CNWRA 98-007

SEISMIC GROUND MOTION AT THREE MILE ISLAND UNIT 2 INDEPENDENT SPENT FUEL STORAGE INSTALLATION SITE IN IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY – FINAL REPORT

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-97-009

Prepared by

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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LIST OF ACRONYMS

AE	Architectural Engineering
ANL	Argonne National Laboratory
ATR	Advanced Test Reactor
BLWN	Band-Limited-White-Noise
CNWRA	Center for Nuclear Waste Regulatory Analyses
CTB	Centennial Tectonic Belt
DBE	Design Basis Earthquake
DBGM	Design Basis Ground Motions
DE	Design Earthquake
DOE	U.S. Department of Energy
DOE-ID	U.S. Department of Energy-Idaho Operations Office
DSHA	Deterministic Seismic Hazard Assessment
ESRP	Eastern Snake River Plain
FPR	Fuel Processing Restoration
HLW	High-Level Waste
HSM	Horizontal Storage Module
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Engineering and Environmental Laboratory
ISB	Intermountain Seismic Belt
ISFSI	Independent Spent Fuel Storage Installation
LA	License Application
LLNL	Lawrence Livermore National Laboratory
LOFT	Loss of Fluid Test
MCE	Maximum Credible Earthquake
MM	Modified Mercalli
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
NRF	Naval Reactor Facility
OBE	Operating Basis Earthquake
PBF	Power Burst Facility
PHA	Peak Horizontal Acceleration
PSHA	Probabilistic Seismic Hazard Assessment
PVA	Peak Vertical Acceleration
RVT	Random Vibration Theory
RWMC	Radioactive Waste Management Complex
SAR	Safety Analysis Report
SE	Safety Earthquake
SIS	Special Isotope Separation
SOC	Statements of Consideration
SRP	Snake River Plain
SSC	Structures, Systems, and Components
SSE	Safe Shutdown Earthquake
TAN	Test Area North
TMI-2	Three Mile Island Unit 2
TREAT	Transient Reactor Text Facility

LIST OF ACRONYMS (cont'd)

UHS	Uniform Hazard Spectra
WCC	Woodward-Clyde Consultants
WCFS	Woodward-Clyde Federal Services
YM	Yucca Mountain
3D	Three-Dimensional

ACKNOWLEDGMENTS

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No CNWRA-generated original data are contained in this report.

ANALYSES AND CODES: No computer codes were used for analyses contained in this report.

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is seeking a Nuclear Regulatory Commission (NRC) license for building an independent spent fuel storage installation (ISFSI) at the Idaho National Engineering and Environmental Laboratory (INEEL) to store fuel debris arising from the 1979 accident at the Three Mile Island Unit 2 (TMI-2). The DOE plans to construct the TMI-2 ISFSI at the Idaho Chemical Processing Plant (ICPP) site within INEEL. The action to build a TMI-2 ISFSI was motivated by a DOE determination that the Test Area North (TAN) pool at INEEL, where the TMI-2 canisters and core debris are currently stored, does not meet the requirements of DOE Order 420.1 regarding facility safety. The schedule for DOE remedial actions is specified in a Settlement Agreement entered into by the State of Idaho, the DOE, and the Department of the Navy. The Settlement Agreement requires the DOE to complete construction of the TMI-2 ISFSI by December 31, 1998.

In order to meet the December 31, 1998, completion date, the DOE decided to commence detailed designs of the facility prior to the issuance of a license and the NRC completion of the National Environmental Policy Act related activities. However, the DOE recognizes that by proceeding with these activities before being granted a license by the NRC, it incurs the risk that the facility or its components may not meet the design criteria eventually required for the license. Further, the DOE postulated that the bulk of the risk associated with proceeding with the facility design involves seismic design criteria that NRC may apply to the fabrication of the horizontal storage modules (HSM) and the concrete pad upon which the HSMs are to be placed.

NRC licensing actions for such facilities are performed in accordance with 10 CFR Part 72. According to 10 CFR 72.122(b)(2), structures, systems, and components (SSC) important to safety must be designed to withstand the effects of natural phenomena, such as earthquakes, without impairing their capability to perform safety functions. For sites west of the Rocky Mountains, such as INEEL, Part 72 requires that seismicity be evaluated by techniques set forth in Appendix A of 10 CFR Part 100 for nuclear power plants. This appendix defines the safe shutdown earthquake (SSE) as the earthquake that produces the maximum vibratory ground motion at the site, and requires that the SSC be designed to withstand the ground motion produced by the SSE. This seismic design method implies use of a deterministic seismic hazard assessment (DSHA) approach because it considers only the most significant event, and it is a time-independent statement (i.e., it does not take into consideration the planned operating period of the facility). Also, 72.102(f)(1) requires that analyses using Appendix A methodology should use a design peak horizontal acceleration (PHA) that is equivalent to that of the SSE for a nuclear power reactor. Furthermore, NUREG-0800 section 2.5.2.6 states the NRC preference that the 84th-percentile value of the ground motion spectrum be used to calculate a reactor SSE PHA.

The U.S. Department of Energy-Idaho Operations Office (DOE-ID) proposes to design the TMI-2 ISFSI based on seismic design criteria contained within the INEEL architectural engineering (AE) standards. In the AE standards related to a reactor or similar higher risk facility, the peak design basis horizontal acceleration for the ICPP is 0.36 g, including effects of soil amplification. This design PHA corresponds to the 84th percentile of the 1970s DOE DSHA results and is supported by the early 1990s DSHA results. However, the latest DSHA conducted by a DOE subcontractor [i.e., Woodward-Clyde Federal Services (WCFS)] suggested a 50th-percentile PHA of 0.34 g and an 84th-percentile PHA of 0.56 g, which exceeds the DOE design PHA for the proposed TMI-2 ISFSI. The recent DOE probabilistic seismic hazard assessment (PSHA) suggests PHAs of 0.30 and 0.47 g for return periods of 2,000 and 10,000 yr, respectively. Based on these deterministic and probabilistic results, the DOE argues that an ISFSI design

PHA of 0.36 g bounds the PHA of the 50th-percentile deterministic value of 0.34 g and the 2,000-yr return period probabilistic value of 0.30 g and, consequently, should be sufficient for the proposed TMI-2 ISFSI, considering that it is a relatively low-risk facility compared to a nuclear power plant. However, 10 CFR Part 72 has not been revised to include PSHA as an acceptable methodology for deriving a design PHA for ISFSIs.

Recognizing the significance of seismic design requirements to the proposed TMI-2 ISFSI and complications with regard to the DOE proposed seismic design approach and the current applicable NRC regulations and standards, the NRC directed the Center for Nuclear Waste Regulatory Analyses (CNWRA) to conduct an investigation on seismic hazard evaluation at the ICPP to provide the NRC with technical bases in commenting on the adequacy and acceptability of the DOE seismic design approach for the proposed TMI-2 ISFSI. The objectives of the CNWRA seismic investigation are threefold: (i) to conduct an independent review of existing seismic hazard investigations at INEEL, in particular, to identify seismic issues important to siting the proposed TMI-2 storage facility; (ii) to evaluate the adequacy of the DOE seismic design approach; and (iii) to make recommendations regarding the DOE-proposed seismic design approach and design basis earthquake (DBE) value. These objectives were accomplished mainly through a survey of state-of-the-art literature and analyses of current relevant NRC regulations.

A large number of pertinent technical reports, journal articles, and conference papers was reviewed to achieve the objectives of this study. The reviewed documents included those referenced in the DOE Safety Analysis Report (SAR) for the proposed TMI-2 ISFSI, other technical reports produced by the DOE and its contractors or subcontractors, and literature referenced in those documents. Literature produced by other organizations and individuals was also identified through a computerized "keywords" search and reviewed accordingly. Seismic issues that are important to siting the proposed TMI-2 storage facility include identification of potential seismic sources, source characteristics, and associated uncertainties; deterministic and probabilistic seismic hazard assessment using state-of-the-art knowledge and techniques, including ground motion attenuation predictions and spectral analyses; and development of design basis parameters in compliance with applicable regulations and regulatory guidances. These issues are summarized in following four paragraphs.

The literature survey indicates that the majority of pertinent literature was produced by the DOE and its contractors or subcontractors. Site characterization at INEEL is an evolving process that has spanned several decades during the almost 50 yr of operations at INEEL. It is important to recognize that the DOE and its contractors and subcontractors have sufficiently identified, utilized, and referenced previous as well as the state-of-the-art knowledge and information that exist in the literature in their site characterization efforts. Seismotectonic characteristics that are significant for seismic hazard evaluation at INEEL have been analyzed, and potential seismic sources have been identified. Three types of seismic sources were considered in the most recent site-specific probabilistic seismic hazard studies at INEEL, including fault sources, Eastern Snake River Plain (ESRP) volcanic rift zone sources, and regional areal sources. Various studies, especially the recent probabilistic and DSHAs conducted by the WCFS, have also sufficiently considered uncertainties associated with seismic source characteristics using the state-of-the-art investigation and analysis techniques.

Fault sources include three late Quaternary Basin and Range faults to the north and northwest of the INEEL, namely the Lost River, Lemhi, and Beaverhead faults. Because of their significance, they have been individually characterized as potential seismic sources. Of the three fault sources, the Lemhi fault has been considered the most important because of its proximity to most of the facility sites at INEEL, including the ICPP. The southern termination of the Lemhi fault has been used to determine source-to-site distance in almost all of the deterministic studies conducted for INEEL facilities, and uncertainty associated with it appears to have been one of the major sources causing inconsistencies in various DSHA results. Sensitivity analyses show that fault sources and regional areal sources appear to contribute more to the total seismic ground motion hazard at ICPP than the volcanic zone sources. Also, the Lost River fault appears to contribute more to the total probabilistic seismic hazard at ICPP than the Lemhi fault, although the latter is closer and more significant if the hazard is evaluated deterministically.

A number of DSHAs at the INEEL has resulted in a few slightly different ground motion hazard estimations. Such differences are mainly associated with uncertainties in the magnitude of the maximum credible earthquake (MCE) and source-to-site distance. It appears there is a trend of increasing magnitude of the MCE, which resulted in increasing deterministic hazard estimation. The most recent MCE of $M_w = 7.1$ appears to represent the DOE best understanding, because it is supported by the most recent paleoseismic investigations. It may be beneficial for the DOE to continue various efforts in paleoseismic studies or alternative studies in the region that may provide more evidence regarding the magnitude of the MCE so that a more definitive conclusion can be reached.

Although not supported by the current NRC regulations, PSHA has many advantages over the DSHA. For example, DSHA considers only the most significant earthquake sources and events (including MCEs) with a fixed site-to-source distance. PSHA, on the other hand, considers contributions from all potential seismic sources and integrates across a range of source-to-site distances and magnitudes. Most importantly, DSHA is a time-independent statement, whereas PSHA estimates the likelihood of earthquake ground motion occurring at the location of interest within the time frame of interest. The most recent DOE probabilistic analyses conducted by WCFS for INEEL, including the ICPP, provide for explicit inclusion of the range of seismologic and tectonic interpretations including seismic source characterization and ground motion estimation consistent with approaches contained in NRC Regulatory Guide 1.165 (previously Draft DG-1032). Based on this study, the PHAs for the ICPP are 0.23, 0.30, and 0.47 g for return periods of 1,000; 2,000; and 10,000 yr, respectively. This study also included sophisticated sensitivity analyses that isolated the contributions to the total ground motion hazard produced by various potential seismic sources and evaluated the relative importance of various uncertainties associated with characterization of these seismic sources. These analyses are consistent with recommendations in Appendix A of 10 CFR Part 100.

As mentioned earlier, NUREG-0800 section 2.5.2.6 states the NRC preference of using the 84th-percentile deterministic response spectra for both spectral shape and ground motion amplitude estimates. Also, the most recent DOE deterministic analyses suggested an 84th-percentile PHA value of 0.56 g and a 50th-percentile value of 0.34 g for the ICPP. A strict interpretation of 72.102(f)(1) may, therefore, lead one to conclude that 0.56 g is the requisite design value for the proposed TMI-2 ISFSI site. However, there is a regulatory basis for a different design value that may be adequate. In 1980, when 10 CFR Part 72 was first promulgated, ISFSIs were largely envisioned to be spent fuel pools or massive dry storage structures and were expected to be built at existing power plant sites. In the Statements of Consideration accompanying the initial rulemaking, the NRC recognized that the design PHA for dry casks and canisters need not be as high as for a power reactor, and should be determined on "a case-by-case basis" until "more experience is gained with licensing these types of units." With over 10 yr of experience licensing dry cask storage, and robust analyses demonstrating cask behavior in accident scenarios, the NRC staff now have a reasonable basis to consider a different design value that is adequate for licensing dry storage ISFSIs, where appropriate.

Although 10 CFR Part 72 does not consider PSHA as an acceptable methodology for deriving a DBE for ISFSIs, the PSHA results are increasingly being accepted by the NRC. For example, the PSHA method is acceptable for power reactors under January 1997 revisions to 10 CFR Part 50 and Part 100. Furthermore, the NRC has accepted the PSHA method for the design and performance assessment of the proposed high-level waste (HLW) repository at Yucca Mountain (YM). The NRC has accepted return periods of 1,000 and 10,000 yr, respectively, for Category 1 and Category 2 design basis events for the PHA estimation for the 100- to 150-yr preclosure design life of the proposed HLW repository at YM. Category 1 design basis events for a repository are those natural and human-induced events that will likely occur regularly, moderately frequently, or one or more times before permanent closure of the geologic repository operations area (i.e., during the 100- to 150-yr preclosure design life). Category 2 design basis events for a repository are other natural and human-induced events that are considered unlikely, but sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on public health and safety. Most of the SSCs at the dry storage ISFSI for TMI-2 fuel debris at INEEL are likely to be designed for Category 1 design basis events. For these SSCs, the use of a 2,000-yr return period to determine probabilistic design acceleration for the 20-yr design life of the proposed TMI-2 ISFSI is conservative. For those SSCs that may need to be designed for Category 2 design basis events, the use of a 2,000-yr return period probabilistic design acceleration for the 20-yr design life of the proposed TMI-2 ISFSI, also appears to be adequate. In summary, the DOE-ID proposed seismic design horizontal acceleration of 0.36 g provides an adequate value for design of the proposed TMI-2 ISFSI at INEEL.

1 INTRODUCTION

The U.S. Department of Energy (DOE) plans to store fuel debris arising from the 1979 accident at the Three Mile Island Unit 2 (TMI-2) in an independent spent fuel storage installation (ISFSI) at the Idaho National Engineering and Environmental Laboratory (INEEL). The TMI-2 ISFSI will be located at the Idaho Chemical Processing Plant (ICPP) site within INEEL. This action was motivated by a DOE determination that the Test Area North (TAN) pool at INEEL where the TMI-2 canisters and core debris are currently stored does not meet the requirements of DOE Order 420.1 (U.S. Department of Energy, 1995a) regarding facility safety. The timing for DOE remedial action is specified in a Settlement Agreement (U.S. Department of Energy, 1995b) entered into by the State of Idaho, the DOE, and the Department of the Navy. The Settlement Agreement requires the DOE to complete construction of a dry-storage facility for TMI-2 fuel debris by December 31, 1998; complete moving fuel debris into the facility by June 1, 2001; and remove the fuel debris from the state of Idaho by January 1, 2035.

On October 31, 1996, the U.S. Department of Energy-Idaho Operations Office (DOE-ID) submitted a license application (LA) (U.S. Department of Energy-Idaho Operations Office, 1996a) to the NRC for a 10 CFR Part 72 license for design, construction, operation (including receipt, handling, transfer, storage, retrieval, surveillance, and maintenance), and decommissioning of the TMI-2 ISFSI at the ICPP site in INEEL.

In order to meet the December 31, 1998, completion date, the DOE decided to commence detailed designs of the facility prior to the issuance of a license and completion of the NRC National Environmental Policy Act process. However, the DOE recognizes that by proceeding with these activities before being granted a license by the NRC, it incurs the risk that the facility or its components may not meet the design criteria eventually required for the license. Further, the DOE postulated that the bulk of the risk associated with proceeding with the facility design involves seismic design criteria that NRC may apply to the fabrication of the horizontal storage modules (HSM) and the concrete pad upon which the HSMs are to be placed.

According to 10 CFR 72.122(b)(2), structures, systems, and components (SSC) important to safety must be designed to withstand the effects of natural phenomena, such as earthquakes, without impairing their capability to perform safety functions. For sites west of the Rocky Mountains, such as INEEL, Part 72 requires that seismicity be evaluated by techniques set forth in Appendix A of 10 CFR Part 100 for nuclear power plants. This appendix defines the safe shutdown earthquake (SSE) as the earthquake that produces the maximum vibratory ground motion at the site and requires that the SSC be designed to withstand the ground motion produced by the SSE. This seismic design method implies use of a deterministic seismic hazard assessment (DSHA) approach because it considers only the most significant event, and it is a time-independent statement (i.e., it does not take into consideration the planned operating period of the facility). Also, 72.102(f)(1) requires that analyses using Appendix A methodology should use a design peak horizontal acceleration (PHA) that is equivalent to that of the SSE for a nuclear power reactor. Furthermore, NUREG-0800 section 2.5.2.6 states the NRC preference that the 84th-percentile value of the ground motion spectrum be used to calculate a reactor SSE PHA (Nuclear Regulatory Commission, 1997b).

The DOE-ID (1996a,b) proposes to design the TMI-2 ISFSI based on seismic design criteria contained within the INEEL architectural engineering (AE) standards (U.S. Department of Energy, 1992). In the AE standards related to a reactor or similar higher risk facility, the peak design basis horizontal acceleration for the ICPP (the host site for the proposed TMI-2 ISFSI) is 0.36 g, including effects of soil amplification. This design PHA corresponds to the 84th percentile of the 1970s DOE DSHA results (Woodward-Clyde Consultants, 1975, 1979) and is supported by the early 1990s DSHA results (Woodward-Clyde Consultants, 1990). However, the latest DSHA conducted by a DOE subcontractor [i.e., Woodward-Clyde Federal Services (WCFS)], suggested a 50th-percentile PHA of 0.34 g and an 84th-percentile PHA of 0.56 g, which exceeds the DOE design PHA for an ISFSI (Woodward-Clyde Federal Services, 1996b). The recent DOE probabilistic seismic hazard assessment (PSHA) suggests PHAs of 0.30 and 0.47 g for return periods of 2,000 and 10,000 yrs, respectively (Woodward-Clyde Federal Services, 1996a). Based on these deterministic and probabilistic results, the DOE argues that an ISFSI design PHA of 0.36 g bounds the PHA of the 50th-percentile deterministic value of 0.34 g and the 2,000-yr return period probabilistic value of 0.30 g and, consequently, should be sufficient for the proposed TMI-2 ISFSI, considering that it is a relatively low-risk facility compared to a nuclear power plant. However, 10 CFR Part 72 has not been revised to include PSHA as an acceptable methodology for deriving a design PHA for ISFSIs.

Recognizing the significance of seismic design requirements to the proposed TMI-2 ISFSI and complications with regard to the DOE-proposed seismic design approach and the current applicable NRC regulations and standards, the NRC directed the Center for Nuclear Waste Regulatory Analyses (CNWRA) to conduct an investigation on seismic hazard evaluation at the ICPP to provide the NRC with technical bases in commenting on the adequacy and acceptability of the DOE seismic design approach for the TMI-2 ISFSI. The objectives of the CNWRA seismic investigation are threefold: (i) to conduct an independent review of existing seismic hazard investigations at INEEL, in particular, to identify seismic issues important to siting the proposed TMI-2 storage facility; (ii) to evaluate the adequacy of the DOE seismic design approach; and (iii) to make recommendations regarding the DOE-proposed seismic design approach and design basis earthquake value. These objectives were accomplished mainly through a survey of state-of-the-art literature and analyses of current relevant NRC regulations.

A large number of pertinent technical reports, journal articles, and conference papers was reviewed to achieve the objectives of the study. The reviewed documents included those referenced in the DOE Safety Analysis Report (SAR) for the proposed TMI-2 ISFSI (U.S. Department of Energy-Idaho Operations Office, 1996b), other technical reports produced by the DOE and its contractors or subcontractors, and literature referenced in those documents. Literature produced by other organizations and individuals was also identified through a computerized "keywords" search and reviewed accordingly.

An initial screening of existing literature shows that the only significant seismic hazard at the proposed TMI-2 ISFSI site is earthquake ground motion. Other seismic hazards (including avalanches, landslides, mudslides, soil settlement, and soil and sand liquefaction) are not likely to occur at the INEEL site because the geologic conditions are not conducive to them (U.S. Department of Energy-Idaho Operations Office, 1996b; Anderson, 1991; Golder Associates, 1992b; Smith et al., 1996b). Evidence of ground deformation, such as subsidence and fissuring, has not been found in surface mapping, numerous boreholes, and excavations to bedrock. Fault-induced ground deformation is also precluded because the proposed TMI-2 ISFSI site is located within the relatively aseismic Eastern Snake River Plain (ESRP) and away from major faults and volcanic rift zones. Therefore, the literature review is concentrated on earthquake ground motion hazards. Section 2 presents the major findings from the literature. Section 3 summarizes these major findings with emphasis on seismic issues important to siting the proposed TMI-2 storage facility. Section 4 discusses the adequacy of the DOE-proposed seismic design approach based on major findings from the literature and relevant NRC regulations.

2 REVIEW OF SEISMIC INVESTIGATIONS

The INEEL site, which is controlled by the DOE, occupies about 890 square miles. The proposed TMI-2 ISFSI would occupy approximately two acres within the ICPP complex (U.S. Department of Energy-Idaho Operations Office, 1996a). The INEEL is remote from major population centers, waterways, and interstate transportation routes. The proposed TMI-2 ISFSI site is located in a flat-lying area near the Big Lost River in the south central part of INEEL. The area is underlain by about 9 to 18 m (30 to 60 ft) of Big Lost River alluvial silts, sands, and gravels that lie on an alternating sequence of basalt lava flows and interbedded sediments extending to a depth of about 600 to 700 m (2,000 to 2,300 ft) (U.S. Department of Energy-Idaho Operations Office, 1996b). Landforms in the vicinity of the proposed ISFSI consist of braided channels of the Big Lost River to the west and north of the site, and irregular flow lobes of basalt lava to the east of the site.

2.1 GEOLOGICAL AND SEISMOTECTONIC SETTINGS

The INEEL is located near the northwestern margin of the ESRP in southeastern Idaho (figure 2-1). The Snake River Plain (SRP) is a topographically-subdued physiographic province that is bordered on the northwest and southeast by the Basin and Range province, on northeast by the Yellowstone Plateau, and on the north by Idaho Batholith provinces. The ESRP is the eastern portion of the SRP extending from the Yellowstone Plateau to the Great Rift (figure 2-2). These four physiographic provinces (the ESRP, the northern Basin and Range, the Yellowstone Plateau, and the Idaho Batholith) also correspond to tectonic or seismotectonic provinces. Figure 2-2 shows earthquake epicenters and Quaternary faults of the SRP and surrounding areas (Woodward-Clyde Federal Services, 1996a). This figure indicates that relatively few earthquakes have occurred within the SRP. However, SRP is wrapped on its southeastern, eastern, and northern boundaries by two seismical activity belts known as the Intermountain Seismic Belt (ISB) and the Centennial Tectonic Belt (CTB). These seismotectonic provinces and seismic belts have been studied in great detail, and a wealth of information exists in the literature (Pierce and Morgan, 1992; Malde, 1991; Hackett and Smith, 1992; Christiansen, 1984), in the DOE-ID (1996b) Safety Analysis Report (SAR), and in various work conducted by DOE subcontractors (Woodward-Clyde Consultants, 1990, 1992a,b; Woodward-Clyde Federal Services, 1994, 1995, 1996a,b). The following is a brief summary of the tectonic and seismic characteristics of these seismotectonic provinces.

2.1.1 Eastern Snake River Plain

The SRP is considered the continental track of a mantle hotspot that now resides beneath the Yellowstone Plateau (Pierce and Morgan, 1992). The hotspot is a mantle plume that started impinging on the base of the lithosphere directly underneath north-central Nevada about 17 million yr ago (Pierce and Morgan, 1992). Since the mantle plume is rooted deep in the earth, it has remained stationary while the North American Plate has shifted southwest across the plume at about 3.5 cm/yr due to plate tectonic movement. This relative movement between the North American Plate and the hotspot, and the subsequent heating and cooling processes have produced the basin of the SRP that extends from the Yellowstone National Park to north-central Nevada.

