# SEISMIC RISK ANALYSIS FOR THE EXXON NUCLEAR PLUTONIUM FACILITY, RICHLAND, WASHINGTON

Submitted to

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## 1.0 INTRODUCTION AND SUMMARY

In this report, TERA Corporation presents the results of a detailed seismic risk analysis of the Exxon Nuclear Plutonium Facility at Richland, Washington.

This report is one part of a larger effort being directed by the U.S. Nuclear Regulatory Commission. The NRC's objective in commissioning the overall report is to assess and improve, to the extent practicable, the ability of this facility to withstand adverse natural phenomena without loss of capacity. This report focuses on earthquakes; the other natural hazards, being addressed in separate reports, are severe weather (strong winds and tornados) and floods. The overall analysis will provide an assessment of the consequences of an accident resulting from any of these natural phenomena. The assessment will express a quantitative probabilistic measure of the potential structural damage and the release function. It will also provide a probabilistic estimate of the resulting dose of radioactivity to the public.

This study was performed under contract to the Lawrence Livermore Laboratory (LLL). The study was directed by Don Bernreuter of the LLL Nuclear Test Engineering Division. At TERA, the study was managed by Lawrence Wight.

To ensure credible results, very sophisticated but well-accepted techniques were employed in this component of the project, an analysis of the seismic risk. The calculational method we used, which is based on Cornell's work (1968), has been previously applied to safety evaluations of major projects.

The historical seismic record used in this analysis is the most current and complete available. The record, which is a synthesis of data from the University of Washington Puget Sound Array, the Eastern Washington Array, and the NEIS data bases, was provided by Battelle Northwest, Richland.

The resulting seismic record, covering the period 1833-1977, was used to identify all possible sources of seismicity that could affect the site. Inadequacies and incompleteness in this record were explicitly considered in the definition of source regions and their activity rates. Where there were uncertainties, we assigned subjective probabilities to the span of uncertainty.

The acceleration attenuation relation used in the analysis was developed based on a careful evaluation of all relevant strong motion data.

To guarantee use of the best available calculational methods and input, the entire project was reviewed by Professor Stewart W. Smith, a University of Washington seismologist, well known for his research on west coast seismicity and tectonics. Dr. Smith is responsible for several seismic arrays in Washington, Oregon, and California, one of which covers the Richland area.

The results of our analysis, which include estimates of the uncertainty, are presented in Figure 1-1. Our best estimate curve indicates that the Exxon facility will experience 10 percent g with a return period of 600 years and 15 percent g with a return period of 2,500 years. The curves on either side of our best estimates represent roughly the one standard deviation confidence limits about this best estimate.

These curves provide the seismic design basis for the Exxon facility in terms of peak ground acceleration. For those structures and equipment that could experience structural amplification, we judge that the mean alluvium response spectrum prescribed in WASH 1255 (AEC, 1973) adequately characterizes the frequency content.

