TENNESSEE VALLEY AUTHORITY
DIVISION OF ENGINEERING DESIGN
CIVIL ENGINEERING BRANCH

JUSTIFICATION OF THE SEISMIC DESIGN CRITERIA USED FOR THE SEQUOYAH, WATTS BAR, AND BELLEFONTE NUCLEAR POWER PLANTS.

PHASE II

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SUMMARY

The seismic design criteria of the Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants are based on the "Tectonic Province" approach in which the largest historic earthquake is assumed to reoccur "at the site" of the plant. This approach is the most conservative approach defined by the guidelines of 10CFR Part 100, Appendix A. In utilizing this approach the following analyses and results are presented in this report to define site specific spectra for these rock sites.

1. The largest historical earthquake (Giles County) considered to have occurred in the tectonic province is best characterized as having a magnitude of 5.8.

2. Appropriate strong motion earthquake recordings were selected and their response spectra calculated. These spectra are compared with the design spectra at Sequoyah, Watts Bar, and Bellefonte. These comparisons show the mean response spectra from the strong motion earthquakes are below the design spectra at the three plants.

3. Procedures were developed to predict strong motion associated with M_{bLg} magnitude of an earthquake similar to the Giles County earthquake. These predictions compare favorably with existing strong motion data. For an earthquake similar to Giles County a top of rock acceleration is predicted to be about 0.08 g. Anchoring a regulatory guide spectra to 0.08 g shows the design spectra at the three plants are not exceeded.

Based on the results in this report, and the results previously submitted in the Phase I report, TVA concludes the seismic design bases used at Sequoyah, Watts Bar, and Bellefonte are conservative and adequately ensure the health and safety of the public.

TABLE OF CONTENTS

	Page
Summary	i
1.0 Introduction	1
2.0 Site Description	3
3.0 Design Response Spectra	5
3.1 Sequoyah Nuclear Plant Design Response Spectra	5
3.2 Watts Bar Nuclear Plant Design Response Spectra	6
3.3 Bellefonte Nuclear Plant Design Response Spectra	6
3.4 Comparison of Sequoyah, Watts Bar, and Bellefonte Design Response Spectra	7
3.5 Discussion of the Various Damping Ratios Used at the Three Plants	7
4.0 Investigations to Resolve Seismic Design Basis	9
4.1 Evaluation of Giles County Earthquake Intensity	9
4.2 Evaluation of Site Conditions on Earthquake Intensity	9
4.3 Evaluation of Variation of Acceleration with Depth and Comparisons of Accelerations Recorded on Rock and Soil During a Given Earthquake at a Given Site	10
4.4 Evaluation of Intensity-Acceleration Relationships	11
4.5 Evaluation of Response Spectra from Strong Motion Records of Earthquakes of Given Intensity	11
4.6 Development of Response Spectra from Strong Motion Records of Appropriate Magnitude and Distances and Comparisons with Design Spectra	12
4.7 Development of Response Spectra Based on Parameters Other than Intensity	16
5.0 Conclusions	19
References	
Tables	
Figures	
Appendix A - Response Spectra for Thirteen Selected United States and Italy Earthquakes	
Appendix B - Comparison of Sequoyah, Watts Bar, and Bellefonte Nuclear Plant Top of Rock Design Spectra with Response Spectra for Thirteen United States and Italy Earthquakes	

LIST OF TABLES

TABLE 3-1 - Damping Ratios Used in the Analysis of Category I Structures, Systems, Components, and Soils at Sequoyah Nuclear Plant

TABLE 3-2 - Damping Ratios Used in the Analysis of Category I Structures, Systems, Components, and Soils at Watts Bar Nuclear Plant

TABLE 3-3 - Damping Ratios Used in the Analysis of Category I Structures, Systems, Components, and Soils at Bellefonte Nuclear Plant

TABLE 4-1 - Comparison of Maximum Ground Acceleration Recorded at S. Rocco and Cornino-Forgaria

TABLE 4-2 - United States and Italian Earthquakes Used in the Strong Motion Analysis

TABLE 4-3 - Specifics of Strong Motion Recording Stations

TABLE 4-4 - Predicted Maximum Horizontal Accelerations for Selected Design Earthquakes

TABLE 4-5 - Comparison of Predicted Accelerations with Three Friuli, Italy September, 1976 Earthquakes

