SEISMOTECTONIC INVESTIGATIONS FOR YUCCA MOUNTAIN HIGH-LEVEL WASTE REPOSITORY: RATIONALE FOR DEFINING SCOPE

Dinesh C. Gupta and Michael E. Blackford
U.S. Nuclear Regulatory Commission,
Washington, D.C. 20555

ABSTRACT

The geologic, seismic, and engineering characteristics of the Yucca Mountain site and its environs need to be investigated in sufficient scope and detail to provide reasonable assurance that they are sufficiently well understood to permit an adequate evaluation of the proposed site for the development of a high-level waste repository. The paper examines the extent of seismotectonic investigations needed for proper evaluation of the geologic setting. At the Yucca Mountain site, a thorough understanding of tectonic phenomena such as seismicity and faulting is critical to the identification of potentially disqualifying conditions. Study of the tectonic movement, stress, or co-tectonic effects that could affect the performance of the waste-handling facilities, waste package, underground openings, shaft and borehole seals, and long-term alteration of geohydrology would be necessary. In addition, the uncertainties involved in evaluating the effect of seismotectonics on the radionuclide transport mechanism need to be thoroughly investigated.

INTRODUCTION

The Nuclear Waste Policy Act of 1982 (NWPA) includes provisions for the development of deep-mined geologic waste repositories for the disposal of high-level radioactive waste and spent nuclear fuel. The Nuclear Waste Policy Amendments Act of 1987 limited the development activity to only the Yucca Mountain site in Nevada. Rules governing the licensing of this type of U.S. Department of Energy (DOE) facility are prescribed in 10 CFR Part 60 (1). These rules include performance objectives for a geologic repository for preclosure and postclosure time periods. A key postclosure provision for overall system performance objective is the limit on the amount of radioactivity that may enter the accessible environment during the 10,000 years following disposal of the waste. The 10,000 year period is based on currently remanded 40 CFR 191.13 (Containment Requirements) established by the the U.S. Environmental Protection Agency (EPA) in 40 CFR Part 191 (2). In addition to various other considerations, the seismotectonic features in and around the vicinity of the site, which could affect the performance of the barriers and the geologic repository operations, must be investigated to a degree commensurate with the long-term and short-term requirements of 10 CFR Part 60.

The objective of this paper is to present a rationale for defining the scope of these seismotectonic investigations. In pursuing this objective, this paper will examine the regulatory requirements of the U.S. Nuclear Regulatory Commission (NRC) found in 10 CFR Part 60. The paper will also examine the site disqualifying conditions related to seismotectonic investigations described by DOE in 10 CFR Part 960 (3). The paper will compare these requirements with those for nuclear reactor sites, including the investigations required for the evaluation of vibratory ground motion and surface faulting. Finally, this paper will consider the uncertainties associated with the prediction of long-term performance as affected by seismotectonic predictions.

The opinions expressed in this paper are personal views of the authors and do not necessarily reflect NRC staff positions on any of the issues.

REGULATORY REQUIREMENTS

The performance objectives and siting and design criteria described in 10 CFR Part 60 establish the bases for considering seismic hazards and for determining the scope of seismotectonic investigations that will be needed.

According to 10 CFR 60.111, the geologic repository operations area is to be designed to provide protection during the preclosure period against radiation exposures and releases of radioactive material in accordance with the standards set forth in 10 CFR Part 20 (4) and such standards for radioactivity as may have been established by 40 CFR Part 191. In addition, the geologic repository operations area is to be designed so that the option to retrieve the emplaced radioactive waste is preserved during the preclosure period.

The criterion in 10 CFR 60.131(b)(1), which requires that facilities important to safety in the geologic repository operations area be designed so that natural phenomena do not interfere with their safety functions, forms the basis for evaluating the preclosure seismic hazard.