The specific processes involved in producing the SRP may include: (i) input of magma and heat into the continental lithosphere and crust from the hotspot that produces uplift, crustal melting, and voluminous silicic volcanism from large calderas; (ii) cooling of the crust, solidification of mid-crustal

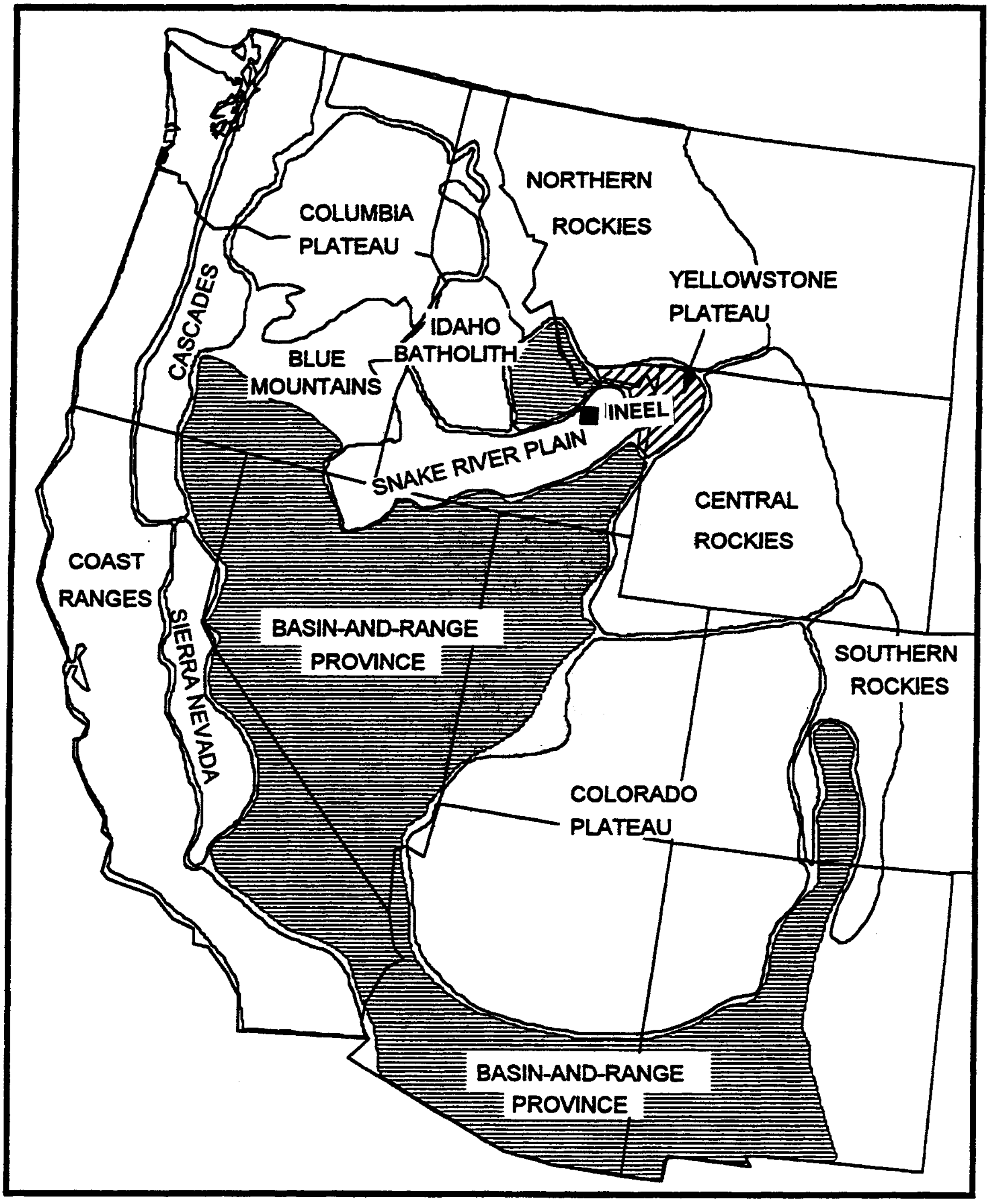


Figure 2-1. Physiographic province map of the Western United States and the location of Eastern Snake River Plain and Idaho National Engineering and Environmental Laboratory

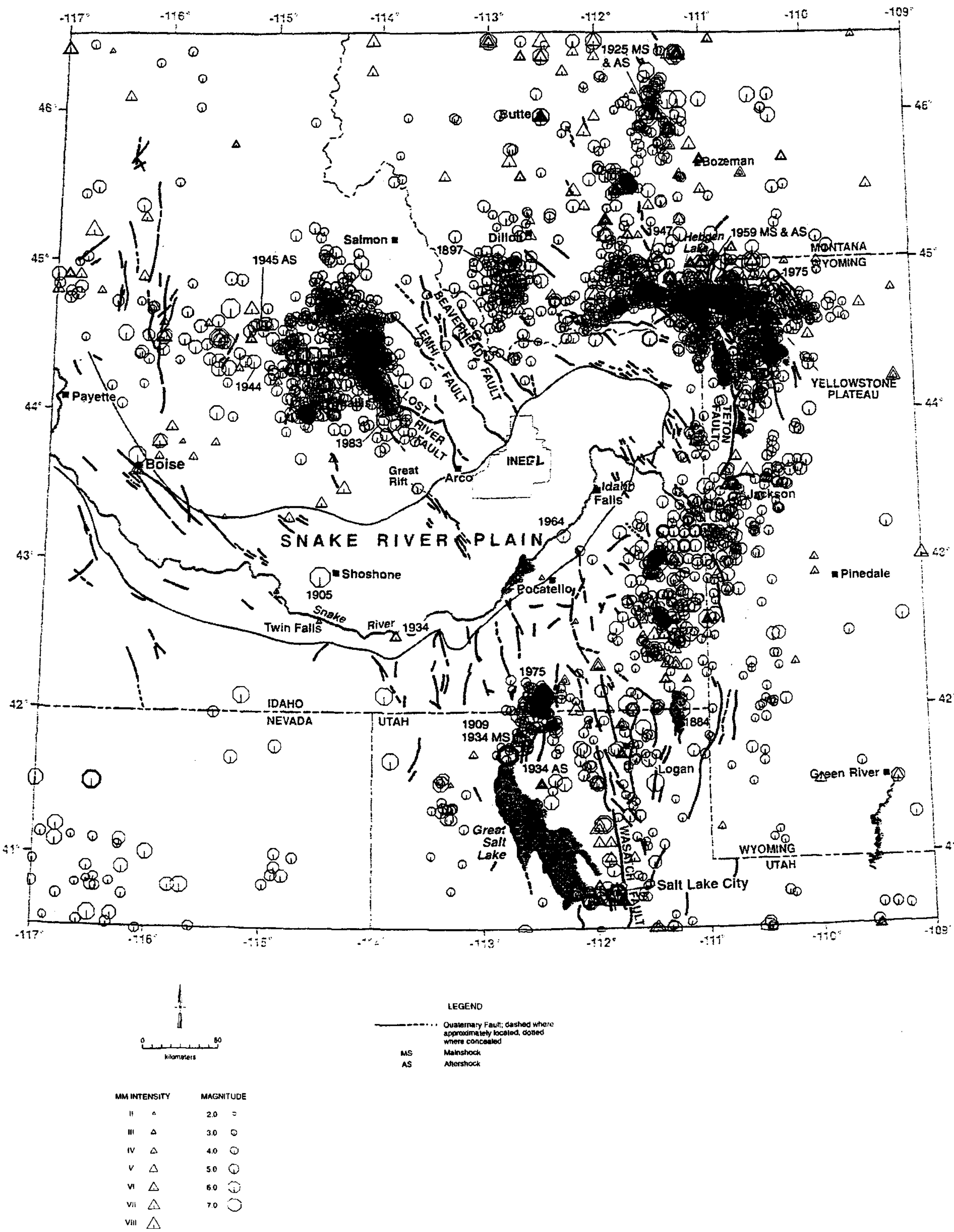


Figure 2-2. Historical seismicity ($M_s \geq 2.5$) from 1884 through 1992 and Quaternary faults of the Snake River Plain and surrounding Basin and Range province (after Woodward-Clyde Federal Services, 1996a)

mafic magmas and upper crustal silicic batholiths, and subsidence due to thermal contraction and densification of the crust in the wake of the hotspot as the plate moves to the southwest; and (iii) filling of the subsiding elongate basin with basalt lava flows and terrigenous clastic sediments to depths as great as 1 to 2 km in the ESRP (Woodward-Clyde Federal Services, 1996a; Sparlin et al., 1982; Brott et al. 1981; Blackwell, 1989).

Vents for basaltic volcanism in the ESRP are not random, but concentrated in volcanic rift zones and along the central axis of the Plain (Kuntz et al., 1992). The volcanic rift zones are characterized by alignments of basaltic vents (fissure eruptions and low-shield volcanoes) and presence of numerous fissures, normal faults, and grabens produced by shallow dike injection processes. They are northwest-trending features, 2 to 20 km wide and 20 to 95 km long (Woodward-Clyde Federal Services, 1996a). The Holocene and Pleistocene volcanic rift zones in the SRP have similar strikes as the late-Quaternary Basin and Range faults northwest of the ESRP. The axial volcanically induced zone is a northeast-trending, topographically-high belt of volcanic vents including basaltic shield volcanoes, silicic domes and magma-induced uplifts. These volcanic rift zones are considered regions of potential volcanically induced seismicity (Woodward-Clyde Consultants, 1992a; Woodward-Clyde Federal Services, 1996a).

2.1.2 Northern Basin and Range Province

The Basin and Range province is characterized by north-northwest-trending mountain ranges bounded on one or more sides by steeply dipping normal faults and surrounded by broad alluvial valleys filled with late Cenozoic-sediments (Ruppel, 1982). The north to northwest trends of normal faults and mountain ranges in the Basin and Range province and various *in situ* stress measurements show that the area is subjected to east-west to northeast-southwest directed extension (Zoback and Zoback, 1989). The development of the SRP by migrating hotspot has essentially divided the Basin and Range province. Stickney and Bartholomew (1987) defined the southern margin of the northern Basin and Range province as the Centennial Tectonic Belt. The belt is the most tectonically and seismically active portion of the northern Basin and Range province.

The Basin and Range province south of the SRP shows asymmetric tilted basins displaced chiefly by a listric or planar low-angle normal fault. It also has complex basins, typically with sub-basins, associated with both planar and listric normal faults that sole into low-angle detachments (Smith and Arabasz, 1991).

The Basin and Range province immediately north of the INEEL includes three major range-front normal faults, the Lost River, Lemhi, and Beaverhead faults that extend for a distance of 140 to 150 km from the northwest edge of the ESRP (Woodward-Clyde Consultants, 1992a,b; Woodward-Clyde Federal Services, 1996a,b). These three faults exhibit prominent evidence of late Pleistocene to Holocene activity, such as fault scarps, and evidence of paleoseismic activity (Scott el al., 1985; Crone and Haller, 1991). Quaternary displacement along these faults is dominantly normal slip that controls the present topography, although a lateral component is also recognized (Scott el al., 1985; Doser and Smith, 1985; Crone et al., 1987).

2.1.3 Yellowstone Plateau

The characteristics of the Yellowstone Plateau have been discussed in many references (Morgan et al., 1977; Smith and Christiansen, 1980; Smith and Braile, 1993; Christiansen, 1989; White et al.,

1975) and have been well summarized in the DOE SAR (U.S. Department of Energy-Idaho Operations Office, 1996b). During the late Quaternary, the Yellowstone area has experienced rapid and continuing uplift over the hotspot underneath it. This resulted in development of large faults with high slip rates (Pierce and Morgan, 1992) and relatively high seismic activity (Smith and Arabasz, 1991). Another characteristic of the Yellowstone Plateau tectonics is that active faults in this area have trends that are inconsistent with the direction of regional extension (Peyton et al., 1991). These characteristics signify that tectonic activity and seismicity in the Yellowstone area are due mainly to the interaction between regional extension and rapid local vertical crustal movement that is accompanied by hydrothermal activity and magma movements in the crust and upper mantle (Woodward-Clyde Federal Services, 1996a).

2.1.4 Intermountain Seismic Belt and Centennial Tectonic Belt

The ISB (figure 2-2) is a zone of concentrated seismicity that extends from northwestern Montana through the Yellowstone Plateau, southeastern Idaho, central Utah, and into southern Nevada (Sbar and Barazangi, 1970; Smith and Sbar, 1970; Smith and Sbar, 1974; Arabasz and Smith, 1981; and Smith and Arabasz, 1991). Smith and Arabasz (1991) considered the CTB as a branch of the ISB that extends from Hebgen Lake, Montana westward into central Idaho (figure 2-2), whereas Stickney and Bartholomew (1987) believe that the CTB is an independent zone of earthquake activity.

The southern portion of the ISB coincides with the transitional zones between the Basin and Range province to the west and the Colorado Plateau and Middle Rocky Mountains to the east. At Yellowstone, the ISB turns northwestward into the Northern Rocky Mountains. The deformational processes occurring along the ISB are principally in response to ongoing tectonic extension as observed throughout the Basin and Range province (Woodward-Clyde Federal Services, 1996a). East of the ESRP, the ISB coincides with a portion of the Idaho-Wyoming Thrust belt, a portion of the Middle Rocky Mountains physiographic province that has been subjected to Cenozoic extensional stresses similar to the Basin and Range province (Royes et al., 1975).

2.1.5 Idaho Batholith

As summarized in DOE-ID (1996b) SAR, the Idaho Batholith is distinguished by high, rugged topography; sparsity of Basin and Range faults; and absence of late Tertiary and Quaternary volcanism and large-magnitude earthquakes. It appears to have been relatively unaffected by regional extension due, possibly, to the granitic rocks that are stronger than rocks in the Basin and Range province to the east and southwest of the Idaho Batholith.

2.2 HISTORICAL SEISMICITY

According to data compiled by WCFS (Woodward-Clyde Federal Services, 1996a; Woodward-Clyde Consultants, 1992a, 1990), the first documented earthquake in the SRP and adjacent Basin and Range province is dated November 10, 1884. The event had an estimated Richter magnitude of 6.3 and may have occurred near Paris, Idaho. Since then, more than 5,800 earthquakes with magnitudes of 2.5 or greater have been documented in the region (figure 2-2). Appendix A of WCFS (1996a) provides detailed descriptions of these historical earthquakes.

2.2.1 Significant Earthquakes

There are two significant earthquakes in the region: the 1959 Hebgen Lake earthquake (moment magnitude M_w = 7.3 and surface wave magnitude M_s = 7.5) and the 1983 Borah Peak earthquakes (M_w = 6.8, M_s = 7.3). The 1959 Hebgen Lake earthquake is the largest historical earthquake that has occurred in the intermountain region. It occurred in an area of complex geology at the juncture of the ISB and the Yellowstone volcano-tectonic system (Doser, 1985). The 1959 earthquake had a reported maximum Modified Mercalli (MM) intensity of X, and it was felt over an area of 600,000 km^2 (Coffman et al., 1982). The mainshock appears to have consisted of two normal faulting subevents that reactivated pre-existing Laramide thrust faults (Doser, 1985). The focal depth was approximately 15 km. Two faults that have ruptured during the earthquake are the Red Canyon fault, which had up to 6.7 m of vertical displacement and a surface rupture length of 23 km; and the Hebgen fault, which exhibited 6.1 m of maximum vertical displacement and a rupture length of 14.5 km (Doser, 1985).

The rupture length of the 1983 Borah Peak earthquake was 36 km, including all of the nearly 21-km long Thousand Springs segment of the Lost River fault (Crone et al., 1987). The maximum MM intensity was IX in the area adjacent to the surface rupture (Stover, 1985). The earthquake occurred in an area characterized by seismic quiescence for at least two decades prior to the event (Dewey, 1987; King et al., 1987).

In addition to these two $M_s \geq 7$ earthquakes, several $M_s \geq 6$ events have occurred in the region (figure 2-2). A list of these earthquakes can be found in WCFS (table 3-1 in Woodward-Clyde Federal Services, 1996a). WCFS (1996a) considers the 1975 Pocatello Valley earthquake (Richter magnitude or local magnitude M_l = 6.0) of particular significance for seismic hazard assessment, because this event occurred on a "blind" fault that was not evident in the surface geology (Arabasz and Smith, 1981). Therefore, it provides justification for using the concept of a random earthquake (or areal source) in seismic hazard evaluations of the ISB to represent the potential for earthquakes other than those occurring on major faults that are individually characterized as potential seismic sources. (Woodward-Clyde Federal Services, 1996a).

As pointed out by WCFS (1996a), it is worth noting that historical earthquake records are often not an accurate indicator of the future occurrence of large-magnitude earthquakes within the ISB, because the recurrence times of such events can be on the order of several to tens of thousands of years. This has been exemplified by the seismic quiescence proceeding the 1983 Borah Peak earthquake. Therefore, the absence of historical seismicity within areas of the ISB should not be assumed as an indicator that individual areas are totally aseismic.

2.2.2 Seismicity in the Snake River Plain

Historical earthquake records in the SRP are scarce and inaccurate. Nevertheless, Stover et al. (1986) noted 14 historic earthquakes that may have been located within the SRP. Among these, the 1905 earthquake near the Shoshone is believed the maximum magnitude earthquake. Oaks (1992) and Oaks et al. (1992) conducted a comprehensive investigation of historical records of the Shoshone earthquake and suggested that it was located near the Idaho-Utah border, had a MM intensity of VI, and the magnitude of $M_l = 5.5 \pm 0.5$.

The improved modern seismographic coverage shows that the ESRP is characterized by infrequent and small-magnitude microearthquakes (Pennington et al., 1974; King et al., 1987; Pelton et al., 1990; Jackson et al., 1993). Jackson et al. (1993) located several microearthquakes that were located at depths less than 8 km based on portable microearthquake surveys, which is consistent with the hypothesis that the elevated crustal temperature in the ESRP confines the brittle portion of the crust, and hence seismogenesis, to the upper 5 to 10 km. Focal mechanisms show similar minimum principal stress directions observed in the Basin and Range province (Jackson et al., 1993).

2.3 POTENTIAL SEISMIC SOURCES AND THEIR CHARACTERISTICS

WCFS (1996a) defined three categories of seismic sources that are significant to the seismic hazard at INEEL (figure 2-3): (i) the late-Quaternary Basin and Range faults immediately north to northwest of the INEEL, including the Lost River, Lemhi, and Beaverhead faults; (ii) the ESRP volcanic rift zones; and (iii) regional area source zones, including the ESRP, northern Basin and Range, ISB, Yellowstone, Idaho Batholith, and central Basin and Range source zones. The northern Basin and Range source zone was used to represent the potential for earthquakes other than those occurring on the Lost River, Lemhi, and Beaverhead faults. The other areal source zones were used to represent both earthquakes occurring on the mapped faults that lie within them and seismicity occurring randomly on small, unmapped faults. WCFS (1996a) used the logic tree approach to incorporate various source characteristics into seismic hazard analyses. Since source characterization in WCFS (1996a) incorporated results from most of the previous studies and results from the most recent paleoseismic investigations, it forms the major basis in the following review.

2.3.1 Basin and Range Faults

Figure 2-4 (Woodward-Clyde Federal Services, 1996a) shows the three major late-Quaternary Basin and Range normal faults (the Lost River, Lemhi, and Beaverhead faults), their segments, fault scarps and trench sites along these faults, and the location of INEEL and the ICPP (the host site of the proposed TMI-2 ISFSI). Because of their significance, these three faults have been individually characterized as potential seismic sources, and their source parameters have been evaluated and presented in individual logic trees. WCFS (1996a) considered these three faults as having certain common source parameters, including dip, depth, recurrence models, weights on segmented versus unsegmented rupture behavior, and empirical relations used to estimate maximum magnitudes.

Fault Dips

Fault dips were assumed to range from 40° to 60°, with a preferred value of 50°. The selection was based on structural and seismological data from the 1983 Borah Peak earthquake (Doser and Smith, 1985, 1989; Barrientos et al., 1985; Richins et al., 1987; Wu and Bruhn, 1994; Woodward-Clyde Consultants, 1992a).

Seismogenic Depth

The seismogenic depth or the thickness of the seismogenic crust was considered to range from 14 to 18 km, with a preferred depth of 16 km. Selection of depth value was based on the 1983 Borah Peak earthquake (Doser and Smith, 1985, 1989; Richins et al., 1987), and compilations of focal depths of moderate to large Basin and Range earthquakes (Doser and Smith, 1989).

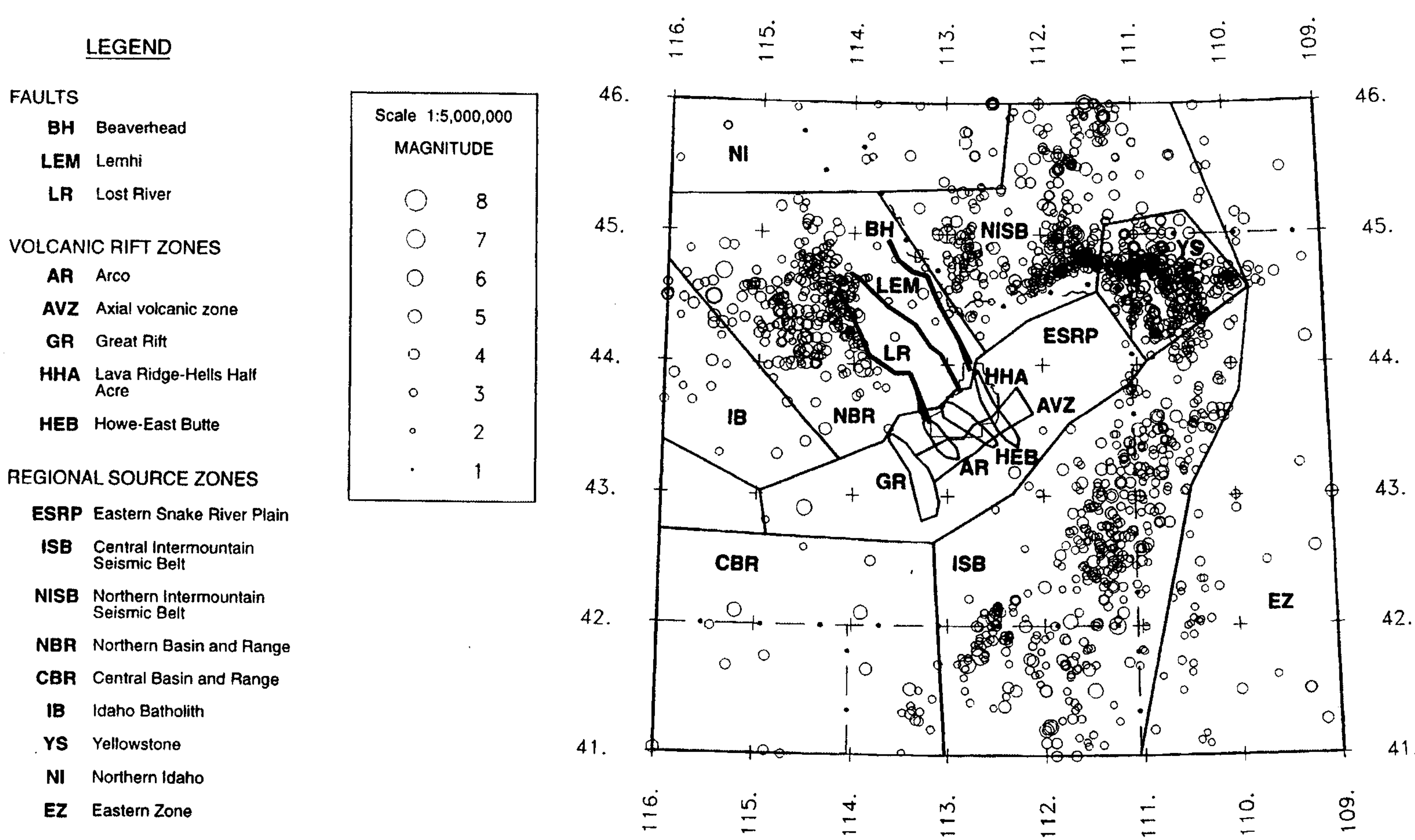
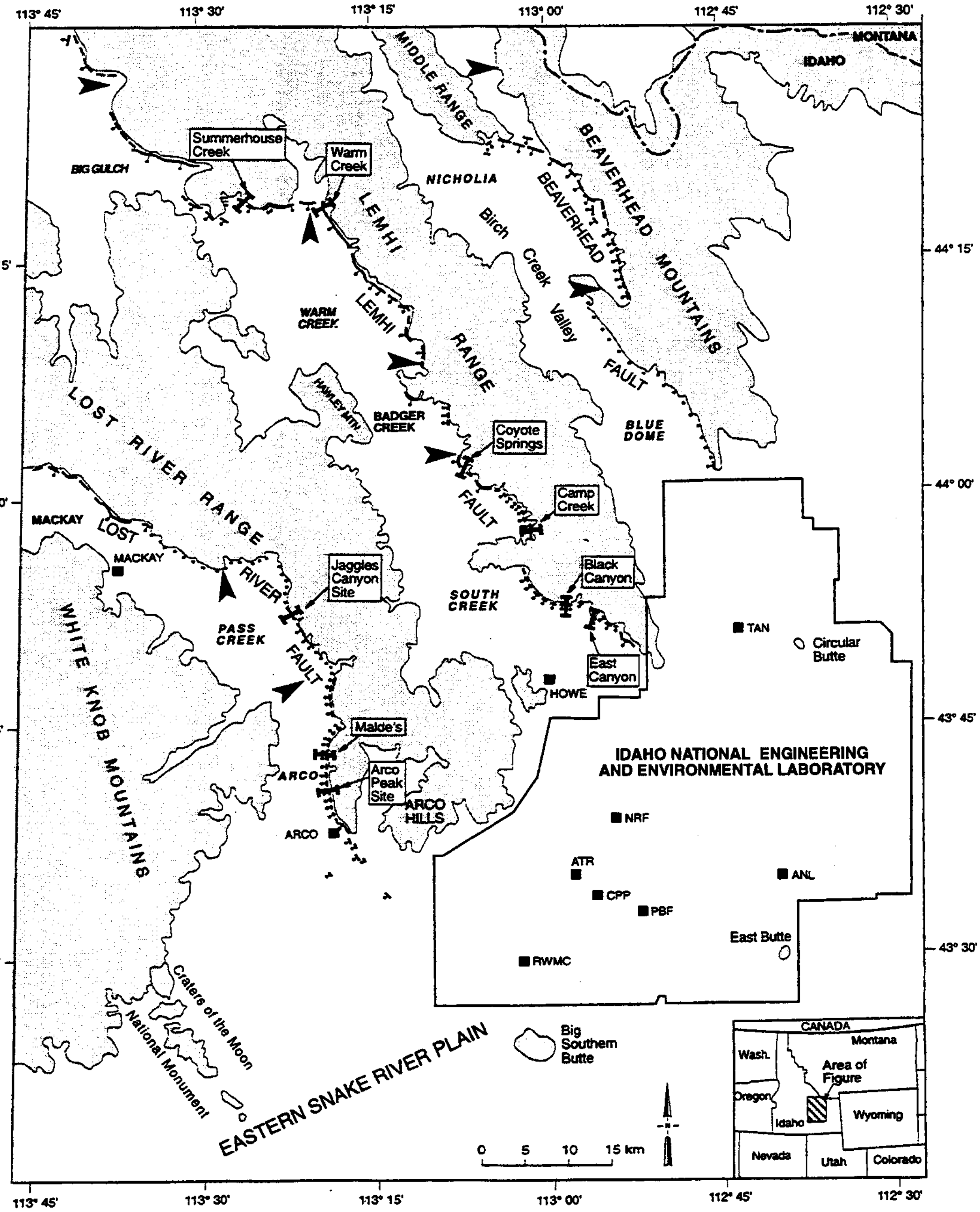


Figure 2-3. Seismic sources considered in Woodward-Clyde Federal Services (1996a) probabilistic assessment



LEGEND: Late Quaternary fault scarp, bar and ball on downthrown side, dotted where inferred.

