SEISMIC SAFETY MARGINS RESEARCH PROGRAM*

(PHASE I)

Project I - Plant/Site Selection

Plant/Site Selection Assessment Report

MASTER

20 July 1979

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EXECUTIVE SUMMARY

Lawrence Livermore Laboratory (LLL) is conducting research on the seismic risk of nuclear power plants through the Seismic Safety Margins Research Program (SSMRP). Phase I of the SSMRP will include a study of an existing plant and site.

This report presents results of a study of existing and planned nuclear power plants in the United States. Selection criteria were developed and a recommendation for a specific plant for the SSMRP Phase I effort is given. Power plant characteristics including types of nuclear steam supply system, containment structure, electric power capacity, geographic location, site seismicity, and foundation soil properties were evaluated.

Based on the results of the evaluation, the Zion Nuclear Power Plant located near Zion, Illinois is recommended, with the additional recommendation that several levels of seismic site hazard be considered in Phase II. A description of specific characteristics of the Zion plant and site is also presented.

1. INTRODUCTION

Lawrence Livermore Laboratory (LLL) is conducting research on the seismic risk of nuclear power plants through the Seismic Safety Margins Research Program (SSMRP). The goal of the SSMRP is to develop methodologies for evaluating the performance of nuclear power plants during an earthquake, including calculation of an estimated probability of release of radioactivity. Phase I of the SSMRP will focus the issues using an existing plant and site. One aim of Phase I is to begin development of a generic methodology which could be applied to any nuclear power plant.

This report presents the results of a study of nuclear power plants performed by Engineering Decision Analysis Company, Inc. (EDAC) under LLL Contract No. 545-3703, Amendment 3. The Zion Nuclear Power Plant has been tentatively selected for the SSMRP Phase I studies. The purpose of EDAC's investigation was to determine if Zion is a reasonably representative plant for the Phase I effort. A description of the analyses and evaluations made, conclusions regarding selection criteria, and recommendations for a specific plant are presented. Based on this study, the Zion nuclear power plant is recommended for Phase I with the proviso that several levels of seismic site hazard should be used in the analyses in Phase II in order to obtain more generic results.

Chapter 2 presents the summary and conclusions on criteria and the selection of the Zion plant. Chapter 3 discusses the plant selection in more detail. Chapter 4 describes specific characteristics and design parameters for the Zion plant and site.

2. SUMMARY AND CONCLUSIONS

Criteria for plant selection were developed to maximize the generic implications from Phase I of the SSMRP. With this goal in mind, the following characteristics were compared:

- Nuclear Steam Supply System
- Containment Structure
- Electric Power Generating Capacity
- Geographic Location
- Site Seismicity
- Foundation Soil Properties

No single nuclear power plant can represent all plants equally well. However, a reasonable selection should optimize the applicability of the results and conclusions of Phase I.

Based upon the above nuclear power plant characteristics, Zion was found to be reasonably representative of operating and future plants. Zion characteristics are in general minimally different from those of other plants. However, it appears the seismic design criteria at the Zion site may have been more conservatively estimated than is typical for peer plants. This is discussed in Chapter 3.

Utility cooperation is also important. Commonwealth Edison has been most helpful in providing information about its Zion nuclear power plant. This cooperation has played a significant role in the preliminary selection of Zion for the SSMRP Phase I effort.

The Zion plant has been validated as an excellent choice for selection as the SSMRP Phase I study plant. However in Phase II, to compensate for the possibility that Zion was designed for an uncharacteristically high Safe Shutdown Earthquake (SSE) peak ground acceleration, it is recommended that several levels of seismic site hazard be used. These levels should correspond to a range of characteristics for United States plants to ensure that the resulting range of values for the probability of failure of structures, systems, or components will bound actual conditions.

3. COMPARISON OF NUCLEAR POWER PLANT CHARACTERISTICS

Pertinent characteristics of present and future nuclear power plants were compared to verify that the Zion Nuclear Power Plant is representative of plants in the United States. Although no single nuclear power plant can completely represent all plants, the purpose of the comparison was to establish that the characteristics of Zion are reasonably representative of the nuclear power plant characteristics related to seismic hazard and structural capacity. The following characteristics were used as the basis for the comparison.

- Nuclear Steam Supply System
- Containment Structure
- Electric Power Generating Capacity
- Geographic Location
- Site Seismicity
- Foundation Soil Properties

A comparison of the above characteristics for plants in the United States is given in the following text. Specific descriptions of the characteristics of the Zion plant are given in Chapter 4.

NUCLEAR STEAM SUPPLY SYSTEM TYPE

Pressurized water reactors (PWR) and boiling water reactors (BWR) are the principal types of nuclear steam supply systems (NSSS) used in nuclear power plants which have been built or are planned for construction in the near future. Table 3-1 presents these two NSSS types by age. Each NSSS type in the table has been further segregated by NSSS vendor. In the

early development of commercial nuclear power plants (the period 1960 to 1971), there were more BWR than PWR plants. However, more than twice as many PWR than BWR plants have been built since 1971. Based on the number of plants under construction or planned, it is clear that the PWR has become established as the most common NSSS type. Zion is a PWR plant with the NSSS for both units supplied by the Westinghouse Electric Corporation (Westinghouse), the largest single vendor of PWRs. As described in Table 3-1, the trend toward PWRs is continuing. Zion is thus typical of nuclear power plants in terms of NSSS type.

CONTAINMENT STRUCTURE TYPE

There are three basic containment structure types for PWRs: reinforced or prestressed concrete, and welded steel with reinforced concrete shielding. The age distribution for the various types is shown in Table 3-2. Note there has been a consistent trend towards the use of prestressed concrete containments. This trend is not as pronounced as that for NSSS. However, it is apparent the most common type of PWR containment construction has been and continues to be prestressed concrete. The Zion reactor buildings are enclosed by prestressed concrete. Hence Zion is representative of typical PWR containment types.