The overall performance objective in 10 CFR 60.112 requires that the geologic setting be selected and the engineered barrier system and the shafts, boreholes, and their seals be designed to limit the release of radioactive materials to the accessible environment following permanent closure in accordance with any standards that may have been established by EPA. In 10 CFR 60.113 specific performance requirements for both the engineered barrier system and the geologic setting are provided. With respect to the engineered barrier system, these requirements involve the specification of a period of substantially complete containment followed by a period of gradual release of radionuclides. Similarly, for the geologic setting, performance is associated with the specification of a ground-water travel time from the disturbed zone to the accessible environment. The seismic hazard associated with the engineered barrier system, as well as the overall system, is to be evaluated in accordance with the appropriate siting criteria of 10 CFR 60.122(c).

The evaluations performed, using the postclosure and preclosure criteria mentioned above, are necessary to satisfy the requirements pertaining to the input to the Safety Analysis Report described in 10 CFR 60.21(c)(1)(ii)(B) and (C) and 60.21(c)(3), respectively. It is expected that much of the information gathered to support the seismic hazard evaluation required by 10 CFR 60.131(b)(1) for the preclosure period also can be used to support the postclosure seismic hazard evaluation.

SITE DISQUALIFYING CONDITIONS RELATED TO SEISMOTECTONIC INVESTIGATIONS

The regulation, 10 CFR Part 960, establishes requirements for evaluating the suitability of a site for development of a repository (3). Specifically, under the "Postclosure Guidelines," in 10 CFR 960.4-2-7(d), "Tectonics," it establishes the following as one of the disqualifying conditions for the site:

> "A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur."

In addition, under the "Preclosure Guidelines," in 10 CFR 960.5-2-11(d), "Tectonics," the following is considered as a disqualifying condition for the site:

> " A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure."

Also, 10 CFR Part 960 establishes the tectonic features that should be considered as favorable or potentially adverse in evaluating a site on the basis of expected repository performance before and after closure.

At the Yucca Mountain site, the geologic, seismic, and engineering investigations should provide sufficient information to support the determinations required by these criteria and to permit adequate engineering solutions of actual or potential geologic and seismic effects at the proposed site. Fig. 1 illustrates interpreted faults at the Yucca Mountain site (5). Thorough understanding of tectonic phenomena is critical to the evaluation of the potentially disqualifying conditions cited from 10 CFR Part 960. A full range of tectonic models reasonably supported by the existing data base needs to be considered in planning the tectonics investigations.

COMPARISON WITH REACTOR SITING REQUIREMENTS

In examining the extent of seismotectonic investigations needed for proper evaluation of the geologic repository setting and in considering the effect of regional and local seismicity on the performance of a geologic repository, the requirements are often compared with those pertaining to the extent of investigations needed for nuclear reactor siting. In general, the investigations required for evaluating vibratory ground motion and surface faulting for repository design and analysis should be similar in scope to those identified for reactor siting. However, in making such a comparison, the following factors should be considered:

(1) It is essential to recognize the historical performance of deep-mined structures during past earthquakes in various parts of the world. Records of these events reveal that many of the deep underground structures have withstood severe vibratory motion due to earthquake shocks with little or no damage. Although this information may not be directly applicable to the proposed location and conceptual design of the repository because of the possible differences in the site and design-specific details, nevertheless they do indicate that deep underground structures are generally resistant to vibratory ground motions. On the other hand, there have been several reported instances of induced seismic activity associated with mining operations. Some of this induced activity has been of sufficient magnitude or proximity to the operations to cause some damage and to disrupt the operations temporarily.

(2) It may not be practical to investigate faulting in the underground facility to the extent that surface faulting is investigated. Faults encountered in the underground facility may have to be correlated where possible with surface expressions. If this correlation is not feasible, special studies may have to be performed to determine the ability of these faults to generate earthquakes.

(3) Another important consideration in evaluating the effects of seismic loads on a geologic repository would be the passive nature of the components of a geologic repository. Because a repository would be basically a passive system, the accident scenarios and the consequences of postulated failures may not be similar to those considered credible for reactors. Also, the consequences of the failures may be significantly less severe for a geologic repository than those for reactors.