LIST OF FIGURES

FIGURE 1-1 - Location of Sequoyah, Watts Bar, and Bellefonte Nuclear Plants

FIGURE 3-1 - Comparison of Response Spectra for Safe Shutdown Earthquake - 1/2 Percent Damping - Sequoyah Nuclear Plant

FIGURE 3-2 - Comparison of Response Spectra for Safe Shutdown Earthquake - 1 Percent Damping - Sequoyah Nuclear Plant

FIGURE 3-3 - Comparison of Response Spectra for Safe Shutdown Earthquake - 2 Percent Damping - Sequoyah Nuclear Plant

FIGURE 3-4 - Comparison of Response Spectra for Safe Shutdown Earthquake - 5 Percent Damping - Sequoyah Nuclear Plant

FIGURE 3-5 - Safe Shutdown Earthquake, Response Spectra for Rock Supported Structures - Watts Bar Nuclear Plant

FIGURE 3-6 - Safe Shutdown Earthquake, Design Response Spectra, Horizontal Motion, Rock Supported Structures - Bellefonte Nuclear Plant

FIGURE 3-7 - Comparison of Sequoyah, Watts Bar, and Bellefonte Nuclear Plants Top of Rock Design Spectra for Steel Structures

FIGURE 3-8 - Comparison of Sequoyah, Watts Bar, and Bellefonte Nuclear Plants Top of Rock Design Spectra for Reinforced Concrete Structures

FIGURE 4-1 - Plan View of the Locations of the Two Accelerographic Stations "S. Rocco" and "Cornino-Forgaria"

FIGURE 4-2 - Geological Cross-Section Passing Through the Accelerographic Stations "S. Rocco" and "Cornino-Forgaria"

FIGURE 4-3 - Histogram of Epicentral Distances of Recorded Earthquakes

FIGURE 4-4 - Histogram of Recorded Earthquake Magnitudes

FIGURE 4-5 - Comparison of Sequoyah, Watts Bar, and Bellefonte Nuclear Plants Top of Rock Design Spectra with 0.08G Regulatory Guide 1.60 Spectrum - 4 Percent Damping

FIGURE 4-6 - Comparison of Sequoyah, Watts Bar, and Bellefonte Nuclear Plants Top of Rock Design Spectra with 0.08G Regulatory Guide 1.60 Spectrum - 7 Percent Damping

1.0 INTRODUCTION

The Tennessee Valley Authority (TVA) has applied to the Nuclear Regulatory Commission (NRC) for licenses to operate Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants. Sequoyah is located in Hamilton County, Tennessee, Watts Bar is located in Rhea County, Tennessee, and Bellefonte is located in Jackson County, Alabama. The locations of these plants are shown in Figure 1-1. The seismic criteria used in the design of these three plants were reviewed and approved by the NRC (then the Atomic Energy Commission) during the reviews which preceded issuance of construction permits for the plants. However, in the course of their review for the operating licenses for these facilities, NRC has requested additional information concerning the seismic design basis used for these plants. This report provides additional information to support the safe shutdown earthquake (SSE) ground motions used in the design of the Sequoyah, Watts Bar, and Bellefonte Nuclear Plants as discussed in the respective plants' Final Safety Analysis Reports (FSAR).

The NRC first informed TVA of their concerns in a letter dated December 27, 1977. On February 6, 1978, TVA outlined a two-part study to address the NRC concern. Phase I (reference 1) of this study was submitted for NRC review on May 1, 1978. Phase II of this study is this report. Also, in March 1978, NRC formed a Working Group (reference 2) to "evaluate the problem, consider various methods of resolution, and recommend a path of resolution that assures safety while taking into account differences in the time and effort that would be required by the applicant [TVA] and

staff [NRC], and the extent to which seismic reanalysis of the plant would be required." On May 30, 1970, the Working Group issued a report covering their work.

This Phase II report combines the results of TVA's initial outline of work and results of suggestions by the NRC Working Group. A brief description of the sites, definition of the present design response spectra for the SSE, a discussion of different analyses performed, and results and conclusions of these analyses are presented in the following sections.

2.0 SITE DESCRIPTION

The Sequoyah, Watts Bar, and Bellefonte Nuclear Plants are all located in the Southern Appalachian Tectonic Province (SATP). Physiographically this region consists of the Blue Ridge, Valley and Ridge Province and a portion of the Appalachian Plateau Province.