ELECTRIC POWER CAPACITY

The size of a nuclear power plant is generally related to its electric power generating capacity. Figure 3-1 shows the relationship between electric power capacity and age. The electric power capacity per unit has increased steadily since plants were constructed in the early 1960's. Current capacities are leveling out and it appears this trend will continue. At present, the average power produced per unit is 728 net MWe, and the average for plants under construction or in planning is 1,120 net MWe. The Zion plant units are presently among the largest, with a capacity of 1,100 net MWe each, and are representative of the newer plants and plants which will be constructed in the near future.

GEOGRAPHIC LOCATION

The seismic hazard to which a nuclear power plant is exposed is related to the geographic location of the plant. The potential for earthquakes is greater on the West Coast compared to other parts of the contiguous United States. Table 3-3 gives the geographic distribution of plants as a function of age. Most nuclear power plants have been built or are being built east of the Rocky Mountains. Zion is located in Illinois, and thus it is representative of a large number of plants. Specific site seismicity is discussed in the following section.

SITE SEISMICITY

The seismic capacity of a plant is determined in part by the value of the SSE peak ground acceleration used to design the plant. However, the relationship between the design SSE (which is related to seismic capacity) and the site seismic hazard (which is related to seismic demand) will more directly influence the probability of radioactive release than the SSE value alone. Even though a plant may be located in a low seismic region, both the plant capacity and the site hazard are required to determine seismic risk.

Figure 3-2 shows a histogram of design SSE accelerations for licensed nuclear power plant units. The average design SSE acceleration is 0.16g, whereas the Zion plant was designed for 0.17g. So from the standpoint of seismic capacity, Zion is representative of nuclear power plants in the United States.

As discussed above, the relationship between the SSE acceleration and the site hazard may be more significant with regard to risk than the SSE acceleration alone. A recent United States Geological Survey (USGS) report prepared by Algermissen and Perkins (Ref. 4) provides a basis for suggesting that SSE acceleration values may not correspond closely to

seismic hazard. Figures 3-3 and 3-4 show the ratios of SSE accelerations to 500-year return period accelerations from the USGS report. The hazard map in the USGS report does not show contour values less than 0.04g. Since many plants, including Zion, are located in zones with acceleration values less than 0.04g, values of 0.04g were arbitrarily assigned for these cases. Three plants (Dresden, Yankee-Rowe, and La Crosse) were not designed for significant accelerations and are not included in either figure.

Figure 3-3 shows a histogram distribution of ratios for licensed nuclear power plants. The average value for all the units is 2.8. However, there is a significant difference between the ratios for plants in seismic zones with accelerations greater than 0.04g as compared to plants in zones with accelerations less than 0.04g. Units located at sites where the map accelerations are less than 0.04g (which includes Zion) have an average ratio of 3.9, while those plants where acceleration values are greater than 0.04g have an average ratio of 2.2.

As shown in Figure 3-4, there is little correlation between the ratios and the year units began commercial operation. Note also that the spread of ratios is large. If actual values for sites with accelerations less than 0.04 were known, it is likely that the spread of ratios would be even larger. The ratio for the Zion units is 4.3, which is higher than the average of 2.8 for all sites. The ratio for Zion is also higher than the 3.9 average value for plants located in seismic zones with accelerations of less than 0.04g. It appears that the seismic hazard at the Zion site may have been more conservatively estimated when the SSE design criteria was established than is typical. Consequently, the Zion plant may be more conservatively designed than is typical for other plants. In order to compensate for this possibility, it is recommended that several levels of site seismic hazard be used to calculate the probability of

failure of structures, systems, and components in Phase II. In this manner the Zion plant can be utilized to simulate risk characteristics for a range of sites and plants.

FOUNDATION SOIL PROPERTIES

Site soil characteristics were obtained from a report prepared for General Atomic Company (Ref. 5). This report categorizes site conditions and gives soil data, including shear wave velocities, for 69 nuclear power plant sites located in the United States. Included in the report are plant sites currently licensed to operate as well as some sites where plants are under construction or planned. There is no reason to believe that there are any significant differences in the distribution of site soil characteristics between present and future sites, nor any bias in the selection of sites used in Reference 5. Hence it is believed that the sites used in the report are reasonably representative of sites in the United States.

Five types of sites were defined in Reference 5 based on thickness of soil layers beneath the plants, and on whether the base rock is plutonic or sedimentary. Table 3-4 lists the soil types, rock categories, and the number of sites in each group. There is a reasonably uniform distribution at soil sites for the 69 plants studied. However, sites underlain by sedimentary rock such as Zion, are more numerous than sites underlain by plutonic rock.

Shear wave velocities were also compared among nuclear power plant sites. This parameter is related to soil stiffness which affects dynamic response characteristics. For sites with a single soil layer, the shear wave velocity values from Reference 5 were used directly. For cases of layered soils, average shear wave velocities were computed by weighting the values for each layer in accordance with the thickness of the layer. Since shear wave velocities were given only for soil layers

down to bedrock, only these values were used to compute the average shear wave velocities.

Figure 3-5 presents shear wave velocities for Type III sites, the category that includes the Zion site. The average of the 11 shear wave velocities shown is 1,630 fps. The shear wave velocity for the Zion site based on Reference 5 is 1,450 fps. Accounting for stiffness properties of the bedrock a value of 1,650 fps was used in the design (Ref. 22). Thus, in terms of soil type, base rock category, and shear wave velocity (for Type III soils), the Zion site appears to be typical and representative of sites in the United States.

CONCLUSION

Based on a comparison of nuclear power plant characteristics, it was found that Zion is reasonably representative of both operating and future plants. Since nuclear power plants in the United States are a diverse group, it is impossible to pick a single plant which represents all plants equally. However, for the Phase I study of the SSMRP, Zion is an excellent choice.

In order to compensate for the possibility that Zion was designed for a SSE peak ground acceleration value which is uncharacteristically high when compared to other plants, it is recommended that several levels of seismic site hazard, which correspond to a range of characteristics for United States plants, be used in the SSMRP analysis in Phase II. This will ensure that a range of values for the probability of failure of structures, systems, or components will bound actual conditions which exist at plants throughout the country.