Fault segment boundary

Trench site

Fault scarps and proposed segment boundaries by: Scott et al. (1985) and WCFS (1995) for the Lost River fault; Turko and Knuepfer (1991) and Gorton (1995) for the Lemhi fault; Crone and Haller (1991) for the Beaverhead fault. The Badger Creek segment is the central segment of Gorton (1995), and the South Creek segment is the southern segment of Gorton (1995).

Figure 2-4. Segments of the Lost River, Lemhi, and Beaverhead faults (after Woodward-Clyde Federal Services, 1996a)

Earthquake Recurrence Model and Slip Rate

Both modified exponential and characteristic recurrence models were used to represent earthquake recurrence on fault-specific sources, with the characteristic model assigned a higher weight. The modified exponential model assumes that magnitudes are exponentially distributed throughout the range of magnitudes, and assumes a truncated density function at the maximum. The characteristic model is based on paleoseismic observations that suggest that surface-faulting earthquakes tend to repeatedly rupture with similar size displacements and lengths (Schwartz and Coppersmith, 1984), suggesting that these events were similar in magnitude. The reasons for assigning a higher weight to the characteristic model are (i) displacement data from paleoseismic studies of the Lemhi and Lost River faults suggest that characteristic behavior dominates many fault segments (Schwartz and Crone, 1985; Schwartz, 1989; Baltzer, 1990; Woodward-Clyde Consultants, 1992b; Woodward-Clyde Federal Services, 1995) and (ii) studies elsewhere in the Basin and Range province indicate that this characteristic model is more appropriate than the exponential model for fault sources (Schwartz and Coppersmith, 1984).

The net slip rate averaged over the area of the fault rupture was used to characterize accumulation of seismic energy and earthquake recurrence. Various measurements of fault slips were converted, whenever possible, to dip slip assuming a 50° dipping fault with the component of lateral slip indicated.

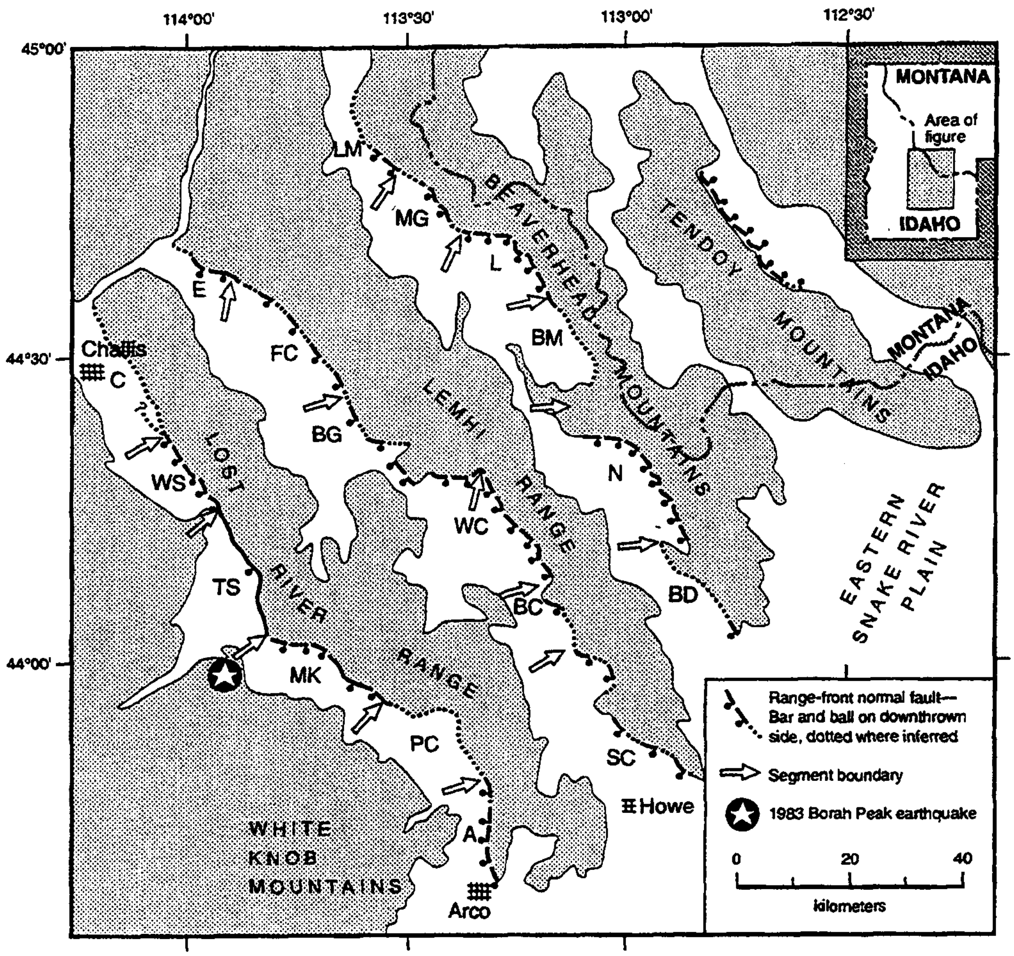
Fault Segment and Maximum Magnitude

There are paleoseismic, structural, geomorphic, seismological, and other geophysical evidences that the Lost River, Lemhi, and Beaverhead faults are segmented, with segments or portions of the faults rupturing independently of each other during large earthquakes or showing complex surface rupturing (Scott et al., 1985; Crone et al., 1987; Crone and Haller, 1989; Schwartz, 1989; Knuepfer et al., 1990; Turko and Knuepfer, 1991; Gorton and Knuepfer, 1993; Hemphill-Haley et al., 1994; Knuepfer, 1994; Woodward-Clyde Federal Services, 1995). Both segmented and unsegmented models were used in WCFS (1996a) analyses with the segmented model having a higher weight (0.7) than the unsegmented model (0.3).

WCFS (1996a) estimated the maximum magnitudes for all of the faults using the relationships between magnitude and surface rupture length or rupture area proposed by Wells and Coppersmith (1994). Rupture lengths were determined by segmentation models and scenarios developed to characterize uncertainty in the southern termination of all three faults. Areas were computed from lengths and down-dip widths.

2.3.1.1 The Lost River Fault

According to WCFS (1996a), the Lost River fault extends for 130 to 140 km along the western front of the Lost River Range from Arco to Challis, Idaho (figure 2-5). The fault was divided into six segments by Scott et al. (1985) based primarily on fault-scarp and range front morphology and structural relief of the range. The resultant segments have an average length of about 24 km and range in lengths from 18 to 29 km (Crone and Haller, 1991). Janecke (1993) and Wu and Bruhn (1994) slightly modified the southern segment boundaries (figure 2-5) based on patterns of late-Quaternary scarps and kinematic considerations, and WCFS (1995, 1996a) adopted such modifications.



Note: The star shows the epicenter of the 1983 Borah Peak earthquake. Arrows show boundaries between segments.

Segments are labeled as follows:

Lost River fault — A, Arco; PC, Pass Creek; MK, Mackay; TS, Thousand Springs; WS, Warm Springs; C, Challis.

Lemhi fault — SC, South Creek; BC, Badger Creek; WC, Warm Creek; BG, Big Gulch; FC, Falls Creek; E, Ellis.

Beaverhead fault — BD, Blue Dome; N, Nicholia; BM, Baldy Mountain; L, Leadore; MG, Mollie Gulch; LM, Lemhi.

Figure 2-5. Modified segments of the Lost River, Lemhi, and Beaverhead faults (after Woodward-Clyde Federal Services, 1996a)

The southern termination of the Lost River fault is not well-defined (Woodward-Clyde Federal Services, 1994; 1995). Three scenarios were considered by WCFS (1996a) as shown in figure 2-6. The fault terminates at less than 1 km southeast of Arco in Scenario 1 (Woodward-Clyde Federal Services, 1994; Wu and Bruhn, 1994). In Scenario 2, the fault terminates further southeast at less than 2 km west-southwest of Butte City (Kuntz et al., 1994). The third scenario terminates the fault further southeast at 12 km southeast of Arco to almost connect with the northern portion of the Arco volcanic rift zone (Smith et al., 1989; Kuntz et al., 1994). WCFS (1996a) assigned these three scenarios weights of 0.5, 0.4, and 0.1, respectively.

WCFS (1996a) used slightly different displacement per event values for different segments of the Lost River fault. Vertical displacement per event based on historic ruptures and trench data was 0.8 to 2.7 m on the Thousand Springs segment (Crone et al., 1987; Salyards, 1985; Schwartz and Crone, 1985), 1.2 to 1.5 m on the Arco segment (Woodward-Clyde Federal Services, 1995), and 2.0 to 2.6 m on the Pass Creek segment (Woodward-Clyde Federal Services, 1995). WCFS (1996a) considered these displacement values and adopted a range (table 2-1) to reflect uncertainty in how well these observations from individual sites might represent slip distributions over the entire segment. Displacement per event data are not available along Mackay, Warm Spring, and Challis segments. Therefore, only slip rate was used for these segments.

Table 2-1. Ranges and assigned weights of displacement and slip rate along the Lost River fault used in Woodward-Clyde Federal Service (1996a) probabilistic seismic hazard assessment

Fault Segment	Displacement per Event (m)			Slip Rate (mm/yr)	
	Average	Maximum	Weight	Slip Rate	Weight
Arco	0.5 1.5 2.0	1.0 1.5 3.0	0.185 0.630 0.185	0.05 0.10 1.00	0.250 0.650 0.100
Pass Creek	0.5 2.0 4.0	1.0 2.5 5.0	0.185 0.630 0.185	0.05 0.10 0.50 1.00	0.200 0.500 0.200 0.100
Mackay	N/A	N/A	N/A	0.10 0.25 1.00	0.185 0.630 0.185
Thousand Springs	0.5 0.8 3.0	1.0 2.7 5.0	0.185 0.630 0.185	0.10 0.25 1.00	0.185 0.630 0.185
Warm Spring	N/A	N/A	N/A	0.10 0.25 1.00	0.185 0.630 0.185
Challis	N/A	N/A	N/A	0.02 0.05 0.50	0.185 0.630 0.185

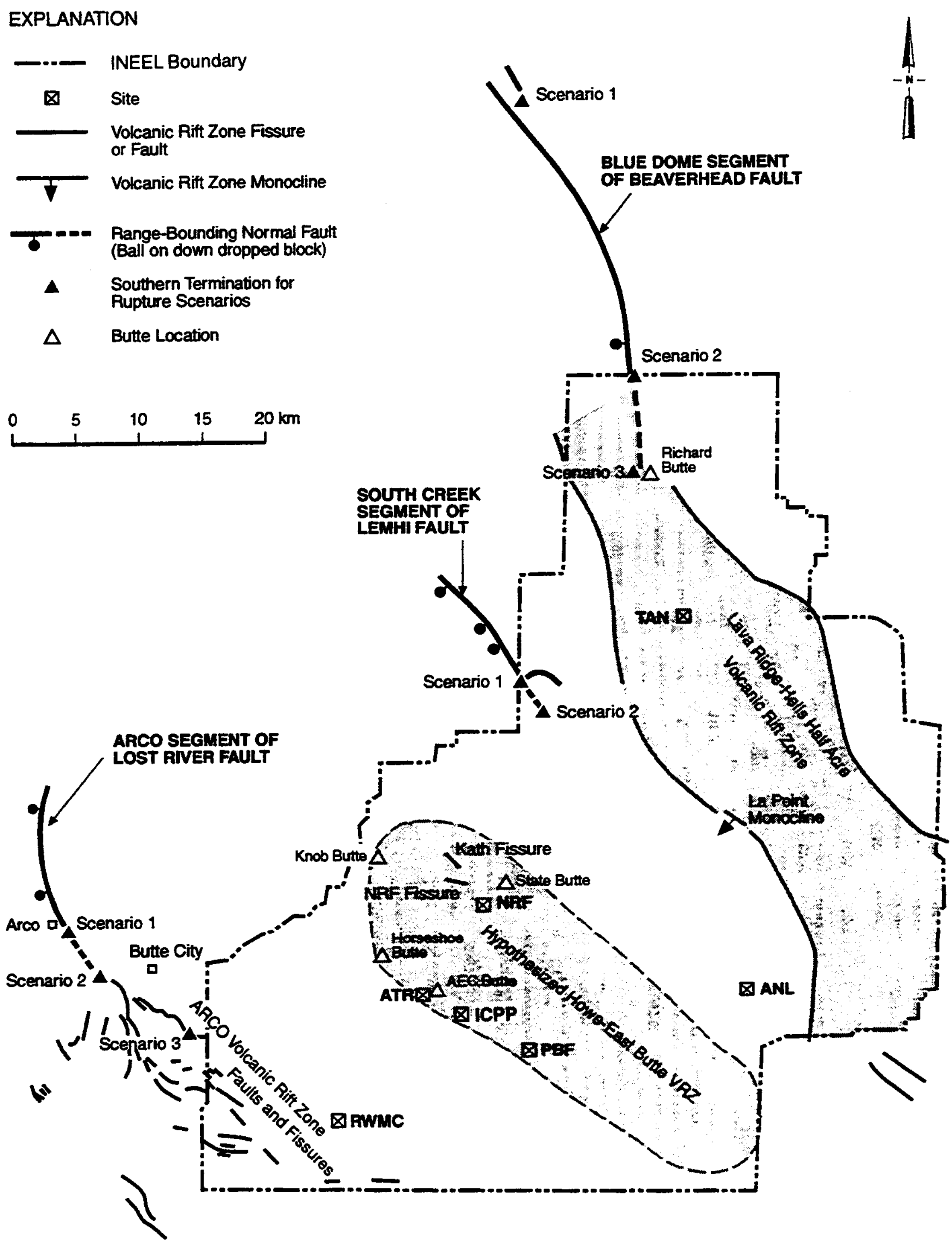


Figure 2-6. Southern terminations of Lost River, Lemhi, and Beaverhead faults (after Woodward-Clyde Federal Services, 1996a)

WCFS (1996a) used both the slip rates and recurrence intervals based on paleoseismic studies (Woodward-Clyde Federal Services, 1995; Malde, 1971, 1987; Pierce, 1985, 1988) to characterize rates of earthquake recurrence on the Pass Creek and Arco segments, with the recurrence intervals having higher weight. Also, surface faulting activities were found to have temporally clustered patterns along the Pass Creek and Arco segments. Table 2-2 shows ranges of intra-cluster, average, and inter-cluster recurrence intervals for these segments.

WCFS (1995) estimated vertical slip rates of 0.05 to 1.1 mm/yr for the Arco segment and about 0.05 to over 1 mm/yr for the Pass Creek segment. Only slip rates were used to characterize earthquake recurrence on the central and northern segments of the Lost River fault because of scarcity in paleoseismic records. A slip rate of 0.25 mm/yr with the maximum of 1.0 mm/yr was selected for the Mackay, Thousand Springs, and Warm Springs segments based on studies carried out by various investigators (Scott et al., 1985; Vincent, 1985; Hanks and Schwartz, 1987; Crone et al., 1987). For the Challis segment, a slip rate of 0.05 mm/yr was selected based on the observation that this segment had

Table 2-2. Recurrence intervals along the Arco and Pass Creek segments of the Lost River fault used in Woodward-Clyde Federal Services (1996a) probabilistic seismic hazard assessment

Fault Segment	Type of Interval	Recurrence Interval (yr)	Weight
Arco	Intra-cluster	500 1,000 9,000	0.185 0.630 0.185
	Average	11,000 25,000	0.500 0.500
	Inter-cluster	10,000 30,000 50,000	0.185 0.630 0.185
Pass Creek	Intra-cluster	100 500 8,000	0.185 0.630 0.185
	Average	18,000 26,000 37,000	0.300 0.400 0.300
	Inter-cluster	15,000 40,000 50,000 80,000	0.200 0.400 0.300 0.100

the lowest rates of late-Quaternary activity in the entire Lost River fault (Crone and Haller, 1991; Scott et al., 1985). Again, ranges of slip rate were adopted to reflect uncertainty in WCFS (1996a) PSHA. These data are shown in table 2-1.

2.3.1.2 The Lemhi Fault

The Lemhi fault is the closest and the most significant to the INEEL facilities. It is about 150 km long and bounds the western front of the Lemhi Range. Similar to the Lost River fault, the Lemhi fault was originally divided into three segments (figure 2-4) and recently revised to six rupture segments (figure 2-5) based on fault scarps, apparent discontinuities in the trace of the fault along its extent, variations in range-front morphology, and structural relief (Turko and Knuepfer, 1991; Crone and Haller, 1991; Knuepfer et al., 1990; Haller, 1988; Turko, 1988). From south to north, the segments are: South Creek, Badger Creek, Warm Creek, Big Gulch, Falls Creek, and Ellis (figure 2-5). Segment boundaries used by WCFS (1996a) follow those of Turko and Knuepfer (1991) from the Warm Creek segment north and modified Turko and Knuepfer (1991) model along the southern part.

Two rupture scenarios were suggested by Woodward-Clyde Consultants (WCC) (1992a,b) and used in WCFS (1996a) analyses to account for uncertainties in the southern termination of the Lemhi fault (figure 2-6). Scenario 2 extends about 2 km further southeast than Scenario 1. Scenarios 1 and 2 were assigned weights of 0.3 and 0.7, respectively in WCFS (1996a).

Table 2-3 summarizes ranges of displacement data and assigned weights in the WCFS (1996a) PSHA. The vertical displacement per event was estimated to be between 1 and 3 m, with an average of 2.0 m for South Creek and Warm Creek segments (Turko and Knuepfer, 1991; Woodward-Clyde Consultants, 1992b; Baltzer, 1990). For Big Gulch segment, vertical displacement per event ranges from 1.5 to 5.0 m, and averages 2.8 m (Turko and Knuepfer, 1991; Knuepfer et al., 1990). For the Falls Creek segment, the surface offsets per event range from nearly 1 to 2.1 m, and average 1.5 m (Turko and Knuepfer, 1991). Displacement per event data are not available for other segments.

WCFS (1996a) used both slip rate and recurrence intervals to characterize earthquake recurrence on the South Creek, Warm Creek, and Big Gulch segments, based on various studies (e.g., Malde, 1971, 1987; Baltzer, 1990; Knuepfer et al., 1990; Woodward-Clyde Consultants, 1992b; Hemphill-Haley et al., 1994) (see tables 2-3 and 2-4). For the South Creek segment, earthquakes were found to have temporal clustering characteristics (table 2-4). Data shown in table 2-4 for intra-cluster, average, and inter-cluster intervals cover results from recent paleoseismic studies and associated uncertainties (Woodward-Clyde Consultants, 1992b; Malde, 1985; Knuepfer et al., 1990). Interval data are not available for the Badger Creek and Falls Creek segments. Slip rates for various segments are summarized in table 2-3. Slip rate for the South Creek segment was determined to be between 0.1 to 1.0 mm/yr, with an average of about 0.2 mm/yr (Woodward-Clyde Consultants, 1992b). Slip rate on Badger Creek segment was based on Gorton (1995), Knuepfer et al. (1990), and Baltzer (1990). The slip rate ranges from 0.02 to 0.5 mm/yr, with an average of 0.05 mm/yr. Slip rates and recurrence intervals for the Warm Creek and Big Gulch segments were primarily based on data from trenches (Baltzer, 1990) and surface-offsets measured for fault scarps (Turko and Knuepfer, 1991). On the Warm Creek segment, the recurrence interval is 5,000 to 15,000 yr, with an average of 10,000 yr. The slip rate ranges from 0.1 to 1 mm/yr and averages 0.25 mm/yr. For Big Gulch segments, the recurrence interval is between 2,000 to 60,000 yr, with an average of 15,000 yr. The slip rate ranges from 0.1 to 1 mm/yr and averages 0.25 mm/yr.

Table 2-3. Ranges and assigned weights of displacement and slip rate along the Lemhi fault used in Woodward-Clyde Federal Service (1996a) probabilistic seismic assessment

Fault Segment	Displacement per Event (m)		Slip Rate (mm/year)	
	Average	Weight	Slip Rate	Weight
South Creek	1.00 2.00 3.00	0.185 0.630 0.185	0.10 0.20 1.00	0.185 0.630 0.185
Badger Creek	N/A	N/A	0.02 0.05 0.50	0.185 0.630 0.185
Warm Creek	1.00 2.00 3.00	0.185 0.630 0.185	0.10 0.25 1.00	0.185 0.630 0.185
Big Gulch	1.50 3.00 5.00	0.185 0.630 0.185	0.10 0.25 1.00	0.185 0.630 0.185
Falls Creek	0.50 1.50 2.00	0.185 0.630 0.185	0.05 0.20 0.50	0.185 0.630 0.185
Ellis	N/A	N/A	0.02 0.07 0.50	0.185 0.630 0.185

2.3.1.3 The Beaverhead Fault

The Beaverhead fault is about 150 km long. It was originally divided into four segments (figure 2-4) and recently revised to six segments (figure 2-5) based on fault scarp and discontinuities in geometry along the strike (Haller, 1988; Crone and Haller, 1991). From south to north, the segments are: Blue Dome, Nicholia, Baldy Mountain, Leadore, Mollie Gulch, and Lemhi (figure 2-5). The Leadore segment is the only segment showing Holocene rupture (Haller, 1988). In the WCFS (1996a) study, only the empirical relations for length and area were used to determine maximum magnitudes due to lack of data on displacements per event.

