, issued date 12-31-73 (27-1 Volume #1, 27-2 Volume #2)	#20
28	"Shock Test Program Piping Segments For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-306-ED-R, Prepared by Wyle, issued date 3-31-74	#5, 12, 17, 25
29	"Shock Test Program 660-Ton Chiller Components For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-308-ED-R, Prepared by Wyle, issued date 5-1-74	#9, 17, 25
30	"Shock Test Program Air Compressor Control Panel - Drive Motor For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-309-ED-R, Prepared by Wyle, issued date 5-1-74	#12, 23, 26

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
31	"Shock Test Program, Switchgear Cabinet, Transfer Function Tests," Document Nos. HNDSP-73-91-ED-R, Prepared by Wyle, issued date 4-15-73	#20
32	"Shock Test Program, Generator Control Panel, For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-310-ED-R, Prepared by Wyle, issued date 6-1-74	#23
33	"Shock Test Program, Generator Neutral Breaker, For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-312-ED-R, Prepared by Wyle, issued date 7-15-74	#20
34	"Shock Test Program Electric Motor Control Centers (E52MC) (E87MC) For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-315-ED-R, Prepared by Wyle, issued date 7-1-74	#26
35	"Shock Test Program Instrument Air Dryer For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-316-ED-R, Prepared by Wyle, issued date 9-30-74	#17
36	"Shock Test Program Monitor and Control Components For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-320-ED-R, Prepared by Wyle, issued date 12-31-74	#17, 22, 25
37	"Shock Test Program, Thermo Water Valve, For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-321-ED-R, Prepared by Wyle, issued date 10-1-74	#17
38	"Shock Test Program, Temperature Switch (I58TS), For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-322-ED-R, Prepared by Wyle, issued date 9-20-74	NA
39	"Shock Test Program, Generator Static Exciter/Regulator, For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-323-ED-R, Prepared by Wyle, issued data 9-1-74	#20

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
40	"Shock Test Program, Diesel Engine Components and M&C Components, For Safeguard TSE Systems and Equipment," Fuel Pump, Control Cabinet, Regulators, Governors, & Transmitters, Document Nos. HNDSP-74-324-ED-R, Vol. I, Prepared by Westinghouse, issued date 12-31-74	#18, 23
41	"Shock Test Program, Diesel Engine Components and M&C Components, For Safeguard TSE Systems and Equipment," Fuel Pump, Control Cabinet, Regulators, Governors, & Transmitters, Document Nos. HNDSP-74-324-ED-R, Vol. II, Prepared by Westinghouse, issued date 12-31-74	#18, 23
42	"Shock Test Program Compressor Control Oil Shutdown Switch For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-340-ED-R, Prepared by Wyle, issued date 11-15-74	#25
43	"Shock Test Program Pressure Control Valve (P83VE) For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-342-Ed-R, Prepared by Wyle, issued date 11-20-74	#17
44	"Shock Test Program Heat Sensing Device Assembly For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74-345-Ed-R, Prepared by Wyle, issued date 11-27-74	#23, 25
45	"Shock Test Program Relay Fragility Test For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-71-57-ED-R, Prepared by Wyle, issued date 5-15-72	NA
46	"Electric Motor Control Center Fragility Test ITC (E89MC)," Document Nos. HNDDSP-72-73-ED-R, Prepared by The Boeing Co., issued date 11-6-72	#26
47	"Electric Motor Control Center Fragility Test ITC (E06MC)," Document Nos. HNDDSP-72-71-ED-R, Prepared by The Boeing Co., issued date 3-30-73	#26
48	"Electric Motor Control Center Fragility Test ITC (E52MC)," Document Nos. HNDDSP-72-74-ED-R, Prepared by The Boeing Co., issued date 11-20-72	#26

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
49	"Shock Test Program, Air Conditioning CBR Filters," Document Nos. HNDSP-73-86-ED-R, Prepared by Wyle, issued date 4-30-73	NA
50	"Safeguard Vibration Testing and Analysis Report of Tactical Support Equipment Final Report Data Supplement," Document Nos. 56137-15-745, Prepared by GE, issued date 9-25-70	#20, 26
51	"Summary of Simulated Nuclear Weapons Effects Tests on Six Selected Mission-Critical Items of Safeguard Facility Equipment," Document Nos. SAF-10, Prepared by RMP, issued date 8-8-69	#12, 21, 24, 26, 29
52	"Electrical Components," Relays & Circuit Breakers, Vol. I, Document Nos. HNDSR-75-349-ED-R, Vol. I & Vol. II, Prepared by Wyle, issued date 7-1-75	NA
53	"Electrical Components," Relays & Circuit Breakers, Vol. II, Document Nos. HNDSR-75-349-ED-R, Vol. I & Vol. II, Prepared by Wyle, issued date 7-1-75	NA
54	"Fragility Testing - Electric Motor Control Centers (ITC'S E06MC, E52MC, E87MC, and E89MC)," Document Nos. HNDSP-73-159-ED-R, Vol. I & Vol. II, Prepared by The Boeing Company, issued date 3-30-73 (54-1 Volume #1, 54-2 Volume #2)	#26
55	"Qualification Tests For Spring Isolators 92095-1 through 6," Document Nos. WD-92095-1 through 6, Prepared by Barry Controls, issued date 11-71	NA
56	"Review of Parb Shock Isolation Platform," Document Nos. PAR-CRI-A&W-112, Prepared by A&W, issued date 12-72	NA
57	"Heat Exchanger Subsystem Hardness Assurance Analysis (SHAA)," Document Nos. TM-39, Prepared by The Boeing Co., issued date 3-1-73	NA
58	"Shock Test Program, Dynamic Analysis - Diesel Engine Generator, For Safeguard TSE Systems and Equipment," Document Nos. HNDTR-73-12-ED-R, Prepared by AA, issued date 12-32-73	#18

U. S. Army Corps of Engineers Huntsville subsystem hardness reports used by SSMRP for fragilities development. (continued)

Report No.	Huntsville subsystem hardness report	Applicable* categories
59	"Shock Test Program Dynamic Analysis of Motor-Generator Set For Safeguard TSE Systems and Equipment," Document Nos. HNDSP-74 344-ED-R, Prepared by USAEDH, issued date 12-31-74	#18
60	"Electric Motor Control Center Fragility Test ITC (E87MC)," Document Nos. HNDDSP-72-72-ED-R, Prepared by The Boeing Co., issued date 3-30-73	#26
61	"Unit Substation (E04SS), Switch, Transformer, Voltage Regulator, Circuit Breaker," Document Nos. HNDSP-74-329-ED-R, Prepared by CERL, issued date 12-31-74	#21, 29
62	"Hardness Program - Non-Emp Subsystem Hardness Assurance Report," Executive Summary, Volume #1 & Volume #2, Document Nos. HNDDSP-72-156-ED-R, Prepared by The Boeing Co., issued date 6-75	NA
63	"Hardness Program - Non-Emp Subsystem Hardness Assurance Analysis For Safeguard TSE Ground Facilities," Volume #2, Document Nos. HNDSP-73-161-ED-R, Prepared by The Boeing Co., issued date 6-1-75	NA

* Consult the Table of Component Categories to define these group numbers.

Table of Component Categories.

Category number	Category description	Category number	Category description
1	Reactor Coolant System Class I Vessels and Supports	16	Small Motor operated valves < 10"
2	Main Coolant Pumps	17	Small Misc. Valves ≤ 8"
3	NSSS Piping	18	Emergency AC Power Units (4160 V Diesel Generator)
4	Large Diameter Piping, 8" and Greater	19	Emergency DC Power (Batteries and Racks)
5	Intermediate Diameter Piping, 2-1/2" - 8"	20	Switchgear (Includes Transformer, Breakers & Busses)
6	Large Vertical Storage Vessels with Formed Heads	21	Transformers (Non ESF-ESF Transformers are in switchgear)
7	Large Flat Bottom Storage Tanks	22	Instrument Panels and Racks
8	Large Horizontal Vessels (Pressurizer Relief Tank)	23	Control Panels and Racks
9	Small - Medium Vessels and Heat Exchangers	24	Auxiliary Relay Cabinets
10	Buried Pipe (Service Water)	25	Local Instruments (Misc. Pressure and Temperature Sensors)
11	Large Vertical Centrifugal Pumps with Motor Drive (Service Water Pumps)	26	Motor Control Center
12	Small - Medium Horiz. & Vertical Motor, Turbine & Diesel Driven Pumps & Compressors	27	Static inverters
13	Large Motor Operated Valves ≥ 10"	28	Cable Trays
14	Large Hydraulic and Pneumatic Valves ≥ 10"	29	Breaker Panels
15	Large Check, Spring Relief & Manual Valves	30	Air Conditioning and Air Handling Power Units
		31	Ducting
		32	Control Rods & Drives
		33	Computers
		34	Offsite Power (Ceramic Insulators)

APPENDIX C

DATA OBTAINED FROM EXPERT-OPINION SURVEY

Experimental data or test results are the preferred way to construct fragility curves, but few data are available for the public record. Consequently, alternative approaches were required. One of these is the use of expert opinion.

While nuclear reactor components are tested to qualification levels, there is no requirement to test to failure. However, we believe that many components might have been tested to failure but that the data were treated as proprietary. We believed the information might be obtained by an expert-opinion questionnaire provided the respondent's anonymity was protected and the response to the questionnaire was treated as opinion.

We contacted 38 manufacturers who were still in business, of the 40 who had supplied components to the Zion plant. Thirty-six out of the 38 agreed to participate in the questionnaire. In addition, organizations possessing an ASME nuclear N stamp were contacted. Included were both domestic and foreign suppliers of nuclear equipment. Companies involved in the construction of nuclear power plants and in the design of plant-related systems were contacted.

Approximately 400 people were contacted from 600 identified, and of that number, 253 agreed to participate. From the solicitation, 143 questionnaires were returned. However, some contained only qualitative information, and only 88 questionnaires were used to construct the analytical fragility descriptions. Results from the questionnaire are documented in the following tables. These tables are organized according to categories and are shown in numerical order. For example, Category 1 is Reactor Core Assembly and Category 2 is Pressurizer and Steam Generator.

Within each category the data is organized according to the following headings.

<u>Respondent</u> - The source of the data (i.e., consulting firm, professor, etc.) and a coded number to identify the source.

<u>Wt.</u> - This is a weighting factor that is based upon the product of two factors: (1) a factor for the presumed expertise of the specialist, and (2) the basis of the response. If the basis is test data, it is given more weight than if it were expert opinion. This product is then normalized by 3. The number 3 represents the highest that could be given. More details are found in Appendix D "Analysis of Expert Opinion Data."

<u>Failure Modes</u> - The three most probable failure modes are listed.

<u>Response Parameter</u> - This is a response parameter that is linked to each of the three failure modes. It could be peak acceleration, spectral acceleration, stress level strain, or even force level.

<u>Percentiles</u> - 10%, 50%, 90%. These represent the response values at 10%, 50%, and 90% probability of failure.

Basis for Response - This lists the primary source of information for establishing the values for probability of failure. These could be test data, analysis, expert opinion, or any other source of data.

Comments - These are clarifying comments about data listed and may include predominant response frequencies, information on damping, or any special information required.

The responses covered virtually every category of component needed for the Zion plant analysis and Phase I of the SSMRP. Comparison of the responses from different experts for the same category showed good agreement with one another.

The expert-opinion data were used to supplement data from other sources. Not all of the data were used. In these instances, the expert response was difficult or impossible to quantify or was inconsistent in form with other fragility information.

Category 1. Reactor Core Assembly.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3201031916)	1.50	Binding of control rods due to seismically induced deformations.	Spectral acceleration.	2.0 g	3.0 g	10.0 g	Analytical methods, expert opinions.	Predominant frequencies: Mode #1, 3 Hz; Mode #2, 3 Hz; and Mode #3, 5 Hz.
	1.50	Deformation of guide tubes due to seismic impact of fuel bundle.	Spectral acceleration.	3.0 g	4.0 g	15.0 g	Analytical methods, expert opinions.	Percentiles include LOCA.
	1.50	Failure of core support structure due to inertia load of fuel.	Spectral acceleration.	3.0 g	5.0 g	20.0 g	Analytical methods, expert opinions.	PWR, all modes. Functional Failure: all modes. Fragility parameter: acceleration at core support attachment to reactor vessel.
Professor (4101022009)	1.00	Interference between moving parts within unit.	Spectral displacement.	0.5 in.	0.7 in.	1.0 in.	Extrapolation from test observation.	Predominant frequency, 3-5 Hz. BWR, Functional Failure.
Consulting Firm (3201041907)	1.50	Binding of control rods due to seismic induced deformation.	Spectral acceleration.	2.0 g	2.5 g	7.0 g	Expert opinion, analytical methods.	All modes: predominant frequency, Mode #1, 3 Hz; Mode #2, 3 Hz; Mode #3, 5 Hz.
	1.50	Deformation of guide tubes due to seismic impact of bundles.	Spectral acceleration.	2.0 g	3.0 g	10.0 g	Expert opinion, analytical methods.	All modal percentiles include LOCA.
	1.50	Failure of core support structure due to inertia load of fuel.	Spectral acceleration.	3.0 g	4.0 g	12.0 g	Expert opinion, analytical methods.	BWR, all modes. Functional failure; all modes. *Acceleration induced displacement
Consulting Firm (3201012005)	1.50	Slow SCRAM time of control rods.	Spectral acceleration.	0.33 g	0.36 g	0.45 g	Expert opinion.	Predominant frequency given for Mode #1 only and it is 4-10 Hz.
	1.50	Plastic distortion which prevents full rod insertion.	Spectral acceleration.	0.39 g	0.45 g	0.76 g	Expert opinion.	BWR, all modes.
	1.50	Lifting fuel and disarranging core configuration	Spectral acceleration.	--	2.0 g	--	Expert opinion.	Functional Failure: all modes

Category 2: Pressurizers and Steam Generators.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3202071913)	2.25	Failure of anchor bolts.	Spectral acceleration.	2.0 g	3.0 g	5.0 g	Analytical methods, expert opinion.	Pressurizer. Both modes: predominant frequency, 7.0 Hz.
	2.25	Buckling of support skirt.	Spectral acceleration	4.0 g	5.0 g	8.0 g	Analytical methods, expert opinion	Percentiles include LOCA. Press. Bound. Fail; all modes.
Consulting Firm (3202061910)	2.25	Failure of connection between support leg and steam generator body.	Spectral acceleration.	2.0 g	3.0 g	4.0 g	Analytical methods, expert opinion.	Steam Generator. All modes: predominant frequency, 7.5 Hz.
	2.25	Failure of steam generator leg embedment in containment floor.	Spectral acceleration.	3.0 g	4.0 g	5.0 g	Analytical methods, expert opinion.	All modes: vertical direction acceleration.
	2.25	Buckling of steam generator leg.	Spectral acceleration.	3.0 g	4.0 g	5.0 g	Analytical methods, expert opinion.	Press. Bound. Fail; all modes.
Consulting Firm (3202022002)	1.50	Nozzles.	Forces.	3.0	5.0	7.0	Expert opinion weighted by exposure to analysis.	Steam Generator. All modes: percentiles are factors times SSE.
	1.50	Supports.	Acceleration.	5.0	7.0	9.0	Expert opinion weighted by exposure to analysis.	Predominant frequencies: Mode #1 10-30 Hz Mode #2 Rigid
	1.50	Tubing.	Spectral acceleration.	7.0	10.0	13.0	Expert opinion weighted by exposure to analysis.	Mode #3 20-100 Hz Press. Bound. Fail; all modes.
Consulting Firm (3202011108)	0.75	Rupture at primary inlet or outlet nozzle, rupture at feedwater nozzle.	Spectral and moments forces.	1.5	1.8	2.5	Expert opinion.	Steam Generator. Both modes: predominant frequency, 10-15 Hz. Mode #1, factors times Sy (Sy from ASME code).
	0.75	Failure of tubes in bundle, particularly when other factors which are detrimental, such as tube denting, exist.	Spectral acceleration.	4.5 g	6.0 g	7.5 g	Expert opinion.	Press. Bound. Fail; all modes.

Category 2: Reactor Vessel.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3202032004)	2.25	Buckling due to horizontal acceleration.	Spectral acceleration.	1.65	2.00	2.25	Analytical methods.	Percentiles: factor times SSE Pool type reactor vessel (liquid sodium).
	2.25	Stress intensity at vessel support.	Spectral acceleration.	4.5	6.0	10.0	Analytical methods.	Predominant frequencies, Mode #1 7 Hz Mode #2 7.5 Hz Mode #3 --
	2.25	Nozzle rupture.	Nozzle loads.	--	--	--		Press. Bound. Fail: all modes.
Consulting Firm (3202051909)	2.25	Failure of skirt anchor bolts.	Spectral acceleration.	3.0 g	4.0 g	6.0 g	Analytical methods.	All modes: predominant frequencies, Mark II 9-15 Hz, Mark III 3-5 Hz. (Mark II &
	2.25	Buckling of skirt.	Spectral acceleration.	4.0 g	5.0 g	8.0 g	Analytical methods.	III refer to GE BWR containments) Press. Bound. Fail: all modes.
Consulting Firm (3202041908)	2.25	Excessive support deformation resulting in attached pipe failure.	Spectral acceleration.	3.0 g	4.0 g	5.0 g	Analytical methods.	Percentiles include effects of LOCA. Predominant frequency, 15 Hz. Press. Bound. Failure.

Category 3: Primary Coolant Piping.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Reactor Designer (1303022601)	0.75	Failure at welded joints, especially at nozzles.	Spectral acceleration.	2.0	3.0	4.0	Expert opinion.	All modes: predominant frequency, 25-50 Hz.
	0.75	Ductile rupture due to hanger/snubber failure.	Spectral acceleration.	2.0	3.0	4.0	Expert opinion.	All percentiles are factor times SSE.
	0.75	Elbow collapse due to excessive forces.	Spectral acceleration.	3.0	4.0	5.0	Expert opinion.	Press. Bound. Fail; all modes.
Consulting Firm (3203032006)	3.00	Pipe support rupture or collapse.	Percent of allowable per ASME eq. (9).	300%	400%	500%	Test data and expert opinion.	All modes: predominant frequency, 5-25 Hz. BWR piping.
	3.00	Excessive pipe deformation.	Percent of allowable per ASME eq. (9).	500%	700%	1200%	Test data and expert opinion.	Press. Bound. Fail; all modes.
	3.00	Opening a crack in an unflawed pipe.	Percent of allowable per ASME eq. (9).	700%	1000%	1500%	Test data and expert opinion.	
Consulting Firm (3203051914)	1.50	Rupture at connections to components due to component support failure.	Spectral acceleration.	2.0 g	3.0 g	4.0 g	Analysis methods and expert opinion.	All modes: predominant frequency, 4.5 Hz.
	1.50	Rupture at connections to components due to pipe overstress.	Spectral acceleration.	5.0 g	8.0 g	12.0 g	Analysis methods and expert opinion.	Press. Bound. Fail; all modes.
Consulting Firm (3203042012)	2.40	Pipe yielding.	Acceleration of attached components.	--	--	--	Analysis methods and field observation.	Predominant frequency, 4-30 Hz.
	2.40	Crack propagation resulting in a small leak.	Acceleration of attached components.	--	--	--	Analysis methods and field observation.	Press. Bound. Fail; all modes.
Reactor Designer (1303010502)	0.75	Tensile failure in support anchor bolts allowing more pipe motion.	Acceleration of pipe, load in supports, relative displacement.	1.5	3.0	4.0	Expert opinion.	Percentiles: factor times SSE.
	3.00	Local failure of small pipe at connection to large pipe.	Acceleration.	3.0	5.0	6.0	Test data and expert opinion.	Predominant frequencies Modes #1 and #2, 8-30 Hz.; Mode #3, 2-5 Hz.
	3.00	Gross failure due to large displacements after supports fail.	Acceleration.	4.0	7.0	8.0	Test data and expert opinion.	Press. Bound. Fail; all modes.

Category 4: Large Piping.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Manufacturer (1205060235)	2.25	Joint leakage.	Displacement.	--	--	--	Analytical methods, expert opinion.	Press. Bound. Fail; all modes.
	2.25	Pipe support rupture.	Force.	--	--	--	Analytical methods, expert opinion.	
	2.25	Pipe failure.	Force.	--	--	--	Analytical methods, expert opinion.	
Consulting Firm (3204032013)	3.0	Yielding.	Moment capacity.	1.2	2.0	2.4	Test data, analytical methods, field experience.	Fragility parameter is yield moment.
	3.0	Small leak or branch connections breaking.	Incompatible design details.	--	--	--	Test data, analytical methods, field experience.	Predominant frequencies are greater than 2 Hz. Press. Bound. Fail; all modes.
	3.0	Large crack resulting in leak or severance.	Incompatible design details.	--	--	--	Test data, analytical methods, field experience.	
Consulting Firm (3204041915)	2.25	Rupture at nozzle connection due to failure of component support.	Spectral acceleration.	2.5 g	3.0 g	5.0 g	Analytical methods.	All modes: predominant frequency, 4-8 Hz.
	2.25	Failure of pipe supports.	Spectral acceleration.	4.0 g	5.0 g	7.0 g	Analytical methods.	Press. Bound. Fail; all modes.
	2.25	Overstress of pipe.	Spectral acceleration.	5.0 g	8.0 g	10.0 g	Analytical methods.	
Consulting Firm (3204011109)	2.25	Rupture at nozzle/equipment connections.	Moments at nozzle.	1.5	1.8	2.5	Analytical methods, expert opinion.	Predominant frequency, 10-30 Hz. Fragility parameter is yield moment times percentile factor. Press. Bound. Fail; all modes.
Consulting Firm (3204020302)	3.0	Failure of the connection at the building interface.	Percent of yield moment.	120%	200%	400%	Expert opinion, analytical methods, field experience.	Predominant frequency, all modes 2-10 Hz.
	3.0	Failure of field welds.	Percent of yield moment.	240%	400%	800%	Expert opinion, analytical methods, field experience.	Press. Bound. Fail; all modes.

Category 5: Intermediate Piping.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	Percentiles 50%	Percentiles 90%	Basis for Response	Comments
Manufacturer (1204050236)	2.25	Joint leakage.	Displacement.	--	--	--	Analytical methods, expert opinion.	Press. Bound. Fail; all modes.
	2.25	Pipe support rupture.	Force.	--	--	--	Analytical methods, expert opinion.	
	2.25	Pipe failure.	Force.	--	--	--	Analytical methods, expert opinion.	
Consulting Firm (3205051916)	2.25	Rupture at nozzle connection due to failure of component.	Spectral acceleration.	2.0 g	3.0 g	4.0 g	Analytical methods, expert opinion.	All modes: predominant frequency, 4-10 Hz.
	2.25	Failure of pipe supports.	Spectral acceleration.	3.0 g	4.0 g	6.0 g	Analytical methods, expert opinion.	Press. Bound. Fail; all modes.
	2.25	Overstress of pipe.	Spectral acceleration.	5.0 g	6.0 g	8.0 g	Analytical methods, expert opinion.	
Consulting Firm (3205011110)	0.75	Rupture at nozzle/equipment connections.	Moments at nozzles.	1.5	1.8	2.5	Opinion based on design experience.	Predominant frequencies 10-30 Hz. Press. Bound. Fail; all Percentiles: factor times yield moment.
modes.								
Consulting Firm (3205020303)	3.0	Failure of the connection at the building interface.	Percent of yield moment.	120%	200%	400%	Expert opinion, analytical methods, field observation.	All modes: predominant frequency, 2-10 Hz.
	3.0	Failure of the field welds.	Percent of yield moment.	240%	400%	800%	Expert opinion, analytical methods, field observation.	Press. Bound. Fail; all modes.

Category 6: Small Pipes.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3206022011)	3.0	Small leak.	Thermal transient + seismic.	--	--	--	Expert opinion, analytical methods, field experience.	Predominant frequencies greater than 2 Hz.
	3.0	Yielding.	--	--		--	Expert opinion, analytical methods, field experience.	Press. Bound. Fail; all modes.
Consulting Firm (3205051916)	2.25	Rupture at nozzle connection due to failure of component support.	Spectral acceleration.	2.0 g	3.0 g	4.0 g	Analytical methods, expert opinion.	All modes: predominant frequency, 4-10 Hz.
	2.25	Failure of pipe supports.	Spectral acceleration.	3.0 g	4.0 g	6.0 g	Analytical methods, expert opinion.	Press. Bound. Fail; all modes.
	2.25	Overstress of pipe.	Spectral acceleration.	5.0 g	6.0 g	8.0 g	Analytical methods, expert opinion.	
Consulting Firm (3206010304)	3.0	Failure of the connection at the building interface.	Percent of yield moment.	120%	200%	400%	Expert opinion, analytical methods, field observation.	All modes: predominant frequency, 2-10 Hz.
	3.0	Failure of field welds.	Percent of yield moment.	240%	400%	800%	Expert opinion, analytical methods, field observation.	Press. Bound. Fail; all modes.

Category 7: Large Vertical Storage Vessels with Formed Heads.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3207012010)	2.25	Local plastic deformation of vessel in vicinity of support locations.	Ultimate load capacity of support structure.	--	--	--	Analytical methods.	Predominant frequency, Mode #1, 6 Hz.
	3.0	Small leak in vessel at nozzle attachment.	Moment from pipe with existing crack.	1.5	2.4	12.0	Field data.	Percentiles: factor times yield moment.
Consulting Firm (3207021918)	2.25	Rupture of anchor bolts.	Spectral acceleration.	1.0 g	1.5 g	3.0 g	Analytical methods.	All modes: predominant frequency, 4-10 Hz.
	2.25	Buckling of support skirt or legs.	Spectral acceleration.	1.5 g	2.0 g	5.0 g	Analytical methods.	

Category 8: Large Vertical Storage Tanks--Flat Bottom.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3208021917)	1.50	Rupture of anchor bolts.	Spectral acceleration.	1.5 g	2.0 g	3.0 g	Analytical methods.	All modes: predominant frequency, 3-8 Hz.
	1.50	Buckling of tank wall.	Spectral acceleration.	2.3 g	3.0 g	5.0 g	Analytical methods.	
	1.50	Tensile rupture of tank wall.	Spectral acceleration.	3.75 g	5.0 g	8.0 g	Analytical methods.	
Manufacturer (1208011905)	0.75	Gross structural buckling.	Force.	--	--	--	Expert opinion.	
	0.75	Local structural buckling.	--	--	--	--	Expert opinion.	
	0.75	Fatigue.	--	--	--	--	Expert opinion.	

Category 9: Large Horizontal Vessels.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3239011112)	1.50	Support system failure (bolts).	Maximum floor acceleration between 12 and 20 Hz : 1.6 g.	1.9 g	2.72 g	3.6 g	Analytical methods, expert opinion.	Predominant frequency: 12 to 20 Hz. Diesel fuel tank.
Consulting Firm (3209011111)	1.50	Support failure (bolts)	Maximum horizontal floor acceleration 3.5 g.	4.0 g	6.0 g	8.0 g	Analytical methods, expert opinion.	Predominant frequency: greater than 12 Hz.

Category 10: Horizontal Tanks, Small Vessels and Heat Exchangers.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3209021919)	2.25	Rupture of anchor bolts.	Spectral acceleration.	1.5 g	2.0 g	3.0 g	Analytical methods.	Both modes: predominant frequency 15-30 Hz.
	2.25	Yielding of support saddles.	Spectral acceleration.	2.5 g	3.0 g	4.5 g	Analytical methods.	Horizontal tanks and heat exchangers.
Consulting Firm (3210021118)	2.25	Structural failure.	Maximum horizontal acceleration.	8.0 g	13.0 g	20.0 g	Analytical methods, expert opinion.	Predominant frequency: greater than 20 Hz. Small vessels.
Military Expert (5110040228)	2.0	--	Acceleration.	--	--	--	Test data.	Huntsville data. Heat exchangers.
Consulting Firm (3210031119)	2.25	Support failure.	Floor spectral acceleration.	1.3 g	2.0 g	3.5 g	Analytical methods, expert opinion.	Predominant frequency: 25-45 Hz. Small-Medium heat exchangers.

Category 11: Buried Pipe.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3211010301)	3.0	Failure at connection to building interface.	Ground acceleration.	1.50	3.00	4.00	Expert opinion, analytical methods, field experience.	Percentiles in terms of peak ground acceleration.
	3.0	Failure at coupling.	Ground acceleration.	2.50	4.00	8.00	Expert opinion, analytical methods, field experience.	

Category 12: Reactor Coolant Pump (PWR).

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3212011911)	1.5	Failure of connection to support legs.	Spectral acceleration.	2.5 g	3.0 g	6.0 g	Analytical methods.	Both modes, predominant frequencies: 4.5 Hz.
	1.5	Buckling of support leg.	Spectral acceleration.	4.0 g	5.0 g	10.0 g	Analytical methods.	Percentiles include LOCA.

Category 13: Large Vertical Centrifugal Pumps.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3249011912	1.5	Rupture of connections to support struts.	Spectral acceleration*	2.0 g	3.0 g	4.0 g	Analytical methods.	Predominant frequency 4.5 Hz., all modes.
	1.5	Tensile failure of support struts.	Spectral acceleration*	4.0 g	·5.0 g	6.0 g	Analytical methods.	

*Questionnaire does not explicitly say spectral acceleration.

Category 14: Large Vertical Pumps.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3215011302)	2.25	Failure of hold down bolts.	Nozzle loads: 30% of Y.S. of attached pipe.	--	50%	--	Some test data, analytical methods.	Percentile: 50% of Y.S. Percentile: 50% of Y.S.
	2.25	Overstress at nozzle.	Nozzle loads: 30% of Y.S. of attached pipe.	--	50%	--	Some test data, analytical methods.	Percentile: factor times SSE.
	2.25	Rotor seizure.	Seismic loads.	--	2.0	--	Some test data, analytical methods.	
Consulting Firm (3213011920)	2.25	Rupture of anchor bolts due to large moments from vertical intake column.	Acceleration.	1.5 g	2.0 g	4.0 g	Analytical methods.	Both modes: predominant frequency, 3 Hz. Percentile 90 is tentative.
	2.25	Rupture of vertical intake column.	Acceleration.	3.0 g	4.0 g	8.0 g	Analytical methods.	
Manufacturer (1248021403)	2.25	Internal rotor seizure.	Floor spectral acceleration.	1.5	2.0	2.5	Analytical methods, expert opinion.	Percentile: factor times SSE. Predominant frequency +33 Hz for modes #1 and #2.
	2.25	Failure of motor support structure or bolting at motor.	Floor spectral acceleration.	2.0	2.5	3.0	Analytical methods, expert opinion.	
	2.25	Internal seizure due to loss of fluid.	Piping rupture.	--	--	--	Expert opinion.	Failure in this mode depends on associated piping system.

Category 15: Centrifugal Pump, Compressors.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Manufacturer (1215041401)	2.25	Internal seizure of rotor.	Connecting pipe forces and moments.	1.3	1.5	2.0	Analytical methods, expert opinion.	All modes: predominant frequency, rigid.
	2.25	Failure of drive shaft couplings.	Connecting pipe forces and moments.	1.5	2.0	2.5	Analytical methods, expert opinion.	Percentiles: factor times SSE specified loads.
	2.25	Break of hold down bolts--shear pins.	Connecting pipe forces and moments.	2.0	2.5	3.0	Analytical methods, expert opinion.	
Consulting Firm (3215011302)	3.0	Hold down bolts break.	Nozzle loads: 30% Y.S.	--	50%	--	Some test data, analytical methods.	All modes: frequencies; Horizontal 33 Hz. Vertical 1-33 Hz.
	3.0	Overstress at nozzle.	Nozzle loads: 30% Y.S.	--	50%	--	Some test data, analytical methods.	Percentages: Percent of nozzle loads.
	3.0	Rotor seizure.	Seismic loads.	--	2.0	--	Some test data, analytical methods.	Percentiles for Mode #3: factor times SSE loads
Manufacturer (1215051803)	2.25	System inlet, outlet nozzle connections.	Floor spectral acceleration.	--	--	--	Analytical methods, field observation.	This questionnaire included a detailed description of design and qualification procedure.
	2.25	Anchor bolt loosening.	Floor spectral acceleration.	--	--	--	Field observation.	
	3.0	Malfunction of system valves.	Floor spectral acceleration.	--	--	--	Some test data.	

Category 16: LMOV's.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Manufacturer (1217032001)	3.0	Actuator components fail and jam.	Spectral acceleration at valve/ actuator interface.	9.0 g	15.0 g	18.0 g	Test data, analytical methods, expert opinion.	All modes: predominant frequency, rigid.
	3.0	Electrical failure in actuator.	Spectral acceleration at valve/ actuator interface.	9.0 g	15.0 g	18.0 g	Test data, analytical methods, expert opinion.	Ball valve with actuator and logic cabinet.
	3.0	Failure of major actuator/ valve component.	Spectral acceleration at valve/ actuator interface.	9.0 g	15.0 g	18.0 g	Test data, analytical methods, expert opinion.	
Consulting Firm (3216031116)	3.0	Structural failure.	Seismic acceleration at valve/pipe interface.	5.0 g	15.0 g	40.0 g	Test data, analytical methods, expert opinion.	Predominant frequency >15 Hz. to rigid.
Consulting Firm (3217011116)	3.0	Structural failure.	Acceleration of pipe.	50.0 g	80.0 g	120.0 g	Test data, analytical methods, expert opinion.	Predominant frequency, rigid.
Consulting Firm (3216041117)	3.0	Failure of structural members.	Seismic acceleration at valve pipe interface.	8.0 g	20.0 g	40.0 g	Test data, analytical methods, expert opinion.	Predominant frequency >20 Hz. to rigid.
Zion Manufacturer (1116061601)	3.0	Binding of stem.	--	--	--	--	--	Gate valve.
	3.0	Buckling of stem.	--	--	--	--	--	
	3.0	Permanent bending of yoke.	--	--	--	--	--	
Manufacturer (1216070234)	3.0	Excessive leakage.	Spectral acceleration.	--	--	--	Test data, analytical methods, expert opinion.	Predominant frequency: Mode #1, rigid; Mode #2, 25-30 Hz; Mode #3, 25-30 Hz.
	3.0	Changes in the normal stroking durations.	Spectral acceleration.	--	--	--	Test data, analytical methods, expert opinion.	Globe and butterfly valves.
	3.0	Loosening of bolted parts.	Spectral acceleration.	--	--	--	Test data, analytical methods, expert opinion.	

Category 16: LMOV's. (Continued.)

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Zion Manufacturer (1116050201)	3.0	Loss of electrical controls or an electrical component.	Input acceleration.	7.5 g	9.0 g	12.0 g	Test data.	
	0.75	Loss of pipe anchorage.	Pipe displacement.	6.75 g	7.5 g	12.0 g	Expert opinion.	Gate and globe valves. Predominant frequency: Mode #1, above 33 Hz; Mode #2, 8-20 Hz; Mode #3, above 27 Hz.
	3.00	Mechanical binding of the valve.	Spectral acceleration.	8.25 g	10.5 g	13.5 g	Test data, analytical methods.	
Reactor Designer (1316022602)	3.00	Stem and bonnet failure due to overturning moment on operator mass.	Spectral acceleration.	9.0 g	12.0 g	18.0 g	Test data, analytical methods, expert opinion.	Predominant frequency: Mode #1, 10-20 Hz; Mode #2, 30-50 Hz; Mode #3, 30-50 Hz.
	3.00	Functional failure of internals.	Spectral acceleration.	15.0 g	18.0 g	24.0 g	Test data, analytical methods, expert opinion.	
	3.00	Breaks at weld ends	Spectral acceleration.	12.0 g	18.0 g	24.0 g	Test data, analytical methods, expert opinion.	
Consulting Firm (3216031922)	2.25	Deformation of valve stem or yoke.	Spectral acceleration.	6.0 g	8.0 g	12.0 g	Expert opinion.	All modes, predominant frequencies 2-10 Hz.
	2.25	Rupture of pipe support at nozzle.	Spectral acceleration.	8.0 g	10.0 g	15.0 g	Expert opinion.	
Manufacturer (1216091804)	2.25	Loss of control air.	Acceleration.	5.0 g	8.0 g	11.0 g		Butterfly valve. Predominant frequency: rigid.

Category 17: Large Relief and Check Valves.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3216011102)	3.00	Fracture of valve actuator top cover at connection to valve body.	Spectral acceleration.	8.0 g	15.0 g	25.0 g	Test data, expert opinion.	Predominant frequency: Mode #1, valve actuator, 27.7 Hz; Mode #2, spring mechanism 10-12 Hz.
	3.00	Failure of spring mechanism due to excessive plastic deformation.	Spectral acceleration.	15.0 g	20.0 g	30.0 g	Test data, expert opinion.	Ruggles-Klingeman Trip valve.
Zion Manufacturer (1117020202)	2.25	Disc becomes disengaged.	Spectral acceleration.	7.5 g	9.0 g	10.5 g	Analytical methods.	Predominant frequencies both modes: rigid.
	2.25	Disc becomes bound.	Spectral acceleration.	11.25 g	12.0 g	15.0 g	Analytical methods.	