TABLE 3-1
NUCLEAR STEAM SUPPLY SYSTEM TYPE VERSUS PLANT AGE
 (Based on Ref. 1)

Age	Type PWR, by Reactor Supplier					Total ²
	BWR ¹	Combustion	Westinghouse	Babcock &	PWR	
		Engineering		Wilcox		
1960-1971	10	1	6	1	8	18
1972-1978	15	6	19 ³	9	34	49
Construction Started or Permit Granted	29	16	41	8	65	94
Planned	<u>8</u>	<u>8</u>	<u>11</u>	<u>9</u>	<u>28</u>	<u>36</u>
Totals	62	31	77	27	135	197

1. All BWR reactors are supplied by General Electric Co., except for the LaCrosse (48 MWe demonstration) plant by Allis-Chalmers, licensed in 1969.
2. Total does not include the high temperature gas reactor at the Fort Saint Vrain Station, built by General Atomic, presently in power ascension for commercial operation in late 1978.
3. Zion is in this category.

TABLE 3-2
CONTAINMENT TYPE VERSUS AGE OF PWR PLANTS
 (Based on Ref. 2)

Age	Containment Type				Total
	Welded Steel With Reinforced Concrete Shielding Spherical ¹	Cylindrical	Reinforced Concrete	Prestressed Concrete	
1960-1971	3	0	1	4	8
1972-1978	0	5	10	19 ²	34
Construction Started or Permit Granted	5	14	18	28	65
Totals	8	19	29	51	107

1. All steel containments include reinforced concrete shield buildings except for the freestanding steel spherical containment at the Yankee-Rowe plant, licensed in 1961.
2. Zion is in this category.

TABLE 3-3
GEOGRAPHIC DISTRIBUTION VERSUS AGE OF PLANTS
 (Based on Ref. 1)

<u>Year Operation Began or is Anticipated</u>	<u>Location</u>		<u>Total</u>
	<u>West of Rockies</u>	<u>East of Rockies</u>	
1960-1971	2	16	18
1972-1978	2	48 ¹	50
Beyond 1973: Construction Started or Permit Granted	12	82	94
Beyond 1978: Planned	<u>6</u>	<u>30</u>	<u>36</u>
Totals	22	176	198

1. Zion is in this category.

NOTE: Table does not include the following plants: Clinch River Breeder Reactor, NORCO-1 (Puerto Rico), or Hanford-N (Richland, Wash.).

TABLE 3-4
NUCLEAR POWER PLANT SITES
BASED ON DAMES & MOORE REPORT CATEGORIES (Ref. 5)

<u>Soil Type</u>	<u>Rock Category</u>		<u>Total</u>
	<u>Category X</u> <u>Underlying Rock</u> <u>is Plutonic</u>	<u>Category S</u> <u>Underlying Rock</u> <u>is Sedimentary</u>	
Type I: Soil Cover 20 ft or less	6	10	16
Type II: Soil Cover 20 ft to 40 ft	4	5	9
Type III: Soil Cover 50 ft to 100 ft	4	12 ¹	16
Type IV: Soil Cover 100 ft to 400 ft	3	11	14
Type V: Soil Cover more than 400 ft	14 Sites (Categories not Applicable)		14

1. Zion is in this category

FIGURE 3-1 ELECTRIC POWER CAPACITY VERSUS AGE OF PLANT

(Based on Ref. 1)

FIGURE 3-2 HISTOGRAM OF DESIGN SSE ACCELERATIONS FOR LICENSED NUCLEAR POWER PLANT UNITS

(Based on Ref. 3)

FIGURE 3-3 HISTOGRAM OF RATIOS OF DESIGN SSE ACCELERATION FOR LICENSED NUCLEAR POWER PLANTS TO ACCELERATION FROM USGS RISK MAP (Based on Ref. 3 and 4)

FIGURE 3-4 RATIOS OF DESIGN SSE ACCELERATION FOR LICENSED
NUCLEAR POWER PLANTS TO ACCELERATION FROM USGS RISK MAP

(Based on Ref. 3 and 4)

FIGURE 3-5 DISTRIBUTION OF SHEAR WAVE VELOCITIES FOR
SITES WITH 50 to 100 FOOT SOIL COVER OVER BEDROCK
(Based on Ref. 5)

4. DESCRIPTION OF ZION NUCLEAR POWER PLANT

INTRODUCTION

In this chapter, general background of the Zion plant, site characteristics, Seismic Category I building structures, piping, and equipment, and design parameters are discussed. This description is based on information from the Final Safety Analysis Report (FSAR) (Ref. 6) and recent information received from Sargent and Lundy Engineers.

GENERAL BACKGROUND

The Zion nuclear power plant is located on Lake Michigan about 1.5 miles east of Zion, Illinois and about 40 miles north of Chicago. The plant was designed by Sargent and Lundy Engineers for Commonwealth Edison, the owner and builder. The plant consists of two NSSS units with a power rating of 1,100 MWe each. The first unit was granted an operating license which became effective April 1973. Zion Unit 2 was licensed to operate in November 1973.

SITE CHARACTERISTICS

The characteristics pertinent to the site are the geology and seismicity, types of foundation soils, and types of foundations used.

Geology and Seismicity

Geology and seismicity characteristics including rock types, regional structures and faulting, and historical seismicity for the Zion plant are given in the FSAR and Reference 7. A discussion of these site characteristics, based on information given in these references, follows.

Rock Types -- Bedrock in the region surrounding the Zion plant generally consists of Paleozoic sedimentary rock overlying Precambrian basement rock. This rock base is generally covered by a mantle of glacial drift, about 80 to 150 feet thick. In addition there are recent layers of unconsolidated sand, silt, and peat deposited by streams and lakes; however, these layers were thin at the site and were removed during excavation for the Zion structures.