The principal Category I structures of each plant are supported by competent rock as confirmed by the shear wave velocities discussed below. The Sequoyah and Watts Bar plants are founded in the Conasauga formation while the Bellefonte plant is founded in the Chickamauga formation. Both formations are of early Paleozic age and are characterized by varying amounts of limestone and shale.

The rock foundation at the Sequoyah site consists mainly of shale with a measured shear wave velocity of approximately 6000 ft/s. The remaining soil overburden thickness has an average depth of 40 feet in the vicinity of the plant. The overburden consists mainly of sandy clay terrace deposit and silt and clay residuum. The shear wave velocity in the overburden ranges from 700 to 1000 ft/s.

The rock foundation at the Watts Bar site is predominantly shale with a shear wave velocity of approximately 5900 ft/s. The remaining soil overburden has an average thickness of 30 feet and consists mainly of terrace deposits of clays, silts, and sands. The shear wave velocity in the overburden ranges from 1000 to 1650 ft/s.

The rock foundation at the Bellefonte site is predominantly limestone with a measured shear wave velocity of approximately 10,000 ft/s. The remaining soil overburden thickness has an average thickness of about 20 feet in the vicinity of the plant. The overburden consists of residual silts and clays. The shear wave velocity ranges from 300 to 1700 ft/s.

A detailed description of each site is contained in the respective FSAR's.

3.0 DESIGN RESPONSE SPECTRA

The Sequoyah, Watts Bar, and Bellefonte Nuclear Plants are all located in the Southern Appalachian Tectonic Province. The maximum historic earthquake in the province occurred in Giles County, Virginia, on May 31, 1897. A discussion of the intensity and influence of this earthquake on the sites in question is contained in the plants' FSAR and the Phase I report. This earthquake occurred 285 miles from the Sequoyah site, 255 miles from the Watts Bar site, and 360 miles from the Bellefonte site. Using the tectonic province approach this earthquake is assumed to occur "at the site" for the purpose of defining the safe shutdown earthquake (SSE) as required by the 10CFR Part 100.

3.1 Sequoyah Nuclear Plant Design Response Spectra

The Sequoyah Nuclear Plant has been designed for a SSE with a maximum acceleration of 0.18 g. The site seismic design response spectra which define the vibratory ground motion of the SSE for rock-supported structures are shown in figures 3-1 to 3-4. These spectra are for damping of 1/2, 1, 2, and 5 percent of critical and are applied to the various structures, systems, and components as shown in table 3-1.

Four artificial earthquake records were produced which appropriately envelop the horizontal spectra. The average response spectra generated from the four artificial records were used in the design and are termed the actual design response spectra. Thus, discussion of the adequacy of the design should be based on the actual design response spectra.

Figures 3-1 to 3-4 illustrate the relationship between the minimum design response spectra (Housner at 0.18 g) and the actual design response spectra for the SSE for all damping ratios used in the design of rock-supported structures.

3.2 Watts Bar Nuclear Plant Design Response Spectra

The Watts Bar Nuclear Plant has been designed for a SSE with a maximum acceleration of 0.18 g. The site seismic design response spectra (modified Newmark) which define the vibratory ground motion of the SSE for rock-supported structures are shown in figure 3-5. These spectra are for damping of 1/2, 1, 2, and 5 percent of critical and are applied to the various structures, systems, and components as shown in table 3-2.

3.3 Bellefonte Nuclear Plant Design Response Spectra

The Bellefonte Nuclear Plant has been designed for a SSE with a maximum acceleration of 0.18 g. The site seismic design response spectra which define the vibratory ground motion of the SSE for rock-supported structures are shown in figure 3-6. These spectra are for damping of 1, 2, 3, 4, 5, 7, and 10 percent of critical and are in accordance with Regulatory Guide 1.60. The specific percentage of critical damping values used for the various structures, systems, and components are shown in table 3-3. This is in accordance with Regulatory Guide 1.61.

3.4 Comparison of Sequoyah, Watts Bar, and Bellefonte Design Response Spectra

Comparisons of the various design response spectra for the Sequoyah, Watts Bar, and Bellefonte Nuclear Plants for the two principal types of structures, steel and reinforced concrete, are shown in figures 3-7 and 3-8 respectively.

These comparisons of the three plants' design response spectra will be used later in this report (section 4.6) for comparison with response spectra from actual recorded accelerograms.