Category 18: Miscellaneous Small Valves.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Test Laboratory (3118021106)	3.0	Leakage.	Spectral acceleration.	10.0 g	12.0 g	15.0 g	Test data.	Predominant frequencies are 20-35 Hz (all modes).
	3.0	Gauling of stem.	Spectral acceleration.	12.0 g	15.0 g	20.0 g	Test data.	Damping is 5%.
	3.0	Structural fatigue at neck.	Spectral acceleration.	12.0 g	15.0 g	20.0 g	Test data.	
Manufacturer (1218031001)	3.0	Bending of valve yoke and operator support structure.	Spectral acceleration.	--	--	--	Test data, analytical methods.	Valves should withstand up to 12.0 g without failure.
	3.0	Bending of valve stem.	Spectral acceleration.	--	--	--	Test data, analytical methods.	Gate, globe and check valves.
	3.0	Failure of auxiliary support structure.	Spectral acceleration.	--	--	--	Test data, analytical methods.	
Zion Manufacturer (1118050203)	1.50	Loss of valve controls.	Input acceleration.	9.0 g	10.5 g	11.25 g	Analytical methods.	
	1.50	Loss of pipe anchorage.	Pipe displacement.	10.5 g	12.0 g	13.5 g	Analytical methods.	Predominant frequency: rigid, all modes.
	1.50	Mechanical binding of valve parts.	Input acceleration spectrum.	10.5 g	12.0 g	14.25 g	Analytical methods.	Gate, globe and check valves.
Consulting Firm (3218041115)	3.00	Structure failure.	Acceleration of pipe.	10.0 g	18.0 g	30.0 g	Test data, analytical methods, expert opinion.	Predominant frequencies are: 28 Hz. to rigid.
Consulting Firm (3218011101)	3.0	Failure of valve actuator.	Spectral acceleration.	11.5 g	15.0 g	25.0 g	Test data, expert opinion.	Predominant frequencies are: Mode #1, 25-50 Hz, Mode #2, >50 Hz, Mode #3, >50 Hz.
	3.0	Internal damage.	Spectral acceleration.	15.0 g	30.0 g	50.0 g	Test data, expert opinion.	
	3.0	Fracture of valve body.	Spectral acceleration.	20.0 g	50 g	100.0 g	Test data, expert opinion.	
Manufacturer (1218062007)	--	Piping (valve support).	Acceleration.	--	--	--	Test data, analytical methods, expert opinion.	The mean value is an estimate for mode #2.
	3.0	Top structure of valve.	Acceleration.	12.0 g	18.0 g	24.0 g	Test data, analytical methods, expert opinion.	

Category 18: Miscellaneous Small Valves (Continued.)

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
	3.0	Valve body.	Piping loads.	4.0	--	8.0	Test data, analytical methods, expert opinion.	Percentiles: factors times the piping load
Test Laboratory (3118070403)	3.0	Internal seat leakage.	Spectral acceleration.	6.6 g	7.8 g	10.8 g	Test data, expert opinion.	Predominant frequencies: Mode #1: 12 to 15 Hz. Mode #2: 17 to 21 Hz. Mode #3: 27 to 35 Hz.
	3.0	Operator accessory malfunction.	Spectral acceleration.	9.0 g	10.2 g	12.0 g	Test data, expert opinion.	
	3.0	Operator malfunction.	Spectral acceleration.	12.0 g	15.0 g	18.0 g	Test data, expert opinion.	
Manufacturer (1218081802)	1.5	Stem binding.	Acceleration.	6.0 g	7.5 g	8.5 g	Analytical methods.	Predominant frequency is + 40 Hz. to 140 Hz.
	--	Seal weld.	--	--	--	--	--	Globe valve.
	--	Bellows.	--	--	--	--	--	

Category 19: Fans, Motor Generators, Electric Motors.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3219041921)	1.50	Binding of rotating parts.	Acceleration.	8.0 g	12.0 g	20.0 g	Analytical methods, expert opinion.	Predominant frequencies are +33 Hz.
	1.50	Rupture of anchor bolts.	Acceleration.	15.0 g	20.0 g	30.0 g	Analytical methods, expert opinion.	

Category 20: Generators.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Professor (4120042009)	1.0	Connection between control panel and engine.	Spectral acceleration.	4.0 g	8.0 g	10.0 g	Proof test data, expert opinion.	Predominant response frequencies: 1st mode 7.0 Hz to 20.6 Hz, 2nd mode 8.3 Hz to 13.8 Hz.
	1.0	Oil level regulator.	Spectral acceleration.	4.0 g	8.0 g	10.0 g	Proof test data, expert opinion.	Diesel generators.
Consulting Firm (3220051923)	0.75	Malfunction of control system.	Acceleration.	3.0 g	5.0 g	8.0 g	Expert opinion.	Predominant response frequencies: +15 Hz.
	0.75	Rupture of attached oil lines.	Acceleration.	5.0 g	8.0 g	10.0 g	Expert opinion.	Diesel generators.
Consulting Firm (3220011114)	2.25	Crankshaft lock up.	Floor acceleration.	7.4 g	10.0 g	15.0 g	Analytical methods, expert opinion.	Predominant response frequencies: 15 Hz.
	2.25	Anchor bolt failure.	Floor acceleration.	3.0 g	6.0 g	10.0 g	Analytical methods, expert opinion.	Diesel generators.
Professor (4120021801)	1.0	Radiator.	Acceleration.	--	--	--	Test data, expert opinion.	Emergency AC power unit, diesel driven generator. Predominant frequencies:
	1.0	Exhaust system.	Acceleration.	--	--	--	Test data, expert opinion.	Mode #1 7.5 Hz Mode #2 5-15 Hz Mode #3 Rigid.
	1.0	Anchorage.	Acceleration.	--	--	--	Test data, expert opinion.	

Category 21: Batteries.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3221041923)	2.25	Failure of battens.	Acceleration.	1.5 g	2.0 g	4.0 g	Analytical methods.	Predominant frequency is >25 Hz.
	2.25	Longitudinal failure of frame.	Acceleration.	3.0 g	4.0 g	8.0 g	Analytical methods.	Battery racks.
Test Laboratory (3121011902)	3.0	Support stand failure.	Acceleration.	13.0 g	20.0 g	30.0 g	Test experience.	Predominant frequency is >15 Hz.
	3.0	Case breakage due to bad stand.	Acceleration.	15.0 g	20.0 g	30.0 g	Test experience.	DC power batteries.
	3.0	Case breakage with good stand.	Acceleration.	25.0 g	30.0 g	35.0 g	Test experience.	
Military Expert (5121030209)	2.0	Rack failure, structural relay chatter, invertor shutdown.	Acceleration.	--	--	--	Test data.	Huntsville data.

Category 22: Switchgear.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Reactor Designer (1322050602)	3.00	Spurious operation of a protective relay.	Spectral acceleration.	1.5 g	2.5 g	4.0 g	Test data and expert opinion.	Frequencies: Side to side = 6-11 Hz. Front to back = 16-20 Hz. Vertical = >30 Hz.
	3.00	Structural failure.	Spectral acceleration.	2.0 g	3.5 g	4.0 g	Test data and expert opinion.	26" Wide Metalclad Switchgear.
Professor (4122082008)	0.25	Contact alignment.	Spectral acceleration.	--	2.0 g	--	Expert opinion.	Frequency: Mode #2 only. Horizontal = 5.6 Hz, 10.6 Hz, 16.5 Hz (x) and 7.8 Hz, 22.9 Hz (y). Vertical = rigid.
	1.00	Support anchorage of unit.	Spectral acceleration.	<2.0 g	2.0 g	4.0 g	Test data and expert opinion.	
Reactor Designer (1322040601)	3.0	Spurious operation of a protective relay.	Spectral acceleration.	1.0 g	2.0 g	3.0 g	Test data.	36" Wide Metalclad Switchgear.
	3.0	Structural failure.	Spectral acceleration.	2.0 g	3.0 g	3.5 g	Test data.	
Consulting Firm (3222011103)	3.00	Fracture of porcelain insulator columns.	Spectral acceleration.	2.0 g	3.0 g	4.75 g	Test data, analysis methods, expert opinion.	Frequencies: 1st Mode = 1.5-4.0 Hz, 2nd Mode = 4.5-8.0 Hz.
Military Expert (5122070212)	2.0	Chattering of contacts, dropping out.	Undamped spectral acceleration.	--	--	--	Test data.	Huntsville data. Metalclad Switchgear.
Test Laboratory (3122031904)	3.00	Chatter of contacts.	Acceleration.	10.0 g	15.0 g	25.0 g	Test data, experience.	Predominant frequencies for all modes >15 Hz.
	3.00	Structural anchoring of cabinet base.	Acceleration.	15.0 g	20.0 g	30.0 g	Test data, experience.	Response is with damping of 5%.
	3.00	Structural mounting of components in cabinet.	Acceleration.	20.0 g	25.0 g	30.0 g	Test data, experience.	
Reactor Designer (1322060602)	3.0	Spurious operation of a protective relay.	Acceleration.	1.5 g	3.0 g	5.0 g	Test data, expert opinion.	Power Vac Metalclad Switchgear.
	3.0	Structural failure.	Acceleration.	3.0 g	5.0 g	>6.0 g	Test data, expert opinion.	Predominant frequencies: Side to side = 6-11 Hz Front to back = 16-20 Hz Vertical = >30 Hz.

Category 23: Dry Transformers.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3223021105)	1.5	Cooler unit pipe failure with loss of transformer oil.	Spectral acceleration.	1.5 g	2.5 g	4.0 g	Analytical methods, expert opinion.	Fragility parameter at floor to transformer interface.
	1.5	Internal structural failure, short of electrical connection.	Spectral acceleration.	2.0 g	4.0 g	8.0 g	Analytical methods, expert opinion.	Predominant frequencies: Cooler unit: 7.5, 7.7 Hz Internal Structure: 7.2, 7.6 Hz.
	1.5	Failure of porcelain HV bushings on top of transformer.	Spectral acceleration.	2.5 g	5.0 g	10.0 g	Analytical methods, expert opinion.	HV Porcelain: 8.1, 10.8 Hz.
Consulting Firm (3223051924)	1.5	Rupture of anchor bolts.	Spectral acceleration.	2.0 g	3.0 g	5.0 g	Analytical methods.	Predominant frequency for all modes: +10 Hz.
	1.5	Failure of support frame.	Spectral acceleration.	4.0 g	5.0 g	8.0 g	Analytical methods.	
	1.5	Electrical malfunction.	Spectral acceleration.	4.0 g	5.0 g	8.0 g	Analytical methods.	

Category 24: Air Handling Units.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3219021113)	1.50	Structural failure.	Floor acceleration.	4.0 g	6.0 g	10.0 g	Design analysis and expert opinion.	Predominant response frequency is 21 Hz. HVAC fans.
Military Expert (5146010226)	2.0	Threaded connections to tank fail.	Undamped floor acceleration.	--	--	--	Test data.	Air compressors, storage tanks, instrument air dryers
	2.0	Shock activates shutdown devices.	Undamped floor acceleration.	--	--	--	Test data.	Huntsville data.

Category 25: Filtering Equipment.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Military Expert (5145010225)	2.0	Temporary shutdown due to tripping devices.	Undamped spectral acceleration.	--	--	--	Test data.	Water chillers. Huntsville data.
	2.0	Failure of structural welds.	Undamped spectral acceleration.	--	--	--	Test data.	
Military Expert (5125010233)	2.0	Filters fall out of rack.	Undamped spectral acceleration.	--	--	--	Test data.	Air conditioning, chemical and biological filters. Huntsville data.
Military Expert (5144010224)	2.0	Possible failure of support legs.	Undamped spectral acceleration.	--	--	--	Test data.	Water purification units. Huntsville data.

Category 26: Instrument Panels and Racks.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3226022003)	3.0	Instrument failure.	Floor acceleration.	1.5	2.0	3.0	Test data.	Predominant frequencies: Mode #1, rigid Mode #2, 11 Hz. Percentiles are factors times SSE. Instrument racks.
	3.0	Weld failure.	Floor acceleration.	3.0	5.0	8.0	Test data.	

Category 27: Control Panels and Racks.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Reactor Designer (1327022001)	3.00	Relay chatter.	Floor acceleration.	3.0 g	5.0 g	8.0 g	Expert opinion.	Predominant response frequency 20 to 33 Hz.
Test Laboratory (3126011903)	3.00	Chatter of contacts.	Acceleration.	12.0 g	15.0 g	25.0 g	Test data, experience.	Predominant frequency for all modes >12 Hz.
	3.00	Structural mounting of components.	Acceleration.	20.0 g	25.0 g	30.0 g	Test data, experience.	These modes of failure also apply to breaker panels, auxiliary relay panels, instrument racks and diesel generators.
	3.00	Structural mounting of cabinets.	Acceleration.	20.0 g	25.0 g	35.0 g	Test data, experience.	
Test Laboratory (3127031901)	3.00	Component malfunction.	Acceleration.	12.0 g	20.0 g	30.0 g	Test data, experience.	Predominant frequency is >20 Hz. Structural failure unlikely with modern design.

Category 30: Local Instruments.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Test Laboratory (3130011107)	3.0	Relay chatter.	Acceleration response spectrum.	6.0 g	10.0 g	12.0 g	Test data.	Predominant response frequency is 5-35 Hz. Damping is 5%. This applies to all failure modes.
	3.0	Loosening of fasteners.	Acceleration response spectrum.	8.0 g	10.0 g	15.0 g	Test data.	
	3.0	Base structural fatigue.	Acceleration response spectrum.	8.0 g	10.0 g	15.0 g	Test data.	
Military Expert (5130040222)	2.0	Leakage at threaded connections.	Undamped spectral acceleration.	--	--	--	Test data.	Device is an "indicator." Huntsville data.
Test Laboratory (3130020401)	3.0	Signal drift.	Acceleration response spectrum.	9.0	12.0	15.0	Test data.	Predominant frequencies: Mode #1, 10-15 Hz. Mode #2, 29-30 Hz. Mode #3, not given.
	3.0	Contact chatter.	Acceleration response spectrum.	10.2	13.2	18.0	Test data.	
	3.0	Set point drift.	Acceleration response spectrum.	10.8	18.0	24.0	Test data.	
Military Expert (5130050223)	3.0	--	Undamped acceleration spectra.	--	--	--	Test data.	Heat sensing device. Response based on Huntsville data.
Military Expert (5130030219)	3.0	Reduction in function.	Undamped acceleration spectra.	--	--	--	Test data.	All modes: Monitoring and control devices.
	3.0	Loss of function.	Undamped acceleration spectra.	--	--	--	Test data.	Response based on Huntsville data.
	3.0	Support failure.	Undamped acceleration spectra.	--	--	--	Test data.	

Category 31: Motor Control Centers.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Test Laboratory (3122031904) (3131011904)	3.0	Chatter of contacts.	Spectral acceleration.	10.0 g	15.0 g	25.0 g	Test data, expert opinion.	Damping is 5% for all modes.
	3.0	Structural anchoring of cabinet base.	Spectral acceleration.	15.0 g	20.0 g	30.0 g	Test data, expert opinion.	Predominant frequency for all modes ±15 Hz.
	3.0	Structural mounting of component in cabinet.	Spectral acceleration.	20.0 g	25.0 g	30.0 g	Test data, expert opinion.	
Military Expert (5132030213)	2.0	Relay chatter.	Spectral acceleration.	--	--	--	Test data.	Response based on Huntsville data. Predominant frequency: 1.25-500 Hz.

Category 33: Light Fixtures.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Test Laboratory (3133030402)	3.0	Dislodging of air duct blanking clips.	Spectral acceleration.	7.2 g	9.0 g	12.0 g	Test data.	
	3.0	Lamp breakage.	Spectral acceleration.	--	--	--	Test data.	Respondent is not clear in answers to questionnaire.
Military Expert (5133040206)	3.0	Sheet metal failures.	Undamped spectral acceleration.	--	--	--	Test data.	Response based on Huntsville data.

Category 36: Cable Trays.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3236010305) (3237020306)	3.0	Failure of the connection at the building interface.	Spectral acceleration.	120	200	350	Analytical methods, expert opinion, field observation.	Predominant response frequency is 1-5 Hz for all modes. Percentiles are percentages of design SSE spectrum.
	3.0	Failure of the field welds.	Spectral acceleration.	200	300	600	Analytical methods, expert opinion, field observation.	
Consulting Firm (3236021925)	1.5	Failure of supports.	Spectral acceleration.	2.0 g	3.0 g	5.0 g	Analytical methods.	Predominant response frequency is 5-10 Hz for all modes.
	1.5	Rupture of parts between supports.	Spectral acceleration.	4.0 g	5.0 g	10.0 g	Analytical methods.	

Category 37: Ducting.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Utility (2137051404)	3.0	Corner tearing.	Floor spectral acceleration.	5.0 g	7.0 g	10.0 g	Test data.	Predominant frequency for response 8.5-11.0 Hz. Damping at 7%.
	3.0	Support failure.	Spectral acceleration.	8.0 g	10.0 g	16.0 g	Test data.	HVAC ducts.
	3.0	Joint separation.	Spectral acceleration.	8.0 g	10.0 g	16.0 g	Test data.	
Consulting Firm (3237061926)	1.5	Support failure.	Spectral acceleration.	3.0 g	4.0 g	6.0 g	Analytical methods.	Predominant frequency for response 5-10 Hz, all modes.
	1.5	Rupture of duct between supports.	Spectral acceleration.	5.0 g	6.0 g	10.0 g	Analytical methods.	
Consulting Firm (3237021119)	1.5	Joint separation.	Ceiling acceleration or differential displacement.	2.0 g	4.0 g	10.0 g	Analytical methods and expert opinion.	Predominant frequency for response 10 Hz, all modes.
	1.5	Duct anchor and support failure.	Ceiling acceleration.	2.5 g	5.0 g	12.0 g	Analytical methods and expert opinion.	
	1.5	Gross bending firm.	Ceiling acceleration.	5.0 g	10.0 g	15.0 g	Analytical methods and expert opinion.	
Architect Engineer (6137041201)	3.0	Corner crippling.	Applicable parameter.	2.0	2.5	3.0	Test data and analytical methods.	Predominant frequency for response 15-20 Hz, all modes.
	3.0	Duct support fail.	Applicable parameter.	2.2	3.0	3.5	Test data and analytical methods.	
	3.0	Duct rupture.	Applicable parameter.	2.5	3.3	4.0	Test data and analytical methods.	A fragility curve was included with this questionnaire.

Category 38: Hydraulic Snubbers.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Reactor Designer (1337010501)	0.75	Loss of function due to leakage or air in cylinder before the seismic event occurs.	Vibration load during normal operation.	--	--	--	Expert opinion.	Impossible to quantify percentiles, Mode #1 Predominant frequency: Mode #1, 20-40 Hz.
	0.75	Failure at embedment to clevis juncture because of undersized welds or poor welds.	High load due to acceleration caused forces.	1.2	1.5	1.8	Expert opinion.	These numbers are the multiplicative factors of the unit rated load, for Modes #2 and #3.
	0.75	Tensile failure in piston rod at thread root diameter or in clamp bolts.	High load due to acceleration caused forces.	1.6	2.0	2.8	Expert opinion.	

Category 41: Circuit Breakers.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Consulting Firm (3222021104)	3.0	Rupture of gasket seals, venting of conducting gas.	Spectral acceleration.	0.75 g	1.0 g	2.0 g	Test data, analytical methods, expert opinion.	In-situ testing. Fragility parameter at circuit breaker footing. These are switchyard circuit breakers.
	3.0	Fracture of porcelain insulation columns, loss of breaker.	Spectral acceleration.	1.00 g	1.25 g	2.25 g	Test data, analytical methods, expert opinion.	Torsional failure. Modes of vibration: 1st 2.4-3.4 Hz, 2nd 7.8-12.2 Hz. Air blast circuit breakers.
Military Expert (5141010215)	2.0	Contact chatter.	Spectral undamped acceleration.	--	--	--	Test data.	This is a different type of circuit breaker than the above. See Huntsville data.

Category 48: Recombiners.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Manufacturer (1205040404)	3.0	Pipe Deformation.	Floor response spectrum.	7.0 g	8.0 g	10.0 g	Testing, analytical methods.	The tests were not taken to failure.
	3.0	Recombiner anchorage.	Floor response spectrum.	--	--	--	--	Predominant frequencies: Mode #1, 9.5 Hz, Mode #2, 21.5 Hz.

Category 49: Ceramic Insulators.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
--	3.0	Fracture of porcelain insulation.	Base acceleration.	0.40 g	0.58 g	0.75 g	Actual field data.	
--	3.0	Fracture of porcelain insulation.	Base acceleration.	0.11 g	0.25 g	0.28 g	Actual field data.	These are Japanese components which are more brittle than American or French.

Category 50: Spent Fuel Racks.

Respondent	Wt.	Failure Modes	Response Parameter	Percentiles 10%	50%	90%	Basis for Response	Comments
Professor (Consultant) (4150011120)	0.75	Destruction of shear connection between modules.	Floor spectral acceleration.	0.15 g	0.28 g	0.50 g	Analytical methods.	Respondent indicated good confidence in response. Predominant frequency: 7-8 Hz.

APPENDIX D - UPDATED INFORMATION ON SSMRP FRAGILITY ESTIMATIONS

This appendix contains recent letters that clarify and correct information about SSMRP fragilities that previously appeared in other reports. (The Appendix D that appeared in earlier drafts of NUREG/CR-3558 has been removed - it contained material repeated elsewhere in this report.)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

May 21, 1985

Mr. Garth Cummings
Lawrence Livermore National Laboratory
Mail Stop L91
P. O. Box 808
Livermore, CA 94550

Dear Mr. Cummings:

The following summarizes information gathered from recent correspondence and telephone conversations regarding the SSMRP's development of both structural and component fragilities. It is important that LLNL verify the following items so that NUREG/CR-3558, "Handbook of Nuclear Power Plant Seismic Fragilities," can be completed and published in the near future. I need your written response by May 31, 1985.

The items to be verified by you are:

1. The fragility information in Appendix F of NUREG/CR-3558 is the most current and supersedes other component fragility data presented in previous SSMRP reports (specifically NUREGs/CR-2405 and CR-3428). Appendix F is what LLNL recommends as the "generic data base" for component fragilities.

2. Enclosure 1 accurately explains inconsistencies in SSMRP-reported relay fragility values and the impact of these inconsistencies.

3. Enclosure 2 accurately describes how expert opinion and other data were combined to derive the values in Appendix F. This description indicates that when more than one type of data was combined, the median fragility value becomes conservatively biased.

4. Except for "Base Mat Uplift," all SSMRP Zion structural fragilities are taken from the work described in NUREG/CR-2320. The fragility values from this SMA report are summarized in Enclosure 3.

5. The information given in the two tables of Enclosure 4 is correct regarding what was actually used (not just "developed for") in the final SSMRP Zion seismic risk calculations.

6. Also, please verify that the "large motor operated valve" fragility pertains to all sizes greater than 4 inches (not 8 inches as indicated in the current text).

Sincerely,

Daniel Guzy

Daniel J. Guzy
Mechanical/Structural Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research

Enclosures: (4)

cc w/encls: R. Langland, LLNL

ENCLOSURE 1

(excerpts from 4/1/85 letter from G.Cummings to D.Guzy)

Question 1: What are the most current fragility values for relays and ceramic insulators?

Answer: The value in Appendix F of NUREG/CR-3558 is the most current value for relay chatter (median = 1.66g, β^R = .57, β^U = 1.40, β^T = 1.51). Please note that relay chatter was not considered a failure in the Zion analysis but relay damage was. At the time of the Zion analysis, the values reported in Table 5.4 of NUREG/CR-3428 (median = 4.00, β^R = 0.48, β^U = 0.75, and β^T = 0.89) for relay chatter were suspect. So the fragility for switchgear having values of median = 2.33; β^R = 0.47; β^U = 0.66 and β^T = 0.81 was used as the value for relay failure due to damage. We subsequently discovered a transcription error for data put into the program calculating relay fragilities resulting in the revised value.

Lambert's report (UCID-20086) used a value of 2.6 g since that was the only data available at that time. In response to your telephone request, the effects on Lambert's conclusions of using a median of 1.66 g and 4.00 g is shown in Addendum A. As you can see, if relay chatter results in relay failure, the 1.66 g median excerbates the concern, the 4.00 g median makes it less of a concern but something still needing further investigation.

The ceramic insulator β^T is 0.35.

ADDENDUM A

H. Lambert 3-25-85

THE EFFECT OF RELAY CHATTER GIVEN VARIOUS VALUES OF MEDIAN CAPACITY, $\hat{A}$, AND BETA, β

EARTHQUAKE LEVEL	PROBABILITY OF EARTHQUAKE PER YEAR	PROBABILITY OF RELAY CHATTER GIVEN EARTHQUAKE LEVEL			
		SMA *	Case 1	Case 2	Case 3
		$\hat{A}$ = 2.59 g β = 1.51	$\hat{A}$ = 1.66 g β = 1.51	$\hat{A}$ = 4.0 g β = .89	$\hat{A}$ = 4.0 g β = .35
1	5.4 E-4	.095	0.15	4.7 E-3	1.2 E-5
2	2.7 E-4	0.15	0.22	1.8 E-2	7.4 E-4
3	1.3 E-5	0.26	0.36	6.7 E-2	8.9 E-3
4	1.6 E-6	0.33	0.44	0.12	1.6 E-2
5	4.2 E-7	0.37	0.49	0.18	6.4 E-2
6	1.6 E-7	0.42	0.53	0.22	0.11

* Case considered in report UCID - 20086

ENCLOSURE 2

(excerpts from 4/1/85 letter from G.Cummings to D.Guzy)

Question 7: How is expert opinion and other data combined?

Answer: This is explained in Section 2, Appendix D and in UCID-19146. Using this technique, one often finds that combining two higher medians results in a lower composite median, particularly if the β's are large. Note that as new data or opinion was added, it was assumed to define an independent failure mode. It would tend to lower the previous fragility estimate. There is a question as to whether this is always appropriate but it is certainly conservative. Addendum B describes the procedure in detail.

ADDENDUM B
CALCULATIONAL PROCEDURE USED FOR APPENDIX F
VALUE OF RELAY FRAGILITY

This addendum reviews estimation of the parameters of the relay fragility function. The review works backward from the parameters, through calculations and assumptions, to the inputs. Figure 1 summarizes the estimation.

The fragility function is approximated by a lognormal distribution with the same median and beta as the true fragility function. This is because responses are assumed to have lognormal distributions conditional on earthquake levels, and, if fragility functions are also lognormal, failure probabilities are easy to compute. The assumption of lognormal distributions is endemic in probabilistic risk analyses.

The median and beta are 1.66 g and 1.51. Given the parameters in Table 1 of strengths in several modes, the median and beta are obtained in two steps. The first step determines the parameters of strength at failure in the weakest mode according to expert opinions. The second step determines whether to use the beta value from expert opinions or the beta value from "Type A" data. The first step determines the distribution function of strength at failure in the weakest failure mode, the distribution function of min[S(1), S(2)] where S(1) and S(2) are the strengths at failure in two relay failure modes. (The two failure modes are failures due to responses in the frequency ranges 20-33 Hz and 5-10 Hz, respectively.) The random variables S(1) and S(2) are assumed to be independent lognormal random variables with parameters in Table 1 taken from page F-16 in NUREG/CR-3558.

Table 1

Parameters of Fragility Functions for Each Failure Mode

Mode	Median	Beta
E.O.	5.67	1.16
S.G.	2.59	1.51

The strength at failure in the weakest mode is min(S(1), S(2)). The logarithms of the strength random variables have normal distributions, and the formula for combining the two modes and obtaining the distribution function of min[ln(S(1)), ln(S(2))] is

$$P(\min[\ln(S(1)),\ln(S(2)] < S) = \Phi\text{Total} = 1 - (1 - \Phi_1(s)]\,[1 - \Phi_2(s)] \quad (1)$$

where $\Phi_1(s)$ and $\Phi_2(s)$ are the (normal) distribution functions of ln(S(1)) and ln(S(2)). This formula is found in appendix D on page D-5 of NUREG/CR-3558. Numerically integrating this distribution function yields the following parameters: the mean of the distribution (1) is .507 and the standard deviation is 1.196. The median of the lognormal representation is exp(.507) = 1.66 and beta(TEO) = 1.196. These are the parameters of min[(S(1), S(2)].

From NUREG/CR-3558, the beta values reported on page F-15 are determined by the rules on page 2-17 from the information in Table 2. The beta's are defined on page 2-12.

TABLE 2

Beta Values for Determining Final Values

Symbol	Value	Symbol in Text
Beta(TEO)	1.196	βTEO
Beta(TS)	1.51	βTS
Beta(RS)	0.57	βRS

The final values for β^T, β^U, and β^R are calculated according to the flow chart shown in Figure 1.

One final point, the selection of the values according to the lower part of Figure 1 was not done as part of the calculation using the code FRAGSTAT done for Appendix E. β values using the Figure 1 process are reported in Appendix F.

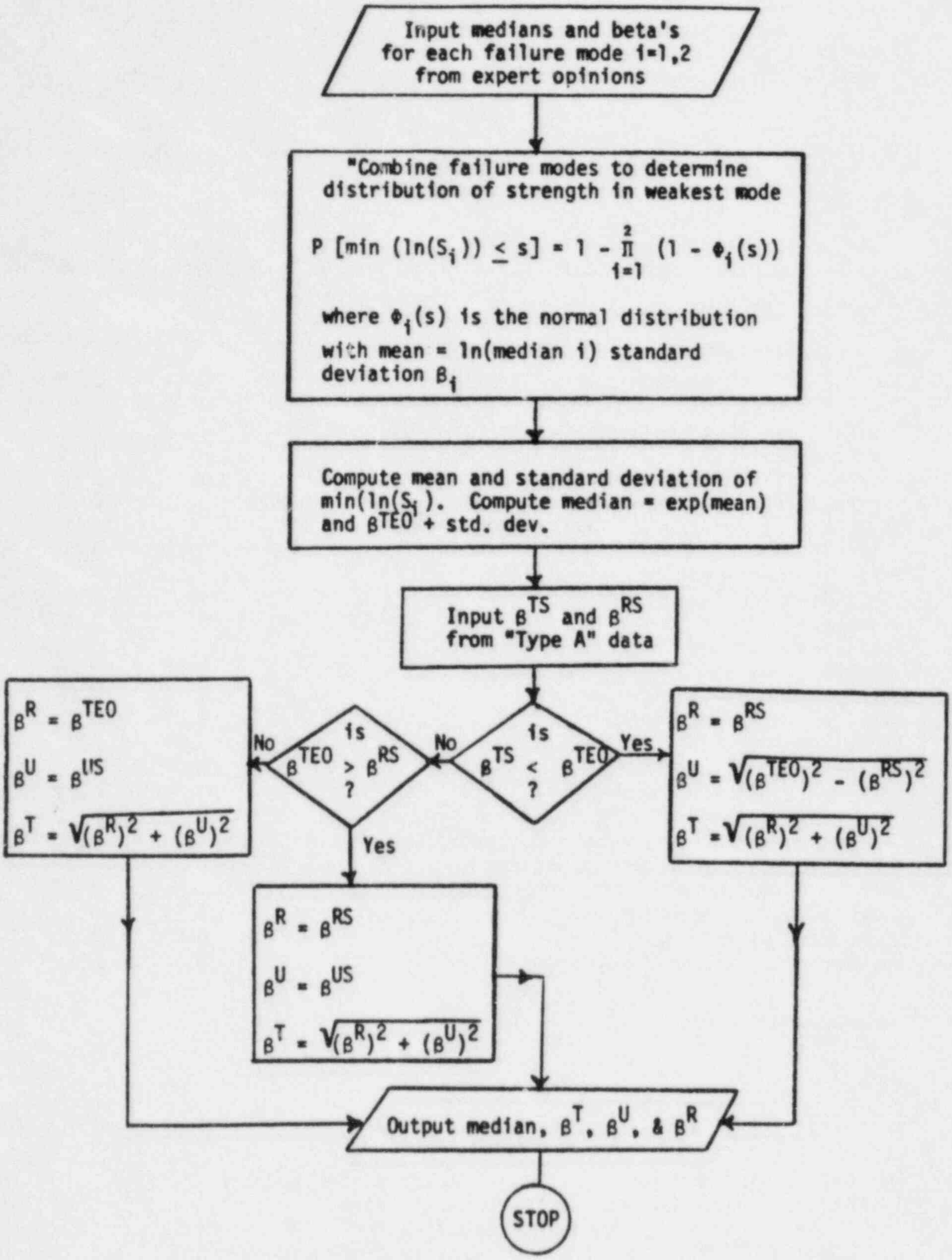

Figure 1: Estimation of Fragility Function Parameters, where β^{TEO} = β for Total Expert Opinion; β^{TS} = β for Total Safeguards; β^{RS} = β for Random Safeguards; β^T = Total β for combined data; β^U = Modeling Uncertainty β for combined data; β^R = Random Uncertainty β for combined data.

ENCLOSURE 3

Zion Structural Fragilities Developed by the SSMRP[a]

Structure Category	Fragility Parameters[b] Median	β^R	β^U	β^T
Reactor Building				
o Collapse of pressurizer enclosure	1.40	0.14	0.15	0.25
o Shear failure of containment wall	4.00	0.13	0.25	0.28
o Vertical shear failure at buttress plates	4.20	0.11	0.20	0.23
o Flexural failure of containment wall	9.00	0.13	0.24	0.27
o Shear failure of base mat	13.00	0.15	0.18	0.23
o Failure of internal shear anchors	5.00	0.11	0.19	0.22
Soil Failure Beneath Base Mat (Base Overturning moment in 10^7K-ft)[c]	1.29	0.20	0.20	0.28
Impact between reactor and auxiliary building (deflection at El.642' - in inches)[c]	0.99	0.11	0.22	0.25
Auxiliary building shear walls				
o Due to North-South ground motion	1.10	0.12	0.20	0.23
o Due to East-West ground motion	2.70	0.11	0.26	0.28
Auxiliary building roof diaphragm	3.00	0.07	0.22	0.23
Diesel generator building walls	1.10	0.07	0.18	0.23
Control room masonry walls	1.70	0.23	0.24	0.33
Crib house pump enclosure roof	0.86	0.24	0.27	0.36
Crib house intake walls				
o Due to North-South ground motion	2.50	0.23	0.27	0.35
o Due to East-West ground motion	5.40	0.27	0.27	0.38
Crib house guide walls (due to North-South ground motion)	3.90	0.22	0.27	0.35
Condensate storage tank	0.81	0.28	0.30	0.41
Service water piping (underground)	1.70	0.20	0.57	0.60

Notes:

a. Reference NUREG/CR-2320.

b. Unless indicated otherwise, median values are for local acceleration and are in units of gravity (g's).
   β^T = single value representing total variability.
   β^R = variability due to random uncertainty.
   β^U = variability due to systematic or modeling uncertainty.

c. Updated by "Base Slab Uplift" category discussed in NUREG/CR-3558 and NUREG/CR-3428.

ENCLOSURE 4

Component Fragilities Developed by the SSMRP [a]

	Fragility Parameters[b]			
Component Category	Median	βR	βU	βT
Reactor core assembly	2.06	0.24	0.32	0.40
Reactor pressure vessel*	3.83	0.23	0.39	0.45
Pressurizer*	2.00	0.21	0.34	0.40
Steam generator*	2.45	0.24	0.37	0.44
Piping (master fragility-moment (in.-lb))*	2.44×10^6	0.18	0.33	0.38
Large vertical vessels with formed heads*	1.46	0.20	0.35	0.40
Large vertical tanks with flat bottoms	2.01	0.25	0.29	0.38
Large horizontal vessels	3.91	0.30	0.53	0.61
Small to medium vessels & heat exchangers*	1.84	0.25	0.45	0.51
Reactor coolant pump*	2.64	0.24	0.37	0.44
Large vertical pumps*	2.21	0.22	0.32	0.39
Motor driven pumps and compressors	3.19	0.21	0.27	0.34
Large motor-operated valves (>4 in.)				
1. Distortion of extended operator*	4.83	0.26	0.60	0.65
2. Rupture*	14.40	0.28	0.56	0.63
Large Hydraulic and Air Actuated Valves	7.61	0.31	0.34	0.46
Large relief, manual, and check valves*	8.90	0.20	0.35	0.40
Miscellaneous small valves	12.50	0.33	0.43	0.54
Small motor-operated valves	9.84	0.26	0.60	0.65
Horizontal motors*	12.10	0.27	0.31	0.41
Generators*	0.65	0.25	0.31	0.40
Battery Racks*	2.29	0.31	0.39	0.50
Switchgear*	2.33	0.47	0.66	0.81
Dry transformers*	2.78	0.28	0.30	0.41
Air handling units**	2.24	0.27	0.31	0.41
Instrument racks and panels	1.15	0.48	0.66	0.82
Control panels and racks	11.50	0.48	0.74	0.88
Auxiliary relay cabinets	7.63	0.48	0.66	0.82
Local instruments*	7.68	0.20	0.35	0.40
Motor control centers	7.63	0.48	0.74	0.88
Light fixtures	9.20	0.14	0.14	0.20
Communications equipment	5.00	0.33	0.35	0.48
Inverters*	15.60	0.26	0.35	0.44
Cable trays*	2.23	0.34	0.19	0.39
Ducting	3.97	0.29	0.46	0.54
Hydraulic snubbers and pipe supports	1.46	0.22	0.49	0.54
Relays (chatter)	1.66	0.57	1.40	1.51
Circuit breakers*	7.63	0.48	0.74	0.88
Ceramic insulators*	0.20	0.25	0.25	0.35

Notes:

a. Appendix F of NUREG/CR 3558 presents more detailed information.

b. Except for piping, median values are for local acceleration and are in units of gravity (g's).