Regional Structures and Faulting -- The predominant structural feature of the region is the Kankakee Arch, which separates the Michigan Basin in the northeast from the Illinois Basin to the south. Several faults have been located in the region, although there is no evidence of recent seismic activity. Approximately 25 miles southwest of the site, near Dec 'laines, a highly complex faulted zone which does not appear to have any relationship to the regional structure has been located. There are several faults in southern Wisconsin; the closest one to the site is located approximately 45 miles away. There are also faults in northeastern Illinois, although none of these faults are within 50 miles of the site. All of the faults discussed above are covered by glacial drift, and there is no evidence of faulting at the ground surface.

Historical Seismicity -- The Zion site is located in an area which is considered to be a region of only minor seismic activity. Figure 4-1, taken from Reference 7, shows the locations of earthquake epicenters in the region. The largest seismic events in the area were the 1804 Ft. Dearborn, Illinois and the 1909 Beloit, Wisconsin earthquakes. Both earthquakes were reported to have epicentral Modified Mercalli Intensities (MMI) of VII. In Reference 7, the 1804 event was discussed and it was reduced to a MMI Intensity VI; however, it appears that little is known about the event.

It is believed that the epicenter and intensity of the 1909 event were more reliably estimated than the parameters of the 1804 event. Intensities near the Zion site for the 1909 event were probably between IV to V.

An earthquake occurred on 14 September 1972, the only seismic event observed in the region since the Zion plant began operation (Ref. 19). The epicenter was located near Holcomb, Illinois, west of Sandwich. A 3.7 Richter magnitude was recorded, and the epicentral intensity was estimated to be a MMI VI. The event was felt over a large area, including Michigan, Ohio, and Minnesota; however, damage was slight even at the epicenter. The intensity at Zion was estimated to be in the range of MMI I to III (Ref. 20).

Soils

An investigation of the Zion site was conducted prior to construction of the plant. Both laboratory and site tests were performed as part of the soils work. Figure 4-2 (Ref. 7) shows the location of the bore holes at the Zion site. Samples from the borings were used to perform direct shear tests, confined and unconfined compression tests, consolidation tests, and tests for density and particle size.

The site tests included geophysical refraction surveys, shear wave velocity surveys, and uphole velocity surveys. Micro-motion measurements were also made.

Typical soil conditions at the Zion site are shown in Figure 4-3 (Ref. 7). Descriptions of the testing methods and results pertaining to soil conditions at the Zion site are included in Reference 7.

Foundations

Based upon the results of the soils investigation, recommendations concerning foundation types, bearing pressures, and excavation details were

made (Ref. 8). The reactor containment building and the turbine building were constructed on separate mat foundations. Conventional spread footings were recommended for the service building and for other light structures. Some bearing pressures recommended for foundations at the Zion site are given in Table 4-1. The values for mat foundations are based on ultimate bearing capacities of 15,000 psf above Elevation 575 feet and 40,000 psf below Elevation 575 feet. The complete recommendations regarding bearing pressures are presented in Reference 8.

For excavations, it was recommended that the banks of excavated areas be constructed at a slope of 1 vertical to 1.5 horizontal or flatter. An exception was made for temporary excavations in the lower glacial till. For this material, it was stated that banks for reactor building excavations having an unsupported height of approximately 20 feet or less and not subjected to significant surcharges may be cut vertically. Sheet piles were used for the construction of the crib house. The necessity of an adequate dewatering system to protect the excavations was also discussed in the FSAR.

Note that the information regarding bearing pressures and excavations described above were recommendations made before construction began. However, the soil bearing pressures recommended in the Dames & Moore report were used as acceptance criteria for the soil pressure calculations.

CATEGORY I BUILDING STRUCTURES

Seismic Category I building structures at the Zion plant (referred to as seismic "Class I" in Ref. 6) include the reactor containment buildings, fuel handling building, auxiliary building, diesel generator buildings, and portions of the turbine and crib house buildings; see Figure 4-4.

The two reactor containment buildings are identical and are constructed of prestressed concrete with ungrouted tendons. Each reactor building

consists of a cylindrical shaped exterior wall with a shallow domed roof and a flat foundation mat. The dimensions of the reactor containment shell are approximately 140 feet in diameter by 212 feet high with 3-foot thick walls and a 9-foot thick foundation mat. The containment structures are lined with 0.25-inch thick welded steel plate to provide vapor tightness. Detailed plans and sections are given in Reference 6.

Design Criteria

Peak ground accelerations and response spectra, and load combinations and acceptance criteria used to design the Zion structures are presented in the FSAR. In the following discussion, emphasis is given to the criteria associated with seismic hazard potential.

Peak Ground Accelerations and Response Spectra -- The Zion plant was designed for a Safe Shutdown Earthquake (SSE) of 0.17g effective peak ground acceleration (EPGA).^{*} It was also designed for an Operating Basis Earthquake (OBE) of 0.08g EPGA.

The design response spectra anchored to the SSE EPGA are shown in Figure 4-5. The corresponding spectra for the OBE are equal to one-half of the SSE spectra. These spectra are less conservative than those in USNRC Regulatory Guide 1.60 (Ref. 9); however, lower damping values were also used which is somewhat compensating.

Load combinations and Acceptance Criteria -- Earthquake loads were considered in combination with dead, thermal, and pressure or pipe rupture loads for Category I buildings other than the reactor containment structures. Examples of seismic load combinations used in the design of most structural members are presented in Table 4-2.

^{*} EPGA is defined as the acceleration to which the design response spectra are anchored.

Acceptance criteria for Category I buildings were based on both the provisions of the American Concrete Institute (ACI) and the American Institute of Steel Construction (AISC) codes which were applicable at the time of design (Ref. 10 and 11). The buildings were designed to remain elastic during the OBE, but concrete ultimate strength or steel yield stress design methods were used for the SSE criteria as noted in Table 4-2.