3.5 Discussion of the Various Damping Ratios Used at the Three Plants

The specific percentage of critical damping values used for Category I structures, systems, and components are provided in tables 3-1 to 3-3 for the Sequoyah, Watts Bar, and Bellefonte Nuclear Plants respectively. As is evident from these tables, different damping ratios are used at different plants for the same type of structures, systems, and components. Thus, to compare the design spectra at each plant, a simple comparison at a fixed damping ratio is not adequate. Rather the type of structure, system, or component considered must be identified and the damping ratios between the plants allowed to vary. This was done in the creation of figures 3-7 and 3-8 which compare the design response spectra for steel and reinforced concrete structures respectively. For example, at Sequoyah, 1 percent damping was used for steel structures while at Watts Bar, 1 percent was used for the steel containment structure (the principal steel structure present) and at Bellefonte, 4 percent was used. Similarly at Sequoyah and Watts Bar, 5 percent damping was used for reinforced concrete structures as compared to 7 percent at Bellefonte.

In addition, any comparison of present design response spectra and damping values with new criteria should consider the damping values listed in Regulatory Guide 1.61. These comparisons are made in section 4.6.

4.0 INVESTIGATIONS TO RESOLVE SEISMIC DESIGN BASIS

The following investigations were performed to provide additional information to resolve the seismic design basis. The first four of these investigations, discussed in sections 4.1 to 4.4, were presented in our Phase I report. They are briefly reiterated here to place them in the context of the Working Group report. The last three investigations, discussed in sections 4.5 to 4.7, represent new work performed for this Phase II report.

4.1 Evaluation of the Giles County Earthquake Intensity

A discussion of the Ciles County earthquake intensity was presented in the TVA Phase I report.

The Giles County earthquake has historically been listed as a Modified Mercalli (MM) intensity VII, VII-VIII, and VIII. It is TVA's opinion after considerable study the Giles County earthquake is best characterized as a MM VII-VIII. Evaluation of the Giles County earthquake intensity is item III.A.3 of the NRC staff Working Group report.

4.2 Evaluation of Site Conditions on Earthquake Intensity

Information was presented in the Phase I report which demonstrated historical earthquake intensities are soil-biased and, during a given earthquake, intensities on rock are less than on soil by 2 to 3 intensity units. Evaluation of the Giles County earthquake indicated the same conditions. The subject plants are all founded on component rock as discussed in section 2. This item is item III.A.4 of the NRC staff Working Group report.

4.3 Evaluation of Variation of Acceleration with Depth and Comparisons of Accelerations Recorded on Rock and Soil During a Given Earthquake at a Given Site

Information was presented in the Phase I report which demonstrated earthquake accelerations reduce with depth at a given site. The subject plants are all founded on rock at depth. The intensity-acceleration relationships are all based on recordings obtained at the surface. Therefore a reduction in the maximum acceleration obtained from these relationships is appropriate for sites founded on rock at depth.

Information was also presented in the Phase I report which indicated accelerations on rock are less than on soil at a given site during a given earthquake. During the investigations for this Phase II report, additional information was obtained to substantiate this. Table 4-1 (reference 3) shows that accelerations on sites of thin alluvium overburden (Cornino-Forgaria) are from 1.5 to 3.8 times greater than the measured peak accelerations on rock sites (S. Rocco). The S. Rocco and Cornino-Forgaria strong motion accelerograph stations are located at a distance of 650 meters from each other (figure 4-1). These stations were located more than 10 kilometers from the earthquake epicenters. Thus, differences in the attenuation effect due to distance can be ruled out. Figure 4-2 shows the geology of the sites which is significant; the S. Rocco station is based on limestone, while the C. Forgaria station is based on a layer of approximately 15 meters of alluvial deposits over marl and marly sandstone rock (reference 4).

4.4 Evaluation of Intensity-Acceleration Relationships

This evaluation was presented in the Phase I report which indicated the Computer Sciences Corporation (Murphy & O'Brien) (reference 5) relationship was the most appropriate. For a MM VIII earthquake an acceleration of 0.15 g is obtained. For a MM VII-VIII earthquake an acceleration of 0.12 g is obtained.

This evaluation is item III.B.3 of the NRC staff Working Group report.

4.5 Evaluation of Response Spectra from Strong Motion Records of Earthquakes of Given intensity

This approach involves determining response spectra for intensities assigned to sites where strong-motion recordings have been obtained. Agbabian Associates (reference 6) and Trifunac and Anderson (reference 7) have performed studies of this type.