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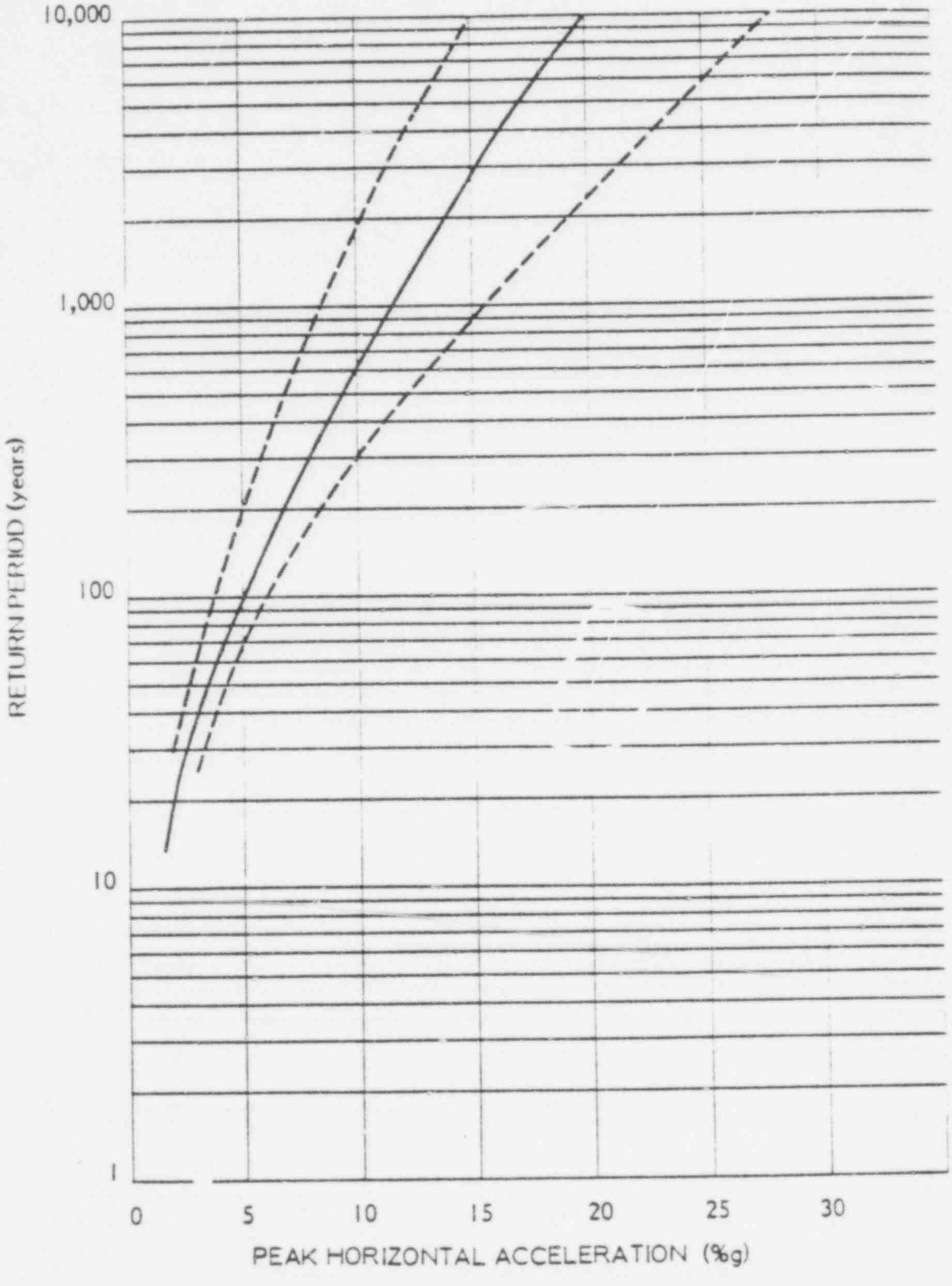


FIGURE 1-1

EARTHQUAKE RISK AT THE EXXON FACILITY

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## 2.0 SEISMIC RISK METHODOLOGY

A seismic risk analysis is only as credible as the risk analysis methodology and the input to it. This section presents the basis for our selection of a probabalistic Poisson model for the risk assessment at the Exxon facility.

There are generally two distinctly different approaches to seismic risk analysis; probabalistic and deterministic.

Using the deterministic approach, the analyst judgmentally decides that an earthquake of a given magnitude or intensity occurs at a specific location. He then attenuates the ground motion from the earthquake source to the site and determines the effects of that quake. The problem in using this approach is that it is difficult to define the margin of safety or the degree of conservatism in the resulting design parameters. Analysts are often asked to provide information on the "maximum possible" or "most probable" earthquakes for design purposes, but the deterministic approach does not easily provide those answers.

A probabalistic approach, on the other hand, quantifies the uncertainty in the number, size, and location of possible future earthquakes and allows an analyst to present the trade-off between more costly designs or retrofits and the economic or social impact of a failure. Because the product of a probabalistic approach is a measure of the seismic risk expressed in terms of return period, this trade-off can easily be quantified.

Although the probabilistic approach requires significantly more effort than the deterministic approach, it has the following advantages:

- It quantifies the risk in terms of return period;
- It rigorously incorporates the complete historical seismic record;
- It can incorporate the judgment and experience of the analyst;

- It accounts for incomplete knowledge regarding the location of faults;

- It has the flexibility to assess the risk at the site in terms of spectral acceleration, velocity, displacement, or earthquake intensity.