Load combinations and acceptance criteria used for the design of the reactor containments were different than criteria for other Category I buildings. The load combinations used in the design included earthquake loads together with dead, prestress, and accident-related loads and are given in Table 4-3. For the first load combination given in the table, the working stress method of ACI 318-63 was used in the design. For the other combinations, a "yield limit design" method was used which is similar to the factored load design of the present concrete containment code, ASME, Section III, Division 2. The allowable stresses of the yield limit design method are similar to the resulting stresses of the ultimate strength method. However, for the yield limit design method, redistribution of loads at strains beyond yielding was not allowed. A more complete description of this approach is given in Reference 6.

The steel liner plates of the reactor containment buildings were designed using the first load combination equations presented in Table 4-3, which was discussed earlier.

Analysis Procedures

Zion was one of the first nuclear power plants to be analyzed during the design process for dynamic loads using computer models. Lumped-mass models were used, and the different locations of the shear and mass centers were considered so as to include torsional motions. At least three different models were used in the analysis to represent the containment, the auxiliary-turbine buildings, and the interconnected fuel

handling, auxiliary, turbine, and crib house (connected by service lines) buildings. Damping values assumed in the analyses for the structures were 2 percent for the OBE and 5 percent for the SSE.

Some effects of soil-structure interaction were considered in the analyses. For the reactor containment building model, a rocking spring was included. The auxiliary-turbine building was originally analyzed using a fixed base model, but later in the analysis a finite-element soil model was developed. Additional information concerning the dynamic analysis models, including the approach used to model soil-structure interaction, is given in Reference 6.

Design forces were obtained by the response spectrum method, except that vertical forces were assumed to be two-thirds of the peak horizontal ground acceleration times the building mass.

Time history analyses were performed to generate horizontal floor response spectra. Vertical floor response spectra were assumed to be two-thirds of the corresponding horizontal spectra.

Analysis Results

The results of the analysis (Ref. 6) verified that the Category I buildings would remain elastic for an OBE and there was adequate strength to withstand an SSE. However, the plant was also designed for other load combinations which may have controlled the design but which did not include seismic loads. Reference 6 gives a comprehensive description of the results of the analysis.

CATEGORY I PIPING AND COMPONENT SYSTEMS

There are several piping systems which were classified as Seismic Category I systems. Table 4-4 gives 15 piping systems which were included in

Category I. These systems can be categorized according to function (e.g., reactor cooling, engineered safety, or auxiliary systems). In terms of seismic safety, the most important systems are those which are required for reactor cooling or are required for other engineered safety-related functions (e.g., emergency core cooling, auxiliary feedwater, containment isolation, and containment spray systems). The reactor cooling systems are discussed below.

Reactor Cooling

The piping and components of the primary cooling systems consist of four heat transfer loops which are connected to the reactor pressure vessel (RPV). Each loop includes a circulating pump, two isolation valves, and a steam generator. Some other components are shared by more than one loop.

Primary cooling piping design data are presented in Table 4-5. More detailed data, including flow diagrams and sectional drawings, are given in Reference 6. Design and analysis criteria for the RPV's, primary piping, and reactor cooling components are discussed next.

Reactor Pressure Vessels -- The RPVs for both Zion units were designed to the criteria of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III (Ref. 12). Detailed stress analyses were performed which included seismic loads. Methods of analyses, as well as testing and quality assurance procedures, are described in Reference 6.

Primary Piping -- Primary cooling system piping was designed in accordance with codes tabulated in the response to FSAR Question 4.14. Specifically, the design of the main piping was based on B31.1 (1955) plus Code Cases N7 and N10 (according to Ref. 21). The branch piping was based on B31.1 (1967) plus Case N7. Two conditions were applied for seismic loading:

Emergency Condition (OBE)

$$P_m + P_b \leq 1.2 S_h$$

Faulted Condition (SSE)

$$P_m + P_b + P_L \leq 2.0 S_h$$

where

P_m = Primary membrane stress

P_b = Primary bending stress

P_L = Primary local membrane stress

S_h = Allowable (hot) stress value

In addition, some guidance was gained from the 1969 ANSI B31.7 code (Ref. 14). Specifically, answers to questions documented in Reference 6 indicate that a load combination was used which included thermal, anchor movement, and seismic inertial loads.

Seismic analyses of piping smaller than 10 inches in diameter were performed using design curves. These curves gave fundamental periods, maximum midspan deflections, and restraint forces, as a function of pipe span length. Two sets of curves were developed for the 0.5 percent damping floor response spectra. The curves were used to design piping in two regions within the plant. Design curves for piping in the lower part of the reactor containment building were based on the floor response spectrum developed at Elevation 617 feet. For higher elevations, a factor of 3.0 was applied to all responses to account for potential building amplification.

In addition to the load combinations of ANSI B31.1, large primary piping runs were designed for loss of coolant accident (LOCA) loads combined with seismic loads. Load combinations were considered for the hot leg,

cold leg, and crossover leg piping runs. LOCA loads were based on a time history analysis of a "single broken loop dynamic model" (Ref. 6).

Seismic analyses of all Seismic Category I piping larger than 10 inches in diameter were performed with lumped mass models based on the response spectrum method. Damping assumed for the OBE loading was 0.5 percent of critical damping and 1 percent for the SSE criteria.

Reactor Cooling Components -- Components associated with the primary cooling system generally were designed and analyzed in accordance with the ASME code (Ref. 12). Table 4-6 lists the codes which were applied to the RPV and associated components.

Components for the NSSS were analyzed by Westinghouse, the NSSS vendor. These components included the heat exchangers, pressurizers, pumps, tanks, valves, and RPV. Lumped-mass multidegree of freedom models were used to analyze these components. For components which were similar to components previously analyzed, the analyses for the previous components were checked to ensure that the Zion loading was less severe. For some components, new analyses were performed using response spectra that enveloped the Zion floor response spectra.

Seismic Category I components which were not supplied by Westinghouse were analyzed or tested using procedures which depended on the complexity and size of the component. Components which were structurally simple were analyzed using single degree of freedom models. More complex components were analyzed using lumped-mass multidegree of freedom models and the response spectrum method. Alternatively, some components were tested by shake tests. Reference 6 discusses in detail the methods of analysis and testing used to qualify the components.