Problems with this approach are that distance effects are not considered. For example, an intensity VI earthquake at a distance of 100 miles has different motions than a VI at 20 miles. This was not considered in the above studies. The Agbabian report indicates there is not enough data at the intensity level assigned to the Giles County earthquake to perform these analyses. The available intensity VIII data are minimal and are for soil sites. No data in this range are available for rock sites.

The Agbabian report compared their spectra at intensities V, VI, and VII with the Regulatory Guide 1.60 spectra anchored to the Trifunac and

Brady intensity-acceleration relationship. The results of the comparison appear to be favorable from which it could be suggested that the Trifunac and Brady relationship is the most appropriate to use. After examination of the studies, it is seen why the two should reasonably agree; both studies used the same data. The development of the Regulatory Guide spectra used some of the earthquakes which Trifunac and Brady used. Thus, this agreement shows that the sample set of earthquakes used to develop Regulatory Guide spectra are representative of the total set used by Trifunac and Brady. It does not mean the Trifunac and Brady relationship is the most appropriate.

In view of the above, further analyses would not be meaningful. This evaluation is item III.B.2 of the NRC staff Working Group report.

4.6 Development of Response Spectra from Strong Motion Records of Appropriate Magnitude and Distance and Comparison with Design Spectra

This analysis is items III.B.1 and C.1.a of the NRC staff Working Group report.

In an effort to develop a site specific design response spectra for the three plants, a suite of existing strong motion records for earthquakes of appropriate magnitude and distance for the existing site conditions was investigated. In this investigation earthquakes of magnitude 5.3 to 6.3 recorded on competent rock within about 25 kilometers of the epicenter are considered. This narrow cross section of all existing strong motion records was selected because:

1. As discussed in the supplemental report (reference 8), the Giles County, Virginia earthquake is best characterized as a magnitude 5.8 event. A range of a half unit about this value was considered appropriate.

2. The three sites in question are compenent rock sites with very shallow overburden. The design response spectra are for rock supported structures.

3. Events greater than 25 kilometers from the site would be sufficiently attenuated so as to be no problem.

Of the strong motion data available, 13 existing records were found which meet these restrictions of magnitude, site conditions, and distance. These records are listed in table 4-2 (references 9, 10, and 11). Table 4-3 lists the location and site geology of the recording sites (references 4, 12, and 13). Of these 13 records, six are western United States records and seven are Italy records.

Figures 4-2 and 4-3 are simple histograms of the data distribution with respect to epicentral distance and magnitude respectively. The average magnitude of these 13 records is 5.7 and range from 5.3 to 6.2. The average epicentral distance is 15.8 kilometers and range from 7 to 27 kilometers.

Response spectra for both horizontal components of these 13 records for 4 and 7 percent of critical damping are presented in figures A-1 to A-26 in appendix A. The use of these damping values is discussed in

section 3. Figures A-27 and A-28 show the spectra of only the United States records for 4 and 7 percent damping, respectively. Similarly, figures A-29 and A-30 are for only the Italy records and figures A-31 and A-32 are for all 13 records. In addition figures A-33 and A-34 show the mean, the mean plus one standard deviation, maximum, and minimum response spectra of only the United States records for 4 and 7 percent damping, respectively. Similarly, figures A-35 and A-36 are for only the Italy records and figures A-37 and A-38 are for all 13 records.

To examine the relationship between the seismic design of these nuclear power plants and the actual ground motion induced by the earthquakes, comparison of these 13 records with the seismic design response spectra used at each plant are given in appendix B. The curves given previously in figures 3-7 and 3-8 are used. Figures B-1 to B-52 show a comparison of each component of each record for either 4 or 7 percent damping with the three plants' criteria.

Figure B-53 compares the mean of the six United States records at 4 percent damping to the design spectra used for steel structures at the three plants. The mean curve is not exceeded.

Figure B-54 compares the mean of the six United States records at 7 percent damping to the design spectra used for reinforced concrete structures at the three plants. The mean curve exceeds the Sequoyah design spectra between frequencies ranging from 13 to 25 Hz (periods from 0.08 to 0.04 seconds) by approximately 0.02 g. The Watts Bar and Bellefonte design spectra are not exceeded.

Figure B-55 compares the mean of the seven Italy records at 4 percent damping to the design spectra used for steel structures at the three plants. The mean curve is not exceeded.