βT = single value representing total variability.

βR = variability due to random uncertainty.

βU = variability due to systematic or modeling uncertainty.

*Used in final accident sequences of SSMRP Zion analysis (NUREG/CR-3428)

**Used only in initial accident sequences (culled out)

Lawrence Livermore National Laboratory

NUCLEAR SYSTEMS SAFETY PROGRAM

May 31, 1985
EM-85-49

Mr. Daniel J. Guzy, Program Manager
Mechanical/Structural Engineering Branch
Division of Engineering Technology
Office Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

Dear Dan:

We are responding to your letter of May 21, 1985, to Garth Cummings about the component and structural fragilities developed as part of the Seismic Safety Margins Research Project. Your letter is included as an addendum for clarity. We will respond to each statement in turn and comment accordingly.

Statement 1. "The fragility information in Appendix F of NUREG/CR-3558 is the most current and supersedes other component fragility data presented in previous SSMRP reports (specifically NUREGs/CR-2405 and CR-3428). Appendix F is what LLNL recommends as the 'generic data base' for component fragilities."

The statement is essentially correct with one clarification. We regarded the fragilities as constituting a "generic data base" only in the sense that a careful interpretation of their applicability to whatever plant is under study must be made on a plant specific basis. The data was developed for use on the SSMRP study of the Zion Nuclear Power Plant. The document NUREG/CR-3558 contains sufficient information about the fragility of the plant equipment that a judgment could be made about the appropriateness of its use at a power plant other than Zion. The use of this data requires a great deal of judgment. This is clear from our own very selective use of the data for the Zion study.

Statement 2. "Enclosure 1 accurately explains inconsistencies in SSMRP-reported relay fragility values and the impact of these inconsistencies."

This statement is correct.

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Statement 3. "Enclosure 2 accurately describes how expert opinion and other data were combined to derive the values in Appendix F. This description indicates that when more than one type of data was combined, the median fragility value becomes conservatively biased."

This statement is correct.

Statement 4. "Except for 'Base Mat Uplift', all SSMRP Zion structural fragilities are taken from the work described in NUREG/CR-2320. The fragility values from this SMA report are summarized in Enclosure 3."

This statement is correct. However, we think one of the footnotes in Enclosure 3, could be misinterpreted and should be changed. It now reads: c. Updated by "Base Slab Uplift" category discussed in NUREG/CR-3558 and NUREG/CR-3428. We think there is less opportunity for misinterpretation if it were changed to read: c. This value for "Base Slab Uplift" has been replaced by median = 0.70 g's; β^R = 0.4, β^T = 0.57. The justification for this change is found in NUREG/CR-3558 and NUREG/CR-3428.

Statement 5. "The information given in the two tables of Enclosure 4 is correct regarding what was actually used (not just 'developed for') in the final SSMRP Zion seismic risk calculations."

This statment is true. However, we would suggest the following changes for clarity and accuracy:

a. Statement 5 should read, "The information given in the two tables of Enclosure 4 is correct regarding what was actually used in the final SSMRP Zion seismic risk calculation.

b. The footnote "c" to the table of "Structure Fragilities Used in the Accident Sequences of the SSMRP Zion Analysis" found in Enclosure 4 should read: c. This category was used instead of "Auxiliary Building N-S Shear Wall" to represent the shear wall between the Zion Auxiliary and Turbine buildings. The median fragilities are the same for the two categories and a judgment was made that the diesel generator building fragility was appropriate for this particular analysis.

Statement 6. Also, please verify that the "large motor operated valve" fragility pertains to all sizes greater than four inches (not eight inches as indicated in the current text).

This statement is true. A correction should be introduced on page 2-8 of NUREG/CR-3558 in the paragraph that starts out "Small Motor-Operated Valves. These are similar to large motor operated valves but are for piping of less than 8-in diam. ...."

The "8-in" should be changed to "4-in."

If you have any further questions, please let us know.

Sincerely,

Garth Cummings
Nuclear Systems Safety Program Leader

Robert Langland
Section Leader
Engineering Mechanics Section

GC/RL:sa

Enclosure

Lawrence Livermore National Laboratory

NUCLEAR SYSTEMS SAFETY PROGRAM
RARE 85-045

March 8, 1985

Mr. Dan Guzy
Mechanical Structural Engineering Branch
Division of Engineering Technology
Office of Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Guzy:

Enclosed please find the results of our re-evaluation of assumptions concerning the consequences of selected structural failures that were made in the SSMRP Zion seismic risk study.

In summary, the assumption of the service water pump enclosure roof failure causing failure of all six service water pumps is judge to be overly pessimistic. This result is based on experience with similar structures and a complete review of the systems needed for the continued operation of at least two service water pumps should an earthquake occur. The assumptions concerning the failure of the common wall between the auxiliary building and the turbine were confirmed. This result is based on structural considerations and the location of vital equipment in the auxiliary building at or above the 592 ft. level.

If you have any questions concerning these results please feel free to contact me.

Sincerely,

Peter G. Prassinos
Risk Assessment and Reliability
Engineering

sr

Enclosure

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Potential Damage to Safety-Related Systems Resulting from Selected Structural Failure Modes of the Zion Nuclear Power Plant

P. S. Hashimoto, J. J. Johnson, P. G. Prassinos

A number of structural failure modes for the Zion Nuclear Power Plant resulting from seismic effects were postulated for the Seismic Safety Margins Research Program (SSMRP). The two failure modes having the most serious consequences were subsequently identified to be failure of the service water pump enclosure roof of the crib house and failure of the common wall between the auxiliary and turbine buildings. Significant potential damage to safety-related systems resulting from these failure modes was hypothesized. A limited re-evaluation of the consequences of structural failure was performed principally through a review of the structural drawings and the load paths available, a detailed walk through of the areas, and a review of the systems models.

Failure of the Service Water Pump Enclosure Room Roof

The service water pumps are housed within the pump enclosure room which is on the operating floor of the crib house. The pump enclosure room is a reinforced concrete box-type structure 165 ft. long by 28 ft. wide. Much of the resistance against the roof and wall seismic inertial forces in the transverse, E-W direction is provided by the north and south side walls which are loaded in-plane. A lesser degree of resistance is provided by the east and west end walls which are loaded out-of-plane. The inertial forces are delivered to the resisting elements by the roof slab which serves as a horizontal diaphragm.

The crib house failure mode having the lowest capacity was found to be failure of the pump enclosure room roof due to the diaphragm loads. This failure was expected to initiate at the large hatch openings adjacent to the north and south side

walls. At the ductility limit assigned to this failure mode, the load transfer capability at the hatch openings was conservatively assumed to be lost completely. The additional lateral load resistance provided by out-of-plane flexural hinging and rigid body rocking of the east and west walls was estimated to be relatively low. Consequently, diaphragm failure at the fragility values reported was conservatively assumed to lead to collapse of the pump enclosure room roof, although the actual collapse capacity was not explicitly calculated.

This failure mode was assumed to cause failure of the six service water pumps supported on the floor beneath it. From a systems standpoint, one service water pump is required for each unit for successful operation of the service water system during an accident condition. During operation of the reactors, two service water pumps for each unit are on-line and operating. Hence, following an earthquake, only one service water pump for each unit (assuming both units are on-line) must be available and operational. Failure of the service water pumps due to pump enclosure roof failure occurs if the pump or its essential perpherals fail. A walk-through of the crib house showed three possible failure modes of a pump: (i) failure of the pump itself; (ii) failure of tanks or lines supplying bearing seal water to the pumps at startup only (one tank and line per pump) or (iii) failure of power cables to the pumps.

The minimum amount of damage associated with diaphragm failure consists of cracking and spalling of the slab concrete, particularly around the hatch openings. These effects may result in a loss of anchorage for the cable trays which contain power cables and are hung from the beams between the hatch openings. However, this loss of anchorage does not necessarily imply a loss of function of the electrical cables in the tray. Failure of the cables themselves can result from the impact of large amounts of concrete fragments. While the electrical power supply to some of the pumps may be disrupted, it is unlikely that all or nearly all

of the pumps will fail. Damage to the pumps themselves will result if concrete fragments fall through any openings in the motor casings. This type of failure has a lower probability of occurrence since it is dependent upon injection of a concrete fragment into a relatively small location. Failure of one of more of the bearing water seal tanks is more probable. Each tank is supported from the crib house wall with a line running between them, however, in a fail safe position. Even though this failure mode is more likely, if a pump is running, this source of water is unneeded.

An analysis to determine the actual collapse capacity of the pump enclosure room roof would likely be difficult and time-consuming. However, past earthquake experience has indicated that structures typically have collapse capacities greater than the capacities corresponding to major structural damage. This would be expected to be true for the pump enclosure roof since it does not exhibit all of the characteristics of structures that have experienced collapse. The collapse capacity of the pump enclosure roof should be somewhat greater than the reported fragility for diaphragm failure, although the actual margin available is not known.

Hence, the SSMRP assumptions of pump enclosure roof failure causing failure of all six service water pumps is judged to be too pessimistic in light of the structural and systems aspects discussed here.

Failure of the Common Wall Between the Auxiliary and Turbine Buildings

The auxiliary and fuel handling building is structurally continuous with the turbine building. The primary lateral load-carrying system of the auxiliary building is composed of reinforced concrete shear walls. The concrete floor slabs serve as diaphragms distributing the seismic inertial loads to the walls. The structural failure mode of the auxiliary building

having the lowest capacity was found to be failure of the common shear wall between the auxiliary and turbine buildings on Column Line G. Below El. 592'-0, this wall consists of solid, continuous reinforced concrete. Above El. 592'-0, the wall is of composite construction consisting of braced steel framing with in-filled reinforced concrete panels. Failure of this wall is initiated by failure of the studs welded to the steel column webs and embedded in the in-fill concrete. This is followed by division of the wall into a series of individual panels separated by the columns and subsequent failure of the individual panels themselves.

The common wall receives much of the applied seismic load of the auxiliary building and also provides much of the strength against the structure seismic loads. Consequently, the fragility evaluation assumed that failure of the common wall is immediately followed by failure of the remaining shear walls and damage to most of the auxiliary building above El. 592'-0. The structure below El. 592'-0 was expected to have greater capacity since more structural resistance is available for these lower elevations.

The fragility values for failure of the common wall were based upon the seismic load predicted by the elastic finite element model. Load redistribution to the remaining shear walls as the common wall progressively fails was not explicitly accounted for. The minimum degree of damage corresponding to these fragility values is therefore a loss-of-function of equipment mounted on the wall itself or on the slabs immediately adjacent to the wall above El. 592'-0. The development of damage throughout the rest of the auxiliary building could possibly be evaluated by further analysis accounting for the load redistribution to the remaining walls. However, due to the complexity of the structure any such analysis would be difficult and expensive. Also, because of the importance of the common wall to the overall structure stiffness and strength, it is very likely that the additional analysis would only provide

confirmation of the previous assumption that damage to most of the auxiliary building above El. 592'-0 corresponds to the original fragility values based upon failure of the common wall. Hence, previous SSMRP assumptions concerning the consequences of failure of this wall were confirmed.

APPENDIX E
EQUIPMENT FRAGILITY DATA BASE

ABSTRACT

Part of the effort of the Seismic Safety Margins Research Program (SSMRP) has been directed at generating a fragility data base for equipment used in control and safety systems in commercial nuclear power plants. Component fragility data have been compiled in various forms, depending on their content, intended use, and level of reduction. The data are stored in a relational data base on the LLNL CDC 7600 computers. This report describes the present structure of the data base and presents its contents through the use of tables. This appendix is a revision of an earlier report (UCRL-53038). Additional data have been included and the presentation has been revised to enhance its usability. It is presented in report format to make it easier for the reader to use and understand.

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EXECUTIVE SUMMARY

This report describes a relational data base, which consists of seismic fragility descriptions for nuclear power plant equipment and data from which many of the fragilities were developed. The fragilities stem primarily from three sources:

1. Design analysis reports from manufacturers of components for the Zion Nuclear Power Plant.
2. Experimental data obtained from the results of component manufacturers' qualification tests, failure data testing by independent laboratories, and data obtained from the U.S. Army Corps of Engineers SAFEGUARD Subsystem Hardness Assurance Program.
3. The results of an extensive expert opinion survey conducted by the Seismic Safety Margins Research Program (SSMRP).

The basic data resulting from the expert opinion survey, including 10th, 50th, and 90th percentile estimates of probability of failure for many categories of equipment and a variety of failure modes are included. Also included are the results of combining both individual opinions within a failure mode and various failure modes within categories. The statistical methods used in making these combinations are discussed.

1.0 INTRODUCTION

One of the primary objectives of the SSMRP is to develop both a methodology and mathematical models that realistically predict the probability of radioactive releases from seismically induced events in nuclear power plants. The Fragilities Development Project was established to help meet this objective. Research in the project centers on the development of power plant structure and component fragility in probabilistic terms. A complete presentation of the sources of data and methodology used by the SSMRP for fragilities development is included in Ref. 1.

Approximately 50 generic categories of mechanical and electrical components were originally identified for this purpose. Of this number, 37 were chosen for subsequent fragility development. The fragilities developed for these categories are based on site-specific data and design reports from the Zion Nuclear Power Plant, the U.S. Army Corps of Engineers Safeguard Program, and the results of an extensive expert opinion survey conducted by the SSMRP. This data base consists of a variety of information, all related in some way to the development of the fragilities for these categories of components.

The data base was structured on LLNL's CDC 7600 computers through the use of the FRAMIS data base management system, and while access to the data is most conveniently accomplished by using FRAMIS, it can also be accomplished with the tables in this report. FRAMIS is documented in Refs. 2 and 3.

Some of the data have been grouped into tables that were structured for convenience in the fragility data reduction process. Other tables were structured simply to allow convenient storage of information. FRAMIS allows easy regrouping of data into virtually any format that the user may find useful. This data base is continuing to expand as new data are collected.

2.0 DATA SOURCES

For various reasons, actual fragility data for mechanical and electrical components are very scarce. Consequently, the SSMRP conducted an extensive expert opinion survey that yielded probabilistic information for several of the component categories. In addition, data and design reports from the Zion Nuclear Power Plant and data from the U.S. Army Corps of Engineers Safeguard Program were used.

2.1 EXPERT OPINION SOURCES

Approximately 50 generic component categories were identified for fragility determination. Experts were asked to identify modes of failure and estimate 10th, 50th, and 90th percentile values for component strength at failure by these modes as a function of an appropriate fragility parameter (usually spectral acceleration). Each set of opinion data was evaluated using several criteria, including source (i.e., manufacturer, test laboratory, professor, etc.), basis (i.e., test, analysis, etc.), and the expert's own evaluation of level of his expertise. Weighting factors reflecting the degree of confidence in the experts' opinions were then applied to each set of estimates.

Thus, for a particular generic category of component and a particular failure mode, one set of data consists of one expert opinion of the 10th, 50th, and 90th percentile values of strength at failure and a subjective weighting factor.

The information obtained in the survey and the results of various levels of reduction of the data are included in this data base.

2.2 ANALYSIS AND TEST DATA SOURCES

Data and design reports from the Zion Nuclear Power Plant and data from the U.S. Army Corps of Engineers Safeguard Program were compiled and reduced for the SSMRP by Structural Mechanics Associates (SMA). Selected data from Ref. 4 are included in this data base. Modifications of these data (as described in Section 3.2 of this report) are also included.

3.0 DATA ANALYSIS

3.1 EXPERT OPINION ANALYSIS

It was assumed that a single fragility curve of normal or lognormal distribution can approximately represent each generic component for a particular failure mode. Since the various sets of expert opinion data could be based on quite different components (because of size, manufacturing techniques, design, etc.) within a single generic category, it was necessary to provide for subgrouping of similar components within a category for each mode.* For each failure mode, the model for the qth percentile estimate provided by the jth expert in the ith group is:

$$x_{ijq} = \mu + Z_q\sigma + T_i + E_{ijq} \quad ,$$

$$i = 1, \ldots, I \quad ,$$

$$j = 1, \ldots, N_i \; ; \quad \sum_{i=1}^{I} N_i = N \quad ,$$

$q = 10, 50, 90$ indicating 10th, 50th, and 90th percentile estimates

where

μ, σ — are the mean and standard deviations to be estimated.

T_i — is the deviation of qth percentile for ith group from overall qth percentile ($\mu + Z_q\sigma$). The T_i's are assumed to be independent, identically distributed (IID) random variables with zero mean and standard deviation, σ_T.

E_{ijq} — is the variation in estimate of qth percentile given by jth expert in ith group. E_{ijq}'s are assumed to be IID random variables with zero mean and standard deviation, σ_E.

Z_q — is the value of the standardized normal cumulative distribution function at the qth percentile.

The parameters to be estimated are μ, σ, σ_E and σ_T as just defined. We assume the weights assigned to each expert opinion to be w_{ij} for the jth expert in the ith group.

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* The statistical analysis methods used were selected and developed for this application by R. W. Mensing and L. L. George. A more complete presentation of the methods can be found in Ref. 5.

1. To estimate (μ, σ), minimize

$$SS(\mu, \sigma) = \sum_i \sum_j w_{ij} \sum_q (x_{ijq} - \mu - Z_q \sigma)^2$$

with respect to (μ, σ) resulting in:

$$\hat{\mu} = \frac{1}{3} \sum_q \sum_i \sum_j w_{ij} x_{ijq} \quad ,$$

$$\hat{\sigma} = \frac{1}{2Z_{90}} \left[\sum_i \sum_j w_{ij} (x_{ij90} - x_{ij10}) \right] .$$

2. Estimation of σ_T and σ_E is based on finding unbiased estimators.

Define the estimators as follows:

$$SSE = \sum_q \sum_i \sum_j w_{ij} (x_{ijq} - \hat{\mu} - Z_q \hat{\sigma})^2 \quad ,$$

$$SST = \sum_q \sum_i \sum_j w_{ij} (x_{ijq} - \bar{x}_{i.q})^2 \quad ,$$

where

$$\bar{x}_{i.q} = \frac{1}{w_{i.}} \sum_j w_{ij} x_{ijq} \quad ,$$

$$w_{i.} = \sum_j w_{ij} \quad ,$$

$$SSM = \sum_q \sum_i \sum_j w_{ij} (\bar{x}_{..q} - \hat{\mu} - Z_q \hat{\sigma})^2 \quad ,$$

where

$$\bar{x}_{..q} = \sum_i \sum_j w_{ij} x_{iq} \quad .$$

The expectations for SSE, SST and SSM are then

$$E[SSM] = \sigma_E^2 \sum_i \sum_j w_{ij}^2 \tag{1}$$

$$E[SST] = 3\sigma_E^2 \left(1 - \sum_i \frac{\sum_j w_{ij}^2}{w_{i.}}\right) . \tag{2}$$

$$E[SSE] = 3(\sigma_{T_2}^2 + \sigma_E^2) - 2\sigma_E^2 \sum_i \sum_j w_{ij}^2 - 3\sigma_T^2 \sum_i w_i^2 \tag{3}$$

Solving Eq. (2) for σ_E^2 and replacing E[SST] with SST,

$$\hat{\sigma}_E^2 = \frac{SST/3}{1 - \sum_i \frac{\sum_j w_{ij}^2}{w_i}} \quad . \tag{4}$$

Similarly from Eq. (1):

$$\hat{\sigma}_E^2 = \frac{SSM}{\sum_i \sum_j w_{ij}^2} \quad . \tag{5}$$

Solving Eq. (3) for σ_T^2 yields

$$\sigma_T^2 = \frac{E[SSE] - 3\sigma_E^2 + 2\sigma_E^2 \sum_i \sum_j w_{ij}^2}{3(1 - \sum_i w_i^2)} . \tag{6}$$

Thus, we have two estimates for σ_T^2

$$\hat{\sigma}_T^2 = \frac{SSE - 3\hat{\sigma}_E^2 + 2\sigma_E^2 \sum_i \sum_j w_{ij}^2}{3(1 - \sum_i w_i^2)} . \tag{7}$$

$$\hat{\hat{\sigma}}_T^2 = \frac{SSE - 3\sigma_E^2 + 2\hat{\hat{\sigma}}_E^2 \sum_i \sum_j w_{ij}^2}{3(1 - \sum_i w_i^2)} . \tag{7}$$

If data for more than one failure mode is available for analysis, the fragilities of the individual modes are combined to yield the union of these modes, i.e.,

$$F_{TOTAL} = [1 - (1 - F_1)\ (1 - F_2) \ldots (1 - F_N)] \ .$$

The application of these statistical methods to the expert opinion data was accomplished through the use of the Fortran program, FRAGSTAT, which is documented in Ref. 6.

3.2 OTHER ANALYSIS

Reference 4 contains fragilities with lognormal distribution only. For consistency and comparison purposes, it was desirable to have both normal and lognormal data; therefore, a procedure for fitting the lognormal data to result in a suitable normal distribution was needed. The following criteria were used:

a. The statistical mean of the normal distribution was assumed to be the same as the median of the lognormal distributions, i.e., $\mu = m$.

b. The standard deviation of the normal distribution was assumed to be

$$\sigma_N = \frac{X_{50} - X_{10}}{Z_{50} - Z_{10}} = \frac{X_{50} - X_{10}}{1.28} ,$$

where

X_{50} = the fragility parameter at 50% probability of failure,

X_{10} = the fragility parameter at 10% probability of failure,

Z_{50} = the value of the standardized normal cumulative distribution function at 50th percentile,

Z_{10} = the value of the standardized normal cumulative distribution function at 10th percentile.

c. The value of the fragility parameter at 90% probability of failure is then given by

$$X_{90} = X_{50} + (Z_{50} - Z_{10})\ \sigma_N = X_{50} + 1.28\ \sigma_N .$$

3.3 EXAMPLE OF COMBINING DATA

To illustrate the procedure used in combining data from several sources to develop a single fragility, consider, for example, the category of small miscellaneous valves (Category 18). There are 15 sets of expert opinion data for Category 18 (OPNO 132 through OPNO 146 in the data base table OPINION).* The first 10 sets will suffice to illustrate the procedure. A portion of the data for these opinions follows:

		Percentile Estimates			
OPNO	Weight	10%	50%	90%	Failure Mode
132	3.0	10.00	12.00	15.00	Leakage
133	3.0	6.60	7.80	10.80	Internal seat leakage
134	3.0	12.00	15.00	20.00	Gauling of stem
135	1.5	6.00	7.50	8.50	Stem binding
136	3.0	15.00	30.00	50.00	Internal damage
137	1.5	10.50	12.00	14.25	Mechanical binding of the valve
138	3.0	10.00	18.00	30.00	Structural failure
139	3.0	12.00	15.00	20.00	Structural fatigue at neck
140	3.0	12.00	18.00	24.00	Top structure of valve
141	3.0	20.00	50.00	100.00	Fracture of valve body

* The data base tables are all listed in Section 6.2.

The fragility parameter for each is spectral acceleration (g).

The failure mode description of the first two sets clearly calls for them to be grouped together as one mode.

The next four (134-137) are similar in failure mode, each indicating a functional problem, and in addition 134 and 135 are probably the same failure mode. Therefore, 134 through 137 will contribute to the same failure but a further subgrouping of 134 and 135 is indicated.

The last four sets all indicate structural failure, and in addition 139 and 140 are for the same location on the valve. Therefore, 138 through 141 will contribute to the same failure mode and further subgrouping of 139 and 140 is indicated. The following summarizes the grouping to be used:

OPNO	Group	Subgroup	Failure Mode
132	1	1	Leakage
133	1	1	Leakage
134	2	1	Functional Failure
135	2	1	Functional Failure
136	2	2	Functional Failure
137	2	3	Functional Failure
138	3	1	Structural Failure
139	3	2	Structural Failure
140	3	2	Structural Failure
141	3	3	Structural Failure

Applying the analysis described in Section 3.1 leads to the following log-normal results.

	Individual		Mode		Total	
OPNO	$\check{m}$	β	$\check{m}$	β	$\check{m}$	β
132	12.1	0.159	10.0	0.329		
133	8.2	0.203			8.5	0.339
134	15.3	0.201				
135	7.3	0.142	15.9	0.620		
136	28.2	0.476				
137	12.2	0.120				
138	17.5	0.430				
139	15.3	0.201	21.6	0.714		
140	17.3	0.275				
141	46.4	0.635				

Thus, for this particular grouping of data, a resulting single distribution for fragility of $\check{m}$ = 8.5 g, β = 0.339 is obtained.

Figure 1 shows the results of combining the groupings of expert opinion data to result in one fragility curve for the functional failure mode. The influence of the high weight factor assigned to OPNO 136 can be seen in the tendency of the result toward higher fragility levels.

Figure 2 shows the results of combining the three failure modes to result in one fragility curve for the category. Here the mode of lowest fragility dominates the result. This will be true in every case of combining modes since the result is computed by the union of the individual modes.

Other groupings might be considered than the preceding ones. For example, leakage might not be considered a failure mode of concern, and in that case OPNO's 132 and 133 would not be used. Data from sources other than expert opinion can be included in the groupings by first determining from the cumulative distribution function the 10th, 50th and 90th percentile values of spectral acceleration (or appropriate parameter), assigning a weight factor, and then treating the data in the same manner as expert opinion.

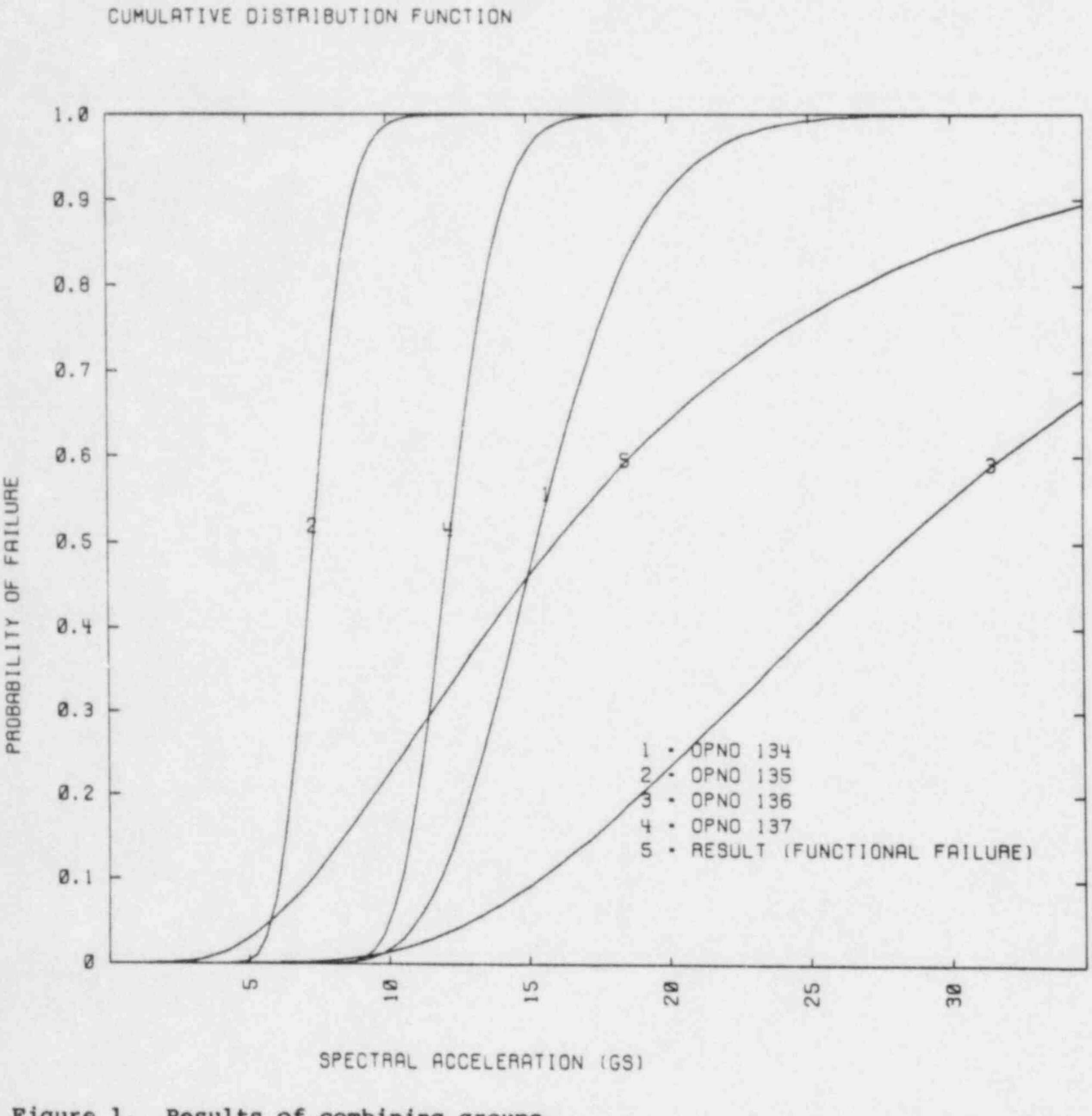

Figure 1. Results of combining groups.

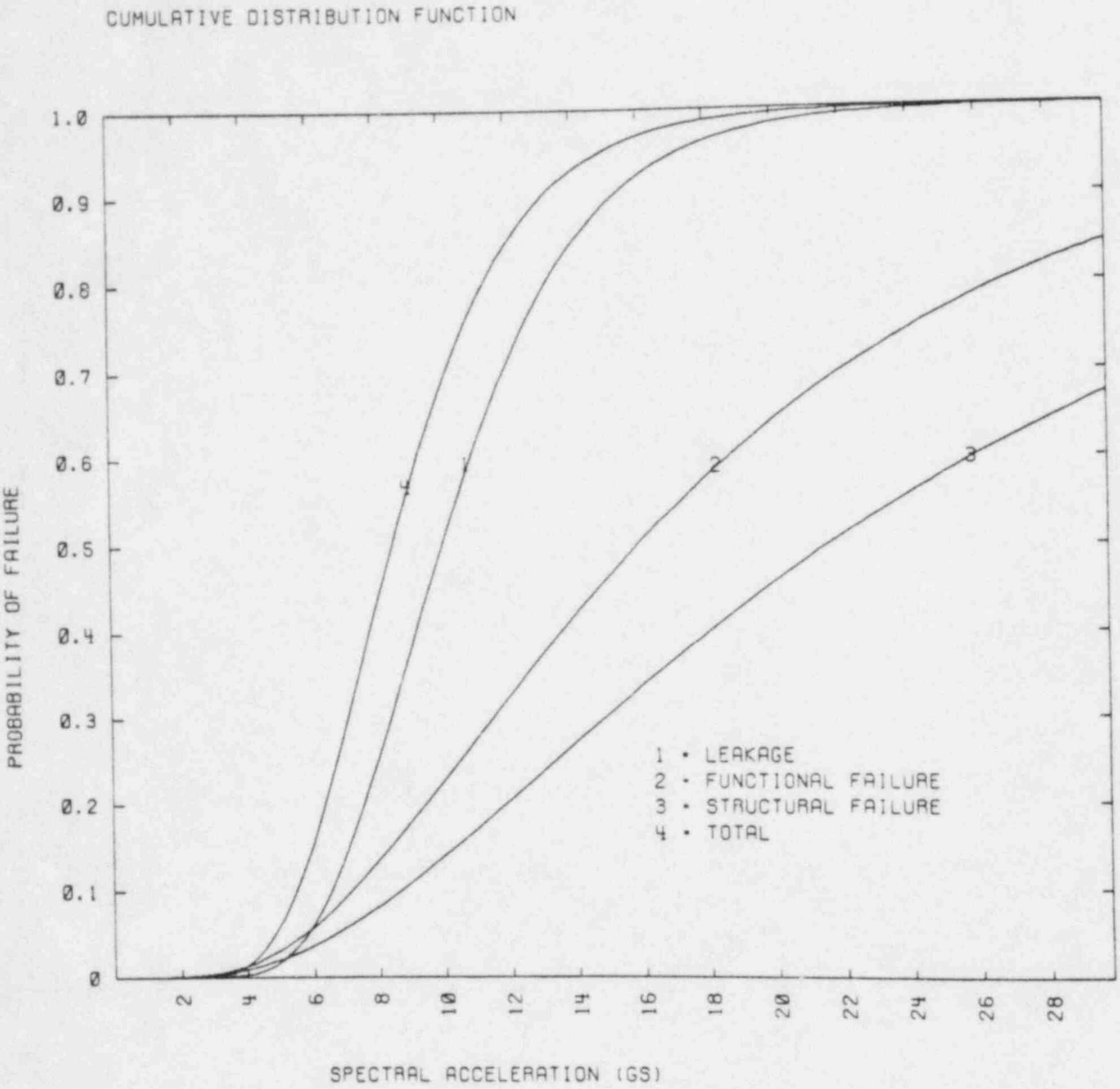

Figure 2. Results of combining modes.

4.0 LOAD SCALE FACTORS FOR PIPING ELEMENTS

The development of fragilities for the piping systems at Zion presented a different kind of problem than other categories of equipment, since fragility descriptions were needed for virtually every conceivable combination of piping elements. The approach taken was to avoid developing separate fragilities for each combination by relating individual pipe element fragilities to a master pipe element fragility by means of a load scale factor, F_p, defined as

$$F_p = \frac{\text{Capacity of reference pipe element}}{\text{Capacity of pipe element under consideration}} .$$

These factors were computed for several sizes and schedules of pipe elements, including straight pipe, butt welds, elbows, miter joints, and branch connections. The development of the load scale factors is discussed in detail in Ref. 4. The data base contains the resulting load scale factors together with the related piping element parameters. They can be found in this report in tables in Section 6.2.

5.0 DATA BASE DESCRIPTION

In its current structure, the data base consists of 12 tables. Some of the data have been grouped into tables that were structured for convenience in the fragility data reduction process. Others were structured on LLNL's CDC 7600 computers through the use of the FRAMIS data base management system. While access to the data is most conveniently accomplished through FRAMIS, it can be accomplished with the tables in this report as illustrated below.

5.1 RELATIONAL STRUCTURE

Each of the 12 tables contains not only lists of data, but also entities that allow relationships to be constructed between tables. For example, many of the tables contain an appropriate category number along with each set of data. This allows relationships to be constructed between all of the tables that contain category numbers. These relationships can be used to build new tables representing compilations or subsets of the other tables. It is also possible to relate data from tables that do not contain common entities if an intermediate table containing an entity common to both is available. For example, the fragilities in table RESULTS* can be related to the expert opinions in table OPINION by first relating RESULTS to GRPMODE using entity RESNO, then relating GRPMODE to GRPDEF using the entity GRPNO, and finally relating to GRPDEF to OPINION using the entity OPNO. Applying this procedure to RES01A (the first entry in table RESULTS) shows that three expert opinions (and two calculated fragilities) were used in the development of RES01Ad. The 10th, 50th, and 90th percentile opinions (along with other information) for each can be found in table OPINION using the pertinent value of OPNO. Relational operations such as these are quickly and easily accomplished using FRAMIS.

*See Sec. 5.2 for descriptions and contents of individual tables.

5.2 DATA TABLES

Computer listings of the data tables that comprise the data base are presented in alphabetical order in this section along with explanations of the contents of each. The name assigned to each column of data and the data type are included in each description since this information is useful when using FRAMIS.

A. BRANCH

Table BRANCH contains load scale factors for branch connections of various representative pipes (see Table PIPE for other pipe elements). It consists of 10 columns as follows:

Column No.	Column name	Type	Contents
1	LINE	Integer	A reference line number.
2	SIZER	Floating	The nominal diameter of the pipe run (in.).
3	SIZEB	Floating	The nominal diameter of the pipe branch. (in.)
4	SCHED	Character	The pipe schedule.
5	MAT	Character	Material: SS = stainless steel; CS = carbon steel.
6	TEMP	Floating	Temperature (°F)
7	FUPR	Floating	Unreinforced branch; scale factor for run.
8	FUPB	Floating	Unreinforced branch; scale factor for branch.
9	FRPR	Floating	Reinforced branch; scale factor for run.
10	FRPB	Floating	Reinforced branch; scale factor for branch.