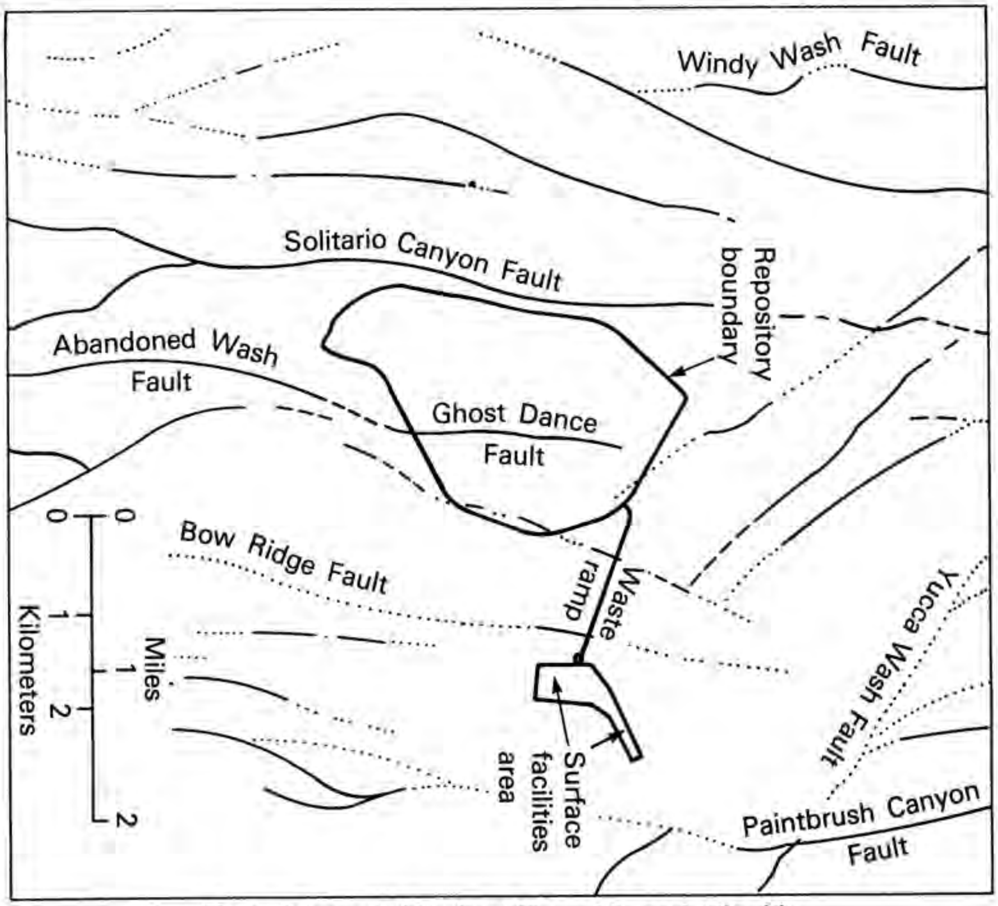

Fig. 1. Interpreted Faults at Yucca Mountain Site (5).

INVESTIGATIONS REQUIRED FOR VIBRATORY GROUND MOTION

One of the most important parameters in any seismic analysis is the definition of design earthquake and the corresponding vibratory ground motion that should be used at a given site. Generally, this definition is predicated on reasonable and conservative considerations of regional and local seismological and geologic setting. A proper site-specific study would involve consideration of the following: (1) estimation of a range of potential earthquake values for the site and the potential recurrence intervals and (2) identification of the likelihood of damage to the facility as a result of these earthquakes. For example, a large earthquake that may occur, let us say, every 2,500 years may cause significant damage to the facility. On the other hand, a smaller earthquake that may occur, let us say, every 25 years may cause only moderate damage to the facility. Thus, a site-specific seismic hazard study may have to deal with more than one earthquake.

In 1968, Cornell described the procedure commonly used for seismic hazard analyses (6). First, active faults and seismotectonic zones or provinces which may be the source of future earthquakes around the site are established. Then, the frequencies of different levels of earthquakes are estimated on the basis of available information. The next step is the selection of attenuation functions that establish acceleration values for various earthquake sizes and source-to-site distances. Finally, the frequencies of exceedance of different levels of earthquake ground acceleration are calculated. In such a study, the potential damage to the facility may have to be investigated in view of the recurrence interval for the earthquake under consideration.