Mapping results show that the southern part of the Beaverhead fault is less active during the late Quaternary than the southernmost segments of the Lemhi and Lost River faults (Haller, 1988; Embree, 1989). Similar to the approach adapted to the southern termination of the previous two faults, WCFS (1996a) considered three rupture scenarios for the Beaverhead fault (figure 2-6). Scenario 1 considers the

Table 2-4. Recurrence intervals along the Lemhi fault used in Woodward-Clyde Federal Service (1996a) probabilistic seismic hazard assessment

Fault Segment	Type of Interval	Recurrence Interval (year)	Weight
South Creek	Intra-Cluster	500 3,500 6,000	0.100 0.500 0.400
	Average	8,000 12,000 26,000	0.300 0.400 0.300
	Inter-cluster	15,000 40,000 100,000	0.185 0.630 0.185
Warm Creek	Average	5,000 10,000 15,000	0.300 0.400 0.300
Big Gulch	Average	2,000 15,000 60,000	0.185 0.630 0.185

Blue Dome segment as inactive and, therefore, the fault terminates at the southern end of the Nicholia segment near Timber Creek (Haller, 1988). This is based mainly on the lack of evidence for late-Quaternary activity (Embree, 1989; Corne and Haller, 1991). Scenario 2 assumes that rupture terminates at the southern end of the range, coincident with the southern end of the most southwestern bedrock splay of the Blue Dome segment (Kuntz et al., 1994). Scenario 3 extends the rupture further south to near Richard Butte (figure 2-6). These three scenarios were assigned weight of 0.5, 0.4, and 0.1, respectively by WCFS (1996a).

Haller (1988) determined dip-slip rates of 0.08 to 0.19 mm/yr for the central Nicholia and Leadore segments, based on surface offsets of deposits that are about 15 ka old. Based mainly on this data, WCFS (1996a) selected a range of 0.05 to 1.0 mm/yr, with an average of 0.15 mm/yr. Very little is known about slip rates on the Blue Dome, Baldy Mountain, and Lemhi segments. The general absence of Quaternary activity suggests lower rates. For example, Haller (1988) inferred that no activity occurred in the past 100 ka along the Blue Dome segment. Based on these information, WCFS (1996a) assumed slip rates for the Blue Dome, Baldy Mountain and Lemhi segments as 0.02 to 0.3 mm/yr, with an average of 0.05 mm/yr. Since no fault-specific recurrence interval data are available for the Beaverhead fault, only slip rate was used to characterize earthquake recurrence.

As summarized by WCFS (1996a), it appears that, in general, the central parts of Basin and Range faults, including the Lost River, Lemhi, and Beaverhead faults, are more active in that they have higher long-term slip rates during the Quaternary relative to other segments (Scott et al., 1985; Crone and Haller, 1991; Pierce and Morgan, 1992). In addition, the central segments of these faults tend to show evidence of more recent surface faulting, as indicated by fault-scarp and paleoseismic trenching.

2.3.2 Eastern Snake River Plain Volcanic Zones

Although the volcanic rift zones and the ESRP have been seismically quiescent during the historical period, studies of active volcanic rift zones worldwide suggest that during times of volcanic activity, the rift zones are usually the locus of dike injection and associated seismic activity. WCFS (1996a) discussed the earthquake potential of the ESRP volcanic rift zones largely based on analogues of active volcanic-rift zones worldwide (Smith et al., 1989; Woodward-Clyde Consultants, 1992a; Jackson, 1994; Hackett et al., 1996). The criteria that were used to identify volcanic rift zones in the INEEL vicinity are the spatial distribution of volcanic vents and dike-induced faults and fissures. Based on these criteria, five volcanic zones were identified: the Arco, Lava Ridge-Hells Half Acre, Great, and Howe-East Butte volcanic rift zones; and the axial volcanic zone (figures 2-3 and 2-7).

The Arco volcanic rift zone is about 20 km long and is characterized by fissures that open vertically and small-displacement faults that offset the basaltic lava flows at the surface. Other features include aligned vents, elongated vents, and small shield volcanos (Kuntz, 1977; Smith et al., 1989). The maximum fault length observed within the Arco volcanic rift zone is 5.3 km. Fault displacements are usually less than 5 m, although the maximum could be as large as 10 m. Usually, the southwest side shows downward movement.

The Lava Ridge-Hell's Half Acre volcanic rift zone has surficial features similar to those along the Arco volcanic rift zone, although it is less well preserved. The most pronounced features are the two sets of fissures associated with the vent area of Hell's Half Acre lava field. These fissures extend over 15 km (Woodward-Clyde Federal Services, 1996a).

Howe-East Butte volcanic rift zone consists of four volcanic vents and two isolated fissures in a broad area south and southeast of Howe (Kuntz, 1978; Golder Associates, 1992a). It also coincides with a positive northwest-trending aeromagnetic anomaly that may reflect the presence of subsurface basaltic dikes (Josten et al., 1993). However, the density of vents is extremely low and, therefore, a low probability of existence (0.1) of this volcanic rift zone was assigned in the study of WCFS (1996a).

The axial volcanic zone extends northeast parallel to the axis of the ESRP. Although it includes few surface deformation features, the axial volcanic zone is comprised of numerous volcanic vents. Also, geochronometry indicates that the axial volcanic zone has been an area of basaltic and rhyolitic volcanism for at least the past 1.2 million yr and coincides with several Holocene lava fields (Woodward-Clyde Federal Services, 1996a).

Evaluation of worldwide volcanic rift zones shows that the maximum magnitudes of earthquakes that can be associated with dike injection are near $M_w = 5.0$ (Jackson, 1994; Smith et al., 1996a; Hackett et al., 1996; Woodward-Clyde Consultants, 1992a). Such earthquakes are usually generated at shallow depths along normal faults above the intruding dikes. The depth extent of these normal faults above or ahead of propagating dikes is about 2 to 4 km (Karpin and Thurber, 1987; Klein et al., 1987; Du and Aydin, 1992; Rubin, 1992). Mainly based on this information, a range of 2 to 4 km was used as the depth extent of normal faults associated with dike injection and a maximum magnitude of $M_w = 5 \pm 0.5$ was assumed in the study of WCFS (1996a).

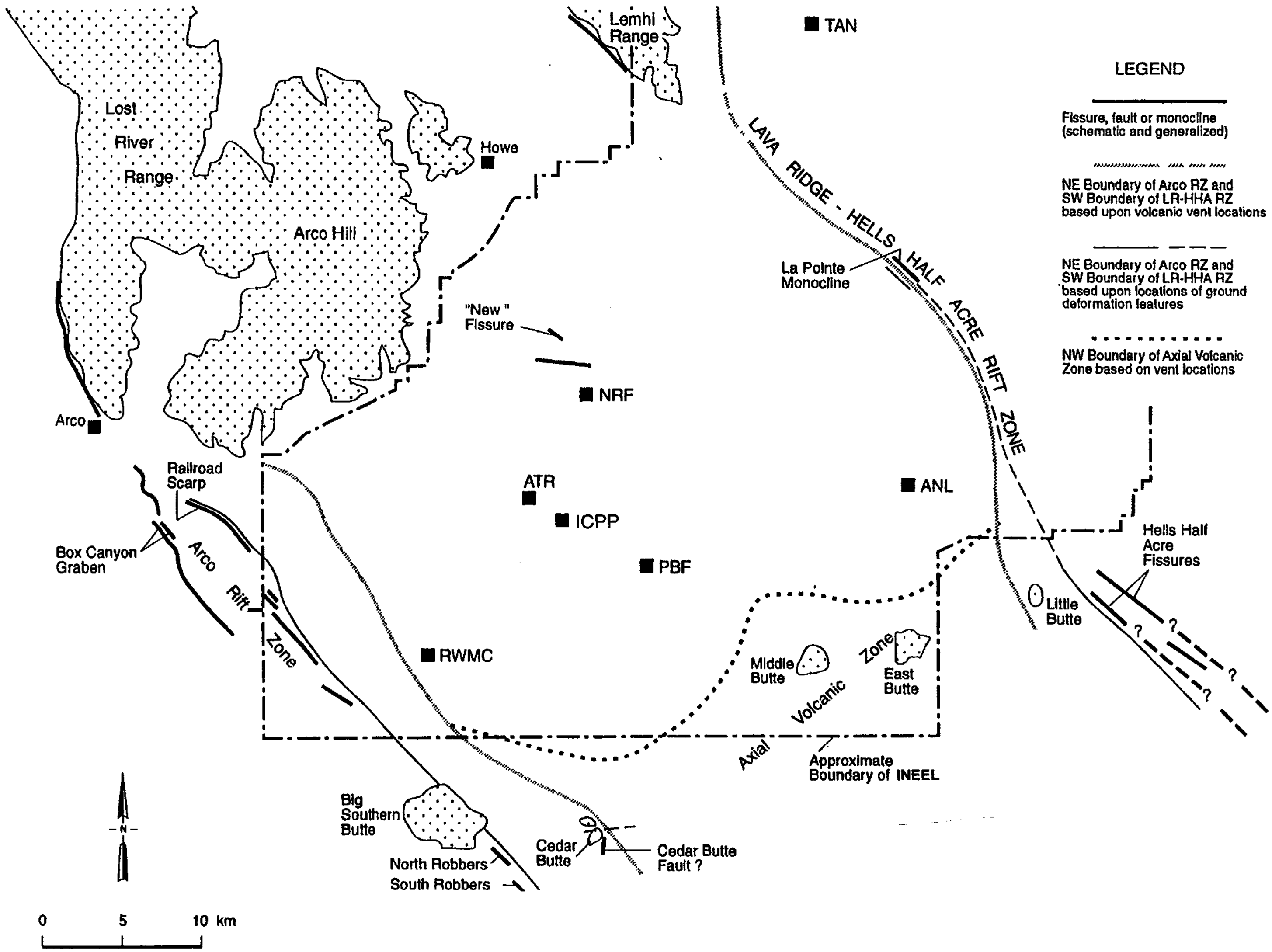


Figure 2-7. Locations of volcanic rift zones near Idaho National Engineering and Environmental Laboratory (after Woodward-Clyde Federal Services, 1996a)

The earthquake recurrence model for volcanic rift zones was assumed to be exponential, and the recurrence intervals were estimated based on the determination of eruptive episodes. This, in turn, was based on estimation of the time interval of volcanism and number of vents, fissures, or flow group. The estimated recurrences are 10,000 to 32,000 yr for axial volcanic zone, with an average of 16,000 yr; 7,000 to 34,000 yr for Arco volcanic rift zone, with an average of 17,000 yr; 25,000 to 80,000 yr for Lava Ridge-Hell's Half Acre volcanic rift zone, with an average of 40,000 yr; and 70,000 to 200,000 yr for Howe-East Butte volcanic rift zone, with an average of 100,000 yr (Woodward-Clyde Federal Services, 1996a).

2.3.3 Regional Source Zones

In addition to the fault and volcanic sources, several regional seismic source zones were also included in WCFS (1996a) seismic hazard analyses (figure 2-3). These are referred to as areal sources.

2.3.3.1 Eastern Snake River Plain Source Zone

In their PSHA, WCFS (1996a) defined the depth or thickness of the seismogenic crust within the ESRP to be 8 km with an uncertainty of about ± 2 km. Estimation of the location and magnitude of the maximum earthquake is mainly based on the 1905 Shoshone earthquake. Two alternatives were considered: (i) the Shoshone earthquake did occur in the ESRP with the maximum magnitude for the ESRP ranging from M_w = 5.5 to 6 and (ii) the Shoshone earthquake occurred outside of ESRP, the maximum magnitude for the ESRP ranges from 5 to 6, with an average of 5.5. Recurrence relationships were selected according to these two different alternatives.

2.3.3.2 Other Seismic Source Zones

WCFS (1996a) used three alternative models to represent seismic source zonation in the region, considering the uncertainty in zonation of the ISB and northern Basin and Range. These alternatives include (i) the northern ISB (north of Yellowstone) and the central ISB (south of Yellowstone, and the northern Basin and Range) are a single-source zone; (ii) the northern ISB and the northern Basin and Range are one source zone and the central ISB is a separate source zone; and (iii) the northern and central ISB and the northern Basin and Range are three separate source zones.

Besides the ISB and northern Basin and Range source zones, WCFS (1996a) also considered the Yellowstone, Idaho Batholith, and central Basin and Range as separate seismic source zones. The characteristic parameters of these source zones were determined based on tectonic and seismic characteristics of each individual province as discussed in section 2.1. Such parameters include maximum earthquake magnitude, and recurrence characteristics (see Woodward-Clyde Federal Services, 1996a for details). Values used by WCFS (1996a) appear to be adequate and conservative based on a review of the existing literature.

2.4 STATUS OF SEISMIC HAZARD ASSESSMENT

Seismic hazard analyses have been carried out both deterministically and probabilistically. It is important to note that there are substantial differences between DSHA and PSHA. The first difference is that DSHA considers only the most significant earthquake sources with a fixed site-to-source distance (usually the minimum) rather than all potential seismic sources within the area of interest (200 miles in the case of most facilities in INEEL as required in Regulatory Guide 1.70). The most significant earthquake is usually referred to as the maximum credible earthquake (MCE), SSE, operating basis earthquake (OBE), design earthquake (DE), or safety earthquake (SE). On the other hand, probabilistic analyses consider contributions from all potential seismic sources and integrate across a range of source-to-site distances. The second difference is that DSHA calculates ground motion based on the MCE, whereas PSHA integrates over a large range of possible earthquake magnitudes. When it comes to presenting and justifying design basis ground motions (DBGM), DSHA has an important advantage in transparency in getting from deterministic earthquake(s) to DBGM, whereas in PSHA it is a more sophisticated exercise because a range of magnitudes and distances contribute to the calculated hazard. The third important difference between DSHA and PSHA is that the latter uses uncertainty analysis and expert opinion. DSHA commonly proceeds without uncertainty analysis and the systematic input of diverse expert opinion, although DSHA could incorporate them. The fundamental difference is that PSHA carries units of time, and DSHA does not. Therefore, the important aspect of DSHA is not that it is deterministic but that it is a time-independent statement (i.e., it does not take into consideration the planned operating period of the facility). The essence of PSHA, on the other hand, is not the inclusion of uncertainty and probability and all the distribution functions, but the capability of giving an estimate of the likelihood of earthquake ground motion occurring at the location of interest within the time frame of interest (Hanks and Cornell, 1996; Reiter, 1990).

2.4.1 General Review

Evaluation of potential seismic hazard at the INEEL started in the late 1960s. From 1967 to 1969, U.S. Geological Survey conducted geological studies that included trenching along the Arco scarp (South Creek segment, figure 2-5) of the Lost River fault and the Howe Scarp (Arco segment, figure 2-5) of the Lemhi fault (Malde et al., 1971). The study yielded a qualitative conclusion that large earthquakes may recur in the future.

WCC (1975) conducted the first DSHA of the Loss of Fluid Test (LOFT) Reactor site (figure 2-8). Their studies assumed that the Howe Scarp fault (i.e., the South Creek segment of the Lemhi fault) is the most significant earthquake source to LOFT, is the closest distance to the site at 13.6 km, and is capable of producing a magnitude 6.75 earthquake. Based on these assumptions, a peak horizontal bedrock acceleration of 0.34 g was predicted. However, in this study, the ground motion attenuation relations were based on data of earthquakes occurring elsewhere in U.S.

Allied Chemical Corporation (1975) conducted DSHA analyses at the ICPP site. They assumed a maximum earthquake of Richter magnitude M_l = 7.75 that could occur either on the southern segment of Lost River or Lemhi fault and predicted a peak horizontal bedrock acceleration of 0.33 g (0.22 g vertical).

Assuming the WCC (1975) design earthquake of M_l = 6.75 on the Howe Scarp fault, Agbabian Associates (1977) estimated a PHA of 0.37 g at the ground surface for the LOFT and 0.30 g for the ICPP. These calculations were based on the mean plus 50-percent curve of a Mercalli intensity-attenuation developed from five Intermountain earthquakes including the 1959 Hebgen Lake earthquake. Agbabian Associates (1977) also conducted the first PSHA, which resulted in similar PHAs.

In a WCC (1979) study of the Transient Reactor Text Facility (TREAT), PHA on bedrock was calculated as 0.2 to 0.22 g. In this study, it was proposed that the low-velocity alluvial interbeds within the basalt resulted in lower ground motion.

TERA Corporation (1984) performed a probabilistic analysis for the Argonne National Laboratory (ANL)—West facility, which resulted in peak accelerations of 0.073, 0.14 and 0.24 g with return periods of 100, 1000, and 10,000 yr, respectively. The LOFT facility appears to have a peak acceleration of 0.36 g with a return period of 10,000 yr. Also, they indicated that sites closer to the northern Basin and Range province have correspondingly higher accelerations.

It was the empirical and non-site specific nature of these early deterministic and probabilistic ground motion estimates and the unresolved value for the maximum earthquake that motivated a series of much more sophisticated and comprehensive site-specific studies. Also, the occurrence of the 1983 Borah Peak earthquake provided the first ground motion record at the INEEL, which enabled a more realistic evaluation of various ground motion attenuation relationships.

2.4.2 Recent Deterministic Seismic Hazard Assessment

2.4.2.1 1990 Woodward-Clyde Deterministic Assessment

WCC (1990) estimated site-specific strong ground motion in terms of peak horizontal ground acceleration and acceleration response spectra for 12 INEEL facilities, including Fuel Processing Restoration (FPR) as a rock site, and Special Isotope Separation (SIS) as a soil site. These two sites are adjacent to the ICPP site (figure 2-8).

The ground motion attenuation was based on a methodology incorporating the Band-Limited-White-Noise (BLWN) ground motion model that was first developed by Hanks and McGuire (1981) (sometimes referred to as the stochastic model) coupled with Random Vibration Theory (RVT). The original BLWN-RVT model that assumed a point earthquake source was slightly modified to incorporate a finite fault source considering simplified fault geometry (Woodward-Clyde Consultants, 1990). The biggest advantage of the stochastic model is that it takes into account the effect of propagation path and site by incorporating various path and site parameters. It has proven successful in capturing the essential engineering aspects of strong ground motions. However, the method treats the problem in a one-dimensional manner. The potential effects of two- and three-dimensional (3D) nature were not studied.

The soil response model considered nonlinear behavior at high-strain levels. Modulus reduction and damping curves developed by Toro et al. (1988) were used. The soil was assumed to be the Lost River flood-plain sands, silts, and gravels having shear velocity of 0.41 km/s and density of 2.0 g/cm^3. Site-specific geologic profiles were developed for each of the 12 sites investigated based on borehole sonic log of the INEEL-1 deep hole (figure 2-8). The thickness of soil at the SIS site was assumed to be 12.2 m.

The bases for selecting earthquake source parameters were the 1983 Borah Peak earthquake that occurred on the Lost River fault as described in section 2.2. Since all three northern Basin and Range faults (i.e., Lost River, Lemhi, and Beaverhead faults) show evidence for repeated Quaternary occurrences of large-magnitude earthquakes, it was assumed for purposes of analysis, that an earthquake similar to the 1983 Borah Peak earthquake would occur on the southern segment of the Lemhi fault because it is closest to most of the INEEL facilities, including FPR and SIS. The maximum earthquake or the MCE was assumed to have a moment magnitude of 6.9 (surface wave magnitude of 7.3), similar to the 1983 Borah Peak earthquake. This number was also supported by estimation using a length-magnitude relationship assuming only the Howe segment (the South Creek segment, figure 2-5) of the Lemhi fault would rupture in a maximum event and the length of the segment is 23 km (Turko, 1988). The Howe segment was assumed to be a 45° southwest-dipping normal fault with the initial point of

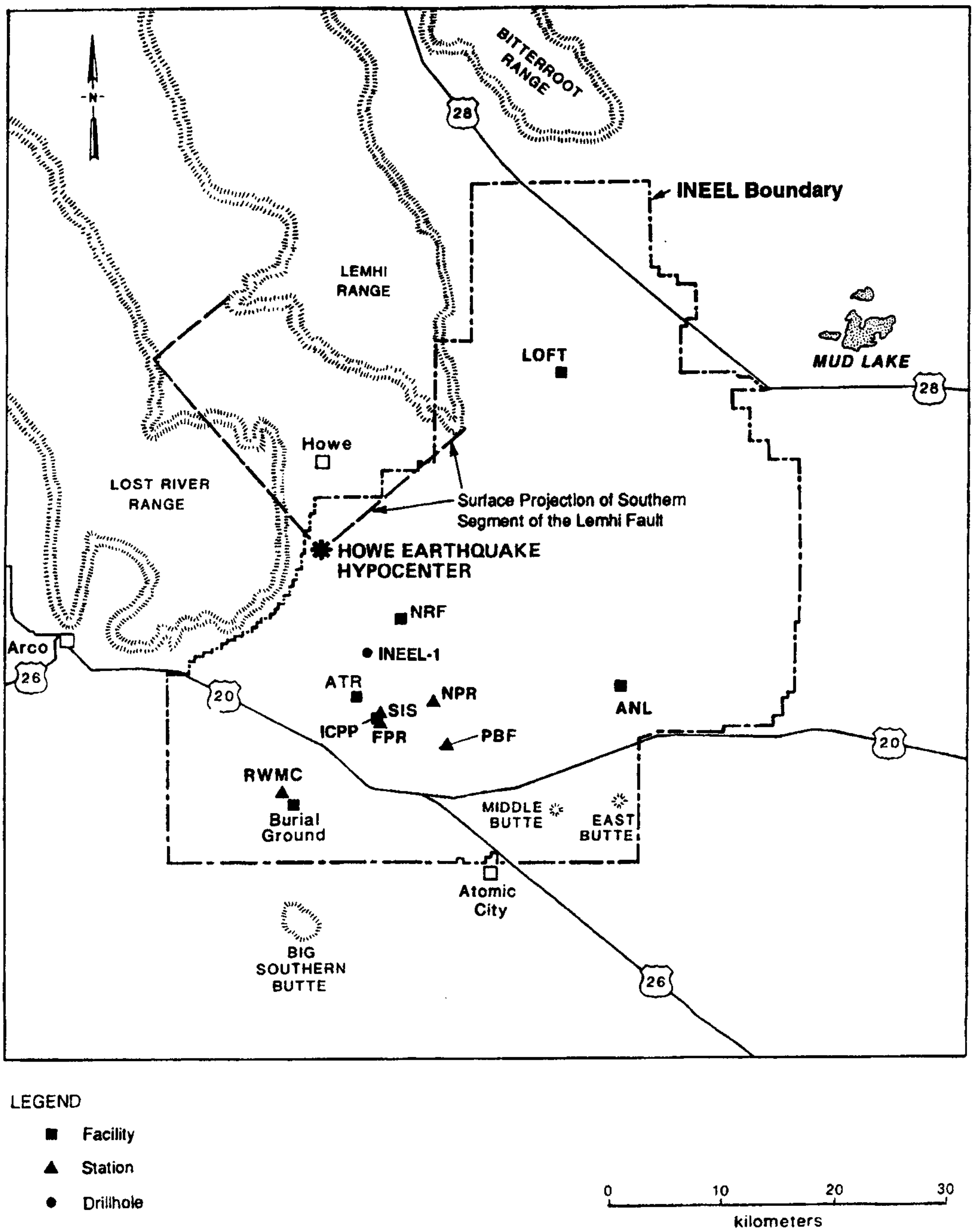


Figure 2-8. Idaho National Engineering and Environmental Laboratory sites investigated in Woodward-Clyde Consultants (1990) deterministic seismic hazard assessment (ANL - Argonne National Laboratory, ATR - Advanced Test Reactor, FPF - Fuel Processing Restoration Facility, ICPP - Idaho Chemical Processing Plant, INEEL-1 - INEEL Exploratory Borehole no. 1, LOFT - Loss of Fluid Test Reactor, NPR - New Production Reactor, NRF - Naval Reactor Facility, PBF - Power Burst Facility, RWMC - Radioactive Waste Management Complex, SIS - Special Isotope Separation Site)

rupture at the southern end at a depth of 16 km for the finite fault model, and the point source model assumed that the MCE would occur at the closest point on the rupture plane to the site. Thus, the hypocentral source-to-site distance is 22.5 km for FPR and 22.1 km for SIS, and the horizontal source-to-site distance is 21.4 km for FPR and 20.8 km for SIS.