BRANCH

LINE	SIZER	SIZEB	SCHED	MAT	TEMP	FUPR	FUPB	FRPR	FRPB
1	3.0	0.50	160	SS	300.	9.620	480.000	9.620	480.000
2	3.0	0.75	160	SS	300.	9.620	254.000	9.620	254.000
3	3.0	2.00	160	SS	300.	10.000	27.000	9.620	27.000
4	3.0	3.00	160	SS	300.	10.000	10.000	9.620	9.620
5	4.0	0.75	160	SS	300.	4.570	254.000	4.570	254.000
6	4.0	1.00	160	SS	300.	4.570	135.000	4.570	135.000
7	4.0	2.00	160	SS	300.	5.150	27.000	4.570	27.000
8	4.0	3.00	160	SS	300.	5.150	9.640	4.570	9.520
9	4.0	4.00	40S	SS	500.	21.000	21.000	10.630	10.630
10	4.0	4.00	120	CS	140.	4.740	4.740	3.630	3.630
11	4.0	4.00	120	SS	300.	6.720	6.720	5.270	5.270
12	4.0	4.00	120	SS	535.	8.210	8.210	6.310	6.310
13	6.0	3.00	160	CS	100.	1.220	6.190	1.000	6.190
14	6.0	4.00	120	CS	140.	1.850	8.210	1.270	3.630
15	6.0	6.00	120	CS	100.	1.280	1.280	1.000	1.000
16	8.0	2.00	40S	SS	500.	2.050	72.400	2.050	60.400
17	8.0	4.00	40S	SS	500.	5.200	19.700	2.050	10.630
18	8.0	8.00	40S	SS	400.	4.840	4.840	1.870	1.870
19	8.0	8.00	40S	SS	500.	5.200	5.200	2.050	2.050
20	10.0	8.00	40S	SS	400.	2.890	4.540	1.050	1.870
21	10.0	10.00	40S	SS	400.	2.890	2.890	1.050	1.050
22	12.0	8.00	40	SS	400.	1.920	4.270	0.670	1.870
23	12.0	12.00	40	SS	400.	1.920	1.920	0.670	0.670
24	14.0	12.00	40	SS	400.	1.510	1.810	0.515	0.671
25	14.0	14.00	TN=.375	CS	100.	1.180	1.180	0.365	0.365
26	14.0	14.00	40	CS	100.	1.020	1.020	0.310	0.310
27	14.0	14.00	60	SS	400.	0.237	0.237	0.186	0.186
28	16.0	3.00	R120,B160	CS	556.	0.124	8.050	0.124	8.050
29	18.0	14.00	40	SS	400.	0.711	1.170	0.244	0.515
30	27.5	4.00	2.38,.438	SS	535.	0.021	6.320	0.021	5.600
31	27.5	8.00	2.38,.812	SS	535.	0.021	0.920	0.021	0.870
32	27.5	10.00	2.38,1.125	SS	535.	0.034	0.438	0.021	0.438
33	29.0	8.00	2.50,.812	SS	595.	0.020	0.949	0.019	0.910
34	29.0	14.00	2.50,1.406	SS	595.	0.030	0.212	0.019	0.212
35	30.0	20.00	.5,.375	CS	100.	0.261	0.589	0.058	0.176
36	36.0	36.00	TN.5	CS	100.	0.203	0.203	0.	0.
37	43.0	20.00	T.625	CS	100.	0.096	0.557	0.	0.
38	48.0	30.00	.625, .5	CS	100.	0.096	0.247	0.	0.
39	48.0	48.00	.625, .5	CS	100.	0.096	0.096	0.	0.

B. CATEGORY

Table CATEGORY relates the descriptions of the generic categories of components to the numbers used to identify data for these categories. It consists of three columns of data as follows:

Column No.	Column name	Type	Contents
1	CATNO	Floating	A floating point number unique to this particular description. (Note: CATNO is a subgrouping of CAT.)
2	CAT	Integer	An integer number unique to a class of generic components.
3	DES	Character	The description of the generic category or specific component represented uniquely by CATNO and generically by CAT.

CATEGORY

CATNO	CAT	DESCRIPTION
1.0	1	REACTOR CORE ASSEMBLY
2.0	2	REACTOR COOLANT SYSTEM VESSELS
2.1	2	REACTOR PRESSURE VESSEL
2.2	2	PRESSURIZER
2.3	2	STEAM GENERATOR
3.0	3	PRIMARY COOLANT PIPING
4.0	4	LARGE PIPING (>8IN.)
5.0	5	INTERMEDIATE PIPING (2IN. < D < 8IN.)
6.0	6	SMALL PIPES (< 2IN.)
7.0	7	LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS
8.0	8	LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS
9.0	9	LARGE HORIZONTAL VESSELS
10.0	10	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS
11.0	11	BURIED PIPE
12.0	12	REACTOR COOLANT PUMP
13.0	13	LARGE VERTICAL CENTRIFUGAL PUMPS WITH MOTOR DRIVE
14.0	14	LARGE VERTICAL PUMPS
15.0	15	MOTOR DRIVEN COMPRESSORS AND PUMPS
16.0	16	LARGE MOTOR OPERATED VALVES (> 4IN.)
17.0	17	LARGE RELIEF AND CHECK VALVES (> 4IN.)
18.0	18	SMALL MISCELLANEOUS VALVES (< 4IN.)
19.0	19	HORIZONTAL MOTORS
20.0	20	GENERATORS
21.0	21	BATTERIES
22.0	22	SWITCHGEAR
23.0	23	DRY TRANSFORMERS
24.0	24	AIR HANDLING UNITS
26.0	26	INSTRUMENT PANELS AND RACKS
27.0	27	CONTROL PANELS AND RACKS
28.0	28	AUXILIARY RELAY CABINETS
29.0	29	BREAKER PANELS
30.0	30	LOCAL INSTRUMENTS
31.0	31	MOTOR CONTROL CENTERS
33.0	33	LIGHT FIXTURES
34.0	34	COMMUNICATIONS EQUIPMENT
35.0	35	INVERTERS
36.0	36	CABLE TRAYS
37.0	37	DUCTING
38.0	38	HYDRAULIC SNUBBERS
39.0	39	SWITCHYARD EQUIPMENT
39.1	39	GENERAL SWITCHYARD EQUIP.
39.2	39	AIR BLAST CIRCUIT BREAKERS
39.3	39	H. V. TRANSFORMER (256 KV)
40.0	40	RELAYS
41.0	41	CIRCUIT BREAKERS
48.0	48	RECOMBINERS
49.0	49	CERAMIC INSULATORS
50.0	50	SPENT FUEL RACKS

C. GRPDEF

Table GRPDEF identifies the data used as input to program FRAGSTAT, which resulted in the data contained in Table GRPMODE. It consists of three columns as follows:

Column No.	Column name	Type	Contents
1	GRPNO	Character	An identifying code relating to a particular set of failure mode data (see Table GRPMODE).
2	EXPLAN	Character	A worded explanation of the data used in the computation of the associated GRPNO set of failure mode data. Usually a list (by OPNO) of those particular sets of expert opinions input to FRAGSTAT for one failure mode (See Tables GRPMODE and OPINION).

GRPDEF

GRPNO	OPNO	EXPLAN
GRP01A	1	OPNO 1 ALONE
GRP01B	2	OPNO 2 ALONE
GRP01C	3	OPNO 3 ALONE
GRP01D	300	SMANO 1 ALONE
GRP01E	300	SMANO 2 ALONE
GRP02A	20	OPNO 20 ALONE
GRP02B	19	OPNO 19 ALONE
GRP02C	17	OPNO 17 ALONE
GRP02D	11	OPNO 11 ALONE
GRP02E	12	OPNO 12 ALONE
GRP02F	27	OPNO 27 ALONE
GRP02G	24	OPNO 24 ALONE
GRP02H	14	OPNO 14 ALONE
GRP02I	13	OPNO 13 ALONE
GRP02J	26	OPNO 26 AND 28 AS INDIVIDUAL SUBGROUPS
GRP02J	28	OPNO 26 AND 28 AS INDIVIDUAL SUBGROUPS
GRP02K	300	SMANO 60 ALONE
GRP03A	35	MASTER PIPING CURVE
GRP04A	300	MASTER PIPING CURVE
GRP05A	300	MASTER PIPING CURVE
GRP06A	300	MASTER PIPING CURVE
GRP07A	75	OPNO 75 ALONE
GRP07B	76	OPNO 76 ALONE
GRP08A	77	OPNO 77 ALONE
GRP08B	78	OPNO 78 ALONE
GRP08C	79	OPNO 79 ALONE
GRP09A	83	OPNO 83 AND 84 AS INDIVIDUAL SUBGROUPS
GRP09A	84	OPNO 83 AND 84 AS INDIVIDUAL SUBGROUPS
GRP10A	85	OPNO 85 ALONE
GRP10B	87	OPNO 87 ALONE
GRP10C	86	OPNO 86 AND 89 AS INDIVIDUAL SUBGROUPS
GRP10C	89	OPNO 86 AND 89 AS INDIVIDUAL SUBGROUPS
GRP10D	300	SMANO 10 ALONE
GRP11A	300	MASTER PIPING CURVE
GRP12A	92	OPNO 92 ALONE
GRP12B	93	OPNO 93 ALONE
GRP12C	300	SMANO 14 ALONE
GRP13A	94	OPNO 94 ALONE
GRP13B	95	OPNO 95 ALONE
GRP14A	99	OPNO 99 ALONE
GRP14B	100	OPNO 100 ALONE
GRP15A	300	SMANO 18 ALONE
GRP15B	300	SMANO 19 ALONE
GRP15C	300	SMANO 20 ALONE
GRP15D	300	SMANO 21 ALONE
GRP15E	300	SMANO 22 ALONE
GRP15F	300	SMANO 16 ALONE
GRP15G	300	SMANO 17 ALONE
GRP16A	124	OPNO 124 ALONE
GRP16B	123	OPNO 123 ALONE
GRP16C	122	OPNO 122 ALONE
GRP16D	121	OPNO 125 AND 121 AS INDIVIDUAL SUBGROUPS
GRP16D	125	OPNO 125 AND 121 AS INDIVIDUAL SUBGROUPS
GRP16E	300	SMANO 23 ALONE
GRP16F	300	SMANO 24 ALONE

GRPNO	OPNO	EXPLAN
GRP16G	128	OPNO 128 ALONE
GRP16H	129	OPNO 129 ALONE
GRP17C	130	OPNO 130 ALONE
GRP17D	131	OPNO 131 ALONE
GRP18A	132	OPNO 132 AND 133 AS ONE SUBGROUP
GRP18A	133	OPNO 132 AND 133 AS ONE SUBGROUP
GRP18B	134	OPNO 134 AND 135 AS ONE SUBGRP AND 136 AND 137 AS INDIVIDUAL SUBGRPS
GRP18B	135	OPNO 134 AND 135 AS ONE SUBGRP AND 136 AND 137 AS INDIVIDUAL SUBGRPS
GRP18B	136	OPNO 134 AND 135 AS ONE SUBGRP AND 136 AND 137 AS INDIVIDUAL SUBGRPS
GRP18B	137	OPNO 134 AND 135 AS ONE SUBGRP AND 136 AND 137 AS INDIVIDUAL SUBGRPS
GRP18C	138	OPNO 139 AND 140 AS ONE SUBGRP AND 138 AND 141 AS INDIVIDUAL SUBGRPS
GRP18C	139	OPNO 139 AND 140 AS ONE SUBGRP AND 138 AND 141 AS INDIVIDUAL SUBGRPS
GRP18C	140	OPNO 139 AND 140 AS ONE SUBGRP AND 138 AND 141 AS INDIVIDUAL SUBGRPS
GRP18C	141	OPNO 139 AND 140 AS ONE SUBGRP AND 138 AND 141 AS INDIVIDUAL SUBGRPS
GRP19A	147	OPNO 147 ALONE
GRP19B	148	OPNO 148 ALONE
GRP20A	149	OPNO 149 AND 150 AS ONE SUBGROUP
GRP20A	150	OPNO 149 AND 150 AS ONE SUBGROUP
GRP20B	151	OPNO 151 AND 155 AS ONE SUBGROUP
GRP20B	155	OPNO 151 AND 155 AS ONE SUBGROUP
GRP20C	153	OPNO 153 ALONE
GRP20D	154	OPNO 154 ALONE
GRP20E	300	SMANO 28 ALONE
GRP20F	300	SMANO 29 ALONE
GRP20G	300	SMANO 30 ALONE
GRP20H	300	SMANO 31 ALONE
GRP21A	156	OPNO 156 ALONE
GRP21B	159	OPNO 159 ALONE
GRP21C	300	SMANO 32 ALONE
GRP22A	161	OPNO 161, 165, AND 171 AS ONE SUBGROUP
GRP22A	165	OPNO 161, 165, AND 171 AS ONE SUBGROUP
GRP22A	171	OPNO 161, 165, AND 171 AS ONE SUBGROUP
GRP23A	174	OPNO 178 ALONE
GRP23B	177	OPNO 177 AND 225 AS INDIVIDUAL SUBGROUPS
GRP23B	225	OPNO 177 AND 225 AS INDIVIDUAL SUBGROUPS
GRP23C	176	OPNO 176 ALONE
GRP24A	179	OPNO 179 ALONE
GRP24B	300	SMANO 38 ALONE
GRP24C	300	SMANO 39 ALONE
GRP24D	300	SMANO 40 ALONE
GRP26A	180	OPNO 180 ALONE
GRP26B	181	OPNO 181 ALONE
GRP26C	300	SMANO 41 ALONE
GRP26D	300	SMANO 42 ALONE
GRP26E	300	SMANO 43 ALONE
GRP27B	185	OPNO 185 AND 186 AS INDIVIDUAL SUBGROUPS
GRP27B	186	OPNO 185 AND 186 AS INDIVIDUAL SUBGROUPS
GRP27C	187	OPNO 187 ALONE
GRP27D	188	OPNO 188 ALONE
GRP27F	300	SMANO 56 ALONE
GRP30A	189	OPNO 189 ALONE
GRP30B	190	OPNO 190 ALONE
GRP30C	191	OPNO 191 ALONE
GRP30D	192	OPNO 192 ALONE
GRP30E	193	OPNO 193 ALONE

GRPNO	OPNO	EXPLAN
GRP30F	194	OPNO 194 ALONE
GRP31A	198	OPNO 198 ALONE
GRP31B	199	OPNO 199 ALONE
GRP31C	200	OPNO 200 ALONE
GRP33A	201	OPNO 201 ALONE
GRP36A	206	OPNO 206 ALONE
GRP36B	207	OPNO 207 ALONE
GRP36C	300	SMANO 53 ALONE
GRP37A	208	OPNO 208 ALONE
GRP37B	209	OPNO 209, 211 AND 214 AS INDIVIDUAL SUBGROUPS
GRP37B	211	OPNO 209, 211 AND 214 AS INDIVIDUAL SUBGROUPS
GRP37B	214	OPNO 209, 211 AND 214 AS INDIVIDUAL SUBGROUPS
GRP37C	210	OPNO 210 AND 213 AS INDIVIDUAL SUBGROUPS
GRP37C	213	OPNO 210 AND 213 AS INDIVIDUAL SUBGROUPS
GRP37D	212	OPNO 212 ALONE
GRP37E	215	OPNO 215 ALONE
GRP39A	167	OPNO 167 ALONE
GRP39B	221	OPNO 221 AND 222 AS INDIVIDUAL SUBGROUPS
GRP39B	222	OPNO 221 AND 222 AS INDIVIDUAL SUBGROUPS
GRP39C	173	OPNO 173, 174, AND 175 AS INDIVIDUAL SUBGROUPS
GRP39C	174	OPNO 173, 174, AND 175 AS INDIVIDUAL SUBGROUPS
GRP39C	175	OPNO 173, 174, AND 175 AS INDIVIDUAL SUBGROUPS
GRP40A	182	OPNO 182,183 AND SMA45 AS INDIVIDUAL SUBGROUPS
GRP40A	183	OPNO 182,183 AND SMA45 AS INDIVIDUAL SUBGROUPS
GRP40B	300	SMANO 55 ALONE
GRP41A	300	SMANO 57 ALONE
GRP41B	300	SMANO 58 ALONE
GRP48A	223	OPNO 223 ALONE
GRP49A	226	OPNO 226 AND 227 AS INDIVIDUAL SUBGROUPS
GRP49A	227	OPNO 226 AND 227 AS INDIVIDUAL SUBGROUPS
GRP50A	224	OPNO 224 ALONE

D. GRPFAIL

Table GRPFAIL lists the predominant failure mode for the various groupings of data that are presented in Table GRPMODE. It consists of two columns as follows:

Column No.	Column name	Type	Contents
1	GRPNO	Character	An identifying code unique to this particular set of data and relatable to other tables.
2	MODE	Character	A description of the predominant failure mode for this particular set of data.

GRPFAIL

GRPNO	MODE
GRP01A	BINDING OF CONTROL RODS DUE TO SEISMICALLY INDUCED DEFORMATIONS
GRP01B	DEFORMATION OF GUIDE TUBES DUE TO SEISMIC IMPACT OF FUEL BUNDLE
GRP01C	FAILURE OF CORE SUPPORT STRUCTURE DUE TO INERTIA LOAD OF FUEL
GRP01D	DEFOR. OF GUIDE TUBES / GUIDE PLATE WELD
GRP01E	CONTROL ROD HOUSING DEFORMATION
GRP02A	BUCKLING OF SKIRT
GRP02B	FAILURE OF SKIRT ANCHOR BOLTS
GRP02C	STRESS INTENSITY AT VESSEL SUPPORT
GRP02D	FAILURE OF SKIRT ANCHOR BOLTS
GRP02E	BUCKLING OF SKIRT
GRP02F	RUPTURE AT PRIMARY INLET OR OUTLET NOZZLE, RUPTURE AT FEEDWATER NOZZLE
GRP02G	NOZZLE FAILURE
GRP02H	FAILURE OF STEAM GENERATOR LEG IMBEDMENT IN CONTAINMENT FLOOR
GRP02I	FAILURE OF CONNECTION BETWEEN SUPPORT LEG AND STEAM GENERATOR BODY
GRP02J	TUBING FAILURE
GRP02K	PRESSURE BOUNDARY FAILURE
GRP03A	RUPTURE AT CONNECTIONS TO COMPONENTS DUE TO COMPONENT SUPPORT FAILURE
GRP03B	RUPTURE AT CONNECTIONS TO COMPONENTS DUE TO PIPE OVERSTRESS
GRP07A	RUPTURE OF ANCHOR BOLTS
GRP07B	BUCKLING OF SUPPORT SKIRT OR LEGS
GRP08A	RUPTURE OF ANCHOR BOLTS
GRP08B	BUCKLING OF TANK WALL
GRP08C	TENSILE RUPTURE OF TANK WALL
GRP09A	SUPPORT SYSTEM FAILURE (BOLTS)
GRP10A	RUPTURE OF ANCHOR BOLTS
GRP10B	STRUCTURAL FAILURE
GRP10C	SUPPORT FAILURE
GRP10D	SUPPORT FAILURE
GRP12A	FAILURE OF CONNECTION TO SUPPORT LEGS
GRP12B	BUCKLING OF SUPPORT LEG
GRP12C	BUCKLING AND FRACTURE
GRP13A	RUPTURE OF CONNECTIONS TO SUPPORT STRUTS
GRP13B	TENSILE FAILURE OF SUPPORT STRUTS
GRP14A	RUPTURE OF ANCHOR BOLTS DUE TO LARGE MOMENTS FROM VERTICAL INTAKE COLUMN
GRP14B	RUPTURE OF VERTICAL INTAKE COLUMN
GRP15A	FLANGE BENDING
GRP15B	SHAFT BENDING
GRP15C	THRUST BEARING FAILURE
GRP15D	SHAFT DEFLECTION
GRP15E	GENERIC FUNCTION
GRP15F	IMPELLER DEFLECTION
GRP15G	MOUNTING BOLT FAILURE
GRP16A	BREAKS AT WELD ENDS
GRP16B	RUPTURE OF PIPE SUPPORT AT NOZZLE
GRP16C	LOSS OF CONTROL AIR
GRP16D	ELECTRICAL FAILURE IN ACTUATOR
GRP16E	OPERATOR DISTORTION
GRP16F	OIL RESERVOIR HOLD DOWN BOLTS
GRP16G	FRACTURE OF VALVE ACTUATOR TOP COVER AT CONNECTION TO VALVE BODY
GRP16H	FAILURE OF SPRING MECHANISM DUE TO EXCESSIVE PLASTIC DEFORMATION
GRP17C	DISC BECOMES DISENGAGED
GRP17D	DISC BECOMES BOUND
GRP17E	GENERIC FUNCTION
GRP18A	LEAKAGE
GRP18B	INTERNAL DAMAGE

GRPNO	MODE
GRP18C	STRUCTURAL FATIGUE
GRP19A	BINDING OF ROTATING PARTS
GRP19B	RUPTURE OF ANCHOR BOLTS
GRP20A	CONTROL FAILURE
GRP20B	OIL LEVEL REGULATOR
GRP20C	ANCHOR BOLT FAILURE
GRP20D	CRANKSHAFT LOCK UP
GRP20E	RELAY CHATTER
GRP20F	FAILED RELAY
GRP20G	VALVE TRIP
GRP20H	STRUCTURAL FAILURE
GRP21A	FAILURE OF BATTENS
GRP21B	CASE BREAKAGE DUE TO A BAD STAND
GRP21C	RUPTURE OF ANCHOR BOLTS
GRP22A	SPURIOUS OPERATION OF A PROTECTIVE RELAY
GRP23A	INTERNAL STRUCTURAL FAILURE, SHORT OF ELECTRICAL CONNECTION
GRP23B	FAILURE OF SUPPORT FRAME
GRP23C	RUPTURE OF ANCHOR BOLTS
GRP24A	STRUCTURAL FAILURE
GRP24B	RUBBING OF FAN ON HOUSING
GRP24C	RUBBING OF MOTOR ROTOR ON HOUSING
GRP24D	GENERIC FUNCTION
GRP26A	INSTRUMENT FAILURE
GRP26B	WELD FAILURE
GRP26C	RELAY CHATTER
GRP26D	BREAKER TRIP
GRP26E	STRUCTURAL FAILURE
GRP27B	COMPONENT MALFUNCTION
GRP27C	STRUCTURAL MOUNTING OF CABINETS
GRP27D	STRUCTURAL MOUNTING OF COMPONENTS
GRP27F	STRUCTURAL FAILURE
GRP30A	RELAY CHATTER
GRP30B	LOOSENING OF FASTENERS
GRP30C	BASE STRUCTURAL FATIGUE
GRP30D	SIGNAL DRIFT
GRP30E	CONTACT CHATTER
GRP30F	SET POINT DRIFT
GRP31A	CHATTER OF CONTACTS
GRP31B	STRUCTURAL ANCHORING OF CABINET BASE
GRP31C	STRUCTURAL MOUNTING OF COMPONENT IN CABINET
GRP33A	DISLODGING OF AIR DUCT BLANKING CLIPS
GRP36A	FAILURE OF SUPPORTS
GRP36B	RUPTURE OF PARTS BETWEEN SUPPORTS
GRP36C	CABLE SUPPORT SYSTEM
GRP37A	CORNER TEARING
GRP37B	SUPPORT FAILURE
GRP37C	JOINT SEPARTION
GRP37D	RUPTURE OF DUCT BETWEEN SUPPORTS
GRP37E	GROSS BENDING FIRM
GRP39A	PORCELAIN FRACTURE
GRP39B	A B CIRCUIT BREAKER FAILURE
GRP39C	H V TRANSFORMER STRUCTURAL FAILURE
GRP40A	RELAY CHATTER
GRP40B	RELAY TRIP
GRP41A	BREAKER TRIP

GRPNO	MODE
GRP41B	STRUCTURAL FAILURE
GRP48A	PIPE DEFORMATION
GRP49A	FRACTURE OF PORCELAIN INSULATION
GRP50A	DESTRUCTION OF SHEAR CONNECTION BETWEEN MODULES
SMA01	DEFOR. OF GUIDE TUBES / GUIDE PLATE WELD
SMA02	CONTROL ROD HOUSING DEFORMATION
SMA03	FRACTURE OF RPV OUTPUT NOZZLE SAFE END
SMA04	SUPPORT COLUMN FAILURE
SMA05	SUPPORT SKIRT BOLTING
SMA06	SUPPORT SKIRT COLLAPSE
SMA07	PLASTIC BUCKLING OF SHELL
SMA08	BUCKLING OF TANK WALLS AT BASE
SMA09	BENDING OF VERTICAL STIFFNER
SMA10	SUPPORT FAILURE
SMA11	SUPPORT LEG FAILURE
SMA12	BUCKLING AND FRACTURE
SMA13	BUCKLING AND FRACTURE
SMA14	SUPPORT COLUMN BOLTING
SMA15	BENDING OF PUMP CASING
SMA16	IMPELLER DEFLECTION
SMA17	MOUNTING BOLT FAILURE
SMA18	FLANGE BENDING
SMA19	SHAFT BENDING
SMA20	THRUST BEARING FAILURE
SMA21	SHAFT DEFLECTION
SMA22	GENERIC FUNCTION
SMA23	DISTORTION OF EXTENDED OPERATOR STRUCTURE
SMA24	OIL RESERVOIR HOLD DOWN BOLTS
SMA25	GENERIC FUNCTION
SMA26	GENERIC FUNCTION
SMA27	GENERIC FUNCTION
SMA28	RELAY CHATTER
SMA29	FAILED RELAY
SMA30	VALVE TRIP
SMA31	STRUCTURAL
SMA32	ANCHOR BOLTS
SMA33	CASE CRACKING & PLATE FAILURE
SMA34	RELAY CHATTER
SMA35	BREAKER TRIP
SMA36	STRUCTURAL
SMA37	STRUCTURAL
SMA38	RUBBING OF FAN ON HOUSING
SMA39	RUBBING OF MOTOR ROTOR ON HOUSING
SMA40	GENERIC FUNCTION
SMA41	RELAY CHATTER
SMA42	BREAKER TRIP
SMA43	STRUCTURAL
SMA44	ELECTRICAL MALFUNCTION
SMA45	RELAY CHATTER
SMA46	BREAKER TRIP
SMA47	STRUCTURAL
SMA48	ELECTRICAL FUNCTION
SMA49	RELAY CHATTER
SMA50	BREAKER TRIP
SMA51	STRUCTURAL

GRPNO	MODE
SMA52	RELAY TRIP
SMA53	CABLE SUPPORT SYSTEM
SMA54	RELAY CHATTER
SMA55	RELAY TRIP
SMA56	STRUCTURAL
SMA57	BREAKER TRIP
SMA58	STRUCTURAL
SMA59	FRACT OF INSULATORS
SMA60	OPERATOR DISTORTION
SMA61	RELAY TRIP
SMA62	BREAKER TRIP
SMA63	FRACTURE OF INSULATORS

E. GRPMODE

Table GRPMODE relates the grouping of data which brought about the resulting fragility data presented in Table RESULTS. Each row of data in the table contains the fragility data for a single failure mode, usually resulting from computations by program FRAGSTAT. It consists of seven columns as follows:

Column No.	Column name	Type	Contents
1	GRPNO	Character	An identifying code unique to this particular set of data for a particular failure mode.
2	RESNO	Character	An identifying code relating this set of data to the final resulting fragility data (see Table RESULTS).
3	NMEAN	Floating	The statistical mean of the data assuming normal distribution.
4	NSIGMA	Floating	The standard deviation of the data assuming normal distribution.
5	LNMEAN	Floating	The statistical mean of the natural logs of the data (i.e., assuming lognormal distribution).
6	LNSIGMA	Floating	The standard deviations of the natural logs of the data (i.e., assuming lognormal distributions).
7	PARAM	Character	The fragility parameter.

GRPMODE

GRPNO	RESNO	NMEAN	NSIGMA	LNMEAN	LNSIGMA	PARAM
GRP01A	RES01A	5.000	3.971	1.365	0.708	SP ACCEL G
GRP01B	RES01A	7.333	6.216	1.731	0.757	SP ACCEL G
GRP01C	RES01A	9.333	8.501	1.901	0.823	SP ACCEL G
GRP02A	RES02A	4.333	1.241	1.426	0.275	SP ACCEL G
GRP02B	RES02A	5.667	1.763	1.692	0.239	SP ACCEL G
GRP02C	RES02A	6.833	2.378	1.866	0.325	SP ACCEL G
GRP02D	RES02B	3.333	1.241	1.134	0.361	SP ACCEL G
GRP02E	RES02B	5.667	1.763	1.692	0.289	SP ACCEL G
GRP02F	RES02C	1.933	0.423	0.637	0.208	SP MOMENTS
GRP02G	RES02D	5.000	1.562	1.551	0.339	FORCES
GRP02H	RES02E	4.000	0.781	1.360	0.201	SP ACCEL G
GRP02I	RES02E	3.000	0.781	1.060	0.275	SP ACCEL G
GRP02J	RES02E	8.670	3.540	2.100	0.422	SP ACCEL G
GRP03A	RES03A	220.000	89.140	5.310	0.406	MOM FT-KIP
GRP04A	RES04A	220.000	89.140	5.310	0.406	MOM FT-KIP
GRP05A	RES05A	220.000	89.140	5.310	0.406	MOM FT-KIP
GRP06A	RES06A	220.000	89.140	5.310	0.406	MOM FT-KIP
GRP07A	RES07A	1.330	0.881	0.501	0.445	SP ACCEL G
GRP07B	RES07A	2.833	1.706	0.903	0.536	SP ACCEL G
GRP08A	RES08A	2.167	0.620	0.732	0.275	SP ACCEL G
GRP08B	RES08A	3.433	1.181	1.180	0.319	SP ACCEL G
GRP08C	RES08A	5.583	1.807	1.670	0.305	SP ACCEL G
GRP09A	RES09A	4.370	2.645	1.364	0.609	FLOOR AC G
GRP10A	RES10A	2.167	0.620	0.732	0.275	ACCEL G
GRP10B	RES10A	13.667	4.758	2.547	0.359	ACCEL G
GRP10C	RES10A	2.800	1.116	0.955	0.452	ACCEL G
GRP11A	RES11A	220.000	89.140	5.310	0.406	MOM FT-KIP
GRP12A	RES12A	3.833	1.706	1.269	0.401	SP ACCEL G
GRP12B	RES12A	6.333	2.856	1.766	0.406	SP ACCEL G
GRP13A	RES13A	3.000	0.781	1.059	0.275	SP ACCEL G
GRP13B	RES13A	5.000	0.781	1.596	0.159	SP ACCEL G
GRP14A	RES14A	2.500	1.153	0.828	0.417	SP ACCEL G
GRP14B	RES14A	5.000	2.305	1.521	0.417	SP ACCEL G
GRP16A	RES16A	18.000	4.688	2.851	0.275	SP ACCEL G
GRP16B	RES16A	11.000	2.996	2.363	0.257	SP ACCEL G
GRP16C	RES16B	8.000	2.344	2.029	0.314	SP ACCEL G
GRP16D	RES16A	11.750	4.396	2.415	0.358	SP ACCEL G
GRP16G	RES16A	12.000	5.990	2.360	0.476	PK ACCEL G
GRP16H	RES16A	7.330	1.990	1.950	0.271	PK ACCEL G
GRP17C	RES17A	9.000	1.172	2.188	0.132	SP ACCEL G
GRP17D	RES17A	12.750	1.730	2.538	0.130	SP ACCEL G
GRP18A		10.367	3.322	2.303	0.329	SP ACCEL G
GRP18B	RES18A	19.042	14.874	2.770	0.620	SP ACCEL G
GRP18C	RES18A	27.417	28.836	3.071	0.714	SP ACELL G
GRP19A	RES19A	13.333	4.964	2.520	0.360	ACCEL G
GRP19B	RES19A	21.667	6.205	3.035	0.275	ACCEL G
GRP20A	RES20A	6.476	2.659	1.783	0.441	SP ACCEL G
GRP20B	RES20A	6.476	2.659	1.783	0.441	SP ACCEL G
GRP20C	RES20A	6.333	2.765	1.731	0.476	SP ACCEL G
GRP20D	RES20A	10.800	3.126	2.337	0.279	SP ACCEL G
GRP21A	RES21A	2.500	1.153	0.828	0.417	ACCEL G
GRP21B	RES21A	21.667	6.205	3.035	0.275	ACCEL G
GRP22A	RES22A	2.611	1.237	0.846	0.486	SP ACCEL G
GRP23A	RES23A	5.167	2.269	1.539	0.503	SP ACCEL G
GRP23B	RES23A	10.822	6.728	2.254	0.680	SP ACCEL G

GRPNO	RESNO	NMEAN	NSIGMA	LNMEAN	LNSIGMA	PARAM
GRP23C	RES23A	3.333	1.241	1.134	0.351	SP ACCEL G
GRP24A	RES24A	6.667	2.482	1.827	0.360	FLOOR AC G
GRP26A	RES26A	2.167	0.620	0.732	0.275	ACCEL G
GRP26B	RES26A	5.333	1.995	1.596	0.383	ACCEL G
GRP27B	RES27A	18.183	7.203	2.823	0.407	SP ACCEL G
GRP27C	RES27A	26.667	6.205	3.257	0.223	SP ACCEL G
GRP27D	RES27A	25.000	3.906	3.205	0.159	SP ACCEL G
GRP30A	RES30A	9.333	2.482	2.193	0.302	SP ACCEL G
GRP30B	RES30A	11.000	2.996	2.363	0.257	SP ACCEL G
GRP30C	RES30A	11.000	2.996	2.363	0.257	SP ACCEL G
GRP30D	RES30A	12.000	2.344	2.463	0.201	SP ACCEL G
GRP30E	RES30A	13.800	3.134	2.598	0.223	SP ACCEL G
GRP30F	RES30A	17.600	5.180	2.816	0.325	SP ACCEL G
GRP31A	RES31A	16.667	6.205	2.743	0.361	SP ACCEL G
GRP31B	RES31A	21.667	6.205	3.035	0.275	SP ACCEL G
GRP31C	RES31A	25.000	3.906	3.205	0.159	SP ACCEL G
GRP33A	RES33A	9.400	1.938	2.219	0.201	SP ACCEL G
GRP36A	RES36A	3.330	1.241	1.134	0.360	SP ACCEL G
GRP36B	RES36A	6.333	2.857	1.766	0.406	SP ACCEL G
GRP37A	RES37A	7.333	1.995	1.953	0.271	SP ACCEL G
GRP37B	RES37A	8.375	4.947	1.966	0.677	SP ACCEL G
GRP37C	RES37A	9.333	5.269	2.077	0.806	SP ACCEL G
GRP37D	RES37A	7.000	2.305	1.901	0.302	SP ACCEL G
GRP37E	RES37A	10.000	3.906	2.207	0.445	SP ACCEL G
GRP39A	RES39A	0.883	0.460	-0.266	0.517	Z PRD ACCE
GRP39B	RES39A	0.347	0.180	-1.150	0.449	Z PRD ACCE
GRP39C	RES39A	1.090	0.711	-0.090	0.610	Z PRD ACCE
GRP40A	RES40A	8.581	8.481	1.735	1.164	SP ACCEL G
GRP48A	RES48A	8.333	1.241	2.109	0.144	FLOOR AC G
GRP49A	RES49A	0.395	0.282	-1.102	0.807	BASE ACCEL
GRP50A	RES50A	0.310	0.142	-1.288	0.471	FLOOR AC G
SMA01	RES01A	2.750	0.808	1.010	0.369	SP ACCEL G
SMA02	RES01A	6.000	1.650	1.790	0.339	SP ACCEL G
SMA04	RES02E	3.300	1.750	1.190	0.440	SP ACCEL G
SMA10	RES10A	7.950	3.320	2.070	0.599	SP ACCEL G
SMA14	RES12A	3.300	1.110	1.190	0.440	SP ACCEL G
SMA16	RES15B	3.200	0.879	1.160	0.338	ACCEL G
SMA17	RES15B	11.700	3.790	2.460	0.419	ACCEL G
SMA18	RES15A	4.660	1.500	1.540	0.413	Z PRD AC G
SMA19	RES15A	7.190	1.680	1.970	0.278	Z PRD AC G
SMA20	RES15A	8.220	2.150	2.110	0.318	Z PRD AC G
SMA21	RES15A	39.600	9.970	3.680	0.304	Z PRD AC G
SMA22	RES15A	32.500	10.330	3.480	0.408	Z PRD AC G
SMA23	RES16A	7.560	3.320	2.020	0.646	SP ACCEL G
SMA24	RES16A	7.300	2.060	1.990	0.350	SP ACCEL G
SMA26	RES17A	47.500	16.900	3.860	0.474	SP ACCEL G
SMA28	RES20A	0.931	0.265	-0.071	0.354	SP ACCEL G
SMA29	RES20A	1.960	0.566	0.673	0.361	SP ACCEL G
SMA30	RES20A	0.735	0.229	-0.308	0.397	SP ACCEL G
SMA31	RES20A	8.910	3.500	2.190	0.546	SP ACCEL G
SMA32	RES21A	17.100	6.180	2.840	0.484	SP ACCEL G
SMA38	RES24A	2.740	0.875	1.010	0.410	SP ACCEL G
SMA39	RES24A	2.930	0.946	1.080	0.416	SP ACCEL G
SMA40	RES24A	11.900	3.890	2.470	0.424	SP ACCEL G
SMA41	RES26A	2.590	1.730	0.951	1.510	SP ACCEL G

GRPNO	RESNO	NMEAN	NSIGMA	LNMEAN	LNSIGMA	PARAM
SMA42	RES26A	9.630	4.880	2.260	0.818	SP ACCEL G
SMA43	RES26A	18.300	9.640	2.900	0.881	SP ACCEL G
SMA44	RES27A	15.700	5.240	2.750	0.436	SP ACCEL G
SMA45	RES40A	2.590	1.730	0.951	1.510	SP ACCEL G
SMA53	RES36A	2.820	1.140	1.040	0.570	Z PD PK AC
SMA57	RES41A	9.630	4.880	2.260	0.818	SP ACCEL G
SMA58	RES41A	18.300	9.640	2.900	0.881	SP ACCEL G

F. GRPNOTES

Table GRPNOTES co. tains qualifying comments pertinent to the various groupings of data in GRPMODE. Information such as predominant frequencies and specific equipment identification is included here. It consists of four columns of data as follows:

Column No.	Column name	Type	Contents
1	CATNO	Floating	A floating point number unique to a particular description of generic category or component description (see Table CATEGORY).
2	GRPNO	Character	An identifying code unique to a particular set of data for a particular failure mode (see Table GRPMODE).
3	LINE	Integer	A line number used for sorting and editing.
4	NOTE	Character	Qualifying comments.