The credibility of the probabilistic approach has been established through detailed technical review of its application to several important projects and areas. Recent applications include assessments of the seismic risk in Boston (Cornell, 1974), in the San Francisco Bay Area (Vugliente, 1973), in the Puget Sound Area (Stepp, 1974) and continental United States (Algermissen and Perkins, 1976). Results of these studies have been applied to, among other areas:

- Development of long-range earthquake engineering research goals;

- Planning decisions for urban development;

- Environmental hazards associated with the milling of uranium; and

- Design considerations for radioactive waste repositories.

This diversity of application demonstrates the inherent flexibility of the risk assessment approach.

THEORY

The risk calculations can be fundamentally represented by the total probability theorem

$$P[A] = \iint P\ [A/m \text{ and } r]\ f_M(m)\, f_R(r)\, dm dr$$

where P indicates probability, A is the event whose probability is sought, and M and R are continuous, independent random variables which influence A. The probability that A will occur can be calculated by multiplying the conditional probability of A, given events m and r, times the probabilities of m and r, and integrating over all possible values of m and r.

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In our assessment of the Exxon facility, A will be taken as maximum acceleration and therefore

$$P\,[A/m \text{ and } r]$$

will be derived from data relating peak acceleration to epicentral distance and earthquake magnitude. Often known as attenuation data, these data are usually lognormally distributed around a mean relationship of the form (McGuire, 1977a).

$$A = C_1 e^{C_2 M} (R+r_o)^{C_3} .$$

The distribution on earthquake magnitude, $f_M(m)$, can readily be derived from an actual or postulated frequency relationship of the form

$$\log N = a - bM$$

where N is the number of earthquakes having magnitude greater than M, and a and b are constants characteristic of the particular source region under consideration. It follows (Cornell, 1968) that $f_M$ can be derived from the cumulative distribution function, $F_M$, which has the form,

$$F_M = k\,(1 - e^{-\beta M})$$

where k is a normalizing constant and $\beta = b\ln 10$.

The distribution on distance, $f_R(r)$, depends on the geometry of the problem under consideration. For simple geometries, the distributions can often be integrated analytically. Realistic geometries however, require numerical evaluation of the integral. A very versatile computer program has been developed (McGuire, 1976b) that incorporates the theory presented above with a numerical integration scheme that allows for evaluation of very complex source-site geometries.

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The overall approach to performing seismic risk assessment by this theory is summarized below. First, the historical earthquake record and local attenuation data are combined with the experience of the analyst to produce the functional relationships applicable to the area under consideration. The source regions are divided into circular sectors and proportional seismicity is allocated to each sector. The total expected number of events causing maximum accelerations at the site greater than a particular test acceleration is obtained by summing the events from each sector within each source region. The risk associated with this test acceleration is then calculated using the conventional assumption that earthquakes have a Poisson distribution in time. It then follows that the return period is simply the reciprocal of the risk.

In recognition of the uncertainties in any seismological analysis, we test the sensitivity of results to variations, corresponding to the uncertainty, in key parameters. The results are then combined by assigning subjective probabilities to the range of variations and weighting the results accordingly. The final synthesized estimate of the seismic risk can be considered a Bayesian estimate (Cornell and Merz, 1974).

# 3.0 GEOLOGY

## SUMMARY

The Exxon Nuclear site is in the Pasco Basin which lies in south-central Washington. It is within the Columbia River Basalt Plateau that extends over 50,000 square miles. The site is underlain by thick, widespread basaltic lava flows at a depth starting at 151 feet and continuing downward over 10,000 feet.

The surface of the site is covered by a layer of Winchester sand of thickness two to seven feet. Site borings and nearby excavations indicate that the superficial few feet of sand is underlain by 20 feet or so of the Pasco gravels. The sand and gravel rest upon the deeply eroded surface of the Ringold Formation which, where not eroded, consists of a thick series of silts, sands and gravels. The Ringold Formation rests on the basalt, the top of which is estimated to be at a depth of 151 feet below the site surface.

## REGIONAL PHYSIOGRAPHY

Regionally, the study area is situated in the Columbia Basin. This geologic and structural basin is physiographically defined as the Columbia Plateau (Hunt, 1974).

The site is situated near the Columbia River which is the major water course in the region. A local physiographic and structural depression in the plateau, the Pasco Basin, contains the site and comprises approximately 1,600 square miles of undulating semiarid plain with low lying hills, dunes and intermittent streams. The northern and southern boundaries of the Pasco Basin are defined by the Saddle Mountains and Rattlesnake Hills, respectively. The easterly ends of Umtanum and Yakima Ridges mark the western boundary of the basin, whereas to the east the basin merges into a vast expanse of dunes, dissected flatlands and coulees northwest of the Snake River.