To investigate the effects of uncertainties in source, propagation path and site parameters, a parametric study was carried out by varying parameters such as shear-wave quality factor (Q_s), shear-wave velocity (V_s), and stress parameter. Results show that the estimated uncertainties in the Q_s of the geologic profiles have the most significant impact on the site-specific response spectra. An increase in Q_s by a factor of two can result in an increase in PHA by 33 percent. Of slightly lesser importance is the uncertainty in the stress parameter. Increasing the stress parameter from 50 bars to 100 bars increases the PHA by a factor of 1.7. V_s was found to have minimal effects on the predicted strong ground motion.

The 5-percent damped absolute acceleration response spectra for each site were assumed to be generally log-normally distributed, and estimations of the 16th, 50th, and 84th percentiles of the distribution were made. In order to determine the percentile spectra, the value of each parameter used in the parameter variations was assigned a weight based on the estimated probability that it is the correct value. Based on analyses using every possible combination of these weights, the 16th-, 50th- and 84th-percentile spectra were computed for one of the 12 sites [the New Production Reactor (NPR) site, figure 2-8]. It was found that NPR median spectrum is very similar in spectral shape to the standard spectrum with standard parameters, but slightly lower in overall level. Thus the standard spectrum was considered a conservative estimation. Therefore, for other sites, the standard spectrum was assumed to be equivalent to the median spectrum. The frequency-dependent standard deviations for NPR were used to produce the 16th- and 84th-percentile spectra for all of the other sites.

The median, 16th- and 84th-percentile PHAs are listed in table 2-5. Figures 2-9 and 2-10 show response spectra of various percentile values and damping levels for FPR and SIS, respectively. The median and 84th-percentile PHA at FPR are 0.130 and 0.196, respectively, and at the SIS soil site, they are 0.197 and 0.297, respectively. These two sites are within 500 m of each other, and, therefore, they have nearly the same distance to the earthquake source. The markedly different ground motion level was believed to be due to the amplifying effects of the 12.2 m soil profile at SIS. Comparison of the difference in ground motion level suggests an amplification factor of 1.5 by the 12.2-m soil column.

WCC (1990) further compared the median values derived by the empirically-based peak acceleration attenuation relationships of Campbell (1989) and Joyner and Boore (1988) developed based principally on western U.S. strong motion data. They found that, in general, the stochastic predictions are lower than the empirical ones. These differences were attributed to the effect of site and propagation path, especially the basaltic lava flows with interbedded sediments underneath INEEL that may largely damp the propagation of seismic waves.

2.4.2.2 1992 Woodward-Clyde Deterministic Assessment

Geomatrix Consultants (1991) computed preliminary deterministic ground motion parameters for the proposed NPR (figure 2-8). They considered two safety earthquakes: a M_w = 7.0 Lemhi fault earthquake at a source-to-site distance of 23 km [Woodward-Clyde Consultants, (1990) assumed a M_w = 6.9 at 20.5 km] and a local event of M_w = 5.5 occurring within 25 km of the site.

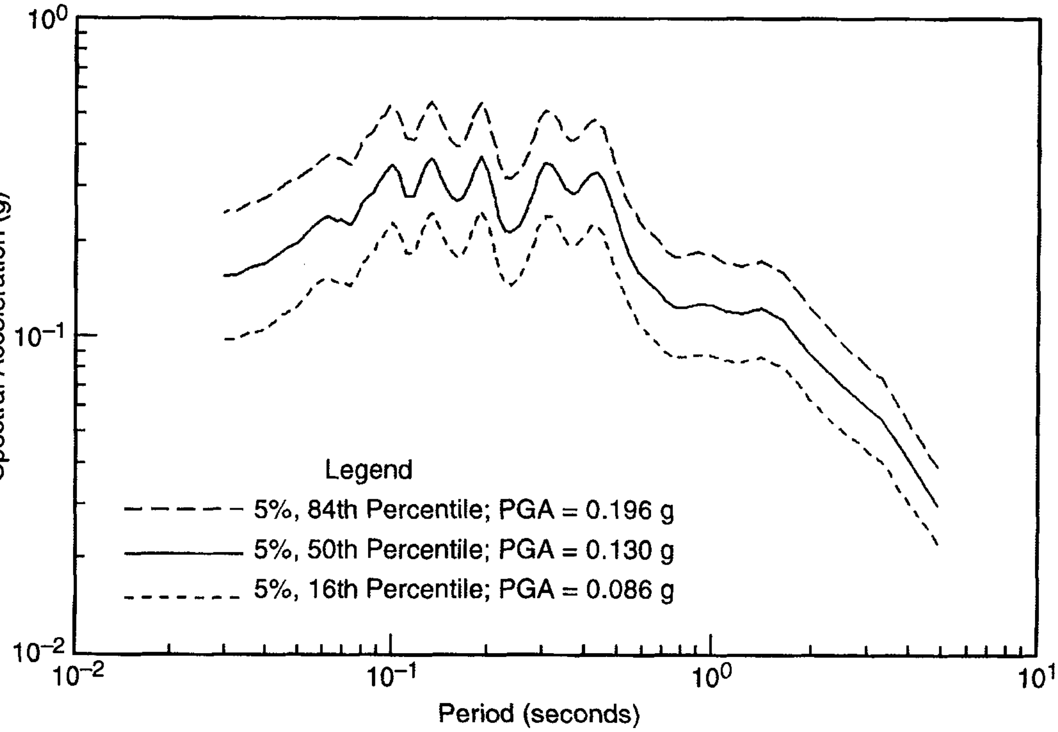
Table 2-5. Predicted site-specific peak horizontal accelerations from Woodward-Clyde Consultants (1990) deterministic seismic hazard assessment

		Peak Horizontal Acceleration (g)		
Site[1]	**Distance (km)**	**16th Percentile**	**50th Percentile**	**84th Percentile**
LOFT (soil)	10.7	0.268	0.404	0.608
LOFT	10.7	0.165	0.248	0.373
NRF	15.3	0.164	0.247	0.372
INEEL-1	16.9	0.096	0.145	0.218
ATR	19.3	0.117	0.176	0.265
NPR	20.7	0.096	0.145[2]	0.219
SIS (soil)	20.8	0.131	0.197	0.297
FPR	21.4	0.086	0.130	0.196
PBF	23.4	0.074	0.112	0.169
ANL	25.9	0.089	0.134	0.202
ANL (soil)	25.9	0.141	0.213	0.321
RWMC	27.4	0.057	0.086	0.130

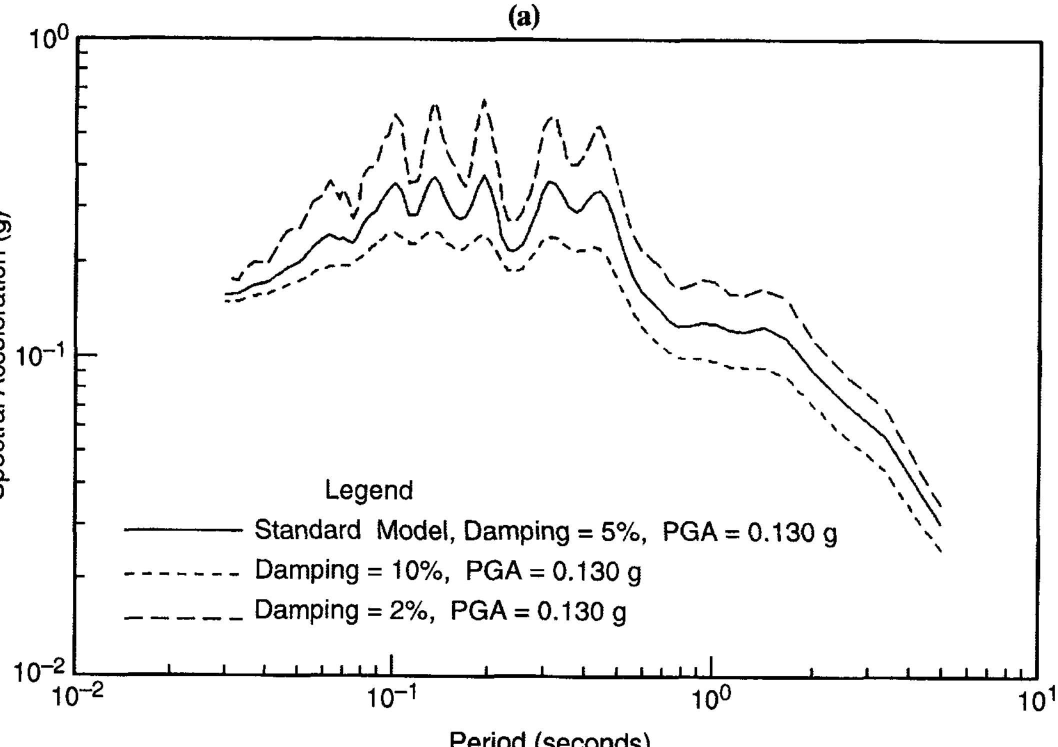
1 All sites are rock sites at the ground surface except those designated as soil sites.
2 True median value. At other sites, the median value is assumed to be approximately equivalent to the value determined from the standard model.

WCC (1992a) performed a deterministic ground motion evaluation of the Lemhi fault and the ESRP for the proposed NPR at INEEL. The NPR site is very close to the ICPP (figure 2-8). Potential seismic sources addressed in this study included the Basin and Range faults immediately north of the INEEL, ESRP volcanic zones, a random nearby earthquake in the ESRP, and the ESRP-Basin and Range boundary. Of these sources, the MCEs were assumed to correspond to a: (i) moment magnitude $M_w = 7.0$ on the southern Lemhi fault at a source-to-site distance of 21.2 km; (ii) $M_w = 5.5$ on the axial volcanic zone at a source-to-site distance of 10.7 km; and (iii) a random ESRP earthquake of $M_w = 5.5$.

The fault geometry and rupture characteristics of the Lemhi fault MCE were characterized based on fault-specific data where available and through comparison with other Basin and Range earthquakes, specifically the 1983 Borah Peak earthquake. The magnitude of MCE was selected based on the evaluation of largest historical Basin and Range earthquakes and the use of empirical relationships between magnitude and rupture dimensions proposed by Wells and Coppersmith (1992). Determination of rupture dimension is largely dependent on the segmentation models of the Lemhi fault. In this study,

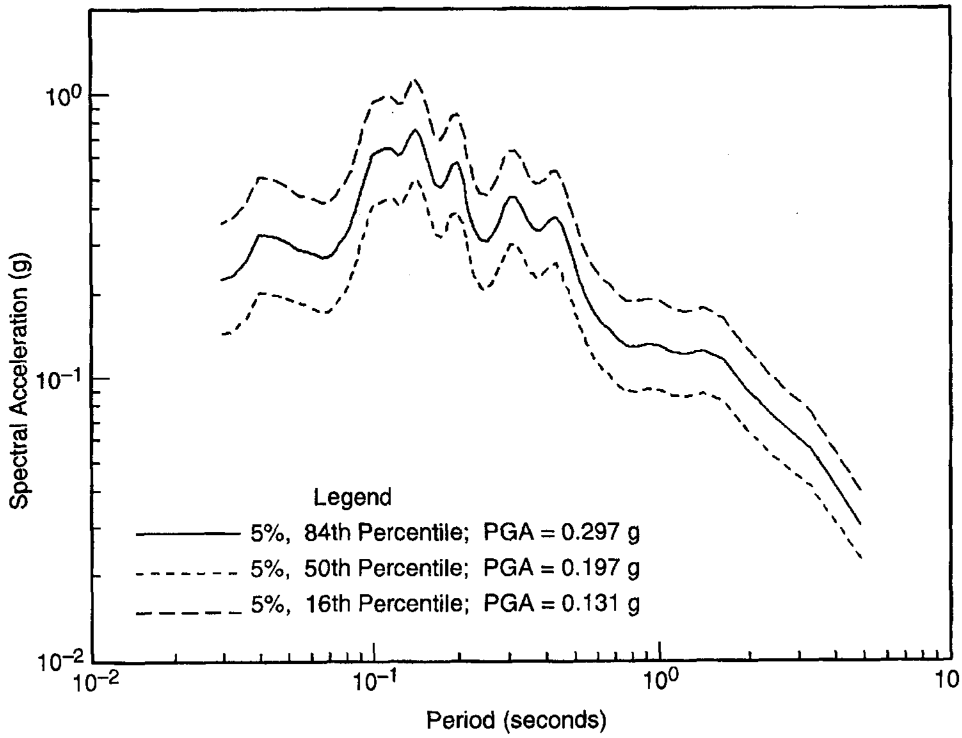


(a)



(b)

Figure 2-9. Response spectra on rock for Fuel Processing Restoration site according to Woodward-Clyde Consultants (1990) deterministic assessment: (a) 16th, 50th, and 84th percentile; (b) 5-percent, 10-percent, and 2-percent damping



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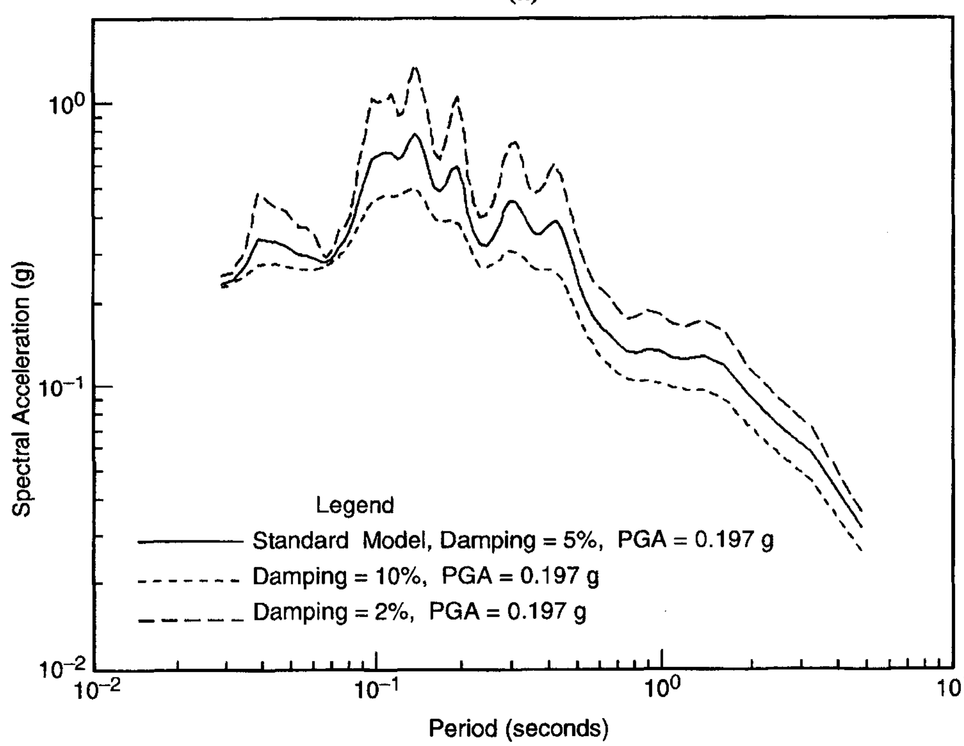


(b)

Figure 2-10. Response spectra on rock for Special Isotope Separation site according to Woodward-Clyde Consultants (1990) deterministic assessment: (a) 16th, 50th, and 84th percentile; (b) 5-percent, 10-percent, and 2-percent damping

four segmentation scenarios were postulated based on comparison of morphology of fault scarps formed in alluvium, identification of possible segment boundaries (Turko and Knuepfer, 1991; Crone and Haller, 1991; Knuepfer et al., 1990; Haller, 1988; Turko, 1988), and trench studies (Woodward-Clyde Consultants, 1992b). The maximum segment length was used in MCE estimation. The shortest source-to-site distance was assumed to be 21.2 km based on recent research on the southern termination of the Lemhi fault (Woodward-Clyde Consultants, 1992b). Also, the Lemhi fault was assumed to be a southwest-dipping normal fault that extends to a depth of 16 km.

The characteristics of the volcanic zone MCE were based on the structural characteristics of the rift zones in ESRP (Kuntz, 1977, 1978; Smith et al., 1989; Golder Associates, 1992a). WCC (1992a) considered that the axial volcanic zone the most significant to the seismic hazard at the NPR site. The magnitude of $M_w = 5.5$ was selected based on the empirical relationships between magnitude and rupture area proposed by Wells and Coppersmith (1992). This selection of the maximum magnitude was also consistent with the observation that seismic events produced by volcanic activities are relatively small and typically have magnitudes of $M_s = 5$ or less from worldwide analog studies (Hoblitt et al., 1987; Rubin and Pollar, 1988; Foulger, 1988; Klein et al., 1987; Karpin and Thurber, 1987; Brandsdottir and Einarsson, 1979; Fedotov et al., 1983).

Ground motion estimation for the southern Lemhi fault and axial volcanic zone MCEs was based on empirical ground motion attenuation relationships and on the BLWN-RVT stochastic modeling methodology. In the BLWN-RVT approach, both a point source and finite fault source were modeled. In the stochastic approach, the site and path effects were considered in the same way as in WCC (1990). A local random MCE was evaluated using only the empirical approach. Based on these two approaches, median and 84th-percentile horizontal and vertical peak ground accelerations and acceleration response spectra were computed. Two empirically based ground motion attenuation relationships were used, namely Campbell (1991) and Sadigh et al. (1989, 1990). In the empirical approach, it was assumed that strong motion data and associated attenuation relationships from California earthquakes may be appropriate for estimating ground motions from Basin and Range earthquakes, and that general path differences between California, and the Basin and Range province or the ESRP are not significant.

Table 2-6 shows the resultant median and 84th-percentile peak ground accelerations. Ground motions from the local random MCE were estimated using the site-specific spectra approach (Kimbell, 1983), which consists of averaging the response spectra from recorded ground motions within the selected magnitude and distance ranges (table 2-6). The stochastic approach yielded similar results, and details were discussed in WCC (1992a).

Comparison of these results indicates that the southern Lemhi fault MCE is the SE for the NPR site. The preferred empirical median and 84th-percentile PHA were about 0.20 g and 0.31 g, respectively. The empirical median and 84-percentile peak vertical acceleration (PVA) were 0.14 g and 0.23 g, respectively. The median stochastic point and finite fault source horizontal values were 0.21 g and 0.20 g, respectively, and the 84th-percentile horizontal values were 0.31 g and 0.27 g, respectively. The stochastic point source PVA was 0.10 g.

Comparing with results from previous deterministic analyses (table 2-5), the 1992 deterministic analyses predicted higher ground motions. This appears to result from a slightly larger magnitude MCE being used in the 1992 study ($M_w = 7.0$) than the 1990 study ($M_w = 6.9$), although the source-to-site distance for the southern Lemhi fault was assumed to be 21.2 km in the 1992 study, whereas it was 20.7 km in the 1990 study. Figures 2-11 through 2-13 show the MCE 84th-percentile response spectra

Table 2-6. The median and 84th-percentile peak ground accelerations for the New Production Reactor site (after Woodward-Clyde Consultants, 1992a)

Attenuation Relationship	Peak Horizontal Acceleration (g)		Peak Vertical Acceleration (g)	
	Median	84th Percentile	Median	84th Percentile
Lemhi Fault MCE				
Campbell (1991)	0.188	0.267	0.167	0.262
Sadigh et al. (1989, 1990)	0.202	0.305	0.144	0.233
Axial Volcanic Zone MCE				
Campbell (1991)	0.157	0.233	0.116	0.213
Sadigh et al. (1989, 1990)	0.150	0.279	0.115	0.244

Local Random MCE

Analysis	Mean Magnitude	Mean Distance (km)	Peak Horizontal Acceleration (g)		Peak Vertical Acceleration (g)	
			Median	84th Percentile	Median	84th Percentile
Unweighted	5.7	11.7	0.151	0.287	0.107	0.185
Weighted	5.8	15.3	0.127	0.215	0.093	0.145

compared with the NPR Title I design developed by Nelson and Short (1991). For the horizontal motions of the Lemhi fault MCE, the Title I spectrum generally envelopes all three site-specific spectra except for the two major peaks centered at periods of about 0.5 sec and 1.0 sec (figure 2-11). At periods longer than about 0.4 sec, the Title I horizontal spectrum is not conservative (figure 2-11). The Title I horizontal spectra envelopes the axial volcanic zone MCE at all periods (figure 2-12). For vertical motions, the Title I spectrum also substantially envelopes the empirically-derived spectra for both the Lemhi fault and the axial volcanic zone MCEs (figure 2-13). These results were found comparable with those from two previous studies addressing seismic design issues for the NPR site: a PSHA completed by the Lawrence Livermore National Laboratory (LLNL) using the "expert opinion" methodology, and the Risk Engineering (1990) calculations of preliminary seismic hazard curves for the ANL site.

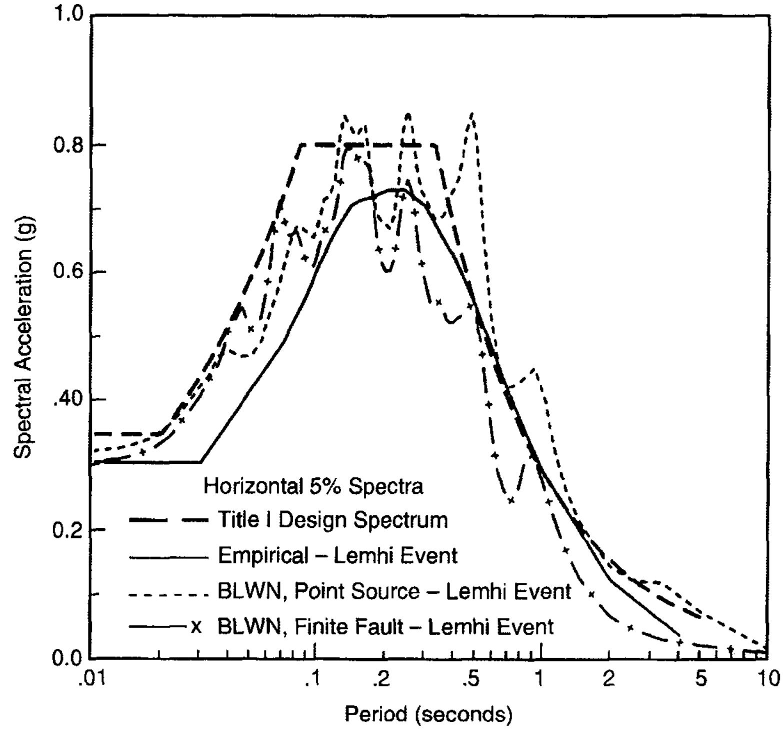


Figure 2-11. Comparison of Lemhi fault maximum credible earthquake empirical and stochastic horizontal response spectra with Title I design (after Woodward-Clyde Consultants, 1992a)

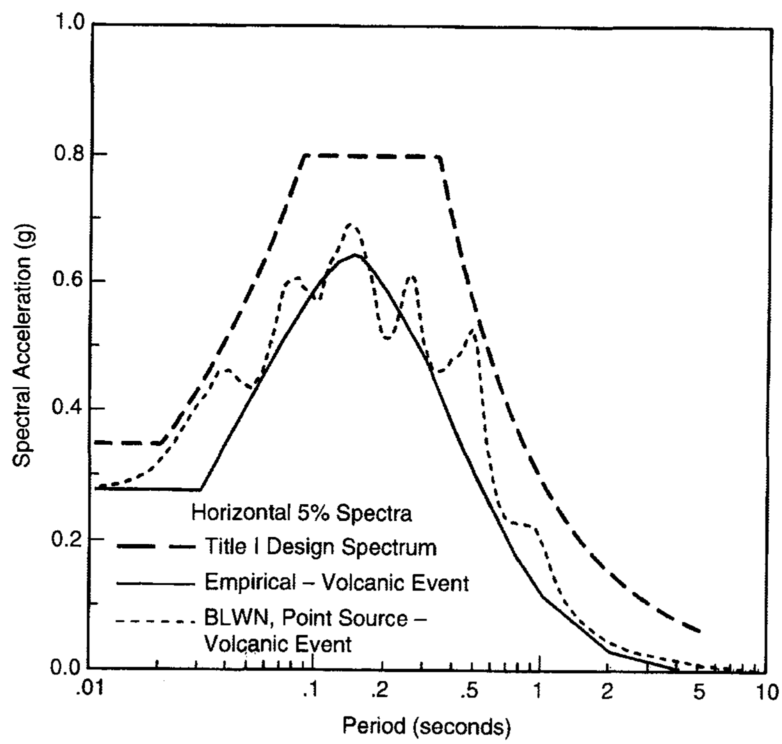


Figure 2-12. Comparison of Axial Volcanic Zone maximum credible earthquake empirical and stochastic horizontal response spectra with Title I design (after Woodward-Clyde Consultants, 1992a)