GRPNOTES

CATNO	GRPNO	LINE	NOTE
1.0	GRP01A	1	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
1.0	GRP01B	1	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
1.0	GRP01C	1	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
1.0	SMA01	131	FREQUENCY 5-13 HZ , 5% DAMPING
1.0	SMA02	131	FREQUENCY 6 HZ , 5% DAMPING
2.1	GRP02A	32	ALL MODES: PREDOMINANT FREQUENCIES, MARK II 9-15 HZ,MARK III 3-5 HZ. MARK II & III REFER TO GE BWR CONTAIN-MENTS PRESS BOUND FAIL. ALL MODES.
2.1	GRP02B	32	ALL MODES: PREDOMINANT FREQUENCIES, MARK II 9-15 HZ,MARK III 3-5 HZ. MARK II & III REFER TO GE BWR CONTAIN-MENTS PRESS BOUND FAIL. ALL MODES.
2.1	GRP02C	26	POOL TYPE REACTOR VESSEL (LIQ. SODIUM) PREDOMINANT FREQUENCIES, MODE # 1-7 HZ MODE #2-7.5 HZ MODES #3--- PRESS. BOUND FAIL; ALL MODES.
2.1	SMA03	44	FREQUENCY 5 HZ , (NSSS SYSTEM)
2.2	GRP02D	42	PRESSURIZER. BOTH MODES PREDOMINANT FREQUENCY, 7.0 HZ. PERCENTILES INCLUDE LOCA. PRESS, BOUND. FAIL; ALL MODES.
2.2	GRP02E	42	PRESSURIZER. BOTH MODES PREDOMINANT FREQUENCY, 7.0 HZ. PERCENTILES INCLUDE LOCA. PRESS, BOUND. FAIL; ALL MODES.
2.2	SMA05	131	FREQUENCY 13-22 HZ , 3% DAMPING
2.3	GRP02F	60	STEAM GENERATOR. BOTH MODES: PREDOMINANT FREQUENCY, 10-15 HZ.

CATNO	GRPNO	LINE	NOTE
			MODE #1 FACTORS TIME SY (SY FROM PRESS. BOUND. FAIL; ALL MODES.
2.3	GRP02G	54	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCIES:MODES # 1 10-30 MODES # 2 RIGID MODES # 3 20-100 HZ. PRESS. BOUND. FAIL; ALL MODES.
2.3	GRP02H	48	STEAM GENERATOR . ALL MODES: PREDOMINANT FREQUENCY 7.5 HZ ALL MODES: VERTICAL DIRECTION ACCELERATION PRESS. BOUND. FAIL; ALL MODES.
2.3	GRP02I	48	STEAM GENERATOR . ALL MODES: PREDOMINANT FREQUENCY 7.5 HZ ALL MODES: VERTICAL DIRECTION ACCELERATION PRESS. BOUND. FAIL; ALL MODES.
2.3	GRP02J	54	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCIES:MODES # 1 10-30 MODES # 2 RIGID MODES # 3 20-100 HZ. PRESS. BOUND. FAIL; ALL MODES.
2.3	SMA04	44	FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP
2.3	SMA14	44	FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP
3.0	GRP03A	1	MASTER PIPING CURVE
4.0	GRP04A	1	MASTER PIPING CURVE
5.0	GRP05A	1	MASTER PIPING CURVE
6.0	GRP06A	1	MASTER PIPING CURVE
7.0	GRP07A	119	ALL MODES: PREDOMINANT FREQUENCY 4-10 HZ
7.0	GRP07B	1	PREDOM. FREQ. 4-10 HZ
7.0	SMA06	131	FREQUENCY 20.7 HZ , 5% DAMPING
7.0	SMA07	131	FREQUENCY 6.3 HZ , 5% DAMPING
8.0	GRP08A	121	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
8.0	GRP08B	121	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
8.0	GRP08C	121	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
8.0	SMA08	44	RIGID TANK + SLOSH
8.0	SMA09	44	RIGID TANK + SLOSH
9.0	GRP09A	123	PREDOMINANT FREQUENCY: 12 TO 20 HZ. DIESEL FUEL TANK.
10.0	GRP10A	128	BOTH MODES: PREDOMINANT FREQUENCY 15-30 HORIZONTAL TANK AND HEAT EXCHANGERS.
10.0	GRP10B	131	PREDOMINANT FREQUENCY: GREATER THEN 20 H SMALL VESSELS.
10.0	GRP10C	128	BOTH MODES: PREDOMINANT FREQUENCY 15-30 HORIZONTAL TANK AND HEAT EXCHANGERS.
10.0	SMA10	131	FREQUENCY 6.9 HZ , 5% DAMPING
10.0	SMA11	131	FREQUENCY 12.8 HZ , 5% DAMPING
10.0	SMA15	131	FREQUENCY 7 HZ , 5% DAMPING
11.0	GRP11A	1	MASTER PIPING CURVE
11.0	SMA12	44	ZION BURIED PIPE
11.0	SMA13	44	ZION BURIED PIPE
12.0	GRP12A	140	BOTH MODES,PREDOMINANT FREQUENCIES: 4.5 PERCENTILES INCLUDE LOCA.
12.0	GRP12B	140	BOTH MODES,PREDOMINANT FREQUENCIES: 4.5 PERCENTILES INCLUDE LOCA.

CATNO	GRPNO	LINE	NOTE
13.0	GRP13A	143	PREDOMINANT FREQUENCY 4.5 HZ. ALL MODES.
13.0	GRP13B	143	PREDOMINANT FREQUENCY 4.5 HZ. ALL MODES.
14.0	GRP14A	149	BOTH MODES: PREDOMINANT FREQUENCY, 3HZ. PERCENTILE 90 IS TENTATIVE
14.0	GRP14B	149	BOTH MODES: PREDOMINANT FREQUENCY, 3HZ. PERCENTILE 90 IS TENTATIVE
15.0	SMA16	44	FREQUENCY 7 HZ , 5% DAMPING
15.0	SMA17	44	FREQUENCY 7 HZ , 5% DAMPING
15.0	SMA18	44	ZION SAFETY INJECTION PUMP , RIGID
15.0	SMA19	44	ZION SAFETY INJECTION PUMP, RIGID
15.0	SMA20	44	ZION CENTR. CHARGING PUMP, RIGID
15.0	SMA21	44	ZION CENTR. CHARGING PUMP, RIGID
15.0	SMA22	44	GENERIC PUMPS & COMPR., RIGID
16.0	GRP16A	184	PREDOMINANT FREQUENCY: MODE #1, 10-20 HZ. MODE #2, 30-50 HZ. MODE #3, 30-50HZ.
16.0	GRP16B	189	ALL MODES: PREDOMINANT FREQUENCIES 2-10 HZ.
16.0	GRP16C	192	BUTTERFLY VALVE PREDOMINANT FREQUENCY: RIGID.
16.0	GRP16D	168	ALL MODES. PREDOMINANT FREQUENCY RIGID. BALL VALVE WITH ACTUATOR AND LOGIC CABINET
16.0	GRP16G	195	PREDOMINANT FREQUENCY: MODE #1 VALVE ACTUATOR 27.7 HZ. MODE " SPRING MECHANISM 10-12 HZ. RUGGLES KLINGEMAN TRIP VALVE.
16.0	GRP16H	195	PREDOMINANT FREQUENCY: MODE #1 VALVE ACTUATOR 27.7 HZ. MODE " SPRING MECHANISM 10-12 HZ. RUGGLES KLINGEMAN TRIP VALVE.
16.0	SMA23	44	RIGID
16.0	SMA24	44	RIGID
16.0	SMA25	44	RIGID
17.0	GRP17C	200	PREDOMINANT FREQUENCIES BOTH MODES: RIGID
17.0	GRP17D	200	PREDOMINANT FREQUENCIES BOTH MODES: RIGID
17.0	SMA26	44	RIGID
18.0	GRP18A	205	PREDOMINANT FREQUENCIES ARE 20-30 HZ. DAMPING IS 5%
18.0	GRP18B	205	PREDOMINANT FREQUENCIES ARE 20-30 HZ. DAMPING IS 5%
18.0	GRP18C	205	PREDOMINANT FREQUENCIES ARE 20-30 HZ. DAMPING IS 5%
18.0	SMA27	44	RIGID
19.0	GRP19A	230	PREDOMINANT FREQUENCIES ARE > 33 HZ.
19.0	GRP19B	230	PREDOMINANT FREQUENCIES ARE > 33 HZ.
20.0	GRP20A	233	PREDOMINANT RESPONSE FREQUENCIES: 1ST MODE 7.0 TO 20.6 HZ. 2ND MODE 8.3 TO 13.8 HZ. DIESEL GENERATORS.

CATNO	GRPNO	LINE	NOTE
20.0	GRP20B	233	PREDOMINANT RESPONSE FREQUENCIES: 1ST MODE 7.0 TO 20.6 HZ. 2ND MODE 8.3 TO 13.8 HZ. DIESEL GENERATORS.
20.0	GRP20C	241	PREDOMINANT RESPONSE FREQUENCIES: 15 HZ. DIESEL GENERATORS.
20.0	GRP20D	241	PREDOMINANT RESPONSE FREQUENCIES: 15 HZ. DIESEL GENERATORS.
20.0	SMA28	44	FREQUENCY 30 HZ , 5% DAMPING
20.0	SMA29	44	FREQUENCY 11 HZ , 5% DAMPING
20.0	SMA30	44	FREQUENCY 22 HZ , 5% DAMPING
20.0	SMA31	44	RIGID
21.0	GRP21A	244	PREDOMINANT FREQUENCY IS >25 HZ. BATTERY RACKS
21.0	GRP21B	247	PREDOMINANT FREQUENCY >15 HZ. DC POWER BATTERIES.
21.0	SMA32	44	FREQUENCY 8 HZ , 5% DAMPING
21.0	SMA33	44	FREQUENCY 8 HZ , 5% DAMPING
22.0	GRP22A	250	FREQUENCIES: SIDE TO SIDE = 6-11 HZ. FRONT TO BACK = 16-20 HZ. VERTICAL = >30 HZ. 26" WIDE METALCLAD SWITCHGEAR.
22.0	SMA34	44	FREQUENCY 5-10 HZ , 5% DAMPING
22.0	SMA35	44	FREQUENCY 5-10 HZ , 5% DAMPING
22.0	SMA36	44	FREQUENCY 5-10 HZ , 5% DAMPING
23.0	GRP23A	20	FRAGILITY PARAMETER AT FLOOR TO TRANSFORMER INTERFACE PREDOMINANT FREQUENCIES: COOLER UNIT: 7.5, 7.7 HZ. INTERNAL STRUCTURE: 7.2, 7.6 HZ. HV PORCELAIN: 8.1, 10.8 HZ.
23.0	GRP23B	27	PREDOMINANT FREQUENCY FOR ALL MODES: >10 HZ.
23.0	GRP23C	27	PREDOMINANT FREQUENCY FOR ALL MODES: >10 HZ.
23.0	SMA37	44	FREQUENCY 5-10 HZ , 5% DAMPING
24.0	GRP24A	30	PREDOMINANT RESPONSE FREQUENCY IS 21 HZ. HVAC FANS.
24.0	SMA38	44	FREQUENCY 4.3 HZ , 5% DAMPING
24.0	SMA39	44	FREQUENCY 4.3 HZ , 5% DAMPING
24.0	SMA40	44	FREQUENCY 10-30 HZ , 5% DAMPING
26.0	GRP26A	33	PREDOMINANT FREQUENCIES: MODE #1 RIGID MODE #2 11 HZ. PERCENTILES ARE FACTORS TIMES SSE. INSTRUMENT RACKS.
26.0	GRP26B	33	PREDOMINANT FREQUENCIES: MODE #1 RIGID MODE #2 11 HZ. PERCENTILES ARE FACTORS TIMES SSE. INSTRUMENT RACKS.
26.0	SMA41	44	FREQ 5-10 HZ , 5% DAMPING
26.0	SMA42	44	FREQ 5-10 HZ , 5% DAMPING
26.0	SMA43	44	FREQ 5-10 HZ , 5% DAMPING

CATNO	GRPNO	LINE	NOTE
27.0	GRP27B	50	PREDOMINANT FREQUENCY IS >20 HZ. STRUCTURAL FAILURE UNLIKELY WITH MODERN DESIGN.
27.0	GRP27C	42	PREDOMINANT FREQUENCY FOR ALL MODES >12 HZ. THESE MODES OF FAILURE ALSO APPLY TO BREAKER PANELS, AUXILIARY RELAY PANELS, INSTRUMENT RACKS AND DIESEL GENERATORS.
27.0	GRP27D	42	PREDOMINANT FREQUENCY FOR ALL MODES >12 HZ. THESE MODES OF FAILURE ALSO APPLY TO BREAKER PANELS, AUXILIARY RELAY PANELS, INSTRUMENT RACKS AND DIESEL GENERATORS.
27.0	SMA44	44	FREQUENCY 5-10 HZ , 5% DAMPING
27.0	SMA46	44	FREQUENCY 5-10 HZ , 5% DAMPING
27.0	SMA47	44	FREQUENCY 5-10 HZ , 5% DAMPING
30.0	GRP30A	54	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
30.0	GRP30B	54	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
30.0	GRP30C	54	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
30.0	GRP30D	59	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
30.0	GRP30E	59	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
30.0	GRP30F	59	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
30.0	SMA48	44	RIGID
31.0	GRP31A	69	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
31.0	GRP31B	69	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
31.0	GRP31C	69	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
31.0	SMA49	44	FREQUENCY 5-10 HZ , 5% DAMPING

CATNO	GRPNO	LINE	NOTE
31.0	SMA50	44	FREQUENCY 5-10 HZ , 5% DAMPING
31.0	SMA51	44	FREQUENCY 5-10 HZ , 5% DAMPING
33.0	GRP33A	1	FREQ. 4.5-6.5 HZ , DAMP 2%
35.0	SMA52	44	FREQUENCY 5-10 HZ , 5% DAMPING
36.0	GRP36A	87	PREDOMINANT RESPONSE FREQUENCY IS 5-10 HZ. FOR ALL MODES.
36.0	GRP36B	87	PREDOMINANT RESPONSE FREQUENCY IS 5-10 HZ. FOR ALL MODES.
36.0	SMA53	44	REFERENCED TO ZPA
37.0	GRP37A	90	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
37.0	GRP37B	90	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
37.0	GRP37C	90	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
37.0	GRP37D	95	PREDOMINANT FREQUENCY FOR RESPONSE 5 - 10 HZ. ALL MODES
37.0	GRP37E	98	PREDOMINANT FREQUENCY FOR RESPONSE 10 HZ. ALL MODES.
39.0	GRP39A	7	FREQUENCIES: 1ST MODE = 1.5-4.0 HZ. 2ND MODE = 4.5-8.0 HZ.
39.0	GRP39B	111	IN-SITU TESTING. FRAGILITY PARAMETER AT CIRCUIT BREAKER FOOTING. THESE ARE SWITCHYARD CIRCUIT BREAKERS. TORSIONAL FAILURE. MODES OF VIBRATION: 1ST 2.4 - 3.4 HZ. 2ND 7.8 - 12.2 HZ. AIR BLAST CIRCUIT BREAKERS.
39.0	GRP39C	20	FRAGILITY PARAMETER AT FLOOR TO TRANSFORMER INTERFACE PREDOMINANT FREQUENCIES: COOLER UNIT: 7.5, 7.7 HZ. INTERNAL STRUCTURE: 7.2, 7.6 HZ. HV PORCELAIN: 8.1, 10.3 HZ.
40.0	GRP40A	39	PREDOMINANT RESPONSE FREQUENCY 20 TO 33 HZ.
40.0	SMA45	44	5-10 HZ , 5% DAMPING
41.0	SMA54	44	5-10 HZ , 5% DAMPING
41.0	SMA55	45	FREQUENCY 5-10 HZ , 5% DAMPING
41.0	SMA56	44	FREQUENCY 5-10 HZ , 5% DAMPING
41.0	SMA57	44	FREQUENCY 5-10 HZ , 5% DAMPING
41.0	SMA58	44	FREQUENCY 5-10 HZ , 5% DAMPING
48.0	GRP48A	121	THE TEST WERE NOT TAKEN TO FAILURE. PREDOMINANT FREQUENCIES: MODE #1 9.5 HZ.

CATNO	GRPNO	LINE	NOTE
			MODE #2 21.5 HZ.
49.0	GRP49A	1	FREQ. 1-4 HZ
49.0	SMA59	44	REFERENCED TO ZPA
50.0	GRP50A	1	FREQ. 7-8 HZ

G. GRPRES

Table GRPRES contains the lognormal results for each failure mode in each generic category along with other pertinent information. It consists of seven columns as follows:

Column No.	Column name	Type	Contents
1	CATNO	Floating	A floating point number unique to a particular description of generic category or component descriptions (see Table CATEGORY).
2	DES	Character	The description of the generic category or specific component (see Table CATEGORY).
3	GRPNO	Character	An identifying code unique to a particular set of data for a particular failure mode (see Table GRPMODE).
4	MEDIAN	Floating	The median of the data assuming lognormal distribution.
5	BETA	Floating	The standard deviation of the natural logs of the data.
6	PARAM	Character	The fragility parameter.
7	MODE	Character	A description of the failure mode.

GRPRES

CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
1.0	REACTOR CORE ASSEMBLY	GRP01A	3.916	0.708	SP ACCEL G	BINDING OF CONTROL RODS DUE TO SEISMICALLY INDUCED DEFORMATIONS
1.0	REACTOR CORE ASSEMBLY	GRP01B	5 646	0.757	SP ACCEL G	DEFORMATION OF GUIDE TUBES DUE TO SEISMIC IMPACT OF FUEL BUNDLE
1.0	REACTOR CORE ASSEMBLY	GRP01C	6.693	0.823	SP ACCEL G	FAILURE OF CORE SUPPORT STRUCTURE DUE TO INERTIA LOAD OF FUEL
1.0	REACTOR CORE ASSEMBLY	SMA01	2.746	0.369	SP ACCEL G	DEFOR. OF GUIDE TUBES / GUIDE PLATE WELD
1.0	REACTOR CORE ASSEMBLY	SMA02	5.989	0.339	SP ACCEL G	CONTROL ROD HOUSING DEFORMATION
2.1	REACTOR PRESSURE VESSEL	GRP02A	4.162	0.275	SP ACCEL G	BUCKLING OF SKIRT
2.1	REACTOR PRESSURE VESSEL	GRP02B	5.430	0.289	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS
2.1	REACTOR PRESSURE VESSEL	GRP02C	6.462	0.325	SP ACCEL G	STRESS INTENSITY AT VESSEL SUPPORT
2.2	PRESSURIZER	GRP02D	3.108	0.361	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS
2.2	PRESSURIZER	GRP02E	5.430	0.289	SP ACCEL G	BUCKLING OF SKIRT
2.2	PRESSURIZER	SMA05	2.000	0.398	SP ACCEL G	SUPPORT SKIRT BOLTING
2.3	STEAM GENERATOR	GRP02F	1.891	0.208	SP MOMENTS	RUPTURE AT PRIMARY INLET OR OUTLET NOZZLE, RUPTURE AT FEEDWATER NOZZLE
2.3	STEAM GENERATOR	GRP02G	4.716	0.339	FORCES	NOZZLE FAILURE
2.3	STEAM GENERATOR	GRP02H	3.896	0.201	SP ACCEL G	FAILURE OF STEAM GENERATOR LEG IMBEDMENT IN CONTAINMENT FLOOR
2.3	STEAM GENERATOR	GRP02I	2.886	0.275	SP ACCEL G	FAILURE OF CONNECTION BETWEEN SUPPORT LEG AND STEAM GENERATOR BODY
2.3	STEAM GENERATOR	GRP02J	8.166	0.422	SP ACCEL G	TUBING FAILURE
2.3	STEAM GENERATOR	SMA04	3.287	0.440	SP ACCEL G	SUPPORT COLUMN FAILURE
2.3	STEAM GENERATOR	SMA04	3.287	0.440	SP ACCEL G	SUPPORT COLUMN FAILURE
3.0	PRIMARY COOLANT PIPING	GRP03A	202.350	0.406	MOM FT-KIP	RUPTURE AT CONNECTIONS TO COMPONENTS DUE TO COMPONENT SUPPORT FAILURE
7.0	LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS	GRP07A	1.650	0.445	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
7.0	LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS	GRP07B	2.467	0.536	SP ACCEL G	BUCKLING OF SUPPORT SKIRT OR LEGS
7.0	LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS	SMA06	21.977	0.407	SP ACCEL G	SUPPORT SKIRT COLLAPSE
7.0	LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS	SMA07	7.925	0.519	SP ACCEL G	PLASTIC BUCKLING OF SHELL
8.0	LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS	GRP08A	2.079	0.275	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
8.0	LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS	GRP08B	3.254	0.319	SP ACCEL G	BUCKLING OF TANK WALL
8.0	LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS	GRP08C	5.312	0.305	SP ACCEL G	TENSILE RUPTURE OF TANK WALL
8.0	LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS	SMA08	0.828	0.389	PK GD AC G	BUCKLING OF TANK WALLS AT BASE

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CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
8.0	LARGE VERTICAL STORAGE TANKS W ITH FLAT BOTTOMS	SMA09	3.597	0.436	PK GD AC G	BENDING OF VERTICAL STIFFNER
9.0	LARGE HORIZONTAL VESSELS	GRP09A	3.912	0.609	FLOOR AC G	SUPPORT SYSTEM FAILURE (BOLTS)
10.0	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS	GRP10A	2.079	0.275	ACCEL G	RUPTURE OF ANCHOR BOLTS
10.0	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS	GRP10B	12.769	0.359	ACCEL G	STRUCTURAL FAILURE
10.0	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS	GRP10C	2.599	0.452	ACCEL G	SUPPORT FAILURE
10.0	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS	SMA10	7.925	0.599	SP ACCEL G	SUPPORT FAILURE
10.0	SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS	SMA11	7.171	0.516	PK ACCEL G	SUPPORT LEG FAILURE
11.0	BURIED PIPE	SMA12	1.399	0.601	PK GD AC G	BUCKLING AND FRACTURE
11.0	BURIED PIPE	SMA13	1.399	0.601	PK GD AC G	BUCKLING AND FRACTURE
12.0	REACTOR COOLANT PUMP	GRP12A	3.557	0.401	SP ACCEL G	FAILURE OF CONNECTION TO SUPPORT LEGS
12.0	REACTOR COOLANT PUMP	GRP12B	5.847	0.406	SP ACCEL G	BUCKLING OF SUPPORT LEG
12.0	REACTOR COOLANT PUMP	SMA14	3.287	0.440	SP ACCEL G	SUPPORT COLUMN BOLTING
12.0	REACTOR COOLANT PUMP	SMA14	3.287	0.440	SP ACCEL G	SUPPORT COLUMN BOLTING
13.0	LARGE VERTICAL CENTRIFUGAL PUM PS WITH MOTOR DRIVE	GRP13A	2.883	0.275	SP ACCEL G	RUPTURE OF CONNECTIONS TO SUPPORT STRUTS
13.0	LARGE VERTICAL CENTRIFUGAL PUM PS WITH MOTOR DRIVE	GRP13B	4.933	0.159	SP ACCEL G	TENSILE FAILURE OF SUPPORT STRUTS
13.0	LARGE VERTICAL CENTRIFUGAL PUM PS WITH MOTOR DRIVE	SMA15	3.490	0.342	SP ACCEL G	BENDING OF PUMP CASING
14.0	LARGE VERTICAL PUMPS	GRP14A	2.289	0.417	SP ACCEL G	RUPTURE OF ANCHOR BOLTS DUE TO LARGE MOM ENTS FROM VERTICAL INTAKE COLUMN
14.0	LARGE VERTICAL PUMPS	GRP14B	4.577	0.417	SP ACCEL G	RUPTURE OF VERTICAL INTAKE COLUMN
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA16	3.190	0.338	ACCEL G	IMPELLER DEFLECTION
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA16	3.190	0.338	SP ACCEL G	IMPELLER DEFLECTION
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA17	11.705	0.419	SP ACCEL G	MOUNTING BOLT FAILURE
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA17	11.705	0.419	ACCEL G	MOUNTING BOLT FAILURE
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA18	4.665	0.413	Z PRD AC G	FLANGE BENDING
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA19	7.171	0.278	Z PRD AC G	SHAFT BENDING
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA20	8.248	0.318	Z PRD AC G	THRUST BEARING FAILURE
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA21	39.646	0.304	Z PRD AC G	SHAFT DEFLECTION
15.0	MOTOR DRIVEN COMPRESSORS AND P UMPS	SMA22	32.460	0.408	Z PRD AC G	GENERIC FUNCTION

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CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16A	17.305	0.275	SP ACCEL G	BREAKS AT WELD ENDS
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16B	10.623	0.257	SP ACCEL G	RUPTURE OF PIPE SUPPORT AT NOZZLE
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16C	7.606	0.314	SP ACCEL G	LOSS OF CONTROL AIR
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16D	11.190	0.358	SP ACCEL G	ELECTRICAL FAILURE IN ACTUATOR
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16G	10.591	0.476	PK ACCEL G	FRACTURE OF VALVE ACTUATOR TOP COVER AT CONNECTION TO VALVE BODY
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	GRP16H	7.029	0.271	PK ACCEL G	FAILURE OF SPRING MECHANISM DUE TO EXCES SIVE PLASTIC DEFORMATION
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	SMA23	7.538	0.646	SP ACCEL G	DISTORTION OF EXTENDED OPERATOR STRUCTUR E
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	SMA23	7.538	0.646	PK ACCEL G	DISTORTION OF EXTENDED OPERATOR STRUCTUR E
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	SMA24	7.316	0.350	SP ACCEL G	OIL RESERVOIR HOLD DOWN BOLTS
16.0	LARGE MOTOR OPERATED VALVES (> 4IN.)	SMA25	43.816	0.468	Z PD PK AC	GENERIC FUNCTION
17.0	LARGE RELIEF AND CHECK VALVES (> 4IN.)	GRP17C	8.917	0.132	SP ACCEL G	DISC BECOMES DISENGAGED
17.0	LARGE RELIEF AND CHECK VALVES (> 4IN.)	GRP17D	12.654	0.130	SP ACCEL G	DISC BECOMES BOUND
17.0	LARGE RELIEF AND CHECK VALVES (> 4IN.)	SMA26	47.465	0.474	Z PD PK AC	GENERIC FUNCTION
17.0	LARGE RELIEF AND CHECK VALVES (> 4IN.)	SMA26	47.465	0.474	SP ACCEL G	GENERIC FUNCTION
17.0	LARGE RELIEF AND CHECK VALVES (> 4IN.)	SMA60	9.875	0.650	Z PD PK AC	OPERATOR DISTORTION
18.0	SMALL MISCELLANEOUS VALVES (< 4IN.)	GRP18B	15.959	0.620	SP ACCEL G	INTERNAL DAMAGE
18.0	SMALL MISCELLANEOUS VALVES (< 4IN.)	GRP18C	21.563	0.714	SP ACELL G	STRUCTURAL FATIGUE
19.0	HORIZONTAL MOTORS	GRP19A	12.429	0.360	ACCEL G	BINDING OF ROTATING PARTS
19.0	HORIZONTAL MOTORS	GRP19B	20.801	0.275	ACCEL G	RUPTURE OF ANCHOR BOLTS
20.0	GENERATORS	GRP20A	5.948	0.441	SP ACCEL G	CONTROL FAILURE
20.0	GENERATORS	GRP20B	5.948	0.441	SP ACCEL G	OIL LEVEL REGULATOR
20.0	GENERATORS	GRP20C	5.646	0.476	SP ACCEL G	ANCHOR BOLT FAILURE
20.0	GENERATORS	GRP20D	10.350	0.279	SP ACCEL G	CRANKSHAFT LOCK UP
20.0	GENERATORS	SMA28	0.931	0.354	SP ACCEL G	RELAY CHATTER
20.0	GENERATORS	SMA29	1.960	0.361	SP ACCEL G	FAILED RELAY
20.0	GENERATORS	SMA29	1.960	0.361	SP ACCEL G	FAILED RELAY
20.0	GENERATORS	SMA30	0.735	0.397	SP ACCEL G	VALVE TRIP

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CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
20.0	GENERATORS	SMA31	8.935	0.546	SP ACCEL G	STRUCTURAL
21.0	BATTERIES	GRP21A	2.289	0.417	ACCEL G	FAILURE OF BATTENS
21.0	BATTERIES	GRP21B	20.801	0.275	ACCEL G	CASE BREAKAGE DUE TO A BAD STAND
21.0	BATTERIES	SMA32	17.116	0.484	SP ACCEL G	ANCHOR BOLTS
21.0	BATTERIES	SMA33	5.259	0.385	SP ACCEL G	CASE CRACKING & PLATE FAILURE
22.0	SWITCHGEAR	GRP22A	2.330	0.486	SP ACCEL G	SPURIOUS OPERATION OF A PROTECTIVE RELAY
22.0	SWITCHGEAR	SMA34	2.588	1.510	SP ACCEL G	RELAY CHATTER
22.0	SWITCHGEAR	SMA35	9.583	0.818	SP ACCEL G	BREAKER TRIP
22.0	SWITCHGEAR	SMA36	18.174	0.881	SP ACCEL G	STRUCTURAL
23.0	DRY TRANSFORMERS	GRP23A	4.660	0.503	SP ACCEL G	INTERNAL STRUCTURAL FAILURE, SHORT OF EL ECTRICAL CONNECTION
23.0	DRY TRANSFORMERS	GRP23B	9.526	0.680	SP ACCEL G	FAILURE OF SUPPORT FRAME
23.0	DRY TRANSFORMERS	GRP23C	3.108	0.351	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
23.0	DRY TRANSFORMERS	SMA37	13.330	0.408	SP ACCEL G	STRUCTURAL
24.0	AIR HANDLING UNITS	GRP24A	6.215	0.360	FLOOR AC G	STRUCTURAL FAILURE
24.0	AIR HANDLING UNITS	SMA38	2.746	0.410	SP ACCEL G	RUBBING OF FAN ON HOUSING
24.0	AIR HANDLING UNITS	SMA39	2.945	0.416	SP ACCEL G	RUBBING OF MOTOR ROTOR ON HOUSING
24.0	AIR HANDLING UNITS	SMA40	11.822	0.424	SP ACCEL G	GENERIC FUNCTION
24.0	AIR HANDLING UNITS	SMA40	11.822	0.424	SP ACCEL G	GENERIC FUNCTION
26.0	INSTRUMENT PANELS AND RACKS	GRP26A	2.079	0.275	ACCEL G	INSTRUMENT FAILURE
26.0	INSTRUMENT PANELS AND RACKS	GRP26B	4.933	0.383	ACCEL G	WELD FAILURE
26.0	INSTRUMENT PANELS AND RACKS	SMA41	2.588	1.510	SP ACCEL G	RELAY CHATTER
26.0	INSTRUMENT PANELS AND RACKS	SMA42	9.583	0.818	SP ACCEL G	BREAKER TRIP
26.0	INSTRUMENT PANELS AND RACKS	SMA42	9.583	0.818	SP ACCEL G	BREAKER TRIP
26.0	INSTRUMENT PANELS AND RACKS	SMA43	18.174	0.881	SP ACCEL G	STRUCTURAL
27.0	CONTROL PANELS AND RACKS	GRP27B	16.827	0.407	SP ACCEL G	COMPONENT MALFUNCTION
27.0	CONTROL PANELS AND RACKS	GRP27C	25.972	0.223	SP ACCEL G	STRUCTURAL MOUNTING OF CABINETS
27.0	CONTROL PANELS AND RACKS	GRP27D	24.655	0.159	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENTS

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CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
27.0	CONTROL PANELS AND RACKS	SMA44	15.643	0.436	SP ACCEL G	ELECTRICAL MALFUNCTION
27.0	CONTROL PANELS AND RACKS	SMA46	9.583	0.818	SP ACCEL G	BREAKER TRIP
27.0	CONTROL PANELS AND RACKS	SMA47	18.174	0.881	SP ACCEL G	STRUCTURAL
28.0	AUXILIARY RELAY CABINETS	SMA61	7.614	0.710	SP ACCEL G	RELAY TRIP
30.0	LOCAL INSTRUMENTS	GRP30A	8.962	0.302	SP ACCEL G	RELAY CHATTER
30.0	LOCAL INSTRUMENTS	GRP30B	10.623	0.257	SP ACCEL G	LOOSENING OF FASTENERS
30.0	LOCAL INSTRUMENTS	GRP30C	10.623	0.257	SP ACCEL G	BASE STRUCTURAL FATIGUE
30.0	LOCAL INSTRUMENTS	GRP30D	11.740	0.201	SP ACCEL G	SIGNAL DRIFT
30.0	LOCAL INSTRUMENTS	GRP30E	13.437	0.223	SP ACCEL G	CONTACT CHATTER
30.0	LOCAL INSTRUMENTS	GRP30F	16.710	0.325	SP ACCEL G	SET POINT DRIFT
30.0	LOCAL INSTRUMENTS	SMA48	47.465	0.474	Z PRD AC G	ELECTRICAL FUNCTION
31.0	MOTOR CONTROL CENTERS	GRP31A	15.534	0.361	SP ACCEL G	CHATTER OF CONTACTS
31.0	MOTOR CONTROL CENTERS	GRP31B	20.801	0.275	SP ACCEL G	STRUCTURAL ANCHORING OF CABINET BASE
31.0	MOTOR CONTROL CENTERS	GRP31C	24.655	0.159	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENT IN CABI NET
31.0	MOTOR CONTROL CENTERS	SMA49	2.588	1.510	SP ACCEL G	RELAY CHATTER
31.0	MOTOR CONTROL CENTERS	SMA50	9.583	0.818	SP ACCEL G	BREAKER TRIP
31.0	MOTOR CONTROL CENTERS	SMA51	18.174	0.881	SP ACCEL G	STRUCTURAL
31.0	MOTOR CONTROL CENTERS	SMA62	7.614	0.710	SP ACCEL G	BREAKER TRIP
33.0	LIGHT FIXTURES	GRP33A	9.198	0.201	SP ACCEL G	DISLODGING OF AIR DUCT BLANKING CLIPS
35.0	INVERTERS	SMA52	15.643	0.436	SP ACCEL G	RELAY TRIP
36.0	CABLE TRAYS	GRP36A	3.108	0.360	SP ACCEL G	FAILURE OF SUPPORTS
36.0	CABLE TRAYS	GRP36B	5.847	0.406	SP ACCEL G	RUPTURE OF PARTS BETWEEN SUPPORTS
36.0	CABLE TRAYS	SMA53	2.829	0.570	Z PD PK AC	CABLE SUPPORT SYSTEM
37.0	DUCTING	GRP37A	7.050	0.271	SP ACCEL G	CORNER TEARING
37.0	DUCTING	GRP37B	7.142	0.677	SP ACCEL G	SUPPORT FAILURE
37.0	DUCTING	GRP37C	7.980	0.806	SP ACCEL G	JOINT SEPARTION
37.0	DUCTING	GRP37D	6.693	0.302	SP ACCEL G	RUPTURE OF DUCT BETWEEN SUPPORTS

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CATNO	DES	GRPNO	MEDIAN	BETA	PARAM	MODE
37.0	DUCTING	GRP37E	9.088	0.445	SP ACCEL G	GROSS BENDING FIRM
39.0	SWITCHYARD EQUIPMENT	GRP39A	0.766	0.517	Z PRD ACCE	PORCELAIN FRACTURE
39.0	SWITCHYARD EQUIPMENT	GRP39B	0.317	0.449	Z PRD ACCE	A B CIRCUIT BREAKER FAILURE
39.0	SWITCHYARD EQUIPMENT	GRP39C	0.914	0.610	Z PRD ACCE	H V TRANSFORMER STRUCTURAL FAILURE
40.0	RELAYS	GRP40A	5.669	1.164	SP ACCEL G	RELAY CHATTER
40.0	RELAYS	SMA45	2.588	1.510	SP ACCEL G	RELAY CHATTER
41.0	CIRCUIT BREAKERS	SMA54	2.588	1.510	SP ACCEL G	RELAY CHATTER
41.0	CIRCUIT BREAKERS	SMA55	9.583	0.818	SP ACCEL G	RELAY TRIP
41.0	CIRCUIT BREAKERS	SMA56	18.174	0.881	SP ACCEL G	STRUCTURAL
41.0	CIRCUIT BREAKERS	SMA57	9.583	0.818	SP ACCEL G	BREAKER TRIP
41.0	CIRCUIT BREAKERS	SMA57	9.583	0.818	SP ACCEL G	BREAKER TRIP
41.0	CIRCUIT BREAKERS	SMA58	18.174	0.881	SP ACCEL G	STRUCTURAL
48.0	RECOMBINERS	GRP48A	8.240	0.144	FLOOR AC G	PIPE DEFORMATION
49.0	CERAMIC INSULATORS	GRP49A	0.332	0.807	BASE ACCEL	FRACTURE OF PORCELAIN INSULATION
49.0	CERAMIC INSULATORS	SMA59	4.998	0.353	PK GD AC G	FRACT OF INSULATORS
49.0	CERAMIC INSULATORS	SMA63	0.200	0.353	PK GD AC G	FRACTURE OF INSULATORS
50.0	SPENT FUEL RACKS	GRP50A	0.276	0.471	FLOOR AC G	DESTRUCTION OF SHEAR CONNECTION BETWEEN MODULES

H. OPINION

Table OPINION contains most elements of the expert opinion data used by the SSMRP in computing component fragilities. This table was structured for convenient input into program FRAGSTAT (Ref. 6). It consists of eight columns of data as follows:

Column No.	Column name	Type	Contents
1	OPNO	Integer	A unique number assigned to each expert opinion.
2	IDENT	Character	A ten character code assigned to the expert to preserve anonymity.
3	CAT	Floating	An integer identifying the generic category of component (see Table CATEGORY).
4	WEIGHT	Floating	The subjective weighting factor applied to the data.
5	TEN	Floating	The estimated 10th percentile probability of failure value of fragility parameter.
6	FIFTY	Floating	The estimated 50th percentile probability of failure value of fragility parameter.
7	NINETY	Floating	The estimated 90th percentile probability of failure value of fragility parameter.
8	MODE	Character	A description of the failure mode.