## Regional Geology

The structure of the region was produced by a combination of volcanic construction and of moderate tectonism during Cenozoic time. The geologic provinces correspond to the physiographic provinces.

## Regional Stratigraphy

The Pasco Basin area is underlain and partially surrounded by an extensive and thick sequence of basalts. The Rattlesnake Hills deep test well west of the project site penetrated more than 10,000 feet of basalt composed of nearly 100 flows and interflow sediments (Raymond and Tillson, 1968). Basalts of Miocene and Pliocene age exposed in the Columbia Basin are defined collectively as the Columbia River Group.

## Regional Structure

The principal structural elements of the region surrounding the Exxon Nuclear site include the stratification of volcanic and sedimentary units, major folds and faults, joints and clastic dikes. On a regional scale, stratification of lithologic units is horizontal or dipping slightly to the west-southwest (Brown, 1968).

Folds - The folds in the Columbia River basalts are the most prominent structural features in the Columbia Basin. The folds can be classified according to three general orientations: east-west trending, west-northwest trending, and northeast trending.

Faults - The relatively few faults that have been mapped in the Columbia Basin are directly related to the folds within the basalt. This relationship suggests that many of the faults represent local adjustment to the folding. In general, the faults found within the basin are (1) of limited length, discontinuously less than 30 miles; (2) of moderate offset, usually less than 500 feet; and (3) characterized by the absence of structural features associated with recent fault activity such as offset streams and truncated alluvial fans (Brown, 1968).

The faults of significance to the proposed site are associated with anticlinal folds:

Wallula Gap fault and Rattlesnake-Wallula alignment

Yakima Ridge anticlines and a minor fault

Umtanum fault and anticline

Gable Brutte and Gable Mountain and minor faults

Saddle Mountain fault and anticline

Fold/Fault Relationships - Folding has been the primary response of the stratigraphic units in the Columbia Basin to tectonic deformation, and faulting has been secondary (Jones and Deacon, 1966 and Brown, 1968). The known faults have short to moderate length, have small cumulative displacement, and lack evidence of recent movement, even though subsidence of the basin may have continued to the present (Bingham, et al., 1970 and Brown, 1968).

In general, faulting has been contemporaneous with folding. Faults were formed when joint surfaces could not relieve accumulated stress developed during folding. Many of the supposed faults that have been mapped in the Pasco Basin area could be interpreted as monoclinal flexures that have been eroded along their axes. This interpretation may explain the steepening of dips and the presence of basalt breccias as erosional remnants of the monoclines (Brown, 1968 and Grolier, 1965).

Regional Ground Water - The ground water in the Hanford region exists as confined water in the permeable parts of the layered basalt bedrock and as unconfined water in the overlying sedimentary deposits. The rubbly tops of some of the basalt flows and the sedimentary interbeds are permeable. These permeable parts transmit ground water in a confined condition and may yield water to wells in the capacity of up to 1,500 gallons per minute. The pressure levels of the ground water in the basalt are controlled by: (1) local structure, which either impedes movement of ground water down the pressure gradient or facilitates its leakage from confinement, and by (2) the meager recharge, which gains entry to the aquifers locally. The ground water level in the basalt in this area varies from a few feet to several tens of feet above the level of the Columbia River. Permeable zones in the stratigraphic succession of lava flows occur irregularly at unequal intervals of several hundreds of feet throughout the basalt sequence. The occurrence of ground water in the basalt has been described in several publications (Newcomb, 1959 and Newcomb, et al., 1973). The structural controls on the ground water for the Hanford Reservation are described in Newcomb et al. (1973) and for type areas in Newcomb (1961). The quality of the ground water has been described for the region in Newcomb (1972).

The sedimentary materials above the basalt contain a regional body of unconfined ground water that discharges to the Columbia River. The regional water table in these materials slopes gently to the river or to the zone of bank storage, which varies from a few hundred to several thousands of feet wide, along the river (Newcomb and Brown, 1961).

Over much of the Pasco Basin, the unconfined water table lies within the Ringold Formation, which consists largely of silt, sand, gravel and clay. Locally along the river and beneath the most recent abandoned channels, the sand and gravel of the glacio-fluvial deposits extend below the water table and below higher stages of the river.