Engineered Safety-Related Piping Systems

Engineered safety features were provided to assure safety of plant in the event of a LOCA. Descriptions of the emergency core cooling, auxiliary feedwater, containment isolation, and containment spray systems are given in the following text.

Emergency Core Cooling System -- The purpose of emergency core cooling is to prevent reactor core damage in the event of a LOCA. Four criteria developed to meet the requirements of Reference 15 were:

- The calculated maximum fuel element cladding temperature should not exceed 2,300 degrees Fahrenheit
- The amount of fuel cladding reacting chemically with water or steam should not exceed 1 percent of the total in the reactor pressure vessel
- The cladding temperature transient should be terminated while the core geometry is still amenable to cooling and before the cladding is embrittled
- The core temperature should be reduced and the decay heat removed for an extended period of time

The emergency core cooling systems (ECCS) in the Zion plant were designed to comply with these criteria by function in two phases. In the safety injection phase, cooling water would be injected immediately following a LOCA. Later, the systems would operate in a recirculation mode in order to provide long-term cooling. Preoperational tests were performed as described in Reference 6 in order to evaluate the capability of the systems to perform these functions. Since the issuance of Zion's FSAR, the ECCS performance has been reanalyzed and found to comply with the NRC's final acceptance criteria. Those criteria are delineated by the NRC in 10CFR50.46 and 10CFR50, Appendix K (according to Ref. 21).

The codes used to design the ECCS included ASME and ANSI codes (Ref. 12 and 13). Table 4-7 summarizes the codes which were used in the design of the ECCS.

Auxiliary Feedwater System -- The function of the auxiliary feedwater system is to provide adequate cooling water to the steam generators in the event of a reactor trip (see the section on protective equipment below) along with a loss of offsite power. Each auxiliary feedwater system consists of two subsystems, one utilizing a turbine-driven pump and the other utilizing motor-driven pumps. Each subsystem was designed to provide feedwater to the four steam generators of its unit.

Piping and components of the auxiliary feedwater systems were carefully inspected. All butt welds in Category I piping were inspected by liquid dye penetrant or magnetic particle tests in accordance with ASME requirements (Ref. 16). Butt welded joints on piping 2.5 inches in diameter and larger were radiographed in accordance with Reference 17. Inspection requirements which apply to auxiliary feedwater components are summarized in Table 4-8.

Containment Isolation System -- The purpose of the containment isolation system provided for each Zion unit is to seal off the containment building from the outside in the event of a LOCA. This system consists of protective barriers together with or in lieu of isolation valves for all lines which penetrate the containment except for lines that are required for service during an accident.

In order to ensure that the containment isolation valves are effective, each containment isolation system includes an isolation valve seal water system which is designed to provide water to the valve seats and stem packing, or into piping between valves, depending on the type of valve.

Some pipes are not connected to the valve seal water system. Reference 6 lists the seven classes of penetrations at the Zion plant which are connected to the valve seal water system.

Containment Spray System -- The purpose of the containment spray system provided for each unit is to remove iodine in the containment atmosphere and to limit the containment pressure below the design level in the event of an accident. This operation would be performed by pumping and spraying a NaOH solution inside the containment. The containment spray systems are divided into three independent subsystems, each having a capacity sufficient to comply with the design criteria.

The containment spray systems have been designed as Seismic Category I systems. The piping and components of these systems have been extensively inspected. All welds on piping 4 inches in diameter and larger have been tested using radiographic and liquid penetrant methods. Inspection requirements for containment spray system components are given in Table 4-9. Other information relating to design, inspection, or testing of these systems is given in Reference 6.

CATEGORY I EQUIPMENT

Equipment and systems may be roughly categorized according to the operating conditions under which they are designed to operate. Normal operating and accident conditions represent extremes. Between these extremes are certain abnormal conditions which by virtue of protective systems do not result in accident conditions. However, seismic criteria were in some cases the same for different pieces of equipment designed to operate under different conditions. Some pieces of equipment were also designed to operate under one or more different operating conditions.

Many systems encompassing a great deal of equipment are required by the plant, regardless of the operating condition. However, most important to

seismic safety are the reactor control systems, equipment associated with primary cooling or engineered safety piping systems, protection systems, and ventilation systems.

Reactor Control

The reactor automatic control systems are utilized during normal operation of the plant. They are designed to reduce nuclear transients due to plant load changes, so that the reactors may continue to operate through these changes. The systems enable each reactor to accept a step load increase or decrease of ten percent, and a ramp increase or decrease of five percent per minute without a reactor trip, within the range of 15 percent to 100 percent of nominal power. Manual operation is used below 15 percent nominal power, and is available at all times.

Control is achieved by the movement of rod cluster control assemblies (RCCA). In conjunction with RCCA insertions, the steam dump system permits the plant to accept a 50 percent reduction without a reactor or turbine trip. Input signals including neutron flux, coolant temperature, and turbine load are used. The control systems make use not only of dedicated instrumentation and measurement devices, but those of protection systems as well. However, isolation amplifiers are provided along the interface of these systems, so that one protective system will not be affected by disturbances in the control systems. The cables connecting the various elements of the control systems are normally supported in cable trays.

Cable trays for the control and other electrical systems have been laterally braced to resist seismic loads. Where convenient, trays were braced with horizontal struts and designed to resist maximum floor slab accelerations. Otherwise, cross bracing was used, in which cases the trays were designed to withstand the peak acceleration from the applicable floor response spectra.

Primary Cooling and Engineered Safety Systems Equipment -- The engineered safety systems use equipment which is entirely independent of equipment for primary cooling. However, in most cases, the same types of equipment are used. For example, many motor-driven valve operators are used by the primary cooling and engineered safety systems.

Seismic analysis and testing procedures are similar to those described for Category I components. Lumped-mass mathematical models or testing procedures were used based on the complexity and size of the equipment. For equipment supplied by Westinghouse, specifications of similar equipment supplied to other plants were checked to see that the loading was more severe than at Zion. Otherwise, new analyses or tests were performed. Overall, the procedures used were similar to those used for qualifying Category I components, except that generally the equipment tended to be somewhat smaller in size than the Category I components. Therefore, testing was relatively more prevalent than analysis in qualifying equipment as compared to Category I components.