OPINION

OPNO	IDENT	CAT	WEIGHT	TEN	FIFTY	NINETY	PARAM	MODE
1	3201031916	1	1.500	2.000	3.000	10.000	SP ACCEL G	BINDING OF CONTROL RODS
2	3201031916	1	1.500	3.000	4.000	15.000	SP ACCEL G	DEFORMATION OF GUIDE TUBES
3	3201031916	1	1.500	3.000	5.000	20.000	SP ACCEL G	FAILURE OF CORE SUPPORT STRUCTURE
4	4101022009	1	1.000	0.500	0.700	1.000	SP ACCEL G	INTERFERENCE BETWEEN MOVING PARTS WITHIN UNIT
5	3201041907	1	1.500	2.000	2.500	7.000	SP ACCEL G	BINDING OF CONTROL RODS
6	3201041907	1	1.500	2.000	3.000	10.000	SP ACCEL G	DEFORMATION OF GUIDE TUBES
7	3201041907	1	1.500	3.000	4.000	12.000	SP ACCEL G	FAILURE OF CORE SUPPORT STRUCTURE
8	3201012005	1	1.500	0.330	0.360	0.450	SP ACCEL G	SLOW SCRAM TIME OF CONTROL RODS
9	3201012005	1	1.500	0.	2.000	0.	SP ACCEL G	LIFTING FUEL AND DISARRANGING CORE CONFIGURATION
10	3201012005	1	1.500	0.390	0.450	0.760	SP ACCEL G	PLASTIC DISTORTION PREVENTING FULL ROD INSERTION
11	3202071913	2	2.250	2.000	3.000	5.000	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS
12	3202071913	2	2.250	4.000	5.000	8.000	SP ACCEL G	BUCKLING OF SKIRT
13	3202061910	2	2.250	2.000	3.000	4.000	SP ACCEL G	CONNECTION BETWEEN SUP. LEG AND S.G. BODY FAILS
14	3202061910	2	2.250	3.000	4.000	5.000	SP ACCEL G	FAILURE OF S.G. LEG IMBEDMENT IN FLOOR
15	3202061910	2	2.250	3.000	4.000	5.000	SP ACCEL G	BUCKLING OF STEAM GENERATOR LEG
16	3202032004	2	2.250	4.950	6.000	6.750	SP ACCEL G	BUCKLING DUE TO HORIZONTAL ACCERELATION
17	3202032004	2	2.250	4.500	6.000	10.000	SP ACCEL G	STRESS INTENSITY AT VESSEL SUPPORT
18	3202032004	2	2.250	0.	0.	0.	NOZZ LOADS	NOZZLE RUPTURE
19	3202051909	2	2.250	3.000	4.000	6.000	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS
20	3202051909	2	2.250	4.000	5.000	8.000	SP ACCEL G	BUCKLING OF SKIRT
21	3202041908	2	2.250	3.000	4.000	5.000	SP ACCEL G	ATTACHED PIPE FAILURE DUE TO SUPPORT DEFORMATION
24	3202022002	2	1.500	3.000	5.000	7.000	FORCE	NOZZLES
25	3202022002	2	1.500	5.000	7.000	9.000	ACCEL	SUPPORTS
26	3202022002	2	1.500	7.000	10.000	13.000	SP ACCEL G	TUBING
27	3202011108	2	0.750	1.500	1.800	2.500	SP ACCEL G	RUPTURE AT PRIMARY INLET OR OUTLET NOZZLE
28	3202011108	2	0.750	4.500	6.000	7.500	SP ACCEL G	FAILURE OF TUBES IN BUNDLE
29	1303022601	3	0.750	2.000	3.000	4.000	SP ACCEL G	FAILURE AT WELDED JOINTS, ESPECIALLY AT NOZZLES
30	1303022601	3	0.750	2.000	3.000	4.000	SP ACCEL G	DUCTILE RUPTURE DUE TO HANGER/SNUBBER FAILURE
31	1303022601	3	0.750	3.000	4.000	5.000	SP ACCEL G	ELBOW COLLAPSE DUE TO EXCESSIVE FORCES
32	3203032006	3	3.000	3.000	4.000	5.000	%ALLOWABLE	PIPE SUPPORT RUPTURE OR COLLAPSE
33	3203032006	3	3.000	5.000	7.000	12.000	%ALLOWABLE	EXCESSIVE PIPE DEFORMATION
34	3203032006	3	3.000	7.000	10.000	15.000	%ALLOWABLE	OPENING A CRACK IN AN UNFLAWED PIPE
35	3203051914	3	1.500	2.000	3.000	4.000	SP ACCEL G	SUPPORT FAILURE
36	3203051914	3	1.500	5.000	8.000	12.000	SP ACCEL G	RUPTURE AT CONNECTIONS DUE TO PIPE OVERSTRESS
40	3203042012	3	2.400	0.	0.	0.	SP ACCEL G	PIPE YIELDING
41	3203042012	3	2.400	0.	0.	0.	SP ACCEL G	CRACK PROPAGATION RESULTING IN A SMALL LEAK
42	1303010502	3	0.750	1.500	3.000	4.000	ACCEL G	ANCHOR BOLT FAILURE
43	1303010502	3	3.000	3.000	5.000	6.000	ACCEL G	FAILURE AT CONNECTION OF SMALL AND LARGE PIPE
44	1303010502	3	3.000	4.000	7.000	8.000	ACCEL G	SUPPORT FAILURE CAUSING LARGE DISPLACEMENTS
45	1205060235	4	2.250	0.	0.	0.	SP ACCEL G	JOINT LEAKAGE
46	1205060235	4	2.250	0.	0.	0.	SP ACCEL G	PIPE SUPPORT RUPTURE
47	1205060235	4	2.250	0.	0.	0.	SP ACCEL G	PIPE FAILURE
48	3204032013	4	3.000	1.200	2.000	2.400	MOMENT CAP	YIELDING
49	3204032013	4	3.000	0.	0.	0.	SP ACCEL G	SMALL LEAK OR BRANCH CONNECTIONS BREAKING
50	3204032013	4	3.000	0.	0.	0.	SP ACCEL G	LARGE CRACK RESULTING IN LEAK OR SEVERANCE
51	3204041915	4	2.250	2.500	3.000	5.000	SP ACCEL G	RUPTURE AT NOZZLE CONN. DUE TO SUPPORT FAIL.
52	3204041915	4	2.250	4.000	5.000	7.000	SP ACCEL G	FAILURE OF PIPE SUPPORTS
53	3204041915	4	2.250	5.000	8.000	10.000	SP ACCEL G	OVERSTRESS OF PIPE
54	3204011109	4	2.250	1.500	1.800	2.500	MOMENT	RUPTURE AT NOZZLE/EQUIPMENT CONNECTIONS
55	3204020302	4	3.000	1.200	2.000	4.000	SP ACCEL G	FAILURE OF CONNECTION AT BUILDING INTERFACE
56	3204020302	4	3.000	2.400	4.000	8.000	SP ACCEL G	FAILURE OF FIELD WELDS
57	1204050236	5	2.250	0.	0.	0.	SP ACCEL G	JOINT LEAKAGE
58	1204050236	5	2.250	0.	0.	0.	SP ACCEL G	PIPE SUPPORT RUPTURE
59	1204050236	5	2.250	0.	0.	0.	SP ACCEL G	PIPE FAILURE
60	3205051916	5	2.250	2.000	3.000	4.000	SP ACCEL G	RUPTURE AT NOZZLE CONN. DUE TO COMPONENT FAIL.

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OPNO	IDENT	CAT	WEIGHT	TEN	FIFTY	NINETY	PARAM	MODE
61	3205051916	5	2.250	3.000	4.000	6.000	SP ACCEL G	FAILURE OF PIPE SUPPORTS
62	3205051916	5	2.250	5.000	6.000	8.000	SP ACCEL G	OVERSTRESS OF PIPE
63	3205011110	5	0.750	1.500	1.800	2.500	MOMENT	MOMMENT AT NOZZLES
64	3205020303	5	3.000	1.200	2.000	4.000	%YLD MOMNT	FAILURE OF CONNECTION AT BUILDING INTERFACE
65	3205020303	5	3.000	2.400	4.000	8.000	%YLD MOMNT	FAILURE OF FIELD WELDS
66	3206022011	6	3.000	0.	0.	0.	SP ACCEL G	SMALL LEAK
67	3206022011	6	3.000	0.	0.	0.	SP ACCEL G	YIELDING
68	3205051916	6	2.250	2.000	3.000	4.000	SP ACCEL G	RUPTURE AT NOZZLE CONN. DUE TO SUPPORT FAIL.
69	3205051916	6	2.250	3.000	4.000	6.000	SP ACCEL G	FAILURE OF PIPE SUPPORTS
70	3205051916	6	2.250	5.000	6.000	8.000	SP ACCEL G	OVERSTRESS OF PIPE
71	3206010304	6	3.000	1.200	2.000	4.000	%YLD MOMNT	FAILURE OF CONNECTION AT BUILDING INTERFACE
72	3206010304	6	3.000	2.400	4.000	8.000	%YLD MOMNT	FAILURE OF FIELD WELDS
73	3207012010	7	2.250	0.	0.	0.	SP ACCEL G	PLASTIC DEFORMATION OF VESSEL NEAR SUPPORT LOC.
74	3207012010	7	3.000	1.500	2.400	12.000	%YLD MOMNT	SMALL LEAK IN VESSEL AT NOZZLE ATTACHMENT
75	3207021918	7	2.250	1.000	1.500	3.000	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
76	3207021918	7	2.250	1.500	2.000	5.000	SP ACCEL G	BUCKLING OF SUPPORT SKIRT OR LEGS
77	3208021917	8	1.500	1.500	2.000	3.000	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
78	3208021917	8	1.500	2.300	3.000	5.000	SP ACCEL G	BUCKLING OF TANK WALL
79	3208021917	8	1.500	3.750	5.000	8.000	SP ACCEL G	TENSILE RUPTURE OF TANK WALL
80	1208011905	8	0.750	0.	0.	0.	SP ACCEL G	GROSS STRUCTURAL BUCKLING
81	1208011905	8	0.750	0.	0.	0.	SP ACCEL G	LOCAL STRUCTURAL BUCKLING
82	1208011905	8	0.750	0.	0.	0.	SP ACCEL G	FATIGUE
83	3239011112	9	1.500	1.900	2.720	3.600	FLOOR AC G	SUPPORT SYSTEM FAILURE (BOLTS)
84	3209011111	9	1.500	4.000	6.000	8.000	FLOOR AC G	SUPPORT FAILURE (BOLTS)
85	3209021919	10	2.250	1.500	2.000	3.000	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
86	3209021919	10	2.250	2.500	3.000	4.500	SP ACCEL G	YIELDING OF SUPPORT SADDLES
87	3210021118	10	2.250	8.000	13.000	20.000	PK ACCEL G	STRUCTURAL FAILURE
89	3210031119	10	2.250	1.300	2.000	3.500	SP ACCEL G	SUPPORT FAILURE
90	3211010301	11	3.000	1.500	3.000	4.000	Z PD PK AC	FAILURE AT CONNECTION TO BUILDING INTERFACE
91	3211010301	11	3.000	2.500	4.000	8.000	Z PD PK AC	FAILURE AT COUPLING
92	3212011911	12	1.500	2.500	3.000	6.000	SP ACCEL G	FAILURE OF CONNECTION TO SUPPORT LEGS
93	3212011911	12	1.500	4.000	5.000	10.000	SP ACCEL G	BUCKLING OF SUPPORT LEG
94	3249011912	13	1.500	2.000	3.000	4.000	SP ACCEL G	RUPTURE OF CONNECTIONS TO SUPPORT STRUTS
95	3249011912	13	1.500	4.000	5.000	6.000	SP ACCEL G	TENSILE FAILURE OF SUPPORT STRUTS
96	3215011302	14	2.250	0.	0.500	0.	SP ACCEL G	FAILURE OF HOLD DOWN BOLTS
97	3215011302	14	2.250	0.	0.500	0.	SP ACCEL G	OVERSTRESS AT NOZZLE
98	3215011302	14	2.250	0.	2.000	0.	SP ACCEL G	ROTOR SEIZURE
99	3213011920	14	2.250	1.500	2.000	4.000	ACCEL G	RUPTURE OF ANCHOR BOLTS
100	3213011920	14	2.250	3.000	4.000	8.000	ACCEL G	RUPTURE OF VERTICAL INTAKE COLUMN
101	1248021403	14	2.250	1.500	2.000	2.500	SP ACCEL G	INTERNAL ROTOR SEIZURE
102	1248021403	14	2.250	2.000	2.500	3.000	SP ACCEL G	FAILURE OF SUPPORT STRUCTURE OR BOLTING
103	1248021403	14	2.250	0.	0.	0.	SP ACCEL G	INTERNAL SEIZURE DUE TO LOSS OF FLUID
104	1215041401	15	2.250	1.300	1.500	2.000	FORCE/MOMT	INTERNAL SEIZURE OF ROTOR
105	1215041401	15	2.250	1.500	2.000	2.500	FORCE/MOMT	FAILURE OF DRIVE SHAFT COUPLINGS
106	1215041401	15	2.250	2.000	2.500	3.000	FORCE/MOMT	BREAK OF HOLD DOWN BOLTS-SHEAR PINS
107	3215011302	15	3.000	0.	0.500	0.	SP ACCEL G	HOLD DOWN BOLTS BREAK
108	3215011302	15	3.000	0.	0.500	0.	SP ACCEL G	OVERSTRESS AT NOZZLE
109	3215011302	15	3.000	0.	2.000	0.	SP ACCEL G	ROTOR SEIZURE
110	1215051803	15	2.250	0.	0.	0.	SP ACCEL G	SYSTEM INLET, OUTLET NOZZLE CONNECTION
111	1215051803	15	2.250	0.	0.	0.	SP ACCEL G	ANCHOR BOLT LOOSENING
112	1215051803	15	3.000	0.	0.	0.	SP ACCEL G	MALFUNCTION OF SYSTEM VALVES
113	3217011116	16	3.000	50.000	80.000	120.000	SP ACCEL G	STRUCTURAL FAILURE
114	3216031116	16	3.000	5.000	15.000	40.000	SP ACCEL G	STRUCTURAL FAILURE
115	3216041117	16	3.000	8.000	20.000	40.000	SP ACCEL G	FAILURE OF STRUCTURAL MEMBERS
116	1316022602	16	3.000	9.000	12.000	18.000	SP ACCEL G	STEM AND BONNET FAILURE

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OPNO	IDENT	CAT	WEIGHT	TEN	FIFTY	NINETY	PARAM	MODE
117	1116050201	16	3.000	8.250	10.500	13.500	SP ACCEL G	MECHANICAL BINDING OF THE VALVE
118	1316022602	16	3.000	15.000	18.000	24.000	SP ACCEL G	FUNCTIONAL FAILURE OF INTERNALS
119	3216031922	16	2.250	6.000	8.000	12.000	SP ACCEL G	DEFORMATION OF VALVE STEM OR YOKE
120	1217032001	16	3.000	9.000	15.000	18.000	SP ACCEL G	ACTUATOR COMPONENTS FAIL AND JAM
121	1116050201	16	3.000	7.500	9.000	12.000	SP ACCEL G	LOSS OF ELECTRICAL CONTROLS OR ELECTRICAL COMPONEN
122	1216091804	16	2.250	5.000	8.000	11.000	SP ACCEL G	LOSS OF CONTROL AIR
123	3216031922	16	2.250	8.000	10.000	15.000	SP ACCEL G	RUPTURE OF PIPE SUPPORT AT NOZZLE
124	1316022602	16	3.000	12.000	18.000	24.000	SP ACCEL G	BREAKS AT WELD ENDS
125	1217032001	16	3.000	9.000	15.000	18.000	SP ACCEL G	ELECTRICAL FAILURE IN ACTUATOR
126	1217032001	16	3.000	9.000	15.000	18.000	SP ACCEL G	FAILURE OF MAJOR ACTUATOR/VALVE COMPONENT
127	1116050201	16	0.750	6.750	7.500	12.000	SP ACCEL G	LOSS OF PIPE ANCHORAGE
128	3216011102	16	3.000	6.000	10.000	20.000	SP ACCEL G	FRACTURE OF ACTUATOR COVER AT VALVE BODY
129	3216011102	16	3.000	5.000	7.000	10.000	SP ACCEL G	FAILURE OF SPRING MECHANISM
130	1117020202	17	2.250	7.500	9.000	10.500	SP ACCEL G	DISC BECOMES DISENGAGED
131	1117020202	17	2.250	11.250	12.000	15.000	SP ACCEL G	DISC BECOMES BOUND
132	3118021106	18	3.000	10.000	12.000	15.000	SP ACCEL G	LEAKAGE
133	3118070403	18	3.000	6.600	7.800	10.800	SP ACCEL G	INTERNAL SEAT LEAKAGE
134	3118021106	18	3.000	12.000	15.000	20.000	SP ACCEL G	GAULING OF STEM
135	1218081802	18	1.500	6.000	7.500	8.500	SP ACCEL G	STEM BINDING
136	3218011101	18	3.000	15.000	30.000	50.000	SP ACCEL G	INTERNAL DAMAGE
137	1118050203	18	1.500	10.500	12.000	14.250	SP ACCEL G	MECHANICAL BINDING OF THE VALVE
138	3218041115	18	3.000	10.000	18.000	30.000	SP ACCEL G	STRUCTURAL FAILURE
139	3118021106	18	3.000	12.000	15.000	20.000	SP ACCEL G	STRUCTURAL FATIGUE AT NECK
140	1218062007	18	3.000	12.000	18.000	24.000	SP ACCEL G	TOP STRUCTURE OF VALVE
141	3218011101	18	3.000	20.000	50.000	100.000	SP ACCEL G	FRACTURE OF VALVE BODY
142	3118070403	18	3.000	9.000	10.200	12.000	SP ACCEL G	OPERATOR ACCESSORY MALFUNCTION
143	1118050203	18	1.500	10.500	12.000	13.500	SP ACCEL G	LOSS OF PIPE ANCHORAGE
144	1118050203	18	1.500	9.000	10.500	11.250	SP ACCEL G	LOSS OF VALVE CONTROLS
145	3218011101	18	3.000	8.000	10.000	20.000	SP ACCEL G	FAILURE OF VALVE ACTUATOR
146	3118070403	18	3.000	12.000	15.000	18.000	SP ACCEL G	OPERATOR MALFUNCTION
147	3219041921	19	1.500	8.000	12.000	20.000	SP ACCEL G	BINDING OF ROTATING PARTS
148	3219041921	19	1.500	15.000	20.000	30.000	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
149	4120042009	20	1.000	4.000	8.000	10.000	SP ACCEL G	CONNECTION BETWEEN CONTROL PANEL AND ENGINE
150	3220051923	20	0.750	3.000	5.000	8.000	ACCEL G	MALFUNCTION OF CONTROL SYSTEM
151	4120042009	20	1.000	4.000	8.000	10.000	SP ACCEL G	OIL LEVEL REGULATOR
153	3220011114	20	2.250	3.000	6.000	10.000	FLOOR AC G	ANCHOR BOLT FAILURE
154	3220011114	20	2.250	7.400	10.000	15.000	FLOOR AC G	CRANKSHAFT LOCK UP
155	3220051923	20	0.750	5.000	8.000	10.000	ACCEL G	RUPTURE OF ATTACHED OIL LINES
156	3221041923	21	2.250	1.500	2.000	4.000	ACCEL G	FAILURE OF BATTENS
157	3221041923	21	2.250	3.000	4.000	8.000	ACCEL G	LONGITUDINAL FAILURE OF FRAME
158	3121011902	21	3.000	15.000	20.000	30.000	ACCEL G	SUPPORT STAND FAILURE
159	3121011902	21	3.000	15.000	20.000	30.000	ACCEL G	CASE BREAKAGE DUE TO A BAD STAND
160	3121011902	21	3.000	25.000	30.000	35.000	ACCEL G	CASE BREAKAGE WITH GOOD STAND
161	1322050602	22	3.000	1.500	2.500	4.000	SP ACCEL G	SPURIOUS OPERATION OF A PROTECTIVE RELAY
162	1322050602	22	3.000	2.000	3.500	4.000	SP ACCEL G	STRUCTURAL FAILURE
163	4122082003	22	0.250	0.	2.000	0.	SP ACCEL G	CONTACT ALLIGNMENT
164	4122082008	22	1.000	2.000	2.000	4.000	SP ACCEL G	SUPPORT ANCHORAGE OF UNIT
165	1322040601	22	3.000	1.000	2.000	3.000	SP ACCEL G	SPURIOUS OPERATION OF A PROTECTIVE RELAY
166	1322040601	22	3.000	2.000	3.000	3.500	SP ACCEL G	STRUCTURAL FAILURE
167	3222011103	39	3.000	0.400	0.750	1.500	SP ACCEL G	FRACTURE OF PORCELAIN INSULATOR COLUMNS
168	3122031904	22	3.000	10.000	15.000	25.000	SP ACCEL G	CHATTER OF CONTACTS
169	3122031904	22	3.000	15.000	20.000	30.000	SP ACCEL G	STRUCTURAL ANCHORING OF CABINET BASE
170	3122031904	22	3.000	20.000	25.000	30.000	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENTS IN CABINET
171	1322060602	22	3.000	1.500	3.000	5.000	SP ACCEL G	SPURIOUS OPERATION OF A PROTECTIVE RELAY
172	1322060602	22	3.000	3.000	5.000	6.000	SP ACCEL G	STRUCTURAL FAILURE

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OPNO	IDENT	CAT	WEIGHT	TEN	FIFTY	NINETY	PARAM	MODE
173	3223021105	39	1.500	0.400	0.600	1.000	SP ACCEL G	COOLER UNIT PIPE FAILURE AND OIL LOSS
174	3223021105	39	1.500	0.500	1.000	2.000	SP ACCEL G	INTERNAL STRUCTURAL FAILURE
175	3223021105	39	1.500	0.600	1.250	2.500	SP ACCEL G	FAILURE OF PORCELAIN HV BUSHINGS
176	3223051924	23	1.500	2.000	3.000	5.000	SP ACCEL G	RUPTURE OF ANCHOR BOLTS
177	3223051924	23	1.500	4.000	5.000	8.000	SP ACCEL G	FAILURE OF SUPPORT FRAME
178	3223051924	23	1.500	4.000	5.000	8.000	SP ACCEL G	ELECTRICAL MALFUNCTION
179	3219021113	24	1.500	4.000	6.000	10.000	FLOOR AC G	STRUCTURAL FAILURE
180	3226022003	26	3.000	1.500	2.000	3.000	FLOOR AC G	INSTRUMENT FAILURE
181	3226022003	26	3.000	3.000	5.000	8.000	FLOOR AC G	WELD FAILURE
132	1327022001	40	3.000	3.000	5.000	8.000	SF ACCEL G	RELAY CHATTER
183	3126011903	40	3.000	12.000	15.000	25.000	ACCEL G	CHATTER OF CONTACTS
184	SMAN000045	40	3.000	0.730	2.590	5.910	SP ACCEL G	
1C5	3127031901	27	3.000	12.000	20.000	30.000	ACCEL G	COMPONENT MALFUNCTION
186	SMAN000044	27	3.000	8.980	15.700	22.420	SP ACCEL G	
187	3126011903	27	3.000	20.000	25.000	35.000	ACCEL G	STRUCTURAL MOUNTING OF CABINETS
188	3126011903	27	3.000	20.000	25.000	30.000	ACCEL G	STRUCTURAL MOUNTING OF COMPONENTS
189	3130011107	30	3.000	6.000	10.000	12.000	SP ACCEL G	RELAY CHATTER
190	3130011107	30	3.000	8.000	10.000	15.000	SP ACCEL G	LOOSENING OF FASTENERS
191	3130011107	30	3.000	8.000	10.000	15.000	SP ACCEL G	BASE STRUCTURAL FATIGUE
192	3130020401	30	3.000	9.000	12.000	15.000	SP ACCEL G	SIGNAL DRIFT
193	3130020401	30	3.000	10.200	13.200	18.000	SP ACCEL G	CONTACT CHATTER
194	3130020401	30	3.000	10.800	18.000	24.000	SP ACCEL G	SET POINT DRIFT
198	3131011904	31	3.000	10.000	15.000	25.000	SP ACCEL G	CHATTER OF CONTACTS
199	3131011904	31	3.000	15.000	20.000	30.000	SP ACCEL G	STRUCTURAL ANCHORING OF CABINET BASE
200	3131011904	31	3.000	20.000	25.000	30.000	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENT IN CABINET
201	3133030402	33	3.000	7.200	9.000	12.000	SP ACCEL G	DISLODGING OF AIR DUCT BLANKING CLIPS
202	3236010305	36	3.000	1.200	2.000	3.500	SP ACCEL G	FAILURE AT CONNECTION TO BUILDING INTERFACE
203	3236010305	36	3.000	2.000	3.000	6.000	SP ACCEL G	FAILURE OF FIELD WELDS
204	3237020306	36	3.000	1.200	2.000	3.500	SP ACCEL G	FAILURE AT CONNECTION TO BUILDING INTERFACE
205	3237020306	36	3.000	2.000	3.000	6.000	SP ACCEL G	FAILURE OF FIELD WELDS
206	3236021925	36	1.500	2.000	3.000	5.000	SP ACCEL G	FAILURE OF SUPPORTS
207	3236021925	36	1.500	4.000	5.000	10.000	SP ACCEL G	RUPTURE OF PARTS BETWEEN SUPPORTS
208	2137051404	37	3.000	5.000	7.000	10.000	SP ACCEL G	CORNER TEARING
209	2137051404	37	3.000	8.000	10.000	16.000	SP ACCEL G	SUPPORT FAILURE
210	2137051404	37	3.000	8.000	10.000	16.000	SP ACCEL G	JOINT SEPARTION
211	3237061926	37	1.500	3.000	4.000	6.000	SP ACCEL G	SUPPORT FAILURE
212	3237061926	37	1.500	5.000	6.000	10.000	SP ACCEL G	RUPTURE OF DUCT BETWEEN SUPPORTS
213	3237021119	37	1.500	2.000	4.000	10.000	SP ACCEL G	JOINT SEPARTION
214	3237021119	37	1.500	2.500	5.000	12.000	SP ACCEL G	DUCT ANCHOR AND SUPPORT FAILURE
215	3237021119	37	1.500	5.000	10.000	15.000	SP ACCEL G	GROSS BENDING FIRM
216	6137041201	37	3.000	2.000	2.500	3.000	SP ACCEL G	CORNER CRIPPLING
217	6137041201	37	3.000	2.200	3.000	3.500	SP ACCEL G	DUCT SUPPORT FAILURE
218	6137041201	37	3.000	2.500	3.300	4.000	SP ACCEL G	DUCT RUPTURE
219	1337010501	38	0.750	1.200	1.500	1.800	LOADS	WELD FAILURE AT EMBEDMENT TO CLEVIS JUNCTURE
220	1337010501	38	0.750	1.600	2.000	2.800	LOADS	TENSILE FAILURE IN PISTON ROD
221	3222021104	39	3.000	0.180	0.250	0.500	SP ACCEL G	RUPTURE OF GASKET SEALS, VENTING OF CONDUCTING GAS
222	3222021104	39	3.000	0.250	0.300	0.600	SP ACCEL G	FRACTURE OF PORCELAIN INSULATION COLUMNS
223	1205010404	48	3.000	7.000	8.000	10.000	SP ACCEL G	PIPE DEFORMATION
224	4140011120	50	0.750	0.150	0.280	0.500	SP ACCEL G	DESTRUCTION OF SHEAR CONNECTION BETWEEN MODULES
225	SMAN000037	23	3.000	7.950	13.400	18.850	SP ACCEL G	STRUCTURAL FAILURE
226		49	3.000	0.400	0.580	0.750	SP ACCEL G	FRACTURE OF PORCELAIN INSULATION
227		49	3.000	0.110	0.250	0.280	SP ACCEL G	FRACT. OF PORCELAIN INSUL. (JAPANESE COMP.)

I. OPNOTES

Table OPNOTES contains additional information related to various expert opinions, such as the predominant frequencies related to the estimated spectral accelerations, limitations in the application of the estimates, etc. It consists of four columns as follows:

Column No.	Column name	Type	Contents
1	LINE	Integer	A reference line number.
2	IDENT	Character	A ten character code identifying the particular expert (see Table OPINION).
3	CAT	Integer	An integer identifying the generic category of component (see Table CATEGORY).
4	NOTE	Character	The notes pertinent to the identified expert opinion.

OPNOTES

LINE	IDENT	CAT	NOTE
1	3201031916	1	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE ALL MODES. FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
10	4101022009	1	PREDOMINANT FREQUENCY, 3-5 HZ; BWR, FUNCTIONAL FAILURE.
13	3201041907	1	ALL MODES: PREDOMINANT FREQUENCY MODES #1,3 HZ; MODES #2,3 HZ; MODES # 3,5 HZ. ALL MODES PRECENTILES INCLUDE LOCA. BWR, ALL MODES. FUNCTIONAL FAILURE ; ALL MODES ACCELERATION INDUCED DISPLACEMENTS
21	3201012005	1	PREDOMINANT FREQUENCY GIVEN FOR MODE #1 ONLY AND IT IS 4-10 HZ. BWR, ALL MODES. FUNCTIONAL FAILURE ALL MODES.
26	3202032004	2	POOL TYPE REACTOR VESSEL (LIQ. SODIUM) PREDOMINANT FREQUENCIES, MODE # 1-7 HZ MODE #2-7.5 HZ MODES #3--- PRESS. BOUND FAIL; ALL MODES.
32	3202051909	2	ALL MODES: PREDOMINANT FREQUENCIES, MARK II 9-15 HZ,MARK III 3-5 HZ. MARK II & III REFER TO GE BWR CONTAIN- MENTS PRESS BOUND FAIL. ALL MODES.
38	3202041908	2	PERCENTILES INCLUDE EFFECTS OF ALL LOCA. PREDOMINANT FREQUENCY 15 HZ. PRESS. BOUND. FAILURE.
42	3202071913	2	PRESSURIZER. BOTH MODES PREDOMINANT FREQUENCY, 7.0 HZ. PERCENTILES INCLUDE LOCA. PRESS, BOUND. FAIL; ALL MODES.
48	3202061910	2	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCY 7.5 HZ ALL MODES: VERTICAL DIRECTION ACCELERATION PRESS. BOUND. FAIL; ALL MODES.
54	3202022002	2	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCIES:MODES # 1 10-30 HZ MODES # 2 RIGID MODES # 3 20-100 HZ. PRESS. BOUND. FAIL; ALL MODES.
60	3202011108	2	STEAM GENERATOR. BOTH MODES: PREDOMINANT FREQUENCY, 10-15 HZ. MODE #1 FACTORS TIME SY (SY FROM PRESS. BOUND. FAIL; ALL MODES.
66	1303022601	3	ALL MODES: PREDOMINANT FREQUENCY 25-50 HZ ALL PERCENTILES ARE FACTOR TIME SSE

LINE	IDENT	CAT	NOTE
			PRESS. BOUND. FAIL; ALL MODES.
70	3203032006	3	ALL MODES: PREDOMINANT FREQUENCY 5-25 HZ.
			LWR PIPING PRESS. BOUND. FAIL; ALL MODES.
			% OF ALLOWABLE PER ASME CODE SEC III EQ. 9
77	1303010502	3	PERCENTILES: FACTOR TIMES SSE
			PREDOMINANT FREQUENCIES
			MODES#1 AND #2, 8-30 HZ.;
			MODE #3, 2-5 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
83	3204032013	4	FRAGILITY PARAMETER IS YIELD MOMENT
			PREDOMINANT FREQ. >2 HZ.
86	3204041915	4	ALL MODES: PREDOMINANT FREQUENCY, 4-8 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
89	3204011109	4	PREDOMINANT FREQUENCY, 10-30 HZ.
			FRAGILITY PARAMETER IS YIELD MOMENT TIMES
			PERCENTILE FACTOR. PRESS. BOUND. FAIL;
			ALL MODES.
94	3204020302	4	PREDOMINANT FREQUENCY, ALL MODES 2-10 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
			% OF YIELD MOMENT.
98	3205051916	5	ALL MODES: PREDOMINANT FREQUENCY, 4-10 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
101	3205011110	5	PREDOMINANT FREQUENCY 10-30 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
			PERCENTILES; FACTOR TIMES YIELD MOMENT.
105	3205020303	5	ALL MODES: PREDOMINANT FREQUENCY 2-10 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
			% OF YIELD MOMENT.
109	3205051916	6	ALL MODES: PREDOMINANT FREQUENCY 4-10 HZ.
			PRESS. BOUND. FAIL; ALL MODES.
112	3206010304	6	ALL MODES: PREDOMINANT FREQUENCY 2-10 HZ.
			PRESS BOUNDS. FAIL; ALL MODES.
			% OF YIELD MOMENT.
116	3207012010	7	PREDOMINANT FREQUENCY MODE #1, 6 HZ.
			PERCENTILES: FACTOR TIMES YIELD MOMENT.
119	3207021918	7	ALL MODES: PREDOMINANT FREQUENCY 4-10 HZ.
121	3208021917	8	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
123	3239011112	9	PREDOMINANT FREQUENCY: 12 TO 20 HZ.
			DIESEL FUEL TANK.
126	3209011111	9	PREDOMINANT FREQUENCY: GREATER THEN 12 HZ.
128	3209021919	10	BOTH MODES: PREDOMINANT FREQUENCY 15-30 HZ.
			HORIZONTAL TANK AND HEAT EXCHANGERS.
131	3210021118	10	PREDOMINANT FREQUENCY: GREATER THEN 20 HZ.
			SMALL VESSELS.
134	3210031119	10	PREDOMINANT FREQUENCY: 25-45 HZ.
			SMALL MEDIUM HEAT EXCHANGERS.
137	3211010301	11	PERCENTILES IN TERMS OF PEAK GROUND
			ACCELERATION.
140	3212011911	12	BOTH MODES,PREDOMINANT FREQUENCIES: 4.5 HZ.
			PERCENTILES INCLUDE LOCA.
143	3249011912	13	PREDOMINANT FREQUENCY 4.5 HZ. ALL MODES.
145	3215011302	14	PERCENTILE: 50% OF Y. S.
			PERCENTILE: 50% OF Y. S.
			PERCENTILE: FACTOR TIMES SSE
149	3213011920	14	BOTH MODES: PREDOMINANT FREQUENCY, 3HZ.