The unconfined water table beneath the Hanford Reservation has a relatively steep eastward slope outward from the lower ends of the mountain valleys and then a more gentle slope north, east and south beneath the terrain lands. Artificial recharge has altered the shape of the general water table of the reservation; however, in the area of the site there are no present significant sources of artificial recharge.

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## SITE GEOLOGY

### General

In general, the area surrounding the plant is open, semi-arid desert land and is very sparsely settled with the exception of the "Tri-Cities" of Richland, Kennewick and Pasco. Most developed land within a five-mile radius of the site is used for agriculture in raising irrigated crops and for residences. The undeveloped area north and east of the site is in the DOE Hanford Reservation.

### Site Geology

Topography - The local area of the site is flat but covered with a series of wind-formed ridges ranging from five to about 30 feet high; the ridges are parallel and extend in the NE-SW directions. The general trend of the surrounding terrain is a gentle upward slope toward the north and northwest (along the Columbia River and Cold Creek), and downward toward the south and southwest. The general slope of the land has been created by the scouring and deposition action of water and wind.

The dominant topographic feature to the northeast and across the Columbia River is a nearly continuous outcropping, known as White Bluffs. The bluff along the east bank of the Columbia River varies in altitude between 670 and 930 feet MSL.

There are no topographic obstructions to the southeast of the site, as the bluff terminates abruptly. The land surface on both sides of the river is essentially the same altitude (100 to 200 feet above the river) and gently rolling.

The confining topography to the west and south are the Rattlesnake Hills and the Horse Heaven Hills. The Rattlesnake Hills are cut in three places. The lowest cut is occupied by the Yakima River (near Benton City). The continuation of the Rattlesnake Hills gradually merges into the Horse Heaven Hills south of Kennewick.

Stratigraphy - The surface of the site is covered by a layer of Winchester sand of thickness two to seven feet. Site borings and nearby excavations indicate that the superficial few feet of sand is underlain by 20 feet or so of the Pasco gravels. The sand and gravel rest upon the deeply eroded surface of the Ringold Formation which, where not eroded, consists of a thick series of silts, sands and gravels. The Ringold Formation rests on the basalt, the top of which is estimated to be at a depth of 151 feet below the site surface. A geologic column is shown in Table 3-1.

Observations by R.E. Brown and others (1958, 1960) show that the total thickness of these deposits was at least 1200 feet. The thickness of the Ringold materials remaining under the building site is only about 150 feet. It is probable, therefore, that almost 1,100 feet were removed by the scouring action of glacial flood streams before the present 22 feet of sand and gravel were deposited by the last (or latter few) flood streams. Therefore, the Ringold materials underlying the building site have been subjected to a consolidating load of at least 33 tons per square foot.

In addition to the preconsolidation loading discussed above, major portions of the Ringold materials have been partially hardened (indurated) by cementation with calcium carbonate in the form of caliche. The average seismic velocity of saturated Ringold materials is reported to be about 10,000 feet per second (Dames and Moore, 1970).

The most detailed nearby information on the basalt bedrock was provided by the logging of an oil well which penetrated over 10,000 feet of basalt flows in the southern portion of Rattlesnake Hills. Although this well did not completely penetrate the entire series of basalt flows, it did pass through over 100 recognizable flows and their associated "interbeds." Raymond and Tillison (1968) and Brown (1958) have obtained evidence to indicate that the entire thickness of the basalt flows is about three miles and that the flows individually developed at long intervals, i.e., about one flow per 500,000 years. The minimum compressed seismic velocity of these flows is reported to be 14,000 feet per second, with an