Figure B-56 compares the mean of the seven Italy records at 7 percent damping to the design spectra used for reinforced concrete structures at the three plants. The mean curve is not exceeded.

Figure B-57 compares the mean of all thirteen United States and Italy records at 4 percent damping to the design spectra used for steel structures at the three plants. The mean curve is not exceeded.

Figure B-58 compares the mean of all thirteen United States and Italy records at 7 percent damping to the design spectra used for reinforced concrete structures at the three plants. The mean curve is not exceeded.

As shown in figures B-53 to B-58 the mean response spectra fall below the design response spectra for the three plants except for one small region in one figure which exceeds only the Sequoyah spectra.

From examination of these response spectra, it is concluded the site specific response spectra developed from selected existing strong motion events supports the conservatism of the design response spectra used at the Sequoyah, Watts Bar, and Bellefonte Nuclear Plants.

4.7 Development of Response Spectra Based on Parameters Other Than Intensity

This analysis is similar to item III.B.6 of the NRC staff Working Group report.

An alternate method for predicting ground motion spectra at specific sites in eastern North America is developed. This approach eliminates many shortcomings of the intensity-acceleration technique by having recourse to the magnitude concept in the prediction of ground motion level for bedrock sites at specified epicentral distances.

The magnitude concept uses instrumental measurements and empirically established distance corrections to scale the relative sizes of earthquakes. By using the M_{bLg} magnitude scale (reference 14) that was derived and confirmed for eastern North America, the present method has the advantage of taking into consideration the appropriate attenuation.

Briefly outlined, the prediction of ground accelerations is achieved through the following six steps:

1. For a specified M_{bLg} value (that of the selected design earthquake), calculate the corresponding 1-second ground displacement amplitude from the source spectrum $S(\omega)$;

2. For a specified epicentral distance, obtain the site displacement spectral level for the 1-second period $\Omega_r(2\pi)$;

3. Obtain the acceleration spectral density function ordinate at $\omega = 2\pi$, $G_r(2\pi)$;

4. Apply random vibration analysis to predict $S_v(2\pi, 0.1)$, the ordinate of the response spectrum at the natural frequency $\omega = 2\pi$ (i.e., natural period, T_n = 1 second) and 10% damping;

5. Utilize western strong motion data to predict peak ground acceleration a_g from $S_v(2\pi, 0.1)$;

6. Scale a set of standard response spectra (such as those in Regulatory Guide 1.60).

The theory, development, and supporting evidence of this approach are discussed in the supplement to this report entitled "Prediction of Strong Motions for Eastern North America" (reference 8).

As presented in the supplemental report, this approach is applied to the selected design earthquake - a hypothetical repetition of the Giles County event (M_{bLg} = 5.8) migrated near the site (15 km) with a duration of strong motion of 4.0 seconds. The predicted maximum horizontal accelerations for the selected values and for smaller and larger variations about these values are given in table 4-4.

As a supporting example, the horizontal components of motion recorded on hard rock at the S. Rocco station during three aftershocks of the 1976 Friuli, Italy, earthquake are presented. Relevant information

about these records is summarized in table 4-5. The mean duration of these S. Rocco records is 2.51 seconds. Prediction of maximum horizontal accelerations for this duration are also given in table 4-4.

On the basis of this method, a top of rock acceleration of 0.08 g is predicted for an earthquake similar to the Giles County event. Anchoring a Regulatory Guide 1.60 spectra to 0.08 g shows the design spectra at the three plants are not exceeded. This is shown in figures 4-5 and 4-6 for spectra with 4 and 7 percent damping, respectively. Thus, TVA concludes the seismic design bases used at Sequoyah, Watts Bar, and Bellefonte are conservative.

5.0 CONCLUSIONS

The seismic design criteria of the Sequoyah, Watts Bar, and Bellefonte Nuclear Power Plants are based on the "Tectonic Province" approach in which the largest historic earthquake is assumed to reoccur "at the site" of the plant. This approach is the most conservative approach defined by the guidelines of 10CFR Part 100, Appendix A. In utilizing this approach the following analyses and results are presented in this report to define site specific spectra for these rock sites.

1. The largest historical earthquake (Giles County) considered to have occurred in the tectonic province is best characterized as having a magnitude of 5.8.