LINE	IDENT	CAT	NOTE
152	1248021403	14	PERCENTILE 90 IS TENTATIVE
			PERCENTILE: FACTOR TIMES SSE
			PREDOMINANT FREQUENCY >33 HZ.
			FOR MODES #1 AND #2.
			FAILURE IN THIS MODE DEPENDS ON
			ASSOCIATED PIPING SYSTEM
158	1215041401	15	ALL MODES: PREDOMINANT FREQUENCY RIGID.
			PERCENTILES: FACTOR TIMES SSE
			SPECIFIED LOADS
162	3215011302	15	ALL MODES: FREQUENCIES, HORIZONTAL 33 HZ.
			VERTICAL 1-33 HZ.
			PERCENTAGES PERCENT OF NOZZLE LOADS.
			PERCENTILES FOR MODE #3: FACTOR TIMES
			SSE LOADS.
168	1217032001	16	ALL MODES. PREDOMINANT FREQUENCY RIGID.
			BALL VALVE WITH ACTUATOR AND
			LOGIC CABINET
172	3216031116	16	PREDOMINANT FREQUENCY > 15HZ.
			TO RIGID.
175	3217011116	16	PREDOMINANT FREQUENCY, RIGID.
177	3216041117	16	PREDOMINANT FREQUENCY > 20 HZ.
179	1116050201	16	GATE AND GLOBE VALVES.
			PREDOMINANT FREQUENCY: MODE
			#1 ABOVE 33 HZ.; MODE #2 8-20 HZ.
			MODE #3 ABOVE 27 HZ.
184	1316022602	16	PREDOMINANT FREQUENCY:
			MODE #1, 10-20 HZ.
			MODE #2, 30-50 HZ.
			MODE #3, 30-50HZ.
189	3216031922	16	ALL MODES: PREDOMINANT
			FREQUENCIES 2-10 HZ.
192	1216091804	16	BUTTERFLY VALVE PREDOMINANT FREQUENCY:
			RIGID.
195	3216011102	16	PREDOMINANT FREQUENCY:
			MODE #1 VALVE ACTUATOR 27.7 HZ.
			MODE " SPRING MECHANISM 10-12 HZ.
			RUGGLES KLINGEMAN TRIP VALVE.
200	1117020202	17	PREDOMINANT FREQUENCIES
			BOTH MODES: RIGID
205	3118021106	18	PREDOMINANT FREQUENCIES ARE 20-30 HZ.
			DAMPING IS 5%
208	1118050203	18	AVERAGE
			CAPACITY 8-10 G'S.
			PREDOMINANT FREQUENCY: RIGID ALL MODES.
			GATE, GLONE AND CHECK VALVES.
213	3218041115	18	PREDOMINANT FREQUENCIES ARE >20 HZ.
			TO RIGID
216	3218011101	18	PREDOMINANT FREQUENCIES ARE
			MODE #1 25-50 HZ.
			MODE #2 > 50 HZ.
			MODE #3 > 50 HZ.
221	3118070403	18	PREDOMINANT FREQUENCIES
			MODE #1 12 TO 15 HZ.
			MODE #2 17 TO 21 HZ.
			MODE #3 27 TO 35 HZ.

LINE	IDENT	CAT	NOTE
226	1218081802	18	PREDOMINANT FREQUENCY IS > 40 HZ. TO 140 HZ.
			GLOBE VALUE
230	3219041921	19	PREDOMINANT FREQUENCIES ARE > 33 HZ.
233	4120042009	20	PREDOMINANT RESPONSE FREQUENCIES: 1ST MODE 7.0 TO 20.6 HZ. 2ND MODE 8.3 TO 13.8 HZ.
			DIESEL GENERATORS.
238	3220051923	20	PREDOMINANT RESPONSE FREQUENCIES: >15 HZ.
			DIESEL GENERATORS.
241	3220011114	20	PREDOMINANT RESPONSE FREQUENCIES: 15 HZ.
			DIESEL GENERATORS.
244	3221041923	21	PREDOMINANT FREQUENCY IS >25 HZ.
			BATTERY RACKS
247	3121011902	21	PREDOMINANT FREQUENCY >15 HZ.
			DC POWER BATTERIES.
250	1322050602	22	FREQUENCIES: SIDE TO SIDE = 6-11 HZ. FRONT TO BACK = 16-20 HZ. VERTICAL = >30 HZ.
			26" WIDE METALCLAD SWITCHGEAR.
0	4122082008	22	FREQUENCY: HORIZONAL = 5.6 HZ. 10.6 HZ. 16.5 HZ. (X) AND 7.8 HZ. 22.9 HZ. (Y) VERTICAL =RIGID.
5	1322040601	22	36" WIDE METALCLAD SWITCHGEAR.
7	3222011103	39	FREQUENCIES: 1ST MODE = 1.5-4.0 HZ. 2ND MODE = 4.5-8.0 HZ.
10	3122031904	22	PREDOMINANT FREQUENCIES FOR ALL MODES >15 HZ.
			RESPONSE IS WITH DAMPING OF 5 %
14	1322060602	22	POWER VAC METALCLAD SWITCHGEAR. PREDOMINANT FREQUENCIES SIDE TO SIDE = 6 - 11 HZ. FRONT TO BACK = 16 - 20 HZ. VERTICAL = > 30 HZ.
20	3223021105	39	FRAGILITY PARAMETER AT FLOOR TO TRANSFORMER INTERFACE PREDOMINANT FREQUENCIES: COOLER UNIT: 7.5, 7.7 HZ. INTERNAL STRUCTURE: 7.2, 7.6 HZ. HV PORCELAIN: 8.1, 10.8 HZ.
27	3223051924	23	PREDOMINANT FREQUENCY FOR ALL MODES: >10 HZ.
30	3219021113	24	PREDOMINANT RESPONSE FREQUENCY IS 21 HZ. HVAC FANS.
33	3226022003	26	PREDOMINANT FREQUENCIES: MODE #1 RIGID MODE #2 11 HZ.
			PERCENTILES ARE FACTORS TIMES SSE. INSTRUMENT RACKS.
39	1327022001	27	PREDOMINANT RESPONSE FREQUENCY 20 TO 33 HZ.

LINE	IDENT	CAT	NOTE
42	3126011903	27	PREDOMINANT FREQUENCY FOR ALL MODES >12 HZ. THESE MODES OF FAILURE ALSO APPLY TO BREAKER PANELS, AUXILIARY RELAY PANELS, INSTRUMENT RACKS AND DIESEL GENERATORS.
50	3127031901	27	PREDOMINANT FREQUENCY IS >20 HZ. STRUCTURAL FAILURE UNLIKELY WITH MODERN DESIGN.
54	3130011107	30	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
59	3130020401	30	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
65	3122031904	31	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
69	3131011904	31	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
77	3236010305	36	PREDOMINANT RESPONSE FREQUENCY IS 1-5 HZ. FOR ALL MODES PERCENTILES ARE PERCENTAGES OF DESIGN SSE SPECTRUM.
82	3237020306	36	PREDOMINANT RESPONSE FREQUENCY IS 1-5 HZ. FOR ALL MODES PERCENTILES ARE PERCENTAGES OF DESIGN SSE SPECTRUM.
87	3236021925	36	PREDOMINANT RESPONSE FREQUENCY IS 5-10 HZ. FOR ALL MODES.
90	2137051404	37	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
95	3237061926	37	PREDOMINANT FREQUENCY FOR RESPONSE 5 - 10 HZ. ALL MODES
98	3237021119	37	PREDOMINANT FREQUENCY FOR RESPONSE 10 HZ. ALL MODES.
101	6137041201	37	PREDOMINANT FREQUENCY FOR RESPONSE 15 - 20 HZ. ALL MODES. PERCENTILES: FACTOR TIMES SSE. A FRAGILITY CURVE WAS INCLUDED WITH THIS QUESTIONAIRE.
107	1337010501	38	THESE NUMBERS ARE THE MULTIPLICATIVE FACTOR OF THE UNIT RATED LOAD.
111	3222021104	39	IN-SITU TESTING. FRAGILITY PARAMETER AT CIRCUIT BREAKER FOOTING. THESE ARE SWITCHYARD CIRCUIT BREAKERS. TORSIONAL FAILURE. MODES OF

LINE	IDENT	CAT	NOTE
			VIBRATION: 1ST 2.4 - 3.4 HZ. 2ND 7.8 - 12.2 HZ.
121	1205040404	48	AIR BLAST CIRCUIT BREAKERS. THE TEST WERE NOT TAKEN TO FAILURE. PREDOMINANT FREQUENCIES: MODE #1 9.5 HZ. MODE #2 21.5 HZ.
127	4150011120	50	RESPONDENT INDICATED GOOD CONFIDENCE IN RESPONSE. PREDOMINANT FREQUENCY: 7 - 8 HZ.
131	BLANK	1	

J. PIPE

Table PIPE contains load scale factors for various pipe elements other than branches. (See Table BRANCH for branch elements.) It consists of nine columns as follows:

Column No.	Column name	Type	Contents
1	LINE	Integer	A reference line number.
2	SIZE	Floating	The nominal pipe diameter (in.).
3	SCHED	Character	The pipe schedule.
4	MAT	Character	Material: SS = Stainless Steel, CS = Carbon Steel.
5	TEMP	Floating	Temperature (°F).
6	ELBOW	Floating	Scale factor for elbow.
7	MITER	Floating	Scale factor for miter joint.
8	RUN	Floating	Scale factor for pipe run.
9	WELD	Floating	Scale factor for butt weld.

PIPE

LINE	SIZE	SCHED	MAT	TEMP	ELBOW	MITER	RUN	WELD
1	0.50	160	SS	300.	492.00	0.	298.00	480.00
2	0.75	160	SS	300.	259.00	0.	157.00	254.00
3	1.00	160	SS	300.	138.00	0.	83.50	135.00
4	2.00	160	SS	300.	27.70	0.	43.50	27.00
5	2.00	40	SS	500.	107.00	0.	37.50	60.40
6	3.00	160	CS	100.	4.80	0.	3.85	6.19
7	3.00	160	CS	140.	4.93	0.	3.96	6.39
8	3.00	160	SS	300.	9.85	0.	5.95	9.62
9	3.00	160	CS	556.	6.24	0.	4.93	8.05
10	4.00	40S	SS	200.	15.81	0.	5.12	8.25
11	4.00	40S	SS	300.	17.65	0.	5.69	9.19
12	4.00	40S	SS	500.	20.54	0.	6.60	10.63
13	4.00	140	CS	140.	3.35	0.	2.26	3.63
14	4.00	140	SS	300.	6.47	0.	3.27	5.27
15	4.00	140	SS	535.	7.72	0.	3.90	6.31
16	4.00	160	SS	300.	4.87	0.	2.83	4.57
17	4.00	160	SS	535.	5.97	0.	3.47	5.60
18	6.00	120	CS	100.	1.27	0.	0.76	1.24
19	6.00	40	CS	100.	3.77	0.	1.40	2.26
20	6.00	120	CS	140.	1.30	0.	0.79	1.27
21	6.00	160	CS	100.	0.86	0.	0.63	1.00
22	8.00	40	CS	100.	2.09	0.	0.71	1.15
23	8.00	40S	SS	200.	3.92	0.	0.99	1.60
24	8.00	40S	SS	300.	4.36	0.	1.11	1.78
25	8.00	40S	SS	350.	4.47	0.	1.13	1.73
26	8.00	40S	SS	400.	4.58	0.	1.16	1.87
27	8.00	40S	SS	500.	5.04	0.	1.28	2.05
28	8.00	140	SS	535.	1.16	0.	0.57	0.92
29	8.00	160	SS	535.	0.99	0.	0.54	0.87
30	8.00	160	SS	595.	1.03	0.	0.56	0.91
31	10.00	40	CS	100.	1.26	2.21	0.40	0.65
32	10.00	40S	SS	400.	2.74	0.	0.65	1.05
33	10.00	160	SS	535.	0.51	0.	0.27	0.44
34	12.00	SW	CS	100.	0.95	0.	0.27	0.44
35	12.00	40S	SS	200.	1.78	0.	0.38	0.62
36	12.00	40S	SS	300.	1.98	0.	0.43	0.69
37	12.00	40S	SS	500.	2.30	0.	0.50	0.80
38	12.00	40	SS	400.	1.83	0.	0.42	0.67
39	14.00	TN=.375	CS	100.	0.84	1.47	0.23	0.37
40	14.00	40	CS	100.	0.64	0.	0.20	0.31
41	14.00	40	SS	400.	1.42	0.	0.32	0.52
42	14.00	160	SS	400.	0.23	0.	0.12	0.19
43	14.00	160	SS	595.	0.26	0.	0.13	0.21
44	16.00	120	CS	140.	0.11	0.	0.06	0.10
45	16.00	120	CS	556.	0.14	0.	0.08	0.12
46	18.00	SW	CS	100.	0.59	0.	0.14	0.22
47	18.00	SW	SS	200.	1.11	0.	0.19	0.30
48	18.00	SW	SS	300.	1.24	0.	0.21	0.34
49	18.00	SW	SS	500.	1.43	0.	0.24	0.39
50	18.00	40	SS	400.	0.67	0.	0.15	0.24
51	20.00	SW	CS	100.	0.52	0.	0.11	0.18
52	20.00	SW	SS	200.	0.97	0.	0.15	0.25
53	20.00	SW	SS	300.	1.07	0.	0.17	0.27
54	20.00	SW	SS	500.	1.24	0.	0.20	0.32
55	20.00	TN = .5	CS	100.	0.32	0.	0.08	0.13

LINE	SIZE	SCHED	MAT	TEMP	ELBOW	MITER	RUN	WELD
56	24.00	SW	CS	100.	0.40	0.	0.08	0.12
57	27.50	TN =2.38	SS	535.	0.03	0.	0.01	0.02
58	29.00	TN = 2.5	SS	595.	0.03	0.	0.01	0.02
59	30.00	TN = .5	CS	100.	0.18	0.	0.04	0.06
60	31.00	TN=2.66	SS	530.	0.02	0.	0.01	0.02
61	36.00	TN = .5	CS	100.	0.	0.26	0.03	0.04
62	48.00	TN=.625	CS	100.	0.	0.12	0.01	0.02

K. RESULTS

Table RESULTS contains the descriptions of the fragility data for generic categories which result from certain groupings and subsequent reduction of expert opinions and other data as computed by program FRAGSTAT. It consists of eight columns of data as follows:

Column No.	Column name	Type	Contents
1	RESNO	Character	An identifying code unique to this particular set of data.
2	CATNO	Floating	A floating point number unique to a particular description of generic category or component description (see Table CATEGORY).
3	NMEAN	Floating	The statistical mean of the data assuming normal distribution.
4	NSIGMA	Floating	The standard deviation of the data assuming normal distribution.
5	LNMEAN	Floating	The statistical mean of the natural logs of the data (i.e., assuming lognormal distribution).
6	LNSIGMA	Floating	The standard deviation of the natural logs of the data (i.e., assuming lognormal distribution).
7	MEDIAN	Floating	The median of the data assuming lognormal distributions.
8	BETA	Floating	Same as LNSIGMA, repeated for convenience in data extraction.

RESULTS

RESNO	CATNO	NMEAN	NSIGMA	LNMEAN	LNSIGMA	MEDIAN	BETA
RES01A	1.0	1.578	2.848	0.721	0.396	2.056	0.396
RES02A	2.1	3.835	1.168	1.344	0.230	3.833	0.230
RES02B	2.2	3.197	1.176	1.106	0.333	3.022	0.333
RES02C	2.3	1.933	0.423	0.637	0.208	1.890	0.208
RES02D	2.3	5.000	1.562	1.551	0.339	4.718	0.339
RES02E	2.3	2.424	0.991	0.894	0.263	2.445	0.263
RES03A	3.0	220.000	89.140	5.310	0.406	201.000	0.406
RES04A	4.0	220.000	89.140	5.310	0.406	201.000	0.406
RES05A	5.0	220.000	89.140	5.310	0.406	201.000	0.406
RES06A	6.0	220.000	89.140	5.310	0.406	201.000	0.406
RES07A	7.0	1.515	0.928	0.378	0.399	1.459	0.399
RES08A	8.0	2.038	0.619	0.700	0.254	2.013	0.254
RES09A	9.0	4.370	2.645	1.364	0.609	3.910	0.609
RES10A	10.0	1.908	0.668	0.610	0.275	1.841	0.275
RES11A	11.0	220.000	89.140	5.310	0.406	201.000	0.406
RES12A	12.0	2.626	1.150	0.971	0.336	2.640	0.336
RES13A	13.0	2.995	0.766	1.054	0.269	2.868	0.269
RES14A	14.0	2.300	1.154	0.792	0.387	2.207	0.387
RES15A	15.0	4.464	1.369	1.462	0.340	4.315	0.340
RES15B	15.0	3.186	0.886	1.158	0.337	3.185	0.337
RES16A	16.0	4.832	2.081	1.575	0.317	4.829	0.317
RES16B	16.0	8.000	2.347	2.029	0.315	7.606	0.315
RES17A	17.0	8.960	1.200	2.190	0.130	8.900	0.130
RES18A	18.0	11.193	16.768	2.523	0.544	12.466	0.544
RES19A	19.0	12.598	4.613	2.472	0.325	12.078	0.325
RES20A	20.0	0.658	0.228	-0.430	0.330	0.651	0.330
RES21A	21.0	2.486	1.169	0.827	0.418	2.287	0.418
RES22A	22.0	2.610	1.240	0.846	0.486	2.330	0.486
RES23A	23.0	2.800	1.480	1.020	0.327	2.780	0.327
RES24A	24.0	2.288	0.766	0.806	0.337	2.238	0.337
RES26A	26.0	1.631	1.107	0.141	0.759	1.151	0.759
RES27A	27.0	13.550	6.430	2.440	0.499	11.460	0.499
RES30A	30.0	7.747	1.937	2.039	0.203	7.683	0.203
RES31A	31.0	15.228	5.105	2.662	0.291	14.331	0.291
RES33A	33.0	9.400	1.938	2.219	0.201	9.196	0.201
RES36A	36.0	2.290	1.014	0.802	0.392	2.229	0.392
RES37A	37.0	4.322	2.578	1.378	0.407	3.966	0.407
RES39A	39.0	0.285	0.214	-1.210	0.416	0.298	0.416
RES40A	40.0	5.700	5.770	1.380	0.893	3.990	0.893
RES41A	41.0	8.500	4.950	2.030	0.710	7.630	0.710
RES48A	48.0	8.333	1.241	2.109	0.144	8.243	0.144
RES49A	49.0	0.395	0.282	-1.102	0.807	0.332	0.807
RES50A	50.0	0.310	0.142	-1.288	0.471	0.276	0.471

L. SMADATA

Table SMADATA contains fragility information derived from data presented in Ref. 4. The calculation of the values in this table is discussed in Sec. 3.2. It consists of eight columns as follows:

Column No.	Column name	Type	Contents
1	GRPNO	Integer	A unique number assigned to each set of data in the table.
2	CATNO	Floating	A floating point number unique to a particular category of component (see Table CATEGORY).
3	CAT	Integer	An integer unique to a class of generic components (see Table CATEGORY).
4	NMEAN	Floating	The statistical mean of the data assuming normal distribution.
5	NSIGMA	Floating	The standard deviation of the data assuming normal distribution.
6	LNEAN	Floating	The statistical mean of the natural logs of the data (i.e., assuming lognormal distribution).
7	LNSIGMA	Floating	The standard deviation of the natural logs of the data (i.e., assuming lognormal distribution).
8	PARAM	Character	The fragility parameter.

SMADATA

GRPNO	CATNO	CAT	NMEAN	NSIGMA	LNMEAN	LNSIGMA	PARAM
SMA01	1.0	1	2.75	0.81	1.01	0.37	SP ACCEL G
SMA02	1.1	1	6.00	1.65	1.79	0.34	SP ACCEL G
SMA04	2.3	2	3.30	1.75	1.19	0.44	SP ACCEL G
SMA05	2.2	2	2.00	0.62	0.69	0.40	SP ACCEL G
SMA06	7.0	7	21.90	6.95	3.09	0.41	SP ACCEL G
SMA07	7.0	7	7.90	3.00	2.07	0.52	SP ACCEL G
SMA08	8.0	8	8.28	0.25	-0.19	0.39	PK GD AC G
SMA09	8.0	8	3.60	1.20	1.28	0.44	PK GD AC G
SMA10	10.0	10	7.95	3.32	2.07	0.60	SP ACCEL G
SMA11	10.0	10	7.20	2.72	1.97	0.52	PK ACCEL G
SMA12	11.0	11	1.40	0.59	0.34	0.60	PK GD AC G
SMA13	11.0	11	1.40	0.59	0.34	0.60	PK GD AC G
SMA14	12.0	12	3.30	1.11	1.19	0.44	SP ACCEL G
SMA15	13.0	13	3.48	0.96	1.25	0.34	SP ACCEL G
SMA16	15.0	15	3.20	0.88	1.16	0.34	SP ACCEL G
SMA17	15.0	15	11.70	3.79	2.46	0.42	SP ACCEL G
SMA18	15.0	15	4.66	1.50	1.54	0.41	Z PRD AC G
SMA19	15.0	15	7.19	1.68	1.97	0.28	Z PRD AC G
SMA20	15.0	15	8.22	2.15	2.11	0.32	Z PRD AC G
SMA21	15.0	15	39.60	9.97	3.68	0.30	Z PRD AC G
SMA22	15.0	15	32.50	10.33	3.48	0.41	Z PRD AC G
SMA23	16.0	16	7.56	3.32	2.02	0.65	PK ACCEL G
SMA24	16.1	16	7.30	2.06	1.99	0.35	Z PD PK AC
SMA25	16.0	16	43.80	15.40	3.78	0.47	Z PD PK AC
SMA26	17.0	17	47.50	16.90	3.86	0.47	Z PD PK AC
SMA27	18.2	18	47.50	16.70	3.86	0.47	Z PD PK AC
SMA28	20.0	20	0.93	0.27	-0.07	0.35	SP ACCEL G
SMA29	20.0	20	1.96	0.57	0.67	0.36	SP ACCEL G
SMA30	20.0	20	0.74	0.23	-0.31	0.40	SP ACCEL G
SMA31	20.0	20	8.91	3.50	2.19	0.55	SP ACCEL G
SMA32	21.0	21	17.10	6.18	2.84	0.48	SP ACCEL G
SMA33	21.0	21	5.25	1.60	1.66	0.39	SP ACCEL G
SMA34	22.0	22	2.59	1.73	0.95	1.51	SP ACCEL G
SMA35	22.0	22	9.63	4.88	2.26	0.82	SP ACCEL G
SMA36	22.0	22	18.30	9.64	2.90	0.88	SP ACCEL G
SMA37	23.0	23	13.40	4.25	2.59	0.41	SP ACCEL G
SMA38	24.0	24	2.74	0.88	1.01	0.41	SP ACCEL G
SMA39	24.0	24	2.93	0.95	1.08	0.42	SP ACCEL G
SMA40	24.0	24	11.90	3.89	2.47	0.42	SP ACCEL G
SMA41	26.0	26	2.59	1.73	0.95	1.51	SP ACCEL G
SMA42	26.0	26	9.63	4.88	2.26	0.82	SP ACCEL G
SMA43	26.0	26	18.30	9.64	2.90	0.88	SP ACCEL G
SMA44	27.0	27	15.70	5.24	2.75	0.44	SP ACCEL G
SMA45	40.0	40	2.59	1.73	0.95	1.51	SP ACCEL G
SMA46	27.0	27	9.63	4.88	2.26	0.82	SP ACCEL G
SMA47	27.0	27	18.30	9.64	2.90	0.88	SP ACCEL G
SMA48	30.0	30	47.30	16.80	3.86	0.47	Z PRD AC G
SMA49	31.0	31	2.59	1.73	0.95	1.51	SP ACCEL G
SMA50	31.0	31	9.63	4.88	2.26	0.82	SP ACCEL G
SMA51	31.0	31	18.30	9.64	2.90	0.88	SP ACCEL G
SMA52	35.0	35	15.70	5.24	2.75	0.44	SP ACCEL G
SMA53	36.0	36	2.82	1.14	1.04	0.57	Z PD PK AC
SMA54	41.0	41	2.59	1.73	0.95	1.51	SP ACCEL G
SMA55	41.0	41	9.63	4.88	2.26	0.82	SP ACCEL G
SMA56	41.0	41	18.30	9.64	2.90	0.88	SP ACCEL G

GRPNO	CATNO	CAT	NMEAN	NSIGMA	LNMEAN	LNSIGMA	PARAM
SMA57	41.0	41	9.63	4.88	2.26	0.82	SP ACCEL G
SMA58	41.0	41	18.30	9.64	2.90	0.88	SP ACCEL G
SMA59	49.0	49	0.20	0.06	1.61	0.35	PK GD AC G
SMΛ60	17.0	17	9.84	5.56	2.29	0.65	Z PD PK AC
SMA61	28.0	28	8.50	4.95	2.03	0.71	SP ACCEL G
SMA62	31.0	31	8.50	4.95	2.03	0.71	SP ACCEL G
SMA63	49.0	49	0.20	0.06	-1.61	0.35	PK GD AC G

6.0 SUMMARY OF FRAGILITIES

Section 5.0 of this report dealt with the details of the data base structure and content. The following tables are computer listings produced from the contents of the data base through the use of the relational capabilities of the FRAMIS data base manager. Each table represents one category of equipment; each set of results consists of the lognormal distribution parameters (median and beta), the failure mode description, associated notes, and group identifier that can be used to obtain further information from the data base tables presented in Sec. 5.2. It illustrates the power and usefulness of the concept and application of a relational data base. It was also an extremely helpful method to store, retrieve, and interrogate the mass of fragility data that was used in these studies.

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CATEGORY: 1.0 REACTOR CORE ASSEMBLY

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP01A	3.916	.708	SP ACCEL G	BINDING OF CONTROL RODS DUE TO SEISMICALLY INDUCED DEFORMATIONS	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
GRP01B	5.646	.757	SP ACCEL G	DEFORMATION OF GUIDE TUBES DUE TO SEISMIC IMPACT OF FUEL BUNDLE	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
GRP01C	6.693	.823	SP ACCEL G	FAILURE OF CORE SUPPORT STRUCTURE DUE TO INERTIA LOAD OF FUEL	PREDOMINANT FREQUENCIES MODE #1,3HZ; MODE #2,3 HZ; AND MODE #3,5 HZ. PRECENTILES INCLUDE LOCA. PWR, ALL MODES. FUNCTIONAL FAILURE FRAGILITY PARAMETER ACCELERATION AT CORE SUPPORT ATTACHMENT TO REACTOR VESSEL.
SMA01	2.746	.369	SP ACCEL G	DEFOR. OF GUIDE TUBES / GUIDE PLATE WELD	FREQUENCY 5-15 HZ , 5% DAMPING
SMA02	5.989	.339	SP ACCEL G	CONTROL ROD HOUSING DEFORMATION	FREQUENCY 6 HZ , 5% DAMPING
RES01A	2.056	.396			GRPMODE LISTS GROUPS INCLUDED IN RES01A

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CATEGORY: 2.1 REACTOR PRESSURE VESSEL

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP02A	4.162	.275	SP ACCEL G	BUCKLING OF SKIRT	ALL MODES: PREDOMINANT FREQUENCIES, MARK II 9-15 HZ,MARK III 3-5 HZ. MARK II & III REFER TO GE BWR CONTAIN-MENTS PRESS BOUND FAIL. ALL MODES.
GRP02B	5.430	.289	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS	ALL MODES: PREDOMINANT FREQUENCIES, MARK II 9-15 HZ,MARK III 3-5 HZ. MARK II & III REFER TO GE BWR CONTAIN-MENTS PRESS BOUND FAIL. ALL MODES.
GRP02C	6.462	.325	SP ACCEL G	STRESS INTENSITY AT VESSEL SUPPORT	POOL TYPE REACTOR VESSEL (LIQ. SODIUM) PREDOMINANT FREQUENC'ES, MODE # 1-7 HZ MODE #2-7.5 HZ MODES #3--- PRESS. BOUND FAIL; ALL MODES.
RES02A	3.833	.230			GRPMODE LISTS GROUPS INCLUDED IN RES02A

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CATEGORY: 2.2 PRESSURIZER

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP02D	3.108	.361	SP ACCEL G	FAILURE OF SKIRT ANCHOR BOLTS	PRESSURIZER. BOTH MODES PREDOMINANT FREQUENCY, 7.0 HZ. PERCENTILES INCLUDE LOCA. PRESS, BOUND. FAIL; ALL MODES.
GRP02E	5.430	.289	SP ACCEL G	BUCKLING OF SKIRT	PRESSURIZER. BOTH MODES PREDOMINANT FREQUENCY, 7.0 HZ. PERCENTILES INCLUDE LOCA. PRESS, BOUND. FAIL; ALL MODES.
SMA05	2.000	.398	SP ACCEL G	SUPPORT SKIRT BOLTING	FREQUENCY 18-22 HZ , 5% DAMPING
RES02B	3.022	.333			GRPMODE LISTS GROUPS INCLUDED IN RES02B

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CATEGORY: 2.3 STEAM GENERATOR

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP02F	1.891	.208	SP MOMENTS	RUPTURE AT PRIMARY INLET OR OUTLET NOZZLE, RUPTURE AT FEEDWATER NOZZLE	STEAM GENERATOR. BOTH MODES: PREDOMINANT FREQUENCY, 10-15 HZ. MODE #1 FACTORS TIME SY (SY FROM PRESS. BOUND. FAIL; ALL MODES.
GRP02G	4.716	.339	FORCES	NOZZLE FAILURE	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCIES:MODES # 1 10-30 MODES # 2 RIGID MODES # 3 20-100 HZ. PRESS. BOUND. FAIL; ALL MODES.
GRP02H	3.896	.201	SP ACCEL G	FAILURE OF STEAM GENERATOR LEG IMBEDMENT IN CONTAINMENT FLOOR	STEAM GENERATOR . ALL MODES: PREDOMINANT FREQUENCY 7.5 HZ ALL MODES: VERTICAL DIRECTION ACCELERATION PRESS. BOUND. FAIL; ALL MODES.
GRP02I	2.886	.275	SP ACCEL G	FAILURE OF CONNECTION BETWEEN SUPPORT LEG AND STEAM GENERATOR BODY	STEAM GENERATOR . ALL MODES: PREDOMINANT FREQUENCY 7.5 HZ ALL MODES: VERTICAL DIRECTION ACCELERATION PRESS. BOUND. FAIL; ALL MODES.
GRP02J	8.166	.422	SP ACCEL G	TUBING FAILURE	STEAM GENERATOR ALL MODES: PREDOMINANT FREQUENCIES:MODES # 1 10-30 MODES # 2 RIGID MODES # 3 20-100 HZ. PRESS. BOUND. FAIL; ALL MODES.
SMA04	3.287	.440	SP ACCEL G	SUPPORT COLUMN FAILURE	FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP
RES02C	1.890	.208			FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP GRPMODE LISTS GROUPS INCLUDED IN RES02C
RES02D	4.718	.339			GRPMODE LISTS GROUPS INCLUDED IN RES02D
RES02E	2.445	.263			GRPMODE LISTS GROUPS INCLUDED IN RES02E

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CATEGORY: 7.0 LARGE VERTICAL STORAGE VESSELS WITH FORMED HEADS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP07A	1.650	.445	SP ACCEL G	RUPTURE OF ANCHOR BOLTS	ALL MODES: PREDOMINANT FREQUENCY 4-10 HZ
GRP07B	2.467	.536	SP ACCEL G	BUCKLING OF SUPPORT SKIRT OR LEGS	PREDOM. FREQ. 4-10 HZ
SMA06	21.977	.407	SP ACCEL G	SUPPORT SKIRT COLLAPSE	FREQUENCY 20.7 HZ , 5% DAMPING
SMA07	7.925	.519	SP ACCEL G	PLASTIC BUCKLING OF SHELL	FREQUENCY 6.3 HZ , 5% DAMPING
RES07A	1.459	.399			GRPMODE LISTS GROUPS INCLUDED IN RES07A

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CATEGORY: 3.0 PRIMARY COOLANT PIPING

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
CRP03A	202.350	.406	MOM FT-KIP	RUPTURE AT CONNECTIONS TO COMPONENTS DUE TO COMPONENT SUPPORT FAILURE	MASTER PIPING CURVE
RES03A	201.000	.406			GRPMODE LISTS GROUPS INCLUDED IN RES03A

CATEGORY: 8.0 LARGE VERTICAL STORAGE TANKS WITH FLAT BOTTOMS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP08A	2.079	.275	SP ACCEL G	RUPTURE OF ANCHOR BOLTS	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
GRP08B	3.254	.319	SP ACCEL G	BUCKLING OF TANK WALL	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
GRP08C	5.312	.305	SP ACCEL G	TENSILE RUPTURE OF TANK WALL	ALL MODES: PREDOMINANT FREQUENCY 3-8 HZ.
SMA08	.828	.389	PK GD AC G	BUCKLING OF TANK WALLS AT BASE	RIGID TANK + SLOSH
SMA09	3.597	.436	PK GD AC G	BENDING OF VERTICAL STIFFNER	RIGID TANK + SLOSH
RES08A	2.013	.254			GRPMODE LISTS GROUPS INCLUDED IN RES08A

CATEGORY: 9.0 LARGE HORIZONTAL VESSELS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP09A	3.912	.609	FLOOR AC G	SUPPORT SYSTEM FAILURE (BOLTS)	PREDOMINANT FREQUENCY: 12 TO 20 HZ. DIESEL FUEL TANK.
RES09A	3.910	.609			GRPMODE LISTS GROUPS INCLUDED IN RES09A

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CATEGORY: 10.0 SMALL-MEDIUM VESSELS AND HEAT EXCHANGERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP10A	2.079	.275	ACCEL G	RUPTURE OF ANCHOR BOLTS	BOTH MODES: PREDOMINANT FREQUENCY 15-30 HORIZONTAL TANK AND HEAT EXCHANGERS.
GRP10B	12.769	.359	ACCEL G	STRUCTURAL FAILURE	PREDOMINANT FREQUENCY: GREATER THEN 20 H SMALL VESSELS.
GRP10C	2.599	.452	ACCEL G	SUPPORT FAILURE	BOTH MODES: PREDOMINANT FREQUENCY 15-30 HORIZONTAL TANK AND HEAT EXCHANGERS.
SMA10	7.925	.599	SP ACCEL G	SUPPORT FAILURE	FREQUENCY 6.9 HZ , 5% DAMPING
SMA11	7.171	.516	PK ACCEL G	SUPPORT LEG FAILURE	FREQUENCY 12.8 HZ , 5% DAMPING
RES10A	1.841	.275			GRPMODE LISTS GROUPS INCLUDED IN RES10A

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CATEGORY: 11.0 BURIED PIPE

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
SMA12	1.399	.601	PK GD AC G	BUCKLING AND FRACTURE	ZION BURIED PIPE
SMA13	1.399	.601	PK GD AC G	BUCKLING AND FRACTURE	ZION BURIED PIPE
RES11A	201.000	.406			GRPMODE LISTS GROUPS INCLUDED IN RES11A

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CATEGORY: 12.0 REACTOR COOLANT PUMP

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP12A	3.557	.401	SP ACCEL G	FAILURE OF CONNECTION TO SUPPORT LEGS	BOTH MODES,PREDOMINANT FREQUENCIES: 4.5 PERCENTILES INCLUDE LOCA.
GRP12B	5.847	.406	SP ACCEL G	BUCKLING OF SUPPORT LEG	BOTH MODES,PREDOMINANT FREQUENCIES: 4.5 PERCENTILES INCLUDE LOCA.
SMA14	3.287	.440	SP ACCEL G	SUPPORT COLUMN BOLTING	FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP FREQUENCY 5 HZ , (NSSS SYSTEM) , 5% DAMP
RES12A	2.640	.336			GRPMODE LISTS GROUPS INCLUDED IN RES12A

CATEGORY: 13.0 LARGE VERTICAL CENTRIFUGAL PUMPS WITH MOTOR DRIVE

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP13A	2.883	.275	SP ACCEL G	RUPTURE OF CONNECTIONS TO SUPPORT STRUTS	PREDOMINANT FREQUENCY 4.5 HZ. ALL MODES.
GRP13B	4.933	.159	SP ACCEL G	TENSILE FAILURE OF SUPPORT STRUTS	PREDOMINANT FREQUENCY 4.5 HZ. ALL MODES.
SMA15	3.490	.342	SP ACCEL G	BENDING OF PUMP CASING	FREQUENCY 7 HZ , 5% DAMPING
RES13A	2.868	.269			GRPMODE LISTS GROUPS INCLUDED IN RES13A

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CATEGORY: 14.0 LARGE VERTICAL PUMPS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP14A	2.289	.417	SP ACCEL G	RUPTURE OF ANCHOR BOLTS DUE TO LARGE MOM ENTS FROM VERTICAL INTAKE COLUMN	BOTH MODES: PREDOMINANT FREQUENCY, 3HZ. PERCENTILE 90 IS TENTATIVE
GRP14B	4.577	.417	SP ACCEL G	RUPTURE OF VERTICAL INTAKE COLUMN	BOTH MODES: PREDOMINANT FREQUENCY, 3HZ. PERCENTILE 90 IS TENTATIVE
RES14A	2.207	.387			GRPMODE LISTS GROUPS INCLUDED IN RES14A

CATEGORY: 15.0 MOTOR DRIVEN COMPRESSORS AND PUMPS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
SMA16	3.190	.338	ACCEL G	IMPELLER DEFLECTION	FREQUENCY 7 HZ , 5% DAMPING
					FREQUENCY 7 HZ , 5% DAMPING
SMA17	11.705	.419	ACCEL G	MOUNTING BOLT FAILURE	FREQUENCY 7 HZ , 5% DAMPING
					FREQUENCY 7 HZ , 5% DAMPING
SMA18	4.665	.413	Z PRD AC G	FLANGE BENDING	ZION SAFETY INJECTION PUMP , RIGID
SMA19	7.171	.278	Z PRD AC G	SHAFT BENDING	ZION SAFETY INJECTION PUMP, RIGID
SMA20	8.248	.318	Z PRD AC G	THRUST BEARING FAILURE	ZION CENTR. CHARGING PUMP, RIGID
SMA21	39.646	.304	Z PRD AC G	SHAFT DEFLECTION	ZION CENTR. CHARGING PUMP, RIGID
SMA22	32.460	.408	Z PRD AC G	GENERIC FUNCTION	GENERIC PUMPS & COMPR., RIGID
RES15A	4.315	.340			GRPMODE LISTS GROUPS INCLUDED IN RES15A
RES15B	3.185	.337			GRPMODE LISTS GROUPS INCLUDED IN RES15B

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CATEGORY: 16.0 LARGE MOTOR OPERATED VALVES (> 4IN.)