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Table 3-1

GEOLOGIC COLUMN, EXXON NUCLEAR SITE*

| Depth and Age | |
|---|---|
| Thickness varies from 2 to 7 feet Recent Deposit | Winchester Sand. Fine to medium sand with occasional gravel. Loose to medium density. Some windblown. |
| Thickness varies from 15 to 20 feet Deposited about 10,000 years ago | Pasco Sand and Gravel with probably some cobbles and boulders. This material was deposited by the last, or latter few, glacial flood streams. |
| 22 to 170 feet Deposited during interval between about 20,000 and 500,000 years ago | Ringold Formation. Composed of silts and fine sands of lakebed deposits and sand, gravels and cobbles of glacial streams. Silty materials predominantly in the bottom portion of the formation. The materials have been partially cemented with calcium carbonate. These materials have been preconsolidated by the submerged weight of about 1,100 feet of material that was eroded by glacial streams prior to the deposition of the overlying sand and gravel. |
| 151 feet to well over 10,000 feet of basalt flows, averaging 90 feet in thickness, with interbeds often present between the flows. It is estimated that the flows occurred at intervals of about 500,000 years prior to 7,000,000 years ago | Basalt. This is a portion of the Columbia River basalts which are the second most extensive in the world. The basalt flows have an unusually uniform thickness. In the main the rock is hard, high density, brittle "trap rock" which is separated by pentagonal vertical columnar jointing and horizontal interbeds. The interval between flows was unusually long so that even some thin coal deposits are present in some of the interbeds between flows. Raymond and Tillison estimated that the total thickness is about 3 miles including the interbeds. If this be so, then the deposit consists of about 170 flows with associated interbeds. |

*Adapted from Dames and Moore, 1970.

average of 16,400. During the average long-term period between the individual flows, semi-continuous "interbeds" often developed and were at least in part buried by the next lava flow. Attention is invited to the fact that these lavas had an unusually low viscosity, which often resulted in basalt flows extending several or more tens of miles, with a fairly uniform thickness. The entrapped interbeds consist of materials with a low seismic velocity, which accumulated during the average 500,000 years between flows. These materials consist of residual soils (saprolites), lake bed and swamp deposits, as well as more isolated stream deposits and thin coal beds. The large number of individual flows, which are often separated by interbeds of softer material, lends additional credence to R.E. Brown's (1968) opinion that stresses resulting from tectonic forces were primarily relieved by slippage between the individual basalt flows rather than by faulting which would tend to produce earthquake forces.

The great majority of the basalt flows mostly occurred during the 14,000,000 years of the Miocene which ended about 11,000,000 years ago. Some few flows are believed to have occurred during the following Pliocene Time and ceased about 7,000,000 years ago. The composition and structural characteristics of the older rocks underlying the basalts have not been determined.

Structure - The fault nearest the site is the Rattlesnake-Wallula Fault which trends southeastward from the Rattlesnake Hills and through the Wallula "water gap" for a distance of 50 miles. The structure passes about seven miles southwest of the site. Recent U.S.G.S. (1966) field work showed that the fault, where exposed in basalt, had formed a crushed zone from 100-200 feet wide. Just northwest of the Wallula water gap, almost vertical offsets ranging from 200 to 300 feet were found in the basalt. The fault has been traced for 27 miles to the southeast from the Yakima River; its trace north of the Yakima River has not been found. Evidence of "geological recent" movement was located by the U.S.G.S. about 35 miles southeast of the site.

Ground Water - The ground water table at the site is related to both the Yakima River to the west and the Columbia River to the east. The site lies in the wye formed by the junction of these two streams so that fundamentally only events occurring in these streams or in the site area will significantly affect the water table.

Borings drilled at the site revealed that the lower two feet of the Pasco gravels are saturated. This puts the ground water table about 19 feet below the surface. This is consistent with the regional water table contours which are accurate to 10 feet in the vicinity of the site (ERDA, 1976).

Construction of the proposed Ben Franklin Dam is expected to affect the water table only nominally. The construction of further upstream storage dams (Canada) is expected to reduce flood levels, and thus maintain the water table at the site at its present elevation or lower.

## GEOLOGIC HAZARDS

### General

Non-tectonic geologic hazards for the Exxon Nuclear facility have been evaluated. This has been done on a preliminary basis with emphasis placed upon a thorough search of the literature and review of existing maps of the area. Personal communications have been established with experts knowledgeable with this particular area. In addition, a brief site visit was made including both the facility proper and the immediate surroundings. The facility site was examined in context within the areal extent of the Pasco Basin.

### Geologic Hazards

Slope Failure - Existing natural slopes have been determined to be stable; only those slopes on the enclosing anticlinal ridges, Gable Mountain, Wahluke Slope and the White Bluffs are steep enough for concern. Of these, the White Bluffs pose the greatest concern because of 1) the clay-rich nature of some beds about

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river level and within the Ringold Formation, 2) discharge of large quantities of irrigation water to ground atop the bluffs, 3) gentle dips of the Ringold beds toward the Columbia River, and 4) the eastward shifting of the Columbia River and its undercutting of the bluffs. Slides of a million or more cubic yards have occurred within the last about 12,000 years; consequently, more are expected. Not likely to be impounded, the river would more likely be diverted to a more westward channel in the slides areas.