Protection Systems

The reactor protection systems are designed to help prevent unsafe operating conditions, thereby enhancing safety. They serve to define allowable regions of power, coolant pressure and temperature.

If a protection system receives indication of an approach to unsafe operating conditions, the system actuates alarms, prevents control rod withdrawal, and initiates load cutback. One or more of the engineered safety systems may be activated. Alternatively or in combination with the above measures, the reactor trip breakers may be opened. Table 4-10 lists conditions for which the reactor may be tripped.

System design philosophy included a conscious goal of reliability. Each protective function was provided with redundant instrumentation channels

which are electrically isolated and physically separated. This also allows individual channels to be tested and calibrated during power operation without a reduction in protection. Furthermore, the system was designed so that a loss of voltage in a channel generally results in a signal to trip the reactor. The exception is containment spray initiation, which may be powered by emergency (diesel) sources if necessary.

The Zion protection systems were designed in accordance with proposed criteria of the Institute of Electrical and Electronic Engineers (IEEE), Reference 18. Seismic qualification was by type testing, using methods similar to those described previously for testing of other equipment or components.

Ventilation and Cooling Systems

Air handling systems are especially important to safety in two kinds of areas at Zion. These include the systems for the control room and also for the containment buildings, which include containment fan cooling, considered an engineered safety feature.

Control Room -- The heating, ventilating, and air conditioning (HVAC) system for the control room was designed to provide filtered air at the proper temperature and humidity under any plant condition, normal or abnormal, thus permitting occupancy during a safe shutdown of the plant.

The control room HVAC system consists of high efficiency particulate air (HEPA) and activated charcoal filters, a cooling and heating coil package, humidifier, and an axial fan. Circulated air is mixed with outside air as necessary to meet minimum ventilation and cooling requirements. Outside air is brought in through a missile-protected wall opening, or in the event of high radiation detection, from the turbine room. Turbine room air is automatically passed through the HEPA and activated charcoal filters.

According to Reference 6, all components and supports of the control room HVAC system meet Seismic Category I requirements.

Containment -- Two air-handling systems are provided for each containment building, the reactor containment fan cooler (RCFCS) and containment purge systems. Each system is designed to operate under both normal and postaccident conditions.

The containment fan cooler systems are each designed for both cooling and filtering air. Each RCFCS consists of five units, each of which is composed of a motor and fan, control and backdraft dampers, roughing and HEPA filters, and a moisture separator. Under normal operating conditions, only four of the five units are employed.

Under postaccident conditions, each containment fan cooler system is designed to limit the containment atmosphere to design pressure following a LOCA assuming that core residual heat is released as steam. Furthermore, the moisture eliminators are designed to remove 95 percent of free water particles of 10 microns and greater in size, protecting the HEPA filters, which in turn help remove radioactive airborne particulates. In the postaccident operation mode, a minimum of three RCFCS units would be required to achieve these functions.

The containment purge systems are designed to reduce airborne particulates in the containment atmosphere prior to release to the outside environment, and provide make-up air. Each system includes supply and exhaust fans, heating and cooling coils, and supply and exhaust filters, including HEPA and activated charcoal filters for exhaust. Seismic Category I equipment in the containment purge systems is listed in Table 4-11. Under normal operating conditions, the containment purge systems are designed to allow personnel access to containment within three hours of reactor shutdown.

Under accident and postaccident conditions, the systems are designed to operate differently than during normal operation. Monitors are designed to sense high radiation levels and automatically seal the containment. Safety is therefore intended to be provided for fuel handling or other activities in addition to reactor operation. In addition, the system is designed to remove hydrogen gas from the containment atmosphere and keep its concentration below the lower flammability limit for 30 days. After this time period, the hydrogen recombiners are activated. After radiation levels decay, the system would be used to vent the containment air through HEPA and activated charcoal filters, which are designed to remove remaining particulate matter.

TABLE 4-1
RECOMMENDED SOIL BEARING PRESSURES FOR ZION
PLANT BUILDING STRUCTURES (Ref. 8)

<u>Foundation Type</u>	<u>Elevation (ft)</u>	<u>Recommended Bearing Pressure (psf)</u>
Reactor Building Mat	554	6,000 to 7,000
Condenser Pit and Turbine Generator Pedestal	548	3,000 to 5,000
Turbine Building Mat	588	3,000 to 6,000
Auxiliary Building Mat	538 to 563	2,500 to 4,000
Fuel Handling Building Mat	577 to 583	2,000 to 5,000
Crib House	545	2,000 to 3,000
Spread Foundations on Granular Lake Deposits	Above 575	3,000 to 4,000*
	Below 575	5,000 to 8,000*
Spread Foundations on Controlled Compacted Fill	Above 575	3,000 to 4,000*
	Below 575	5,000 to 8,000*
Foundations on Glacial Till	-	15,000

*Recommended value depends upon depth of embedment

TABLE 4-2
SEISMIC LOAD COMBINATIONS AND ACCEPTANCE CRITERIA, ZION
PLANT CATEGORY I BUILDINGS OTHER THAN CONTAINMENT (Ref. 6)*

<u>Load Combination</u>	<u>Acceptance Criteria</u>	
$D + T_0 + E + P'$	Working Stress	ACI 318-63
		AISC 6th Edition
$D + T_0 + E' + R$	Ultimate Strength	ACI 318-63 USD
		Yield Strength of Steel

where

D = Dead load and permanent equipment load

T_0 = Thermal loading

P' = Reactor internal structures internal design load (14 psi)

R = Pipe rupture including dynamic effects

E = OBE load

E' = SSE load

*Load combinations given governed the design of most structural members (Ref. 22).