2. Appropriate strong motion earthquake recordings were selected and their response spectra calculated. These spectra are compared with the design spectra at Sequoyah, Watts Bar, and Bellefonte. These comparisons show the mean response spectra from the strong motion earthquakes are below the design spectra at the three plants.

3. Procedures were developed to predict strong motion associated with M_{bLg} magnitude of an earthquake similar to the Giles County earthquake. These predictions compare favorably with existing strong motion data. For an earthquake similar to Giles County a <u>top of rock</u> acceleration is predicted to be about 0.08 g. Anchoring a regulatory guide spectra to 0.08 g shows the design spectra at the three plants are not exceeded.

Based on the results in this report, and the results previously submitted in the Phase I report, TVA concludes the seismic design bases used at Sequoyah, Watts Bar, and Bellefonte are conservative and adequately ensure the health and safety of the public.

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TABLES

TABLE 3-1**

DAMPING RATIOS USED IN THE ANALYSIS OF CATEGORY I

STRUCTURES, SYSTEMS, COMPONENTS AND SOIL AT SEQUOYAH NUCLEAR PLANT

Item	Damping Ratio, Percent of Critical Viscous Damping		
	1/2 Safe Shutdown Earthquake	Safe Shutdown Earthquake	
Steel Containment Vessel	1	1	1*
Concrete Shield Building and Internal Concrete Structure	2	5	7
Other Welded Steel Structures	1	1	2
Bolted Steel Structures	2	2	5
Other Reinforced Concrete Structures	5	5	7
Bolted or Nailed Wooden Structures	5	5	5
Damping for Determining Amplification through Soils for Soil-Supported Structures	10	10	10
Vital Piping Systems	0.5	0.5	1

*Damping values used when stress levels are at or near yield. All other damping values are for lower stress levels.

**This is Table 3.7-2 of the Sequoyah FSAR.

TABLE 3-2**

DAMPING RATIOS USED IN THE ANALYSIS OF CATEGORY I

STRUCTURES, SYSTEMS, COMPONENTS AND SOIL AT WATTS BAR NUCLEAR PLANT

Item	Damping Ratio, Percent of Critical Viscous Damping		
	1/2 Safe Shutdown Earthquake	Safe Shutdown Earthquake	
Steel Containment Vessel	1	1	1*
Concrete Shield Building and Internal Concrete Structure	2	5	7
Other Welded Steel Structures	2	2	5
Bolted Steel Structures	5	5	7
Other Reinforced Concrete Structures	5	5	7
Bolted or Nailed Wooden Structures	7	7	10
Damping for Determining Amplification through Soils for Soil-Supported Structures	10	10	10
Vital Piping Systems	1	0.5	1

*Damping value used when stress levels are at or near yield.

**This is Table 3.7-2 of the Watts Bar FSAR.

TABLE 3-3*

DAMPING RATIOS USED IN THE ANALYSIS OF CATEGORY I

STRUCTURES, SYSTEMS, COMPONENTS AND SOIL AT BELLEFONTE NUCLEAR PLANT

Item	Damping Ratio, Percent of Critical Viscous Damping	
	Operating Basis Earthquake(a)	Safe Shutdown Earthquake
Post-tensioned concrete containment building	2	5
Interior concrete structure	4	7
Secondary Containment	4	7
Other reinforced concrete structures	4	7
Welded steel structures	2	4
Bolted steel structures	4	7
Soil	(b)	(b)
Piping system, all diameters greater than 12 inches(c)	2	3
Other piping systems	1	2
Equipment	2	3

(a) In the dynamic analysis of active components, these values should also be used for SSE.

(b) Strain dependent.

(c) For NSS includes both material and structural damping. For piping systems consisting of only one or two spans, with little structural damping, the values for small diameter piping were used.

*This is Table 3.7.1-2 of the Bellefonte FSAR.

TABLE 4-1

COMPARISON OF MAXIMUM GROUND ACCELERATION RECORDED

AT S. ROCCO AND CORNINO-FORGARIA

Date	Magnitude	Hypocentral Distance (km)	Max. Acceleration N-S Component		Ratio of Max. Acceleration
			Cornino-Forgaria	S. Rocco	C. Forgaria / S. Rocco
5-18-76	4.3	11.7	.059	.039	1.51
6-9-76	4.2	13.7	.072	.030	2.4
6-11-76	4.4	18.4	.100	.065	1.54
9-11-76	5.5	18.0	.095	.042	2.26
9-11-76	5.9	15.7	.133	.092	1.45
9-15-76	6.1	12.7	.263	.069	3.81
9-15-76	6.0	23.2	.353	.146	2.42