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP16A	17.305	.275	SP ACCEL G	BREAKS AT WELD ENDS	PREDOMINANT FREQUENCY: MODE #1, 10-20 HZ. MODE #2, 30-50 HZ. MODE #3, 30-50HZ.
GRP16B	10.623	.257	SP ACCEL G	RUPTURE OF PIPE SUPPORT AT NOZZLE	ALL MODES: PREDOMINANT FREQUENCIES 2-10 HZ.
GRP16C	7.606	.314	SP ACCEL G	LOSS OF CONTROL AIR	BUTTERFLY VALVE PREDOMINANT FREQUENCY: RIGID.
GRP16D	11.190	.358	SP ACCEL G	ELECTRICAL FAILURE IN ACTUATOR	ALL MODES. PREDOMINANT FREQUENCY RIGID. BALL VALVE WITH ACTUATOR AND LOGIC CABINET
GRP16G	10.591	.476	PK ACCEL G	FRACTURE OF VALVE ACTUATOR TOP COVER AT CONNECTION TO VALVE BODY	PREDOMINANT FREQUENCY: MODE #1 VALVE ACTUATOR 27.7 HZ. MODE " SPRING MECHANISM 10-12 HZ. RUGGLES KLINGEMAN TRIP VALVE.
GRP16H	7.029	.271	PK ACCEL G	FAILURE OF SPRING MECHANISM DUE TO EXCES SIVE PLASTIC DEFORMATION	PREDOMINANT FREQUENCY: MODE #1 VALVE ACTUATOR 27.7 HZ. MODE " SPRING MECHANISM 10-12 HZ. RUGGLES KLINGEMAN TRIP VALVE.
SMA23	7.538	.646	PK ACCEL G	DISTORTION OF EXTENDED OPERATOR STRUCTUR E	RIGID RIGID
SMA24	7.316	.350	SP ACCEL G	OIL RESERVOIR HOLD DOWN BOLTS	RIGID
SMA25	43.816	.468	Z PD PK AC	GENERIC FUNCTION	RIGID
RES16A	4.829	.317			GRPMODE LISTS GROUPS INCLUDED IN RES16A
RES16B	7.606	.315			GRPMODE LISTS GROUPS INCLUDED IN RES16B

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CATEGORY: 17.0 LARGE RELIEF AND CHECK VALVES (> 4IN.)

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP17C	8.917	.1[illegible]	SP ACCEL G	DISC BECOMES DISENGAGED	PREDOMINANT FREQUENCIES BOTH MODES: RIGID
GRP17D	12.654	.130	SP ACCEL G	DISC BECOMES BOUND	PREDOMINANT FREQUENCIES BOTH MODES: RIGID
SMA26	47.465	.474	SP ACCEL G	GENERIC FUNCTION	RIGID RIGID
RES17A	8.900	.130			GRPMODE LISTS GROUPS INCLUDED IN RES17A

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CATEGORY: 18.0 SMALL MISCELLANEOUS VALVES (< 4IN.)

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP18B	15.959	.620	SP ACCEL G	INTERNAL DAMAGE	PREDOMINANT FREQUENCIES ARE 20-30 HZ. DAMPING IS 5%
GRP18C	21.563	.714	SP ACELL G	STRUCTURAL FATIGUE	PREDOMINANT FREQUENCIES ARE 20-30 HZ. DAMPING IS 5%
RES18A	12.466	.544			GRPMODE LISTS GROUPS INCLUDED IN RES18A

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CATEGORY: 19.0 HORIZONTAL MOTORS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP19A	12.429	.360	ACCEL G	BINDING OF ROTATING PARTS	PREDOMINANT FREQUENCIES ARE > 33 HZ.
GRP19B	20.801	.275	ACCEL G	RUPTURE OF ANCHOR BOLTS	PREDOMINANT FREQUENCIES ARE > 33 HZ.
RES19A	12.078	.325			GRPMODE LISTS GROUPS INCLUDED IN RES19A

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CATEGORY: 20.0 GENERATORS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP20A	5.948	.441	SP ACCEL G	CONTROL FAILURE	PREDOMINANT RESPONSE FREQUENCIES: 1ST MODE 7.0 TO 20.6 HZ. 2ND MODE 8.3 TO 13.8 HZ. DIESEL GENERATORS.
GRP20B	5.948	.441	SP ACCEL G	OIL LEVEL REGULATOR	PREDOMINANT RESPONSE FREQUENCIES: 1ST MODE 7.0 TO 20.6 HZ. 2ND MODE 8.3 TO 13.8 HZ. DIESEL GENERATORS.
GRP20C	5.646	.476	SP ACCEL G	ANCHOR BOLT FAILURE	PREDOMINANT RESPONSE FREQUENCIES: 15 HZ. DIESEL GENERATORS.
CRP20D	10.350	.279	SP ACCEL G	CRANKSHAFT LOCK UP	PREDOMINANT RESPONSE FREQUENCIES: 15 HZ. DIESEL GENERATORS.
SMA28	.931	.354	SP ACCEL G	RELAY CHATTER	FREQUENCY 30 HZ , 5% DAMPING
SMA29	1.960	.361	SP ACCEL G	FAILED RELAY	FREQUENCY 11 HZ , 5% DAMPING
SMA30	.735	.397	SP ACCEL G	VALVE TRIP	FREQUENCY 22 HZ , 5% DAMPING
SMA31	8.935	.546	SP ACCEL G	STRUCTURAL	RIGID
RES20A	.651	.330			GRPMODE LISTS GROUPS INCLUDED IN RES20A

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CATEGORY: 21.0 BATTERIES

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP21A	2.289	.417	ACCEL G	FAILURE OF BATTENS	PREDOMINANT FREQUENCY IS >25 HZ. BATTERY RACKS
GRP21B	20.801	.275	ACCEL G	CASE BREAKAGE DUE TO A BAD STAND	PREDOMINANT FREQUENCY >15 HZ. DC POWER BATTERIES.
SMA32	17.116	.484	SP ACCEL G	ANCHOR BOLTS	FREQUENCY 8 HZ , 5% DAMPING
SMA33	5.259	.385	SP ACCEL G	CASE CRACKING & PLATE FAILURE	FREQUENCY 8 HZ , 5% DAMPING
RES21A	2.287	.418			GRPMODE LISTS GROUPS INCLUDED IN RES21A

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CATEGORY: 22.0 SWITCHGEAR

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP22A	2.330	.486	SP ACCEL G	SPURIOUS OPERATION OF A PROTECTIVE RELAY	FREQUENCIES: SIDE TO SIDE = 6-11 HZ. FRONT TO BACK = 16-20 HZ. VERTICAL = >30 HZ. 26" WIDE METALCLAD SWITCHGEAR.
SMA34	2.588	1.510	SP ACCEL G	RELAY CHATTER	FREQUENCY 5-10 HZ , 5% DAMPING
SMA35	9.583	.818	SP ACCEL G	BREAKER TRIP	FREQUENCY 5-10 HZ , 5% DAMPING
SMA36	18.174	.881	SP ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
RES22A	2.330	.486			GRPMODE LISTS GROUPS INCLUDED IN RES22A

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CATEGORY: 23.0 DRY TRANSFORMERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP23A	4.660	.503	SP ACCEL G	INTERNAL STRUCTURAL FAILURE, SHORT OF EL ECTRICAL CONNECTION	FRAGILITY PARAMETER AT FLOOR TO TRANSFORMER INTERFACE PREDOMINANT FREQUENCIES: COOLER UNIT: 7.5, 7.7 HZ. INTERNAL STRUCTURE: 7.2, 7.6 HZ. HV PORCELAIN: 8.1, 10.8 HZ.
GRP23B	9.526	.680	SP ACCEL G	FAILURE OF SUPPORT FRAME	PREDOMINANT FREQUENCY FOR ALL MODES: >10 HZ.
GRP23C	3.108	.351	SP ACCEL G	RUPTURE OF ANCHOR BOLTS	PREDOMINANT FREQUENCY FOR ALL MODES: >10 HZ.
SMA37	13.330	.408	SP ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
RES23A	2.780	.327			GRPMODE LISTS GROUPS INCLUDED IN RES23A

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CATEGORY: 24.0 AIR HANDLING UNITS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP24A	6.215	.360	FLOOR AC G	STRUCTURAL FAILURE	PREDOMINANT RESPONSE FREQUENCY IS 21 HZ. HVAC FANS.
SMA38	2.746	.410	SP ACCEL G	RUBBING OF FAN ON HOUSING	FREQUENCY 4.3 HZ , 5% DAMPING
SMA39	2.945	.416	SP ACCEL G	RUBBING OF MOTOR ROTOR ON HOUSING	FREQUENCY 4.3 HZ , 5% DAMPING
SMA40	11.822	.424	SP ACCEL G	GENERIC FUNCTION	FREQUENCY 10-30 HZ , 5% DAMPING FREQUENCY 10-30 HZ , 5% DAMPING
RES24A	2.238	.337			GRPMODE LISTS GROUPS INCLUDED IN RES24A

1

CATEGORY: 26.0 INSTRUMENT PANELS AND RACKS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP26A	2.079	.275	ACCEL G	INSTRUMENT FAILURE	PREDOMINANT FREQUENCIES: MODE #1 RIGID MODE #2 11 HZ. PERCENTILES ARE FACTORS TIMES SSE. INSTRUMENT RACKS.
GRP26B	4.933	.383	ACCEL G	WELD FAILURE	PREDOMINANT FREQUENCIES: MODE #1 RIGID MODE #2 11 HZ. PERCENTILES ARE FACTORS TIMES SSE. INSTRUMENT RACKS.
SMA41	2.588	1.510	SP ACCEL G	RELAY CHATTER	FREQ 5-10 HZ , 5% DAMPING
SMA42	9.583	.818	SP ACCEL G	BREAKER TRIP	FREQ 5-10 HZ , 5% DAMPING
					FREQ 5-10 HZ , 5% DAMPING
SMA43	18.174	.881	SP ACCEL G	STRUCTURAL	FREQ 5-10 HZ , 5% DAMPING
RES26A	1.151	.759			GRPMODE LISTS GROUPS INCLUDED IN RES26A

1

CATEGORY: 27.0 CONTROL PANELS AND RACKS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP27B	16.827	.407	SP ACCEL G	COMPONENT MALFUNCTION	PREDOMINANT FREQUENCY IS >20 HZ. STRUCTURAL FAILURE UNLIKELY WITH MODERN DESIGN.
GRP27C	25.972	.223	SP ACCEL G	STRUCTURAL MOUNTING OF CABINETS	PREDOMINANT FREQUENCY FOR ALL MODES >12 HZ. THESE MODES OF FAILURE ALSO APPLY TO BREAKER PANELS, AUXILIARY RELAY PANELS, INSTRUMENT RACKS AND DIESEL GENERATORS.
GRP27D	24.655	.159	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENTS	PREDOMINANT FREQUENCY FOR ALL MODES >12 HZ. THESE MODES OF FAILURE ALSO APPLY TO BREAKER PANELS, AUXILIARY RELAY PANELS, INSTRUMENT RACKS AND DIESEL GENERATORS.
SMA44	15.643	.436	SP ACCEL G	ELECTRICAL MALFUNCTION	FREQUENCY 5-10 HZ , 5% DAMPING
SMA46	9.583	.818	SP ACCEL G	BREAKER TRIP	FREQUENCY 5-10 HZ , 5% DAMPING
SMA47	18.174	.881	SP ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
RES27A	11.460	.499			GRPMODE LISTS GROUPS INCLUDED IN RES27A

1

CATEGORY: 30.0 LOCAL INSTRUMENTS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP30A	8.962	.302	SP ACCEL G	RELAY CHATTER	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
GRP30B	10.623	.257	SP ACCEL G	LOOSENING OF FASTENERS	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
GRP30C	10.623	.257	SP ACCEL G	BASE STRUCTURAL FATIGUE	PREDOMINANT RESPONSE FREQUENCY IS 5 - 35 HZ DAMPING IS 5%. THIS APPLIES TO ALL FAILURE MODES.
GRP30D	11.740	.201	SP ACCEL G	SIGNAL DRIFT	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
GRP30E	13.437	.223	SP ACCEL G	CONTACT CHATTER	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
GRP30F	16.710	.325	SP ACCEL G	SET POINT DRIFT	PREDOMINANT FREQUENCIES MODE #1 10-15 HZ. MODE #2 29-30 HZ. MODE #3 NOT GIVEN
SMA48	47.465	.474	Z PRD AC G	ELECTRICAL FUNCTION	RIGID
RES30A	7.683	.203			GRPMODE LISTS GROUPS INCLUDED IN RES30A

1

CATEGORY: 31.0 MOTOR CONTROL CENTERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP31A	15.534	.361	SP ACCEL G	CHATTER OF CONTACTS	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
GRP31B	20.801	.275	SP ACCEL G	STRUCTURAL ANCHORING OF CABINET BASE	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
GRP31C	24.655	.159	SP ACCEL G	STRUCTURAL MOUNTING OF COMPONENT IN CABI NET	DAMPING IS 5% FOR ALL MODES. PREDOMINANT FREQUENCY FOR ALL MODES >15 HZ.
SMA49	2.588	1.510	SP ACCEL G	RELAY CHATTER	FREQUENCY 5-10 HZ , 5% DAMPING
SMA50	9.583	.818	SP ACCEL G	BREAKER TRIP	FREQUENCY 5-10 HZ , 5% DAMPING
SMA51	18.174	.881	[illegible] ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
RES31A	14.331	.291			GRPMODE LISTS GROUPS INCLUDED IN RES31A

1

CATEGORY: 33.0 LIGHT FIXTURES

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP33A	9.196	.201	SP ACCEL G	DISLODGING OF AIR DUCT BLANKING CLIPS	FREQ. 4.5-6.5 HZ , DAMP 2%
RES33A	9.196	.201			GRPMODE LISTS GROUPS INCLUDED IN RES33A

1

CATEGORY: 35.0 INVERTERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
SMA52	15.643	.436	SP ACCEL G	RELAY TRIP	FREQUENCY 5-10 HZ , 5% DAMPING

1

CATEGORY: 36.0 CABLE TRAYS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP36A	3.108	.360	SP ACCEL G	FAILURE OF SUPPORTS	PREDOMINANT RESPONSE FREQUENCY IS 5-10 HZ. FOR ALL MODES.
GRP36B	5.847	.406	SP ACCEL G	RUPTURE OF PARTS BETWEEN SUPPORTS	PREDOMINANT RESPONSE FREQUENCY IS 5-10 HZ. FOR ALL MODES.
SMA53	2.829	.570	Z PD PK AC	CABLE SUPPORT SYSTEM	REFERENCED TO ZPA
RES36A	2.229	.392			GRPMODE LISTS GROUPS INCLUDED IN RES36A

1

CATEGORY: 37.0 DUCTING

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP37A	7.050	.271	SP ACCEL G	CORNER TEARING	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
GRP37B	7.142	.677	SP ACCEL G	SUPPORT FAILURE	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
GRP37C	7.980	.806	SP ACCEL G	JOINT SEPARTION	PREDOMINANT FREQUENCY FOR RESPONSE 8.5 - 11.0 HZ. DAMPING AT 7% HVAC DUCTS.
GRP37D	6.693	.302	SP ACCEL G	RUPTURE OF DUCT BETWEEN SUPPORTS	PREDOMINANT FREQUENCY FOR RESPONSE 5 - 10 HZ. ALL MODES
GRP37E	9.038	.445	SP ACCEL G	GROSS BENDING FIRM	PREDOMINANT FREQUENCY FOR RESPONSE 10 HZ. ALL MODES.
RES37A	3.966	.407			GRPMODE LISTS GROUPS INCLUDED IN RES37A

1

CATEGORY: 39.0 SWITCHYARD EQUIPMENT

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP39A	.766	.517	Z PRD ACCE	PORCELAIN FRACTURE	FREOUENCIES: 1ST MODE = 1.5-4.0 HZ. 2ND MODE = 4.5-8.0 HZ.
GRP39B	.317	.449	Z PRD ACCE	A B CIRCUIT BREAKER FAILURE	IN-SITU TESTING. FRAGILITY PARAMETER AT CIRCUIT BREAKER FOOTING. THESE ARE SWITCHYARD CIRCUIT BREAKERS. TORSIONAL FAILURE. MODES OF VIBRATION: 1ST 2.4 - 3.4 HZ. 2ND 7.8 - 12.2 HZ. AIR BLAST CIRCUIT BREAKERS.
GRP39C	.914	.610	Z PRD ACCE	H V TRANSFORMER STRUCTURAL FAILURE	FRAGILITY PARAMETER AT FLOOR TO TRANSFORMER INTERFACE PREDOMINANT FREQUENCIES: COOLER UNIT: 7.5, 7.7 HZ. INTERNAL STRUCTURE: 7.2, 7.6 HZ. HV PORCELAIN: 8.1, 10.8 HZ.
RES39A	.298	.416			GRPMODE LISTS GROUPS INCLUDED IN RES39A

CATEGORY 40.0 RELAYS

	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP40A	5.669	1.164	SP ACCEL G	RELAY CHATTER	PREDOMINANT RESPONSE FREQUENCY 20 TO 33 HZ.
SHA45	2.588	1.510	SP ACCEL G	RELAY CHATTER	5-10 HZ , 5% DAMPING
RES40A	**1.660**	**1.195**			GRPMODE LISTS GROUPS INCLUDED IN RES40A

1

CATEGORY: 41.0 CIRCUIT BREAKERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
SMA54	2.588	1.510	SP ACCEL G	RELAY CHATTER	5-10 HZ , 5% DAMPING
SMA55	9.583	.818	SP ACCEL G	RELAY TRIP	FREQUENCY 5-10 HZ , 5% DAMPING
SMA56	18.174	.881	SP ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
SMA57	9.583	.818	SP ACCEL G	BREAKER TRIP	FREQUENCY 5-10 HZ , 5% DAMPING
					FREQUENCY 5-10 HZ , 5% DAMPING
SMA58	18.174	.881	SP ACCEL G	STRUCTURAL	FREQUENCY 5-10 HZ , 5% DAMPING
RES41A	7.630	.710			GRPMODE LISTS GROUPS INCLUDED IN RES41A

1

CATEGORY: 48.0 RECOMBINERS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP48A	8.240	.144	FLOOR AC G	PIPE DEFORMATION	THE TEST WERE NOT TAKEN TO FAILURE. PREDOMINANT FREQUENCIES: MODE #1 9.5 HZ. MODE #2 21.5 HZ.
RES48A	8.243	.144			GRPMODE LISTS GROUPS INCLUDED IN RES48A

1

CATEGORY: 49.0 CERAMIC INSULATORS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
CRP49A	.332	.807	BASE ACCEL	FRACTURE OF PORCELAIN INSULATION	FREQ. 1-4 HZ
SMA59	4.998	.353	PK GD AC G	FRACT OF INSULATORS	REFERENCED TO ZPA
RES49A	.332	.807			GRPMODE LISTS GROUPS INCLUDED IN RES49A

1

CATEGORY: 50.0 SPENT FUEL RACKS

GROUP	MEDIAN	BETA	FRAG. PARAM.	FAILURE MODE	NOTES
GRP50A	.276	.471	FLOOR AC G	DESTRUCTION OF SHEAR CONNECTION BETWEEN MODULES	FREQ. 7-8 HZ
RES50A	.276	.471			GRPMODE LISTS GROUPS INCLUDED IN RES50A

7.0 REFERENCES

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2. Dittli, A. L., Introduction to FRAMIS - A Tutorial, Lawrence Livermore National Laboratory, Livermore, CA, UCID-30173 (1979).

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4. Kennedy, R. P. and R. C. Campbell, Seismic Safety Margins Research Program (Phase I) Subsystem Fragility, Structural Mechanics Associates, Newport Beach, CA, SMA 12205.06.01 (1979).

5. George, L. L. and R. W. Mensing, Using Subjective Percentiles and Test Data for Estimating Fragility Functions, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-84157 (1981).

6. Cover, L. E., FRAGSTAT - A Computer Code for Analysis of Expert Opinion Fragility Data, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19146 (1982).

APPENDIX F
DESCRIPTIONS OF CONTRIBUTORS TO FINAL ZION COMPONENT FRAGILITIES

The following document lists the component fragilities as developed for the final Zion analysis and describes specifically the contributing data used to develop them. Not all of the fragilities presented here were actually used in the final analysis. The information presented here can be determined (except for the separation of random and modeling variability) from the Equipment Fragility Data Base Report (UCRL-53038, Rev. 1) (Appendix E in this report) but the process is rather cumbersome. The process used in making the separation of variability is documented in Chapter 2 of this report.

In the actual development, whenever expert opinion was used it was in the form of percentile data, and whenever expert opinions and other data were combined using the program FRAGSTAT* the data that were expert-opinion data were converted to equivalent percentiles for input to the program. To avoid the confusion of mixing 10th, 50th, and 90th percentile data with median and beta data, the equivalent median and beta are shown in each case.

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* L. E. Cover, FRAGSTAT - A Computer Code for Analysis of Expert Opinion Fragility Data, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19146 (1982).

Component Fragilities Developed by the
Seismic Safety Margins Research Program

Reactor Core Assembly

Median = 2.06
Beta (T) = .40
Beta (R) = .24
Beta (U) = .32

Parameter = spectral acceleration (g)
Frequency = 6 Hz
Damping = 5%

Predominant failure mode = deformation of guide tubes

Five individual fragilities were combined for this category.

Source*	Median	Beta	Reference** OPNO	GRPNO
E.O.	3.92	.71	1	
E.O.	5.65	.76	2	
E.O.	6.69	.82	3	
D.D.	6.00	.24		SMA01
D.D.	2.75	.24		SMA02

Reactor Pressure Vessel

Median = 3.83
Beta (T) = .45
Beta (R) = .23
Beta (U) = .39

Parameter = spectral acceleration (g)
Frequency = 5 Hz
Damping = 5%

Predominant failure mode = fracture of RPV outlet nozzle

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* E.O. = expert opinion
D.D. = design data from NUREG/CR-2405
SG = SAFEGARD data from NUREG/CR-2405

** These identifiers can be used to locate the specific data entries in the Equipment Fragility Data Base report (UCRL-53038, Rev. 1) (Appendix E). Where more than one value of OPNO is given for one source, it means that expert opinions were combined as one failure mode.

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	4.16	.27	20	
E.O.	5.43	.29	19	
E.O.	6.46	.32	17	

Pressurizer

Median = 2.00
Beta (T) = .40
Beta (R) = .21
Beta (U) = .34

Parameter = spectral acceleration (g)
Frequency = 18-22 Hz
Damping = 5%

Predominant failure mode = failure of support skirt bolting

The source of this fragility is design data and it was calculated from capacities in NUREG/CR-2405 (GRPNO = SMA05).

Steam Generator

Median = 2.45
Beta (T) = .44
Beta (R) = .24
Beta (U) = .37

Parameter = spectral acceleration (g)
Frequency = 5-8 Hz
Damping = 5%

Predominant failure mode = support failure

Four individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	3.91	.20	14	
E.O.	2.88	.28	13	
E.O.	8.20	.42	26 & 28	
D.D.	3.30	.44		SMA04

Piping (Master Fragility)

Median = 2.44×10^6
Beta (T) = .38
Beta (R) = .18
Beta (U) = .33

Parameter = Moment (in.-lb)

Predominant failure mode = plastic collapse

This fragility was derived from test data and analysis and was calculated from capacities in NUREG/CR-2405 (GRPNO = GRPO3A).

Large Vertical Vessels with Formed Heads

Median = 1.46
Beta (T) = .40
Beta (R) = .20
Beta (U) = .35

Parameter = zero period accleration (g)
Frequency = assumed rigid with slosh

Predominant failure mode = failure of anchor bolts

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	1.65	.44	75	
E.O.	2.46	.54	76	

Large Vertical Tanks with Flat Bottoms

Median = 2.01
Beta (T) = .38
Beta (R) = .25
Beta (U) = .29

Parameter = zero period acceleration (g)
Frequency = assumed rigid with slosh

Predominant failure mode = fracture of anchor bolts

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	2.08	.28	77	
E.O.	3.26	.31	78	
E.O.	5.31	.31	79	

Large Horizontal Vessels

Median = 3.91
Beta (T) = .61
Beta (R) = .30
Beta (U) = .53

Parameter = spectral acceleration (g)
Frequency = 12-20 Hz
Damping = 5%

Predominant failure mode = failure of anchor bolts

Two expert opinions were combined as one failure mode to develop this fragility (OPNO's = 83 & 84).

Small Medium Vessels and Heat Exchangers

Median = 1.84
Beta (T) = .51
Beta (R) = .25
Beta (U) = .45

Parameter = spectral acceleration (g)
Frequency = 10-30 Hz
Damping = 5%

Predominant failure mode = failure of anchor bolts

Four individual fragilities were combined in this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	2.08	.28	85	
E.O.	12.77	.36	87	
E.O.	2.60	.45	86 & 89	
D.D.	7.92	.60		SMA10

Reactor Coolant Pump

Median = 2.64
Beta (T) = .44
Beta (R) = .24
Beta (U) = .37

Parameter = spectral acceleration (g)
Frequency = 5 Hz
Damping = 5%

Predominant failure mode = support failure

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	3.56	.40	92	
E.O.	5.78	.41	93	
E.O.	3.29	.44		SMA14

Large Vertical Pumps

Median = 2.21
Beta (T) = .39
Beta (R) = .22
Beta (U) = .32

Parameter = spectral acceleration (g)
Frequency = 5 Hz
Damping = 5%

Predominant failure mode = failure of support connections

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	2.29	.42	99	
E.O.	4.58	.42	100	

Motor Driven Pumps and Compressors

Median = 3.19
Beta (T) = .34
Beta (R) = .21
Beta (U) = .27

Parameter = spectral acceleration (g)
Frequency = 7 Hz
Damping = 5%

Predominant failure mode = impeller deflection

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
D.D.	3.19	.34		SMA16
D.D.	11.70	.42		SMA17

Large Motor Operated Valves (>4 in.)

Median = 4.83
Beta (T) = .65
Beta (R) = .26
Beta (U) = .60

Parameter = piping peak acceleration (g)
Frequency = rigid

Predominant failure mode = distortion of extended operator

For a failure mode of "distortion of extended operator," seven individual fragilities were combined.

			Reference	
Source	Median	Beta	OPNO	GRPNO
E.O.	17.29	.28	124	
E.O.	10.59	.26	123	
E.O.	11.19	.36	125 & 121	
E.O.	10.59	.48	128	
E.O.	7.03	.27	129	
S.G.	7.54	.65		SMA23
D.D.	7.31	.35		SMA24

Large Motor Operated Valves (>4 in.)

Median = 14.40
Beta (T) = .63
Beta (R) = .28
Beta (U) = .56

Parameter = piping peak acceleration (g)
Frequency = 15 Hz

Predominant failure mode = structural failure

For a failure mode of "structural failure" one expert opinion was used (OPNO=114). This was the lowest (i.e., most conservative) structural failure estimate given by the experts.

Large Hydraulic and Air Actuated Valves

Median = 7.61
Beta (T) = .46
Beta (R) = .31
Beta (U) = .34

Parameter = piping peak acceleration (g)
Frequency = rigid

Predominant failure mode = loss of control air

One expert opinion (OPNO=122) was used for this category.

Large Relief, Manual, and Check Valves

Median = 8.90
Beta (T) = .40
Beta (R) = .20
Beta (U) = .35

Parameter = piping peak acceleration (g)
Frequency = rigid

Predominant failure mode = internal damage

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	8.92	.13	130	
E.O.	12.70	.13	131	
S.G.	47.50	.47		SMA26

Misc. Small Valves

Median = 12.50
Beta (T) = .54
Beta (R) = .33
Beta (U) = .43

Parameter = piping peak acceleration (g)
Frequency = rigid

Predominant failure mode = internal damage

Two individual fragilities were combined for this category. Note that each of these utilized four different expert opinions in their development.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	16.00	.62	133, 135, 136, 137	
E.O.	21.60	.71	138, 139, 140, 141	

Small Motor Operated Valves (≤4 in.)

Median = 9.84
Beta (T) = .65
Beta (R) = .26
Beta (U) = .60

Parameter = piping peak acceleration (g)
Frequency = rigid

Predominant failure mode = distortion of extended operator

The source of this fragility is SAFEGARD data and it was calculated from capacities in NUREG/CR-2405 (GRPNO=SMA60). Note: This GRPNO was added to the fragility data base after publication of UCRL-53038, Rev. 1 (Appendix E).

Horizontal Motors

Median = 12.10
Beta (T) = .41
Beta (R) = .27
Beta (U) = .31

Parameter = zero period acceleration (g)
Frequency = rigid

Predominant failure mode = binding of rotating parts

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	12.40	.36	147	
E.O.	20.80	.28	148	

Generators

Median = .65
Beta (T) = .40
Beta (R) = .25
Beta (U) = .31

Parameter = spectral acceleration (g)
Frequency = 22 Hz
Damping = 5%

Predominant failure mode = shutdown valve trip

Eight individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	5.95	.44	149 & 150	
E.O.	5.95	.44	151 & 155	
E.O.	5.65	.48	153	
E.O.	10.40	.28	154	
S.G.	.93	.35		SMA28
S.G.	1.96	.36		SMA29

S.G.	.74	.40		SMA30
S.G.	8.94	.55		SMA31

Battery Racks

Median = 2.29
Beta (T) = .50
Beta (R) = .31
Beta (U) = .39

Parameter = zero period acceleration (g)
Frequency = rigid

Predominant failure mode = failure of battens

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	2.30	.42	156	
E.O.	20.80	.28	159	
D.D.	17.10	.48		SMA32

Switchgear

Median = 2.33
Beta (T) = .81
Beta (R) = .47
Beta (U) = .66

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = spurious operation of a protective relay

Three expert opinions (OPNO's = 161, 165, 171) of the same failure mode were combined for this category.

Dry Transformers

Median = 2.78
Beta (T) = .41
Beta (R) = .28
Beta (U) = .30

Parameter = spectral acceleration (g)
Frequency = 10 Hz
Damping = 5%

Predominant failure mode = failure of anchor bolts

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	4.66	.50	178	
E.O.	9.53	.68	177 & 225	
E.O.	3.11	.35	176	

Air Handling Units

Median = 2.24
Beta (T) = .41
Beta (R) = .27
Beta (U) = .31

Parameter = spectral acceleration (g)
Frequency = 5 Hz
Damping = 5%

Predominant failure mode = rubbing of fan on housing

Four individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	6.22	.36	179	
S.G.	2.75	.41		SMA38
S.G.	2.94	.42		SMA39
S.G.	11.80	.42		SMA40

Instrument Racks and Panels

Median = 1.15
Beta (T) = .82
Beta (R) = .48
Beta (U) = .66

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = relay chatter

Five individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	2.08	.28	180	
E.O.	4.93	.38	181	
S.G.	2.59	1.51		SMA41
S.G.	9.58	.81		SMA42
S.G.	18.20	.88		SMA43

Control Panels and Racks

Median = 11.50
Beta (T) = .88
Beta (R) = .48
Beta (U) = .74

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = dislodging or malfunction of component

Four individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O. & S.G.	16.80	.41	185 & 186	
E.O.	26.00	.22	187	
E.O.	24.70	.16	188	
S.G.	18.20	.88		SMA47

Auxiliary Relay Cabinets

Median = 7.63
Beta (T) = .82
Beta (R) = .48
Beta (U) = .66

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = relay trip

The source of this fragility is SAFEGARD data and it was calculated from capacities in NUREG/CR-2405 (GRPNO = SMA61).

Local Instruments

Median = 7.68
Beta (T) = .40
Beta (R) = .20
Beta (U) = .35

Parameter = spectral acceleration (g)
Frequency = 5-35 Hz
Damping = 5%

Predominant failure mode = loosening of fasteners

Six individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	8.96	.30	189	
E.O.	10.60	.26	190	
E.O.	10.60	.26	191	
E.O.	11.70	.20	192	
E.O.	13.40	.22	193	
E.O.	16.70	.32	194	

Motor Control Centers

Median = 7.63
Beta (T) = .88
Beta (R) = .48
Beta (U) = .74

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = breaker trip

The source of this fragility is SAFEGARD data and it was calculated from capacities in NUREG/CR-2405 (GRPNO = SMA62).

Light Fixtures

Median = 9.20
Beta (T) = .20
Beta (R) = .14
Beta (U) = .14

Parameter = spectral acceleration (g)
Frequency = 20-30 Hz
Damping = 5%

Predominant failure mode = dislodging of components

One expert opinion was used for this fragility (OPNO = 201).

Communication Equipment

Median = 5.00
Beta (T) = .48
Beta (R) = .33
Beta (U) = .35

Parameter = spectral acceleration (g)
Frequency = 10-50 Hz
Damping = 5%

Predominant failure mode = dislodging of components

Source: expert opinion.

Inverters

Median = 15.60
Beta (T) = .44
Beta (R) = .26
Beta (U) = .35

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = relay trip

The source of this fragility is SAFEGARD data and it was calculated from capacities in NUREG/CR-2405 (GRPNO = SMA52).

Cable Trays

Median = 2.23
Beta (T) = .39
Beta (R) = .34
Beta (U) = .19

Parameter = zero period acceleration (g)
Frequency = rigid

Predominant failure mode = support system failure

Three individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	3.11	.36	206	
E.O.	5.85	.41	207	
S.G. & D.D.	2.83	.57		SMA53

Ducting

Median = 3.97
Beta (T) = .54
Beta (R) = .29
Beta (U) = .46

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 7%

Predominant failure mode = structural failure

Five individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	7.05	.27	208	
E.O.	7.14	.68	209, 211, 214	
E.O.	7.98	.81	210, 213	
E.O.	6.79	.30	212	
E.O.	9.09	.44	215	

Hydraulic Snubbers and Pipe Supports

Median = 1.46
Beta (T) = .54
Beta (R) = .22
Beta (U) = .49

Parameter = rated load

Predominant failure mode = weld failure

Source: expert opinion.

Relays

Median = 1.66
Beta (T) = 1.51
Beta (R) = .57
Beta (U) = 1.40

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = relay chatter

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
E.O.	5.67	1.16	182	
S.G.	2.59	1.51		SMA45

Circuit Breakers

Median = 7.63
Beta (T) = .88
Beta (R) = .48
Beta (U) = .74

Parameter = spectral acceleration (g)
Frequency = 5-10 Hz
Damping = 5%

Predominant failure mode = breaker trip

Two individual fragilities were combined for this category.

Source	Median	Beta	Reference OPNO	Reference GRPNO
S.G.	9.58	.82		SMA55
S.G.	18.17	.88		SMA56

Ceramic Insulators

Median = .20
Beta (T) = .35
Beta (R) = .25
Beta (U) = .25

Parameter = peak ground acceleration (g)
Frequency = 2-8 Hz
Damping = 5%

Predominant failure mode = fracture of porcelain

The source of this fragility is expert opinion verified by actual earthquake data (GRPNO = SMA63).

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16. ABSTRACT (200 words or less)

The Seismic Safety Margins Research Program (SSMRP) is an NRC-funded, multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete and fully-coupled analysis procedure, including methods and computer codes, for estimating the risk of earthquake-induced radioactive release from a commercial nuclear power plant. As part of this program, calculations of the seismic risk from a typical commercial nuclear reactor were made. These calculations required a knowledge of the probability of failure (fragility) of safety-related components in the reactor system that actively participate in the hypothesized accident scenarios. This report describes the development of the required fragility relations and the data sources and data reduction techniques upon which they are based. Both building and component fragilities are covered. The building fragilities are for the Zion Unit 1 reactor, the specific plant used for development of methodology in the program. Some of the component fragilities are site-specific, but most would be usable for other sites as well.

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