In its licensing process for reactors, the NRC has also allowed the use of site-specific spectra as a means of estimating design ground motion. This approach is based on an analysis of historical earthquakes. Typically, suites of acceleration time histories recorded from earthquakes at sites similar to the facility site and with similar source-to-facility distance are collected. A mean plus one standard deviation of the response spectra from the selected recorded time histories is then used to characterize the design response spectrum. Mention of the use of seismic hazard analyses or the site-specific spectra for reactor licensing should not be interpreted as staff endorsement in the context of geologic repository design.

Factors to be investigated in the seismotectonic evaluations include regional setting, seismic history of the area, seismotectonic structures, local or site geology, and seismic attenuation and amplification. The size of the region to be investigated and the type of data pertinent to the investigations should be determined by the nature of the region surrounding the proposed site. The investigations required for evaluating the vibratory ground motion that address these factors can be summarized as follows:

1. Determination of lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the region surrounding the site, including its geologic history;
2. Identification and evaluation of the tectonic structures underlying the site and the region surrounding the site;
3. Evaluation of physical evidence concerning the behavior during previous earthquakes of surficial geologic materials and the substrata underlying the site from the lithologic, stratigraphic, and structural geologic studies;
4. Determination of the static and dynamic engineering properties of the materials underlying the site;
5. Listing of all historically reported earthquakes that have affected or could reasonably be expected to have affected the site, including date of occurrence, magnitude, highest intensity, and epicenter;
6. Correlation of epicenters or locations of highest intensity of historically reported earthquakes, where possible, with tectonic structures;
7. For faults, a determination of whether these faults are to be considered as having the ability to generate earthquakes;
8. For faults having the ability to generate earthquakes, that may be considered significant, determination of

    (a) the length of the fault;

    (b) the relationship of the fault to regional tectonic structures; and

    (c) the nature, amount, and geologic history of displacements along the fault.

INVESTIGATIONS REQUIRED FOR SURFACE FAULTING

If the Yucca Mountain site is found suitable for the development of a high-level radioactive waste repository, the repository design may be influenced by the potential for surface faulting at the site (5). To meet the performance objectives, the principal design goals should be to (1) prevent significant amounts of surface water from reaching emplaced waste and (2) prevent significant amounts of gaseous radionuclides from escaping through man-made and natural openings to the accessible environment. The potential for surface faulting and the nature, and estimated amount of maximum fault displacement should be key factors to be considered in the design of the repository and the analysis of the design. For example, in order to avoid the possible adverse consequences of such movements, the design of the emplaced drifts within the host rock will have to consider the proximity of these drifts to the sources of the movements with regard to fulfilling the performance objectives.

The investigations required for evaluating surface faulting that address these factors can be summarized as follows:

1. Determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the area surrounding the site, including geologic history;
2. Evaluation of the tectonic structures underlying the site;
3. Determination of the geologic evidence of fault offset at or near the ground surface at or near the site;
4. For faults that can significantly affect the facilities important to safety and waste isolation, determination of whether these faults are to be considered as faults having the ability to generate earthquakes;
5. Listing of all historically reported earthquakes that can reasonably be associated with faults that can significantly affect facilities important to safety and waste isolation, including the date of occurrence and magnitude, highest intensity, and epicenters;
6. Correlation of the epicenters or location of highest intensity of historically reported earthquakes with faults, which have the ability to generate earthquakes, that can significantly affect facilities important to safety and waste isolation;
7. For faults, which have the ability to generate earthquakes, that can significantly affect facilities important to safety and waste isolation, determination of

    (a) the length of the fault;

    (b) the relationship of the fault to regional tectonic structures;

    (c) the nature, amount, and geologic history of displacements along the fault; and

    (d) the outer limits of the fault.