The site proper is relatively flat and totally lacking in slopes of a size sufficient to cause problems. Surficial materials are stable.

Many landslides are present in the region and have been attributed to earthquake activity, as earlier noted. However, they are only occasionally directly caused by earthquakes and more commonly result from excess water in the ground. A classic case is that of the slides along the north face of the Saddle Mountains, attributed by some persons to earthquakes, especially the Corfu quake. In view of the findings in recent years, the indications are that most of the features are related to the glacial Lake Missoula flood of about 12,000 years ago, not historically recent quakes.

Geologically Related Problems - Actual or potential problems related to surface or subsurface subsidence, uplift or collapse are not known to exist at the site. Karst terrains, cavernous conditions, tectonic depressions and related features have not been identified either in the region or in the vicinity including the nuclear facility.

Borings show that surficial deposits consist of from two to seven feet of loose "blow sand" and gravel underlain by denser sand and gravel. Conditions are essentially the same throughout the site area.

Pasco sands and gravels with a thickness of slightly less than 20 feet underlie the surface material. The penetration resistance blow counts indicate that the material is dense. Conditions are generally uniform and no fault is known within or adjacent to the area.

Differential compaction is common in unconsolidated alluvium and was a major cause of damage in Alaska during the Prince William Sound (Anchorage) earthquake of 1964. The sediments at Hanford have a high degree of natural compaction. The Ringold Formation sediments at one time filled the Basin to an altitude of about 1,000 feet (the crest of the White Bluffs), but have been eroded in part from the Hanford Reservation. They have been irregularly covered subsequently by later sediments, the Pasco Gravels. Hence, at one time 200 to 600 feet more sediments existed as a static load than now are present over the topmost Ringold Formation beds, a factor in their compaction. The beds, too, are low in permeability, owing to their age, the resulting cementation and opportunity for compaction subsequent to deposition. Those factors and the relatively high seismic (P) wave velocity of about 6,000 to 12,000 ft/sec confirm the compaction.

The Pasco Gravels and their fine-grained equivalent, the Touchet Beds, were laid down by the glacial Lake Missoula floods. The gravels that underlie all but the basin margins commonly are open-work or semiopen-work gravels with high permeabilities. Seismic (P) wave velocities are consistently low, about 2,000 ft/sec. However, their load-bearing capacity without undue settlement is high, generally in excess of 6,000 $lb/ft^2$ even for materials directly at the ground surface. Commonly 10,000 to 12,000 $lb/ft^2$ are measured. That high load-bearing capacity of the flood deposits is attributed to the point-to-point contact between cobbles and pebbles and the subsequent interstitial filling by finer-grained sediments as the floodwater velocities slackened. Thus, loads are supported on columns of cobbles and pebbles.

The Ringold Formation generally is saturated and the Pasco Gravels commonly are dry except locally where they are normally saturated for only a few tens of feet of depth at the base of the gravel. Consequently the opportunity for reworking and compaction is minimal. Even where large quantities of water pass to ground and where vibrational and differential loading occur on undisturbed ground, settlement has been negligible. Differential compaction on undisturbed ground is of minimal concern.

Due to the prevailing dry environment and as long as the potentially liquefiable sediments remain confined, the likelihood of liquefaction of Hanford sediments is very remote. The sediments lying at and near the ground surface (the Pasco Gravels and uppermost Ringold Formation beds) to depths of 110 feet have been compared to the range of gradation of liquefiable soils. Most materials had a high relative density (were compact), a coarse grain size and good size gradations. The silts and clays that lie below the ground water table were of high plasticity but "are also insensitive and exhibit high shear strength in excess of 3 to 5 tons per square foot." This is, in part, the result of deposition in calcium-rich environment, some resulting cementation, compaction under high load, and maintenance of the calcium-rich environment for millions of years. The deposited clays were not changed to forms liable to liquefaction in a chemically changed environment (WPPSS, 1973).

Some sands in the Ringold Formation are clean, uncemented and well sorted. Upon penetration by wells (a face toward which to flow), the sand rises in the wells. This is not liquefaction in the sense of rearrangement of particles to occupy a lesser volume; it is controlled by appropriate confinement of the sand.