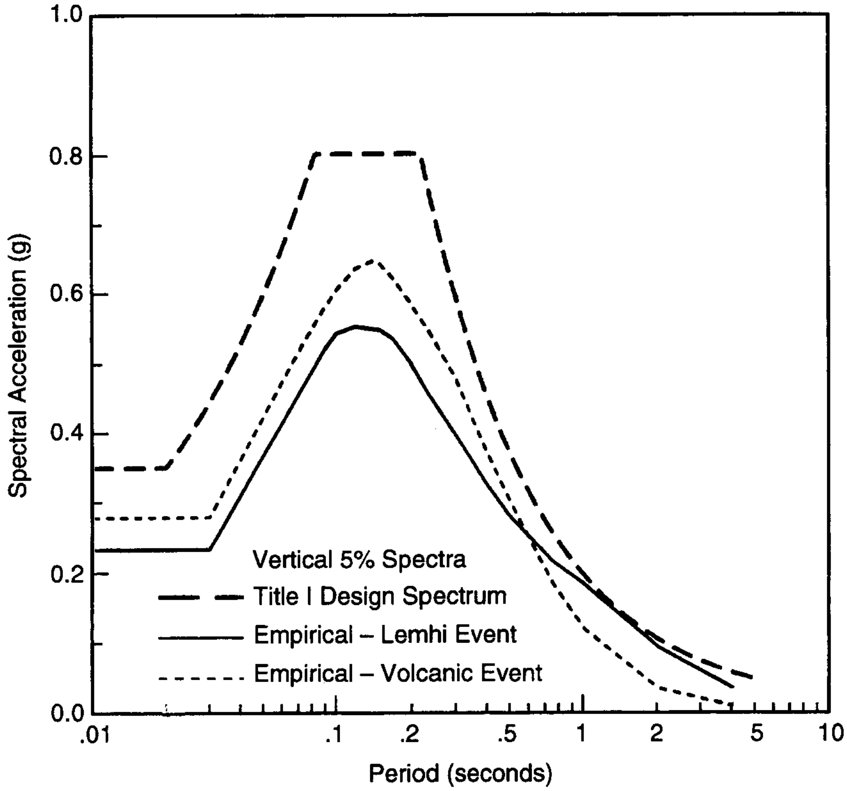


Figure 2-13. Comparison of maximum credible earthquake empirical vertical response spectra with Title I design (after Woodward-Clyde Consultants, 1992a)

2.4.2.3 1996 Woodward-Clyde Deterministic Assessment

The 1996 WCFS deterministic analysis (Woodward-Clyde Federal Services, 1996b) is the only one specifically conducted for the proposed TMI-2 ISFSI. In previous studies (Woodward-Clyde Consultants, 1992a), the southern Lemhi fault was considered the closest potential source of large surface-faulting earthquakes to ICPP. The MCE was defined as a $M_w = 7.0$ event on the southern Lemhi fault at a source-to-site distance of 21.2 km (Woodward-Clyde Consultants, 1992a). In WCFS (1996b) studies, the magnitude of the MCE and the southern termination of the Lemhi fault were reevaluated in light of recent paleoseismic investigations and other geologic and geophysical studies performed by WCFS and others (Woodward-Clyde Consultants, 1992b; Woodward-Clyde Federal Services, 1995, 1996a)

Fault characteristics used to determine maximum magnitudes are represented in table 2-7. The specific characteristics are based on numerous studies (e.g. Malde, 1987; Turko and Knuepfer, 1991; Woodward-Clyde Consultants, 1992b; Jackson et al., 1995; Gorton, 1995), which are briefly described in section 2.3 and summarized in greater detail in WCFS (1996a). In determining rupture area and length, the possibility of a 53-km-long two-segment rupture was allowed, including the 36-km-long South Creek and the 17-km-long Badger Creek segments rupturing together. This is somewhat conservative. However, there are evidences of possible multiple segment ruptures (Woodward-Clyde Federal Services, 1995) and in their analysis of 11 historical surface-faulting earthquakes that occurred throughout the Basin and Range province, dePolo et al. (1991) found an average rupture length of 50 km.

Table 2-7. Expected moment magnitudes (M_w) for the southern Lemhi fault (after Woodward-Clyde Federal Services, 1996b)

Empirical Relation[1]	Parameter Input[2]	See Footnotes Below	M_w
Surface Rupture Length (SRL) $M_w = 5.08 + 1.16 \log (SRL)$ $\sigma = 0.28$	53 km	3	7.1
Rupture Area (RA) $M_w = 4.07 + 0.98 \log (RA)$ $\sigma = 0.24$	1,199 km^2	4	7.1
Average Displacement (AD) $M_w = 6.93 + 0.82 \log (AD)$ $\sigma = 0.39$	2 m	5	7.2
Maximum Displacement MD) $M_w = 6.69 + 0.74 \log (MD)$ $\sigma = 0.040$	3 m	6	7.0
		AVERAGE	7.1

[1] Relations for all types of faults from Wells and Coppersmith (1994).
[2] Input considered appropriate for MCE.
[3] Based on rupture of both the South Creek and Badger Creek segments (Gorton, 1995; Woodward-Clyde Consultants, 1992a)
[4] Assuming a fault dip of 45°, rupture length of 53 km, and seismogenic depth of 16 km.
[5] Average vertical displacement per event of 11 measurements observed at four different trench sites on the South Creek segment (Woodward-Clyde Consultants, 1992a).
[6] Maximum vertical displacement per event observed on the South Creek segment (Woodward-Clyde Consultants, 1992a).

Displacements from four trench sites on the South Creek segment were used to determine an average and maximum displacement per event of 2 m and 3 m, respectively. It was recognized that the calculated displacement may be larger than the true average because trench sites are usually located where fault scarps are most prominent. On the other hand, the maximum displacement is probably less than the true maximum given the large variation of displacements typically observed along strike of a surface rupture and the unlikely chance of exposing this single point of maximum displacement along the fault.

As shown in table 2-7, the expected magnitudes for the southern Lemhi fault range from M_w = 7.0 to 7.2 and average M_w = 7.1. Since M_w based on average displacement may be slightly high and one based on maximum displacement may be slightly low, a M_w = 7.1 seems to be a reasonable choice for the MCE. Also, the M_w = 7.1 corresponds to the 65th-percentile value on the cumulative probability plot for the distribution of the maximum magnitude developed for the South Creek segment (Woodward-Clyde Federal Services, 1996a).

Four empirical attenuation relationships (Campbell and Bozorgnia, 1994; Sadigh et al., 1993; Idriss, 1991; and Boore et al. 1993) and the WCFS stochastic approach (the BLWN-RVT model, Woodward-Clyde Federal Services, 1996a) were used to calculate the weighted mean PHA for the MCE. The empirical relationships were weighted equally for a total weight of 0.4. The site-specific stochastic relationship was weighted 0.6. The median and 84th-percentile values from each of these relationships are shown in table 2-89. The weighted mean PHAs, assuming a rock site, are a 50th-percentile value of 0.17 g and an 84th-percentile value of 0.28 g. By assuming an amplification factor of about 2 (Woodward-Clyde Federal Services, 1996b), the MCE mean and 84th-percentile PHAs on soil are about 0.34 and 0.56 g, respectively.

2.4.3 Recent Probabilistic Seismic Hazard Assessment

2.4.3.1 1992 Woodward-Clyde Probabilistic Assessment

Besides deterministic analysis summarized in section 2.4.2, WCC also conducted a PSHA for the proposed NPR (Woodward-Clyde Consultants, 1992a). The main purpose in this probabilistic analysis was to evaluate the probability of exceeding the deterministic ground motion values determined for NPR. The seismic sources that were considered important to the probabilistic seismic hazard at NPR included both fault sources and areal sources. The fault sources were the Lost River, Lemhi, and Beaverhead faults. Each fault was modeled by parameters that define its 3D geometry, maximum earthquake magnitude, and earthquake recurrence rate.

Volcanic zones, including three volcanic rift zones (the Arco, Lava Ridge-Hell's Half Acre, and Great Rift) and the axial volcanic zone, were modeled as source zones that incorporate the volcanic vents and deformational features related to dike emplacement within rift zones. Another possible rift zone, the Howe-East Butte zone, was also included with an assigned possibility that is relatively low. Regional seismic source zones included the ESRP, the Yellowstone, the northern Basin and Range source zone, the Idaho Batholith source zone, and the central Basin and Range source zone.

The ground motion attenuation relationships used in this PSHA are the same as the 1992 WCC deterministic analyses (Woodward-Clyde Consultants, 1992a), including three empirical relationships—Joyner and Boore (1982), Sadigh et al. (1989), and Campbell (1991)—and the BLWN-RVT stochastic relationship. The computed mean annual frequency of exceeding the deterministic peak acceleration estimates of 0.30 to 0.31 g is about 4 to 3 $\times 10^{-5}$. The computed mean 10^{-4} annual exceedance peak acceleration level is 0.23 g.

Sensitivity analyses show that at low ground motion levels, the Lemhi fault has the largest contribution to the hazard. At high ground motion levels, the hazard is dominated by the ESRP areal source. Also, important contributors to the uncertainty in hazard at high peak acceleration levels are the size and location of the 1905 Shoshone earthquake and seismicity rates in the ESRP. At low acceleration levels, the primary sources of uncertainty are selection of the appropriate attenuation relationship and the recurrence rates on the Lemhi fault.

Table 2-8. Maximum credible earthquake peak horizontal accelerations in g (after Woodward-Clyde Federal Services, 1996b)

	Magnitude (M_w)	Horizontal Distance[1]	Seismogenic Distance[2]	Rupture Distance[3]	Campbell & Bozorgnia (1994)	Idriss (1991)	Sadigh et al. (1993)	Boore et al. (1993)	WCFS Stochastic (1996a)	Weighted Mean
Median (50th percentile)										
Lemhi Fault	7.1	16.3 km	22.1 km	22.1 km	0.18	0.21	0.21	0.17	0.16	0.17
84th percentile										
Lemhi Fault	7.1	16.3 km	22.1 km	22.1 km	0.26	0.31	0.31	0.28	0.27	0.28

[1] Used in Boore et al. (1993) and WCFS (1996a)
[2] Used in Campbell and Bozorgnia (1994)
[3] Used in Idriss (1991) and Sadigh et al. (1993)

Equal-hazard spectra were developed for annual exceedance frequencies of 10^{-3}, 10^{-4}, and 10^{-5}. A comparison of the equal-hazard spectra with the deterministic spectra from Volume I (Woodward-Clyde Consultants, 1992a) shows that the deterministic spectra lie between the 10^{-4} to 10^{-5} levels. It was observed that the Title I design spectrum developed by Nelson and Short (1991) for the NPR site lies between the 10^{-4} to 10^{-5} levels throughout the range of frequencies.

2.4.3.2 1996 Woodward Clyde Probabilistic Assessment

The 1996 WCFS site-specific seismic hazard analyses (Woodward-Clyde Federal Services, 1996a) is the most sophisticated probabilistic analysis carried out at the INEEL. Seven facility sites were investigated (figure 2-4), including the ICPP. Probabilistic peak ground accelerations and uniform hazard spectra accelerations were generated assuming a rock site. The study provides for the explicit inclusion of the range of possible interpretations in components of the model including seismic characterization and ground motion estimation. The logic tree approach was utilized to incorporate uncertainties in models and parameters. The final report (Woodward-Clyde Federal Services, 1996a) provided detailed documentation of the choices of the parameter values on the logic trees, their relative credibilities, and the basis for the assessments in the available geologic, seismologic, geophysical, and geotechnical data. Some of this information has been summarized in section 2.1 through 2.3 of this review report.

Consideration of potential seismic sources was similar to the 1992 WCC probabilistic analysis conducted for the once-proposed NPR site (Woodward-Clyde Consultants, 1992a). Specifically, it included active faults, volcanic zones, and areal source zones as depicted in figure 2-3 and summarized in section 2.3 of this report.

A few significant aspects that made this most recent probabilistic seismic study different from previous studies include: (i) it incorporated various results from the 1995 paleoseismic studies along the northern Basin and Range faults, especially the Lost River fault; (ii) it used more-recent empirical ground motion attenuation relationships, including Joyner and Boore (1982), Idress (1991), Sadigh et al. (1993);

and (iii) it is site specific for many sites (seven) at INEEL, including ICPP, so that the results from this study are applicable to the proposed ISFSI after necessary modifications for soil amplification. The site-specific BLWN-RVT approach was also used in a manner identical to that used in the 1992 probabilistic and deterministic study (Woodward-Clyde Consultants, 1992a).

Figure 2-14 shows the computed hazard curves for the ICPP site for peak acceleration and spectral accelerations at periods of 0.1 and 1.0 sec, including the mean hazard and the 5th-, 15th-, 50th-, 85th-, and 95th-percentile hazard curves resulting from the input parameter distributions defined by the hazard model logic trees. Peak ground accelerations on rock at the ground surface for the ICPP site are 0.08, 0.10, 0.13, and 0.22 at annual exceedance probabilities of 2×10^{-3}, 1×10^{-3}, 5×10^{-4}, and 1×10^{-4}, respectively.

The distributions in the computed hazard shown in figure 2-14 represent the cumulative effect of all levels of parametric uncertainty included in the hazard model logic trees (described in sections 2.1 through 2.3). The relative contribution of various components of the model to the overall uncertainty was also identified from the logic tree formulation by computing the hazard holding individual parameters fixed at specific values.

Figure 2-15 shows the contribution of the three main source types to the mean hazard at the ICPP. The regional source zones and the fault sources have similar contributions to the total hazard as compared to the volcanic rift zones that contribute very little. The fault sources become more significant at lower probability levels. Also, the relative contribution of the fault sources increases as one considers longer period motions because of the increased effect of magnitude on ground motion levels at longer periods, resulting in an increased domination of the hazard by larger magnitude events. The fault zones are expected to have higher frequency of larger-magnitude events and the maximum magnitudes compared to the nearby regional source zones. Figure 2-16 shows that the Lost River fault contributes the most hazard at the ICPP site because of its proximity and its relatively higher recurrence rates than the other two faults (Woodward-Clyde Federal Services, 1996a). Of various volcanic sources, the Hells Half Acre contributes the most, and the axial zone contributes the least. Of various areal sources, the contribution from the northern Basin and Range source is significantly higher than other sources at peak acceleration and short period spectral acceleration. At longer periods, the northern Basin and Range source is still the largest contributor, however, the difference is not as significant.

Figure 2-17 shows the percentage contribution of events at different magnitudes and distances to the computed mean hazard for four return periods and for peak ground acceleration. The figure shows that for short return periods, seismic hazard at ICPP comes from almost all size earthquakes from distance range of 20 to 50 km. As return period increases, the larger earthquakes contribute more significantly to the total hazard. This is because at longer return periods, fault sources that are capable of generating large earthquakes start making significant contributions to the probability of peak ground acceleration exceeding various levels.

The study also shows that the choice of attenuation relationships is a major portion of the uncertainty for short-period motions. The effect of local geology on the site-specific attenuation model predictions led to significantly different predictions of the site-specific ground motions than the empirical relationships. The stochastic model ground motion predictions tend to be lower than those obtained using empirical attenuation relationships at periods lower than about 0.1 sec. At longer periods such as 1.0 sec, the two approaches lead to similar estimates of ground motion hazard.

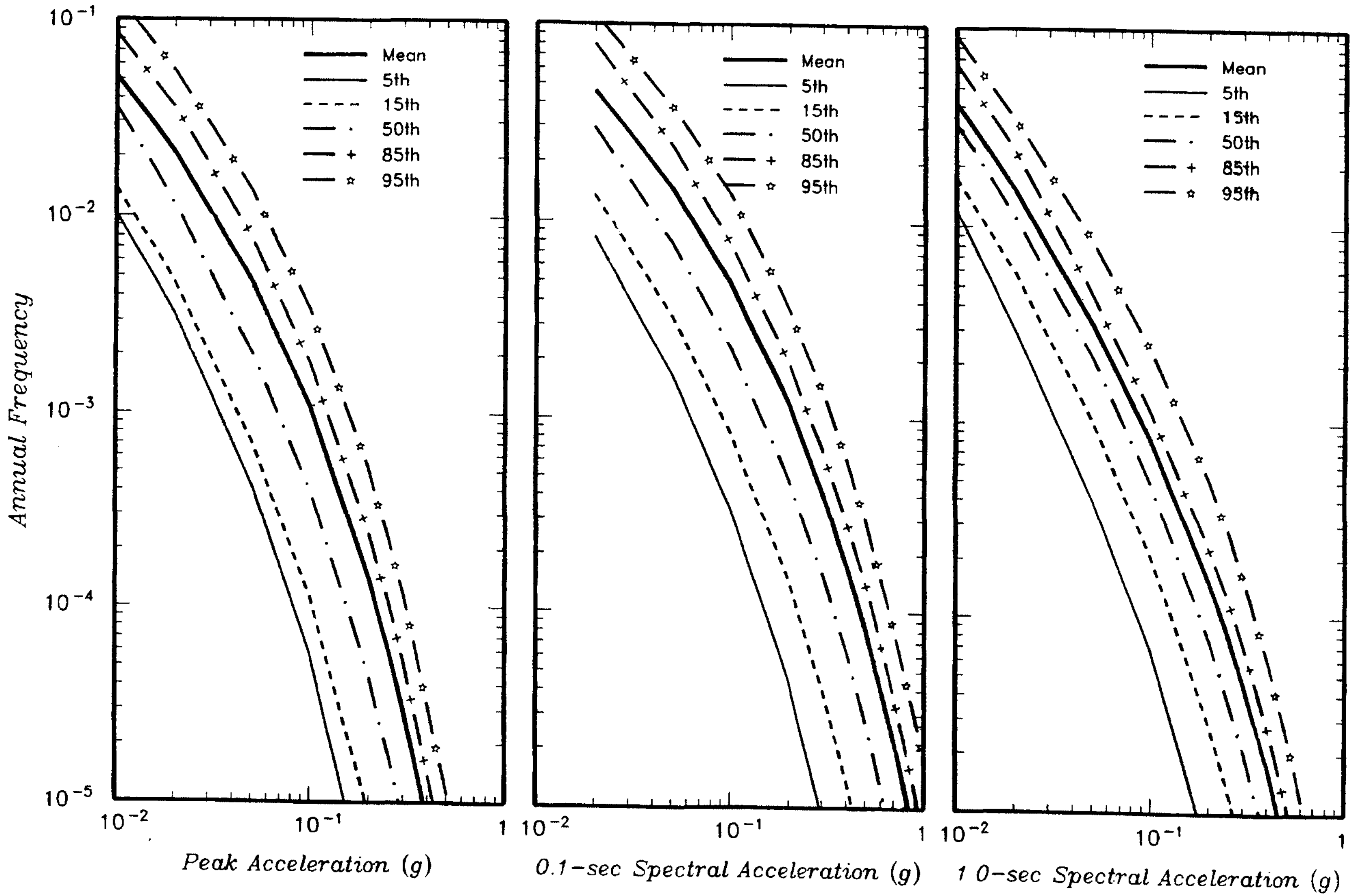


Figure 2-14. Mean and 5th- to 95th-percentile seismic hazard curves for Chemical Processing Plant (after Woodward-Clyde Federal Services, 1996a)

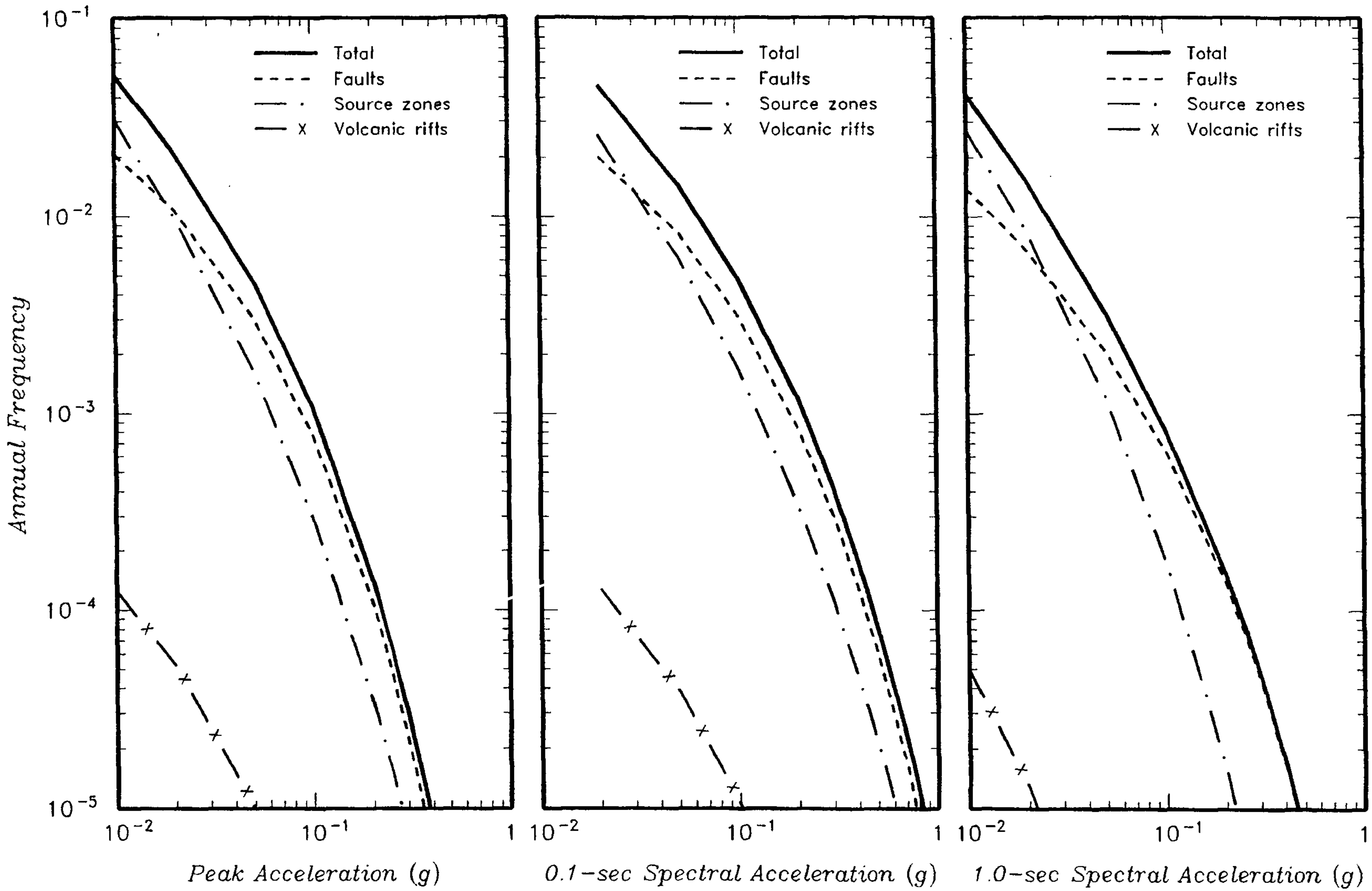


Figure 2-15. Contributions of seismic sources to the mean seismic hazard at Chemical Processing Plant (after Woodward-Clyde Federal Services, 1996a)