TABLE 4-3
SEISMIC LOAD COMBINATIONS AND ACCEPTANCE
CRITERIA, ZION PLANT CONTAINMENT BUILDINGS (Ref. 6)*

<u>Load Combination</u>	<u>Acceptance Criteria</u>
$D + F + P + T_A + E$	Working Stress (ACI 318-63)
$D + F + 1.25P + T_A + 1.25E$	Yield Limit Design - Concrete strain held to ultimate, steel allowed to just yield
$D + F + P_A + T + E'$	

where: D = Dead load
F = Prestress load
P = Accident pressure load
 T_A = Accident thermal load
E' = OBE load
E = SSE load

*Load combinations given governed the design of most structural members (Ref. 22).

TABLE 4-4
ZION NUCLEAR POWER PLANT
CATEGORY I PIPING SYSTEMS (Ref. 6)

- Reactor pressure vessel and cooling systems
- Emergency Core Cooling Systems
- Containment Spray Systems
- Penetration pressurization piping
- Isolation valve seal water piping
- Main steam and feedwater piping and penetration (including isolation valve)
- Main steam relief valve piping
- Component cooling
- Chemical and volume control
- Residual heat removal
- Spent fuel cooling
- Service water piping
- Waste gas piping
- Fire water piping
- Liquid radwaste piping

TABLE 4-5
PRIMARY COOLING PIPING AND COMPONENTS DATA (Ref. 6)

Item	Data Value
System design pressure	2,485 psig
Nominal operating pressure	2,235 psig
Coolant temperature at reactor inlet	530° F
Coolant temperature at reactor outlet	594° F
Total coolant flow rate (four loops)	1.35×10^6 lb/hr
Reactor vessel inside diameter of shell	173 inches
Reactor vessel thickness of shell	8.44 inches (min.)
Closure head thickness	6.50 inches
Vessel design temperature	650° F
Piping inside diameter, reactor inlet	27.50 inches
Nominal thickness at inlet	2.38 inches
Piping inside diameter, reactor outlet	29.00 inches
Nominal thickness at outlet	2.50 inches
Piping inside diameter, coolant pump suction	31.00 inches
Nominal thickness at coolant pump suction	2.66 inches
Piping design temperature	650° F

TABLE 4-6
CODES APPLIED TO ZION
PRIMARY COOLING SYSTEM COMPONENTS (Ref. 6)

<u>Component</u>	<u>Code</u>
Reactor Vessel	ASME III Class A
Rod Driving Mechanism Housing	ASME III Class A
Steam Generators	
Tube Side	ASME III Class A
Shell Side	ASME Class C
Reactor Coolant Pump Casing	No code, designed in accordance with ASME III, Article 4
Pressurizer	ASME III Class A
Pressurizer Relief Tank	ASME III Class C
Loop Isolation Valves	ASME III
Other Valves	ASA B16.5, MSS-SP-66, and ASME, Sec. III, 1968 Edition

TABLE 4-7
CODES APPLIED TO ZION
EMERGENCY CORE COOLING SYSTEM COMPONENTS (Ref. 6)

<u>Component</u>	<u>Code</u>
Refueling Water Storage Tank	Not Applicable
Residual Heat Exchanger	
Tube Side	ASME Section III Class C
Shell Side	ASME Section VIII
Accumulators	ASME Section III Class C
Valves	ANSI B16.5 or MSS-SP-66, and ASME III, 1968 Edition
Boron Injection Tank	ASME Section III Class C

TABLE 4-8
INSPECTION REQUIREMENTS FOR THE ZION
AUXILIARY FEEDWATER COMPONENTS (Ref. 6)

<u>Components or Parts of Components</u>	<u>Procedures and Codes</u>
Surfaces of pressure containing parts of pumps and turbine drives	Magnetic particle tests per ASME VII Appendix VII plus hydrostatic test per ASME VIII
Pressure containing welds of pumps and turbine drives	Radiography per ASME VII and magnetic particle tests per ASME VIII Appendices VI and VII
Condensate storage tank welded joints	Radiography and leak testing per USAS B96.1-1967
Valves	All seismic category I valve bodies have been 100 percent radiographed

TABLE 4-9
INSPECTION REQUIREMENTS APPLIED TO ZION
CONTAINMENT SPRAY SYSTEM COMPONENTS (Ref. 6)

<u>Components or Parts of Components</u>	<u>Procedures and Codes</u>
Pressure containing welds of pumps	Radiography per ASME VIII and magnetic particle tests per ASME VIII Appendices VI and VII
Spray additive tank, Eductor	Radiography per ASME VIII and liquid penetrant tests per ASME VIII Appendix VIII
Valves	All castings are 100 percent radiographed, all forgings are tested ultrasonically, and all accessible surfaces of either type are liquid penetrant tested.

TABLE 4-10ZION PROTECTION SYSTEM REACTOR TRIP CONDITIONS (Ref. 6)

- High neutron flux in any of three power ranges
- Negative neutron flux rate
- Overtemperature
- Overpower
- Low pressurizer pressure
- High pressurizer pressure
- High pressurizer water level
- Low reactor coolant flow
- Safety injection system actuation
- Turbine generator low oil pressure
- Low feedwater flow
- Low steam generator water level
- Manual initiation

TABLE 4-11ZION CONTAINMENT PURGE SEISMIC CATEGORY I EQUIPMENT (Ref. 6)

- Air sampling systems
- High efficiency particulate air (HEPA) filters
- Activated charcoal filters
- Purge isolation valves
- Vacuum isolation valves
- Hydrogen purge fans

FIGURE 4-1. EARTHQUAKES IN THE REGION OF THE ZION SITE (Ref. 7)

FIGURE 4-2 TEST BORINGS AT ZION SITE (Ref. 7)

FIGURE 4-3 TYPICAL SOIL CONDITIONS AT THE ZION SITE (Ref. 7)

FIGURE 4-4 ARRANGMENT OF MAJOR BUILDING STRUCTURES
AT ZION NUCLEAR POWER PLANT

FIGURE 4-5 ZION PLANT DESIGN RESPONSE SPECTRA FOR SAFE SHUTDOWN EARTHQUAKE (Ref. 6)

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