TABLE 4-2

UNITED STATES AND ITALIAN EARTHQUAKES

USED IN THE STRONG MOTION ANALYSIS

Earthquake	Date/Time	Recording Station	Magnitude	Epicentral Distance (km)	Instrument Orientation	Maximum Acceleration (g)
Helena, Montana	10-31-35/1138 MST	Carroll College	6.0	7	S00W	.146
					S90W	.145
San Francisco, California	3-22-57/1627 PST	Golden Gate Park	5.3	12	N10E	.084
					S80E	.105
Parkfield, California	6-27-66/2026 PST	Temblor	5.6	11	N65W	.270
					S25W	.348
Lytle Creek, California	9-12-70/0630 PST	Allen Ranch	5.4	24	S85E	.071
					S05W	.056
Lytle Creek, California	9-12-70/0630 PST	Devils Canyon	5.4	19	S00E	.161
					S90E	.165
Oroville, California	8-1-75/1320 PST	Oroville Dam	5.7	12	N53W	.185
					N37E	.113
Friuli, Italy	5-6-76/2000 GMT	Tolmezzo	6.2	27	N-S	.346
					E-W	.311
Friuli, Italy	5-9-76/0053 GMT	Tolmezzo	5.5	22	N-S	.036
					E-W	.032
Friuli, Italy	5-11-76/2244 GMT	Tolmezzo	5.3	13	N-S	.027
					E-W	.027
Friuli, Italy	9-11-76/1631 GMT	S. Rocco	5.5	16	N-S	.040
					E-W	.069
Friuli, Italy	9-11-76/1635 GMT	S. Rocco	5.9	14	N-S	.089
					E-W	.089
Friuli, Italy	9-15-76/0315 GMT	S. Rocco	6.1	9	N-S	.066
					E-W	.121
Friuli, Italy	9-15-76/0921 GMT	S. Rocco	6.0	20	N-S	.142
					E-W	.235

TABLE 4-3

SPECIFICS OF STRONG MOTION RECORDING STATIONS

Stn No.	Station Name	Coordinates	Location	Site Geology
2202	Carroll Col Helena, MT	46.58° N 112.03° W	Basement	Rock
111	Cedar Springs Miller Canyon, CA	34.28° N 117.33° W	Basement	Rock
116	Devils Canyon San Bernardino, CA	34.20° N 117.33° W	Basement	Rock
1117	Golden Gate Park San Francisco, CA	37.77° N 122.48° W	Instrument Shelter	Rock
1140	Oroville Dam CA	39.55° N 121.48° W	Lower Gallery of Dam	Rock
1438	Temblor CA	35.71° N 120.17° W	Instrument Shelter	Rock
-	Tolmezzo, Italy	46.38° N 12.98° E	Dam Abutment	Rock
-	S. Rocco, Italy	46.23° N 13.00° E	Mobile Unit	Rock

TABLE 4-4

PREDICTED MAXIMUM HORIZONTAL ACCELERATIONS

FOR SELECTED DESIGN EARTHQUAKES

Distance / m_{bLg}	10 km Duration		15 km Duration		20 km Duration	
	4.0 Sec	2.5 Sec	4.0 Sec	2.5 Sec	4.0 Sec	2.5 Sec
5.6	.06g	.07g	.04g	.05g	.03g	.04g
5.8	.10g	.12g	.07g	.08g	.05g	.06g
6.0	.16g	.18g	.11g	.12g	.08g	.09g

TABLE 4-5

COMPARISON OF PREDICTED ACCELERATIONS

WITH THREE FRIULI, ITALY SEPTEMBER 1976 EARTHQUAKES

Date M D Y	Comp.	Mag.	Dist. (Km)	Duration S_b (Sec)	Acceleration (g) Observed	Acceleration (g) Predicted
9 11 76 16:21GMT	NS	5.9	15.7	1.30	0.09	0.105
	EW			2.68	0.085	0.091
9 15 76 3:15GMT	NS	6.1	12.7	5.96	0.061	0.141
	EW			2.10	0.119	0.188
9 15 76 9:21GMT	NS	6.0	23.2	2.43	0.137	0.08
	EW			0.59	0.242	0.082
Mean		6.0	17.2	2.51	0.122	0.115
Std. Dev.					0.06	0.04