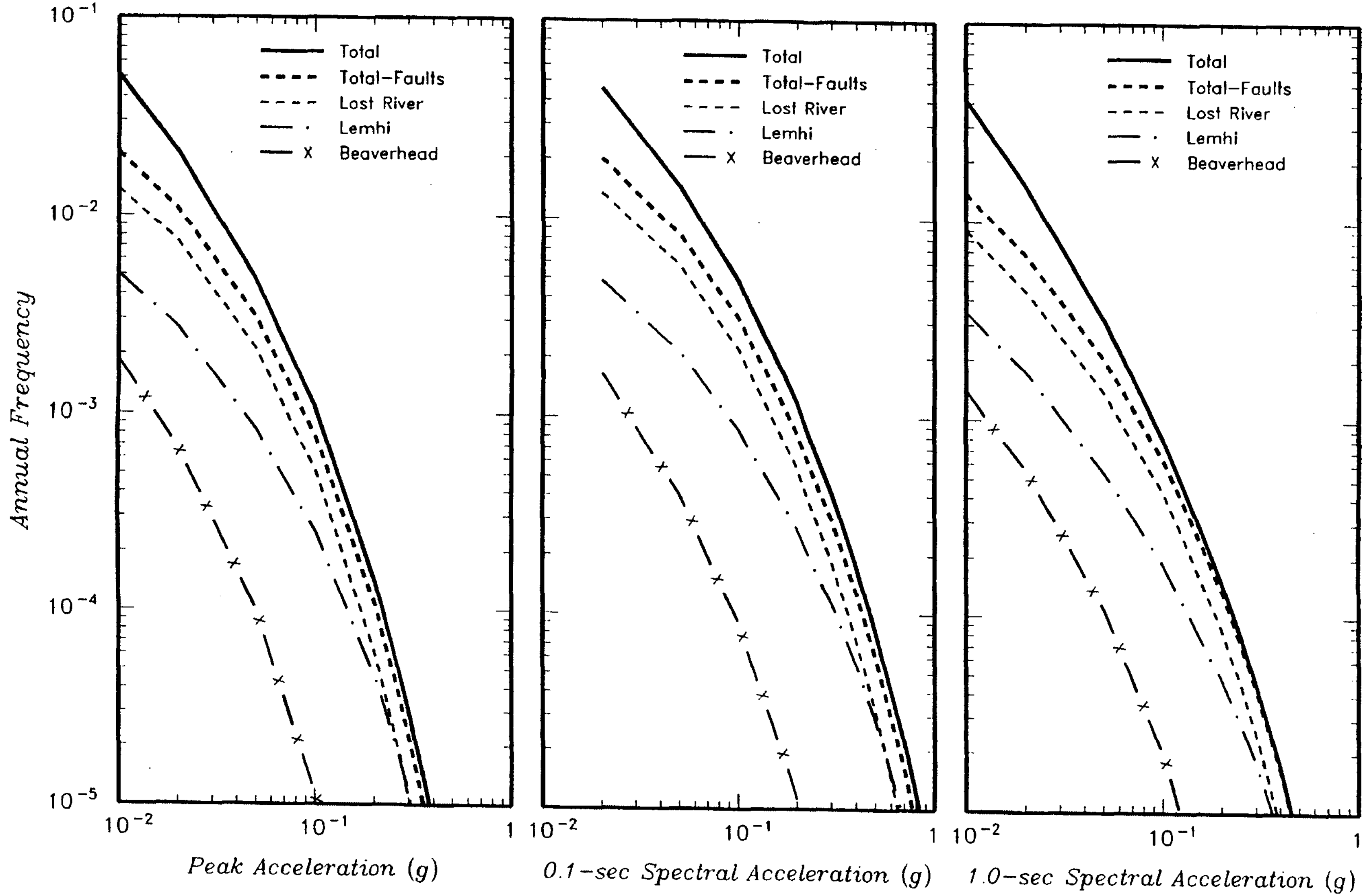
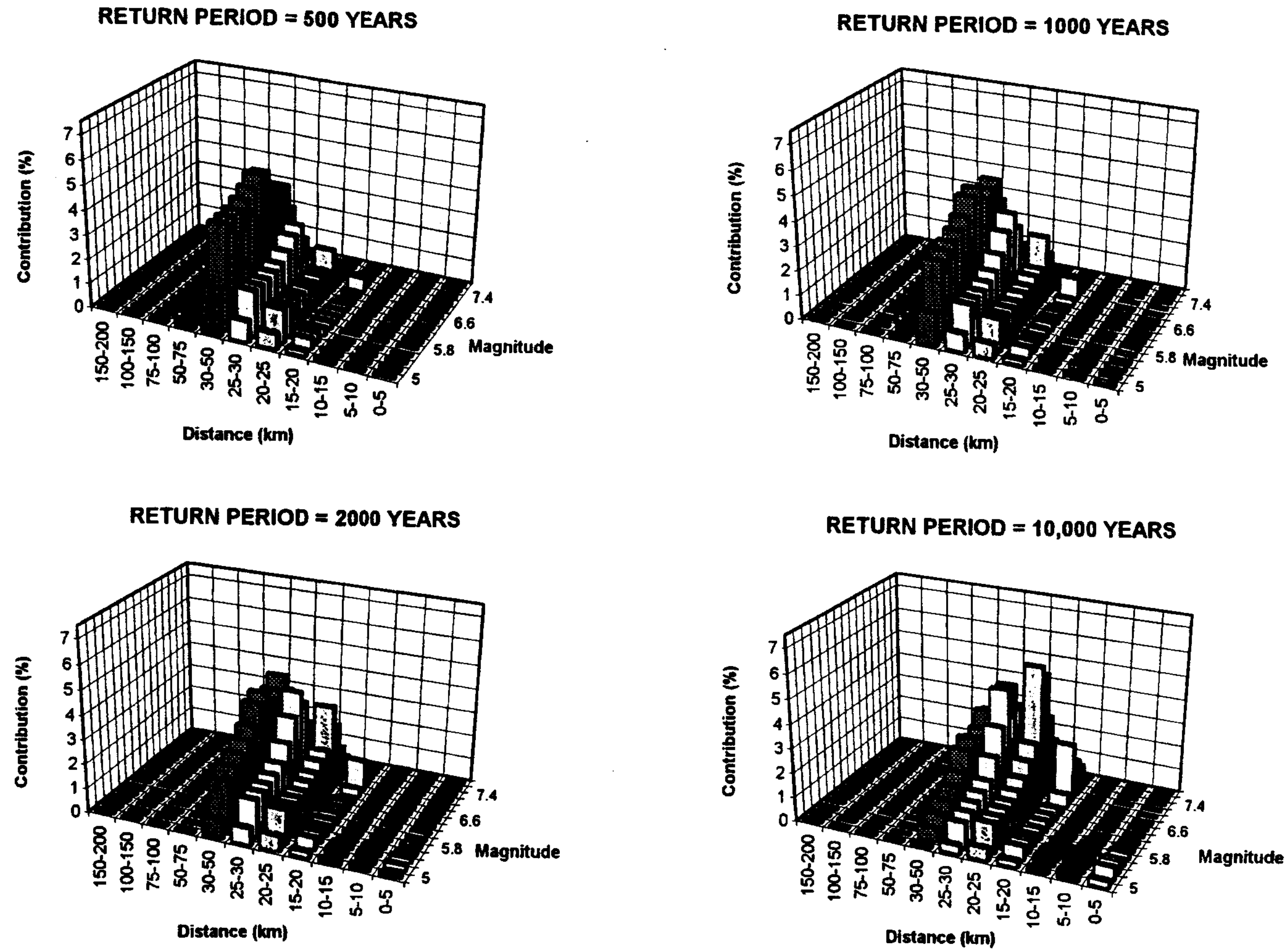


Figure 2-16. Contributions of fault sources to the mean seismic hazard at Chemical Processing Plant (after Woodward-Clyde Federal Services, 1996a)



PEAK HORIZONTAL ACCELERATION

Figure 2-17. Magnitude and distance contributions to the mean seismic hazard at Chemical Processing Plant (after Woodward-Clyde Federal Services, 1996a)

Equal-hazard spectra were developed by selecting the peak ground motion levels from the mean hazard curves at the various spectral acceleration periods for the four return periods of 500, 1,000, 2,000, and 10,000 yr. Figure 2-18 presents composite plots of the mean hazard curves computed for the nine spectral periods [0.02 (peak), 0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1.0, and 2.0 sec]. Peak spectral amplitudes were interpolated from these hazard curves for the four return periods and are summarized in table 2-9.

2.5 DEVELOPMENT OF DESIGN BASIS EARTHQUAKE PARAMETERS

To comply with DOE Standards 1020-94 and 1023-94 (U.S. Department of Energy, 1994a,d), and to be consistent with NRC regulations, WCFS (1996b) developed design basis earthquake (DBE) ground motion parameters for the proposed TMI-2 ISFSI site based mainly on the WCFS site-specific PSHA (Woodward-Clyde Federal Services, 1996a). These parameters are in the form of acceleration response spectra and time histories. The basis for the DBE response spectra is the mean uniform hazard spectra (UHS) computed from the site-specific probabilistic analysis of the ICPP, adjusted for the dominant earthquakes at intermediate and long periods.

As discussed in review of the 1996 WCFS probabilistic studies (Woodward-Clyde Federal Services, 1996a), the dominant contributor to hazard at ICPP is the Lost River fault followed by the Lemhi fault despite the fact the former is closer to the site (figure 2-6). This is because in terms of probabilistic seismic hazard, the Lost River fault has a range of shorter recurrence intervals than the Lemhi fault. The source-to-site distances of the Lost River and Lemhi faults to the ISFSI site are 28.0 and 22.1 km, respectively.

Table 2-9. Equal hazard spectral accelerations at the Chemical Processing Plant (5-percent damping, after Woodward-Clyde Federal Services, 1996a)

	Annual Hazard Exceedance Probability (Return Period)			
Spectral Period (sec)	**2×10^{-3} (500 yr)**	**1×10^{-3} (1,000 yr)**	**5×10^{-4} (2,000 yr)**	**1×10^{-4} (10,000 yr)**
0.02	0.075	0.102	0.130	0.220
0.03	0.082	0.111	0.144	0.248
0.05	0.092	0.124	0.163	0.285
0.10	0.154	0.213	0.279	0.471
0.20	0.173	0.238	0.318	0.551
0.30	0.150	0.211	0.282	0.502
0.50	0.113	0.157	0.215	0.394
1.00	0.064	0.090	0.123	0.232
2.00	0.029	0.042	0.058	0.110

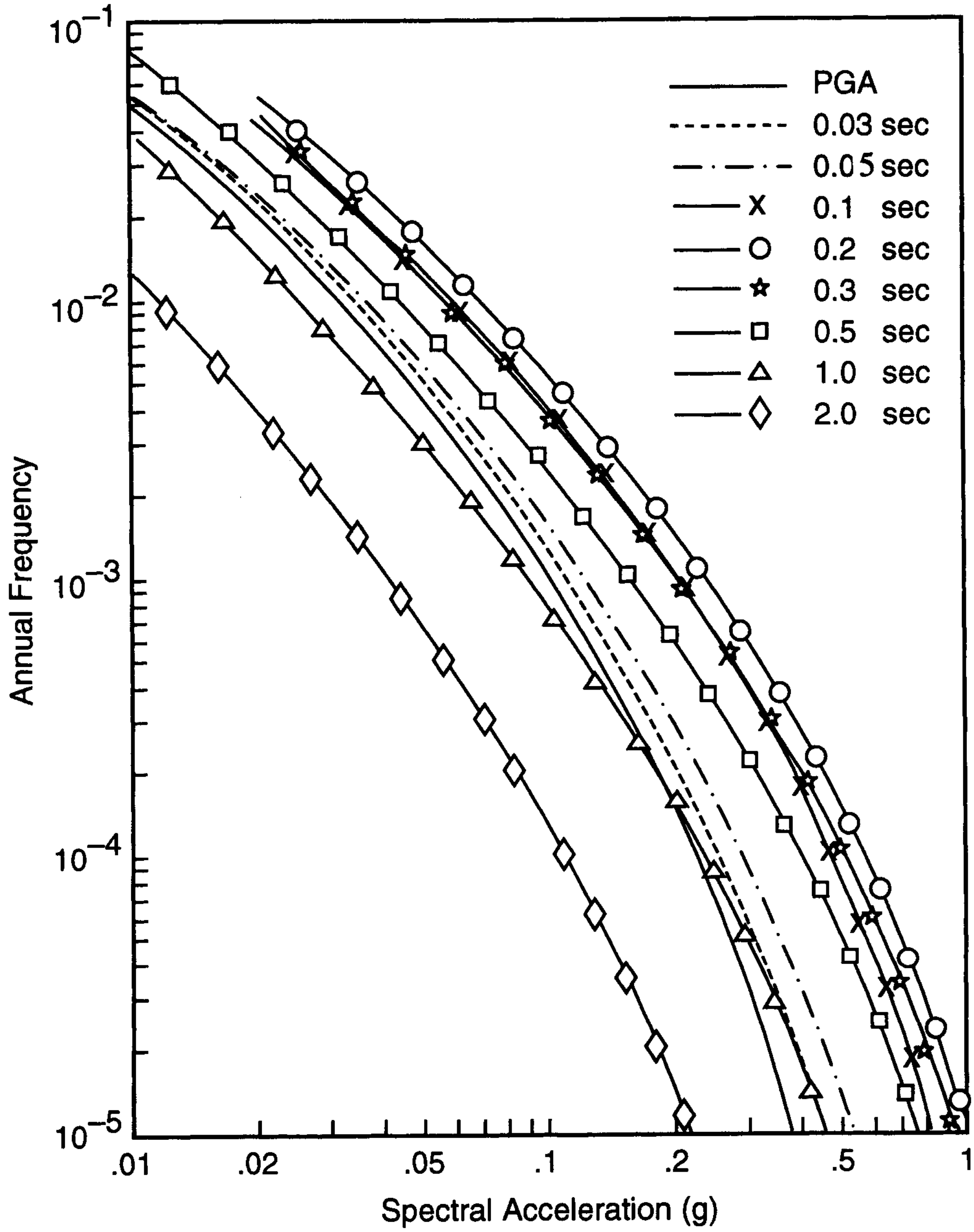


Figure 2-18. Mean seismic hazard curves for peak acceleration and spectral acceleration at Chemical Processing Plant (after Woodward-Clyde Federal Services, 1996a)

The DOE Standard 1023-94 (U.S. Department of Energy, 1994d) recommends that the dominant or controlling earthquake characterized by the mean magnitude and mean distance be determined through the deaggregation process similar to those used to obtain figure 2-18 and table 2-9. Table 2-10 was obtained following this recommended procedure. DOE Standard 1023-94 further recommends that the uniform hazard spectrum associated with the seismic hazard annual probability of exceedance (those obtained from table 2-9) should be supplemented by response spectral shapes of the dominant earthquakes at low frequencies (1 to 2.5 Hz) and intermediate frequencies (5 to 10 Hz) to arrive at a DBE response spectrum. In addition, the standard requires that "the DBE ground motion at a site shall be specified in terms of smooth and broad frequency content horizontal and vertical response spectra defined at a specific control point."

Following the steps outlined in DOE Standard 1023-94, response spectral shapes of the dominant earthquakes at 0.1 and 1.0 sec (table 2-10) were computed by taking the weighted average of four empirical and one stochastic numerical modeling response spectra derived from the same attenuation relationships used in the 1996 WCFS probabilistic studies (Woodward-Clyde Federal Services, 1996a). These average spectra were then normalized per DOE Standard 1023-94 by the spectral acceleration at either 0.1 or 1.0 sec and superimposed on the appropriate uniform hazard spectra (figures 2-19 through 2-21) (Woodward-Clyde Federal Services, 1996b). All spectra were then generally enveloped to obtain the DBE horizontal rock spectra that are also shown in figures 2-19 through 2-21.

2.5.1 Design Basis Earthquake Horizontal Soil Spectra

Since the proposed TMI-2 ISFSI is located on an alluvial soil consisting predominantly of sand and gravel that ranges in thickness from about 9.1 to 15.2 m, soil response needs to be incorporated into the DBE horizontal rock spectra. The soil response was evaluated by calculating power spectra that are derived by spectrally matching the DBE horizontal rock spectra and propagating them through the one-dimensional soil and shallow rock profile using a frequency-domain equivalent-linear formulation similar to the computer program SHAKE (Silva et al., 1996). The resultant 5-percent damped and smoothed soil spectra are shown in figure 2-22, 9nd the DBE PHAs for soil are shown in table 2-11. Table 2-11 also gives the amplification factors between the soil and rock peak accelerations.

2.5.2 Design Basis Earthquake Vertical Rock and Soil Spectra

Vertical-to-horizontal ratios were developed as a function of spectral periods for both soil and rock based on two approaches with different weights. The first is an equivalent-linear approach based on site-specific P-wave velocity profiles for rock and soil. The second is the empirical ratios for rock developed by Abrahamson and Silva (1996). Ratios from these two approaches were weighted at 0.60 and 0.40, respectively, and combined to obtain the smoothed ratios that were then applied to the DBE horizontal spectra to obtain DBE vertical spectra (table 2-11).

2.5.3 Design Basis Earthquake Time Histories

It was recommended that both DBE response-spectra-compatible synthetic time histories as well as actual strong motion records be used in dynamic analysis for design purpose. DBE time histories for acceleration, velocity, and displacement were generated by spectrally matching the DBE response spectra. Also, a few strong motion records from the Basin and Range normal-faulting earthquakes were recommended to be used in the dynamic analyses.

Table 2-10. Dominant earthquakes (after Woodward-Clyde Federal Services, 1996b)

	Spectral Period					
	0.02 sec (PHA)		0.1 sec		1.0 sec	
Return Period (yr)	M (M_w)	D (km)	M (M_w)	D (km)	M (M_w)	D (km)
500	6.1	34	6.1	34	6.5	43
1,000	6.2	32	6.2	31	6.6	38
2,000	6.3	29	6.3	29	6.7	34
10,000	6.5	25	6.4	25	6.9	29

Table 2-11. Chemical Processing Plant soil and rock probabilistic peak accelerations (after Woodward-Clyde Federal Services, 1996b)

	Rock		Soil		Amplification Factors	
Return Period (yr)	PHA (g)	PVA (g)	PHA (g)	PVA (g)	$\frac{PHA_{Soil}}{PHA_{Rock}}$	$\frac{PVA_{Soil}}{PVA_{Rock}}$
1,000	0.10	0.06	0.23	0.16	2.3	2.7
2,000	0.13	0.08	0.30	0.21	2.3	2.6
10,000	0.22	0.13	0.47	0.33	2.1	2.5

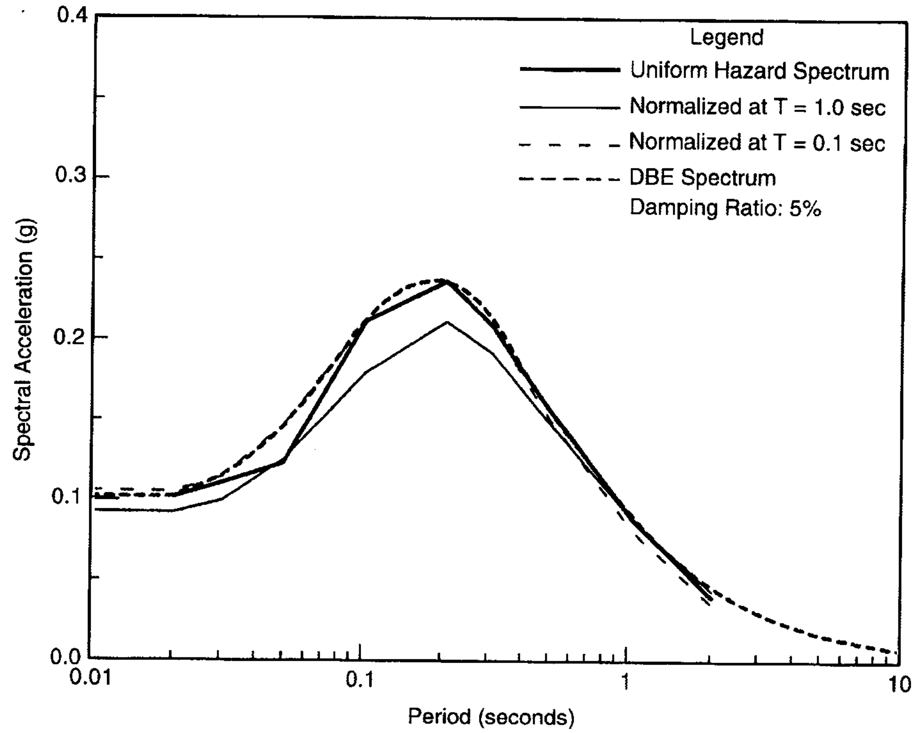


Figure 2-19. Uniform hazard and design basis earthquake horizontal spectra for rock and 1,000-yr return period (after Woodward-Clyde Federal Services, 1996b)

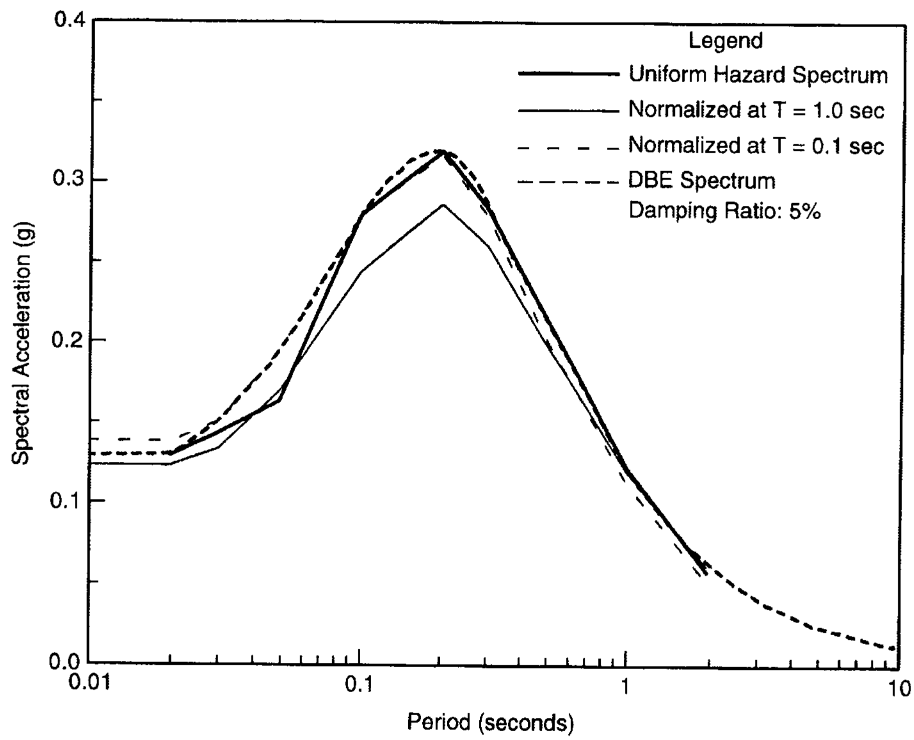


Figure 2-20. Uniform hazard and design basis earthquake horizontal spectra for rock and 2,000-yr return period (after Woodward-Clyde Federal Services, 1996b)

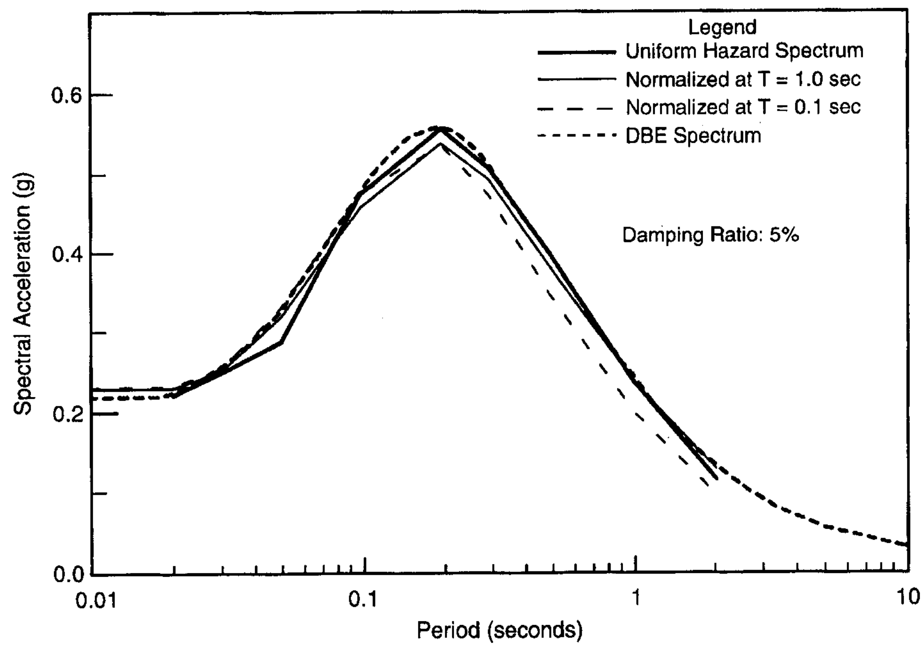


Figure 2-21. Uniform hazard and design basis earthquake horizontal spectra for rock and 10,000-yr return period (after Woodward-Clyde Federal Services, 1996b)

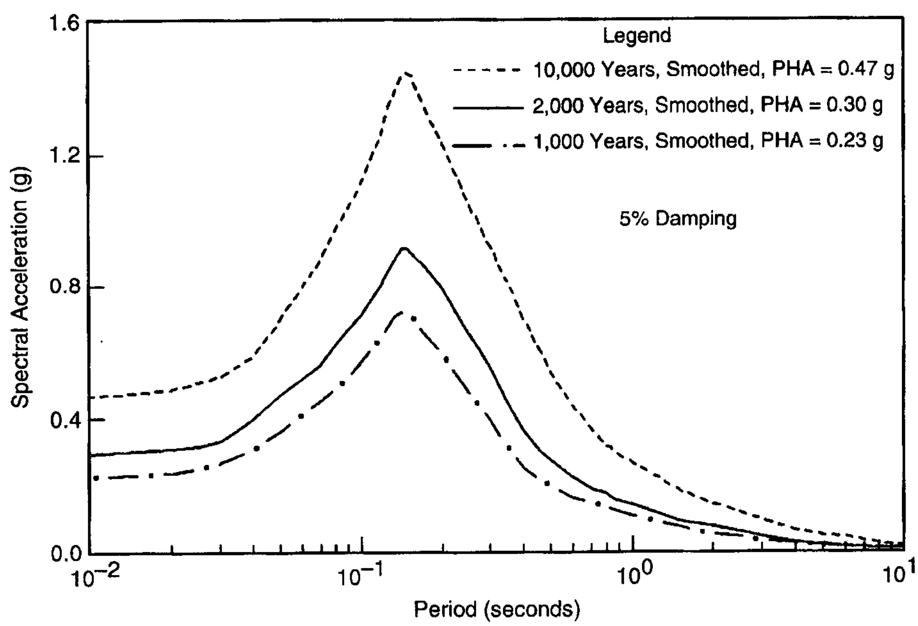


Figure 2-22. Smoothed design basis earthquake horizontal spectra for soil (after Woodward-Clyde Federal Services, 1996b)

3 SUMMARY OF LITERATURE REVIEW

Seismic issues that are important to siting the proposed TMI-2 storage facility include identification of potential seismic sources based on historical earthquakes and paleoseismic studies, source characteristics, deterministic and probabilistic seismic hazard assessments, and development of design basis parameters. These issues are summarized in this section.