NEED FOR INTEGRATION AND COORDINATION

In evaluating the adequacy of the investigation program for determining sèismic hazard, it is important that alternative tectonic models for the site be integrated into the site characterization plan. These tectonic models should form a conceptual basis from which realistic judgments are made about the likelihood and magnitude of future tectonic events. For example, consideration should be given to fault models in which faults within and outside the waste emplacement areas may be related to each other. Also, the importance of characterizing the underlying tectonic processes should be recognized for use in predicting future tectonic events at the site.

The need for conducting nonintrusive geophysical and geological activities should be considered before drilling and trenching operations so as to optimize the locations of needed drill holes and trenches. Proper coordination and integration of investigation activities are essential for a thorough understanding of tectonic phenomena at the site and are critical to the identification of potentially disqualifying conditions.

CONSIDERATION OF UNCERTAINTIES

After defining the characteristics of the expected seismic ground motion and surface faulting at the geologic repository site, an analysis of the facility may be performed and the adequacy of the facility to withstand design vibratory ground motion and other tectonic activities may be evaluated using generally accepted procedures. However, in performing these analyses and in evaluating their results, it should be considered that there are bound to be uncertainties associated with the prediction of the long-term performance as affected by seismotectonic predictions.

In general, two types of uncertainties are often recognized. These are commonly known as random and systematic uncertainties. Random uncertainty is that which is associated with randomness or natural variation of the phenomenon. For example, the earthquake source, wave propagation, and material properties vary randomly in nature. The other type of uncertainty, systematic uncertainty, is associated with our imperfect knowledge of the seismotectonic behavior (e.g., that describing attenuation) or numerical model of the facility. The level of total uncertainties depends on the technique used for the analytical modeling and analysis procedure. These concepts are well documented in many earlier publications (e.g., 7 and 8).

It is generally considered that the vibratory ground motion significantly reduces with depth. However, the degree of reduction in amplitude of motion with depth depends on the details of the site geology and the geomechanical properties of surface and subsurface material. Large uncertainty exists in this area and needs particular attention during the investigation, design, and analysis phase.

CONCLUDING REMARKS

Seismotectonic investigations and the interpretation of data from these investigations are likely to play a major role in determining the suitability of the Yucca Mountain site for the development of a repository. If the site is found suitable, the investigations will contribute significantly to the establishment of major design criteria for repository design with respect to faulting and seismic design loads.

The main objectives of seismotectonic investigations at the Yucca Mountain site should be to determine at an early stage if potentially disqualifying tectonic conditions exist at the site. These conditions are enumerated in 10 CFR Part 960. If no disqualifying conditions are found at the site, then the data from the same investigations can contribute to the information needed for the design of the repository.

Before it can be concluded that the Yucca Mountain site is suitable for the development of a repository, it should be demonstrated that the geologic setting at the site has an appropriate combination of the favorable conditions listed in 10 CFR 60.122(b). If the seismotectonic investigations reveal any potentially adverse conditions at the site, an analysis should be performed to determine if these conditions could compromise the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. On the basis of these needs, it is apparent that a well-coordinated and integrated seimotectonic investigations program is essential for demonstrating that the site meets the performance objectives for a geologic repository.

REFERENCES

1. U.S. Code of Federal Regulations, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Part 60, Chapter I, Title 10, "Energy."
2. U.S. Code of Federal Regulations, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Part 191, Chapter I, Title 40, "Protection of Environment."
3. U.S. Code of Federal Regulations, "General Guidelines for the Recommendations of Sites for Nuclear Waste Repositories," Part 960, Chapter III, Title 10, "Energy."
4. U.S. Code of Federal Regulations, "Standards for Protection against Radiation," Part 20, Chapter I, Title 10, "Energy."
5. U.S. Department of Energy, "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," DOE/RW-0199 (December 1988).
6. C.A. CORNELL, "Engineering Seismic Risk Analysis," Bulletin Seismic Society of America," Vol. 58 (1968).
7. S.T. ALGERMISSEN ET. AL., "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States," USGS Open-File Report 82-1033 (1982).

8. D. VENEZIANO, "State-of-the-Art for Assessing Earthquake Hazards in the United States, Errors in Probabilistic Seismic Hazard Analysis," U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, Miscellaneous Paper S-73-1, Report 18 (1982).