3.1 SIGNIFICANT HISTORICAL EARTHQUAKES

There were two significant earthquakes in the region: the 1959 Hebgen Lake M_w = 7.3 earthquake (surface wave magnitude M_s = 7.5) and the 1983 Borah Peak M_w = 6.8 earthquakes (M_s = 7.3). The 1959 Hebgen earthquake was the largest historical earthquake in the Intermountain region. The mainshock appears to have consisted of two normal faulting subevents that reactivated pre-existing Laramide thrust faults. Two faults appear to have ruptured during the earthquake: the Red Canyon fault and the Hebgen fault.

The 1983 Borah Peak earthquakes are of particular interest because of their proximity to INEEL. The earthquake produced a surface rupture of 36 km long, including all of the nearly 21-km long Thousand Springs segment of the Lost River fault. The magnitude of the 1983 Borah Peak earthquakes confirmed the selection of the magnitude of the most significant earthquake in earlier DSHA at the INEEL [e.g, Woodward-Clyde Consultants (1975, M_s = 6.75) for LOFT, Allied Chemical Cooperation (1975, M_l = 7.75) for ICPP, Agbabian Associates (1977, M_s = 6.75) for LOFT, and Woodward-Clyde Consultants (1979) for TREAT]. It has also been referenced, together with evidences of paleoseismic study in selecting magnitude of the most significant earthquake for fault sources in the recent DSHAs [WCC (1990, M_s = 7.3), WCC (1992, M_w = 7.0), and WCC (1996, M_w = 7.1)].

Another earthquake of significance in estimating seismic hazard at INEEL is the 1905 earthquake near Shoshone. However, there are significant uncertainties in both the location and magnitude of the 1905 Shoshone earthquake. A commonly accepted magnitude is $M_l = 5.5 \pm 0.5$. Based on the estimated magnitude of the 1905 Shoeshone earthquake, an M_w = 5.5 earthquake was selected as the maximum magnitude in the 1992 WCC probabilistic study (Woodward-Clyde Consultants, 1992a) and as the average maximum magnitude in the WCFS (1996a) probabilistic studies for the ESRP areal source.

The fourth earthquake that is of particular interest is the 1975 Pocatello Valley earthquake (M_l = 6.0), because it occurred on a "blind" fault that was not evident in the surface geology. Therefore, it provided justification and a reference magnitude for areal sources based on the concept of a "random" earthquake in seismic hazard evaluation.

3.2 POTENTIAL SEISMIC SOURCES

Site characterization at INEEL is an evolving process that has spanned several decades during the almost 50-yr existence of INEEL. Literature exists addressing the regional geological and seismotectonic settings as reviewed in section 2.1 through 2.3. Based on this literature, seismotectonic characteristics that are significant for seismic hazard evaluation at INEEL have been analyzed, and potential seismic sources have been identified mainly by DOE and its subcontractors, such as WCFS. Three types of seismic sources were considered in the most recent site-specific probabilistic seismic hazard studies (Woodward-Clyde Federal Services, 1996a) for seven facility sites at INEEL and in the 1992 WCC probabilistic analyses (Woodward-Clyde Consultants, 1992a) for the once proposed NPR site.

These include fault sources, ESRP volcanic rift zone sources, and regional areal sources. Results from the WCFS (1996a) probabilistic studies show that fault sources and regional areal sources contribute much more to the total seismic hazard at ICPP than volcanic source zones (figure 2-15). Contributions from the fault sources become more significant at lower probability levels and for longer ground motions periods.

Because of their significance, three faults have been individually characterized as potential seismic sources in most of the probabilistic studies at INEEL. These include the Lost River, Lemhi, and Beaverhead faults. The most significant uncertainties associated with these fault sources are their southern termination and segmentation model. Of the three fault sources, the Lemhi fault has been considered the most important because of its proximity to most of the facility sites at INEEL, and its southern termination has been used to determine source-to-site distance in almost all of the deterministic studies. Since the WCFS (1996) study incorporated the most up-to-date paleoseismic investigations, their suggestion of the southern termination of the Lemhi fault represents the best understanding to date. Uncertainty in the southern determination of the Lemhi fault is one of the major sources causing inconsistencies in various deterministic studies. However, sensitivity analyses by WCFS (1996a) have shown that this uncertainty has little effect on the probabilistic hazard contributed by the Lemhi fault to the ICPP. This study also indicated that the Lost River fault contributes more probabilistic hazard to the ICPP site than the Lemhi fault because of the relatively higher recurrence rates of the Lost River fault resulting, mainly, from the most recent paleoseismic studies (Woodward-Clyde Federal Services, 1995).

The ESRP volcanic zones include the Arco volcanic rift zone, Lava Ridge-Hells Half Acre, Howe-Fast Butte, Great volcanic rift zones; and the Axial volcanic zone. The maximum magnitude along volcanic zones was estimated to be $M_w = 5.5 \pm 0.5$ by WCFS (1996a) based mainly on empirical relationships of rupture area and magnitudes. Their earthquake recurrence models were assumed to be exponential, and the recurrence intervals were estimated based on the determination of eruptive episodes. Sensitivity analyses (Woodward-Clyde Federal Services, 1996a) show that the contribution of these volcanic zones to the total seismic hazard at the ICPP is very limited (figure 2-15). Of all of the volcanic zones, the Great Rift zone seems to contribute more than other rift zones, followed by the Arco rift zone. The Axial volcanic zone contributes the least to the seismic hazard at ICPP.

The regional areal sources usually include the ESRP source zone. Consideration for other source zones have not been consistent. For example, the WCC (1992a) probabilistic study included only the ESRP-Basin and Range boundary zone. In the WCFS (1996a) probabilistic study, the northern Basin and Range source zone was used to represent the potential for earthquakes other than those occurring on the Lost River, Lemhi, or Beaverhead faults. Other areal source zones were used to represent both earthquakes occurring on the mapped faults that lie within them and seismicity occurring on small, unmapped faults. These include the ISB, Yellowstone, Idaho Batholith, and central Basin and Range sources (figure 2-3). In taking into consideration these areal source zones, WCFS (1996a) developed three alternative models to represent the zonation in the region (Woodward-Clyde Federal Service, 1996a). Their results show that the northern Basin and Range source zone is the controlling regional source zone because of its proximity to the INEEL and its relatively high rate of seismicity compared to the ESRP. The ESRP source contributes to the hazard at very low-probability levels.

3.3 DETERMINISTIC SEISMIC HAZARD ASSESSMENT

The various DSHAs conducted for the INEEL have resulted in a few slightly different hazard estimations. Such differences are mainly associated with uncertainties in the magnitude of the most significant earthquake and source-to-site distance. A few earlier studies yielded rather similar predictions for the PHA. For example, WCC (1975) suggested a peak bedrock horizontal acceleration of 0.34 g for the LOFT using a magnitude 6.75 earthquake and a source-to-site distance of 13.6 km. Allied Chemical Corporation (1975) predicted a peak bedrock horizontal acceleration of 0.33 g at the ICPP site using a M_w = 7.75 earthquake on the Arco Pass or Howe scarp faults. Agbabian Associates (1977) estimated a 0.30-g PHA at the ground surface for a M_w = 6.75 earthquake and source-to-site distance of 24 km. WCC (1979) predicted a bedrock PHA of 0.22 g at the TREAT facility with a source-to-site distance of 30 km. Also, WCC (1979) recommended less than a 0.2-g peak acceleration at a distance of 48 km for rupture of the Arco Pass scarp fault. It is interesting to note that DOE selected the 0.36-g design acceleration value for the proposed TMI-2 ISFSI based on these earlier deterministic studies.

Results from a few recent deterministic studies carried out for sites at or close to the ICPP are compared in table 3-1, along with the MCE and source-to-site distances. It seems that there is a trend of increasing magnitude of the MCE, which resulted in increasing hazard estimation. However, it appears that the most recent selection of MCE (i.e., Woodward-Clyde Federal Services, 1996b) represents the DOE best understanding, because it is supported by the most recent paleoseismic studies. It seems necessary to continue paleoseismic studies in the region, especially along the three most significant northern Basin and Range faults (the Lost River, Lemhi, and Beaverhead faults). Obviously, the DOE current 0.36-g horizontal design value for the proposed TMI-2 ISFSI bounds the latest 50th-percentile deterministic event (0.34 g in table 3-1) and the 84th-percentile deterministic event according to result for the SIS soil site obtained by WCC (1990). However, it does not bound the latest 84th-percentile

Table 3-1. Comparison of results from a few recent deterministic studies carried out for sites at or close to the Chemical Processing Plant

Site and Site Condition	Horizontal Peak Acceleration (g)		MCE Maximum Credible Earthquake	Source to Site Distribution (km)	Study
	50th Percentile	84th Percentile			
FPR rock	0.13	0.196	M_w = 6.9	21.4	WCC (1990)
SIS soil	0.197	0.297	M_s = 7.3	20.8	
NPR rock	0.20	0.31	M_w = 7.0	2.12	WCC (1992a)
CPP rock	0.17	0.28	M_w = 7.1	22.1	WCFS (1996a,b)
CPP soil	0.34	0.56			

deterministic event (0.56 g in table 3-1). It is worth noting that the return periods for the PHAs on rock from the latest 50th- and 84th-percentile deterministic events are 3,300 and 25,000 yr, respectively, based on the WCFS (1996a) PSHA.

3.4 PROBABILISTIC SEISMIC HAZARD ASSESSMENT

The first PSHA at INEEL was conducted by Agbabian Associates (1977) at the LOFT facility. This study suggested a lower-bound PHA of 0.1 g and an upper bound PHA of 0.4 g at a probability of 0.01 percent.

TERA (1984) probabilistic analysis for the ANL facility indicated peak accelerations of 0.073, 0.14, and 0.24 g with return periods of 100, 1000, and 10,000 yr, respectively. It was interpreted by WCC (1992a) that the LOFT facility would be subjected to a peak acceleration of approximately 0.36 g with a return period of 10,000 yr according to the TERA Corporation (1984) hazard curves. Since both of these sites are at considerable distances away from the proposed TMI-2 ISFSI site, these studies have little reference value to the seismic hazard estimation for the proposed ISFSI.

Results of bedrock PHAs from the WCC (1992a) probabilistic analyses for the NPR and WCFS (1996a, 1996b) probabilistic analyses for the ICPP yielded quite similar results (table 3-2), despite the fact that much more up-to-date information obtained from a few recent source characterization projects in the region, especially along the fault sources, were included in the 1996 study. The 1996 study, however, included sophisticated sensitivity analyses that isolated the contributions to the total seismic hazard produced by various potential seismic sources and evaluated the relative importance of various uncertainties associated with characterization of these seismic sources, as reviewed in more detail in section 2.4.

Table 3-2. Comparison of bedrock peak horizontal accelerations from probabilistic assessment carried out by the Woodward-Clyde Consultants (1992a) for the New Production Reactor and by the Woodward-Clyde Federal Services (1996a,b) for the Chemical Processing Plant

		(Mean) Horizontal Peak Acceleration (g) Annual Exceedance Probability (Return Period)				
Site and Conditions		2×10^{-3} (500 yr)	1×10^{-3} (1,000 yr)	5×10^{-4} (2,000 yr)	1×10^{-4} (10,000 yr)	Studies
NPR rock[1]		0.06	0.11	0.14	0.23	WCC (1992a)
ICPP	Rock	0.08	0.10	0.13	0.22	WCFS (1996a,b)
	Soil	–	0.23	0.30	0.47	

[1] Interpreted according to the Woodward-Clyde Consultants (1992a) mean PHA hazard curve.

It is interesting to note that the DOE's current 0.36-g horizontal design value for the proposed TMI-2 ISFSI soil site bounds the 2,000-yr return period probabilistic event (0.30 g, table 3-2). However, it does not bound the 10,000-yr return period event (0.47 g, table 3-2).

3.5 DEVELOPMENT OF DESIGN BASIS EARTHQUAKE PARAMETERS

To comply with DOE Standards 1020-94 and 1023-94 and to be consistent with NRC regulations, WCFS (1996b) developed DBE ground motion parameters for the proposed ISFSI site based on the WCFS (1996a) PSHA. These parameters were developed according to procedures described in DOE Standards 1023-94 and are in the form of acceleration response spectra and time histories as reviewed in more detail in section 2.5 and illustrated in figures 2-19 through 2-21 and tables 2-6.

4 DISCUSSION AND RECOMMENDATION

4.1 DISCUSSION

Seismic issues that are important to siting the proposed TMI-2 storage facility include identification of potential seismic sources, source characteristics, and associated uncertainties; deterministic and probabilistic seismic hazard assessment using state-of-the-art knowledge and techniques, including ground motion attenuation predictions and spectral analyses; and development of design basis parameters in compliance with applicable regulations and regulatory guidance. These issues have been discussed in detail in chapters 2 and 3.

In the TMI-2 SAR, the DOE-ID (1996b) has proposed a seismic design horizontal acceleration of 0.36 g. This is based on seismic design criteria contained within the INEEL AE standards (U.S. Department of Energy, 1992) that provide technical direction and guidance to architects and engineers in the development of designs for construction-type work performed for DOE-ID at INEEL. The PHAs for rock in the AE standards are based on deterministic studies conducted in the 1970s (Woodward-Lungren and Associates, 1971; Woodward-Clyde Consultants, 1975; Allied Chemical Corporation, 1975; Agbabian Associates, 1977) and supported by the results of a further deterministic analysis conducted by WCC (1990). In the AE standards related to a reactor or similar higher risk facility, the peak design basis horizontal acceleration for the ICPP is 0.36 g, including effects of soil amplification. This corresponds to the 84th percentile of the 1970s DSHA studies. This acceleration was used as the design basis SSE for the chemical processing plant, and it is intended to serve as the design basis SSE for the proposed TMI-2 ISFSI at the ICPP.

However, DOE-ID continued DSHA to develop site-specific seismic design criteria for the proposed TMI-2 ISFSI site. This analysis was based in part on the results of the 1990 deterministic evaluation for INEEL (Woodward-Clyde Consultants, 1990) and recent fault-trenching studies conducted along the Lemhi and Lost River faults (Woodward-Clyde Consultants, 1992b; 1995). The Lemhi fault is the closest Basin and Range normal fault to the proposed TMI-2 ISFSI site and controls the deterministic seismic hazard. The resulting 50th- and 84th-percentile deterministic values of PHAs at the proposed TMI-2 ISFSI site are 0.34 g and 0.56 g, respectively.

Since the 1980s, the DOE-ID also conducted PSHA for INEEL. TERA Corporation (1984) performed a PSHA for the ANL—West Facility. The site-specific seismic hazard curves developed by TERA Corporation have been used by LLNL (Coats and Murrary, 1984) to calculate peak horizontal ground surface accelerations for the INEEL for various return periods. The PHAs for INEEL are 0.14, 0.21, and 0.24 g for return periods of 1,000, 5,000, and 10,000 yr. However, recently the DOE-ID has completed another probabilistic seismic hazard evaluation for facility areas of INEEL, including the ICPP (Woodward-Clyde Federal Services, 1996a). The methodology used in the new probabilistic study provides for explicit inclusion of the range of seismologic and tectonic interpretations including seismic source characterization and ground motion estimation consistent with approaches contained in NRC Guide 1.165 (Draft was DG-1032, Nuclear Regulatory Commission, 1997a). Based on this study, the PHAs for the proposed TMI-2 ISFSI site are 0.23, 0.30, and 0.47 g for return periods of 1,000, 2,000, and 10,000 yr, respectively.

In the light of new deterministic and probabilistic hazard assessment data, the DOE-ID has proposed to the NRC (U.S. Department of Energy-Idaho Operations Office, 1996b) for NRC acceptance of the DOE-ID SAR a DE value of 0.36 g that will envelope the 50th-percentile deterministic value of 0.34 g and 2,000-yr return period probabilistic value of 0.30 g.

The literature survey conducted herein indicates that the majority of the pertinent literature was produced by the DOE and its contractors or subcontractors. It is important to recognize that the DOE has sufficiently identified, utilized, and referenced previous as well as the state-of-the-art knowledge and information that exist in the literature in its site characterization efforts. Seismotectonic characteristics that are significant for seismic hazard evaluation at INEEL have been analyzed and potential seismic sources have been identified. Various studies, especially the recent probabilistic and deterministic seismic hazard analyses conducted by a DOE subcontractor, the WCFS (1996a,b), have also taken sufficient considerations of uncertainties associated with seismic source characteristics using the state-of-the-art investigation and analysis techniques. This study by WCFS (1996a,b) also included sophisticated sensitivity analyses that isolated the contributions to the total ground motion hazard produced by various potential seismic sources and the evaluated relative importance of various uncertainties associated with characterization of those seismic sources. Those analyses are consistent with recommendations in Appendix A of 10 CFR Part 100. In summary, the DOE seismic hazard analysis approach for the proposed TMI-2 ISFSI appears to be technically sound, and resultant ground motion values represent the best estimates. However, the DOE-proposed design PHA of 0.36 g does not bound the most recent 84th-percentile deterministic value of 0.56 g and 10,000-yr return period probabilistic value of 0.47 g. Therefore, a judgment of whether the DOE-design approach is acceptable depends on whether there are regulatory and technical bases to accept an ISFSI-design value that bounds the 50th-percentile deterministic value and the 2,000-yr return period probabilistic value.

Section 2.5.2.6 of NUREG-0800 (Nuclear Regulatory Commission, 1997b) provides guidance on assessing the SSE ground motion. Substantial uncertainties are inherent in deriving spectra for seismic ground motions, and the guidance states NRC preference that the 84th-percentile (median plus one standard deviation) response spectra be used for both spectral shape and ground motion amplitude estimates. Although a strict interpretation of 72.102(f)(1) may lead one to conclude that 0.56 g is the requisite DE value for the proposed TMI-2 ISFSI site, there is a regulatory basis for a different design value that may be adequate. In 1980, when 10 CFR Part 72 was first promulgated, ISFSIs were largely envisioned to be spent fuel pools or massive dry-storage structures. Moreover, ISFSIs were expected to be built at existing power plant sites where SSE values are already determined. In the Statements of Consideration (SOC) accompanying the initial rulemaking, the NRC recognized that the design PHA for dry casks and canisters need not be as high as a power reactor SSE: "For ISFSIs which do not involve massive structures, such as dry-storage casks and canisters (*sic*), the required design earthquake will be determined on a case-by-case basis until more experience is gained with licensing these types of units." With over 10 yr of experience licensing dry-cask storage, and robust analyses demonstrating cask behavior in accident scenarios, the NRC staff now have a reasonable technical basis to consider a different design PHA that is adequate for licensing dry storage ISFSIs.

The NRC selected the 84th-percentile DE for power reactors to provide an extra level of conservatism for those higher risk facilities. An operating ISFSI is inherently less hazardous and less vulnerable to earthquake-initiated accidents than is an operating nuclear power reactor (Hossain et al., 1997). Unlike a nuclear power plant, an ISFSI does not have an active nuclear reaction, and hence does not need to meet requirements for active cooling and safe shutdown systems in order to ensure the integrity of the high-pressure reactor coolant boundary and for shutting down the reactor in the event of a very large earthquake. Operations in an ISFSI facility need not be continuous but can be shut down, except for possible filtered ventilation systems and other confinement systems, in the event of a very large earthquake in order to repair any potential damage caused by the earthquake.

For these reasons, the potential consequences of an accident are significantly smaller than from a nuclear power plant. Hence, it is appropriate that the design requirements for ISFSI structures, which are important to public safety, be less stringent than the requirements for a nuclear power plant facility (Hossain et al., 1997).

Although 10 CFR Part 72 does not consider PSHA as an acceptable methodology for deriving a DE for an ISFSI, the PSHA results are being accepted increasingly by the NRC. The PSHA method is acceptable for power reactors under the January 1997 revisions to 10 CFR Part 50 and Part 100. Furthermore, the NRC has accepted the PSHA method for the design and performance assessment of the proposed high-level waste repository at YM (U.S. Department of Energy, 1994c).

As discussed earlier, the design requirements for ISFSI structures that are important to public safety may be permitted to be less stringent than the requirements for a nuclear power plant facility. There are also similarities between an ISFSI and a geologic repository as far as risk to the public is concerned. Neither has an active nuclear reaction and thus do not need to meet requirements for active cooling and safe shutdown systems; their operations need not be continuous but can be shut down, except for filtered ventilation and other confinement systems; and the radioactive inventory that may be released from them to the environment in case of an accident is small (Hossain et al., 1997). The NRC has accepted a return period of 1,000 and 10,000 yr, respectively for Category 1 and Category 2 design basis events for the PHA estimation for the 100- to 150-yr preclosure design life of the proposed HLW repository at YM (U.S. Department of Energy, 1996). Category 1 design basis events for a repository are those natural and human-induced events that are reasonably likely to occur regularly, moderately frequently, or one or more times before permanent closure of the geologic repository operations area (i.e., during the 100- to 150-yr preclosure design life of HLW repository). Category 2 design basis events for a repository are other natural and human-induced events that are considered unlikely, but sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on public health and safety. Most of the SSCs at the dry storage ISFSI for TMI-2 fuel debris at INEEL are likely to be designed for Category 1 design basis events. For these SSCs, the use of 2,000-yr return period to determine probabilistic design acceleration for the 20-yr design life of the proposed TMI-2 ISFSI is conservative. For those SSCs that may need to be designed for Category 2 design basis events, the use of a 2,000-yr period probabilistic design acceleration for the 20-yr design life of the proposed TMI-2 ISFSI appears to be adequate. In summary, the DOE-ID proposed seismic design horizontal acceleration of 0.36 g provides an adequate value for design of the proposed TMI-2 ISFSI at INEEL.

4.2 RECOMMENDATIONS

Based on the activities reported herein, the following recommendations are made.

(i) The DOE has sufficiently identified, utilized, and referenced previous information as well as state-of-the-art knowledge that exists in the literature in its TMI-2 ISFSI site characterization efforts. Seismotectonic characteristics that are significant for seismic hazard evaluation at INEEL have been analyzed, and potential seismic sources have been identified by the DOE. Thus, the DOE seismic hazard consideration for the design of the proposed TMI-2 ISFSI is adequate.

(ii) The DOE PSHA should be considered as an acceptable methodology for deriving the DE for the proposed TMI-2 ISFSI.

(iii) The DOE-ID-proposed seismic design horizontal acceleration of 0.36 g that envelopes the 50th-percentile deterministic value of 0.34 g and 2,000-yr return period probabilistic value of 0.30 g provides an adequate design value for the design of the proposed TMI-2 ISFSI at INEEL.

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