The extraction and recharge of ground water in the region and site vicinity is not expected to have any measurable effect upon stability conditions. The lower two feet of the Pasco gravels are saturated. The Pasco gravel was deposited by the last of a series of great floods resulting from the rapid draining of large glacial lakes. The materials have a dry density of about 130 pounds per cubic foot, and exhibit high shear strength and low compressibility characteristics.

Actual or potential problems related to surface or subsurface subsidence uplift or collapse have been assessed. The abandoned Rattlesnake Hills gas field is located on the northeast slope of the Rattlesnake Hills, Benton County, Washington, approximately 12 miles west-southwest of the proposed site. The nature of this withdrawal and the distance from the proposed site indicate that it presents no problem to stability of the site.

Studies by R.E. Brown (1969) and Tillson (1970) suggest that the Pasco Basin is continuing to subside. Brown indicates rates of one foot in 5,000 years to one foot in 1,000 years and Tillson determined an average rate of one mm per year from available leveling data. Although these analyses are not positive indicators of continued basining, they do provide data which preclude regional warping as a problem at the proposed site.

# 4.0 SEISMOLOGY

While the detailed elements of the seismic risk assessment are discussed in Section 5.0, the historical seismic record is of such significance that it is discussed separately below.

A complete evaluation of the historical record is the keystone to the risk assessment because of the important time and spatial distribution information it contains. With regard to time, the record provides detailed historical earthquake frequency information that can best be represented by the relationship, $\log N = a - bM$. Further, the spatial distribution of earthquakes around the site can often be used to delineate seismic source regions within which earthquakes have common characteristics.

The historical record for the Pacific Northwest is based predominantly upon earthquake intensity reports. Instrumental earthquake information began to accumulate beginning in 1906 when a seismograph was installed in Seattle. Although additional instrumentation was installed in the intervening years, significant improvement in coverage was not achieved until 1962, when instrumentation for the World-Wide Network was introduced. Finally, several local seismic or microseismic arrays have been deployed within the last decade, resulting in excellent coverage of the nearby Hanford Reservation and the Puget Sound area.

The earthquake data that have been collected for statistical analysis and incorporation into the seismic risk assessment include all reported or recorded earthquakes from 1833-1977. Data from the World-Wide Network, the University of Washington, Puget Sound and Hanford Networks, and the Dominion Observatory in British Columbia were collected and evaluated, as were the historical intensity reports (Rasmussen, 1967). Much of this data has been compiled and made publicly available by the Washington Public Power Supply System.

Because of the spatial and temporal variability of coverage, we have directed particular attention to the stability of earthquake statistics. This effort, which is described in detail below, results in a most accurate description of earthquake recurrence.

## SEISMICITY

The spatial variability of earthquakes around the site is illustrated in an earthquake epicenter map, Figure 4-1. Note that there are obvious zones of seismicity that are clearly unique in their occurrence of earthquakes. Most dramatic among these zones is the Puget Sound area. This area is unique not only because of the frequency of earthquakes, but also their magnitude distribution (there have been several in the 6-7 range) and their depth (roughly 60 km compared to less than 20 km elsewhere). The area is unique in other geological and geophysical respects. For example, the Puget Sound area is a significant gravity anomaly, with Seattle being at the center with an isostatic anomaly of -93 mgal. There is, therefore, a firm geophysical basis for identification of the Puget Sound area as a unique earthquake source region.

The seismicity map further suggests that a similar portioning of source regions is appropriate elsewhere. For example, the identification of a Cascade Mountain Range source region is not only intuitively appealing, but is further supported by the physiography, surface geology, and the historical seismic record.

South of the site is another concentration of seismic activity in the Milton, Oregon-Walla Walla, Washington area. As with the other concentrations of seismicity, there is a geophysical explanation for this localized seismicity. The known surface structure in this area, and elsewhere in the northwest, is generally a manifestation of shallow stresses (irrigation patterns, erosional crustal unloading, etc.) while the more significant deep-seated tectonic stresses have no surface manifestation. For these reasons we emphasize the indirect results of geophysical gravity and aeromagnetic reconnaissance.

## SITE EFFECTS

Because of the sparce seismic instrumentation coverage discussed earlier, the historical record of significant site effects can only be inferred from isoseismals. The seismic network that covers the Richland area has operated for only eight years and surrounding instrumentation is very sparse resulting in very little

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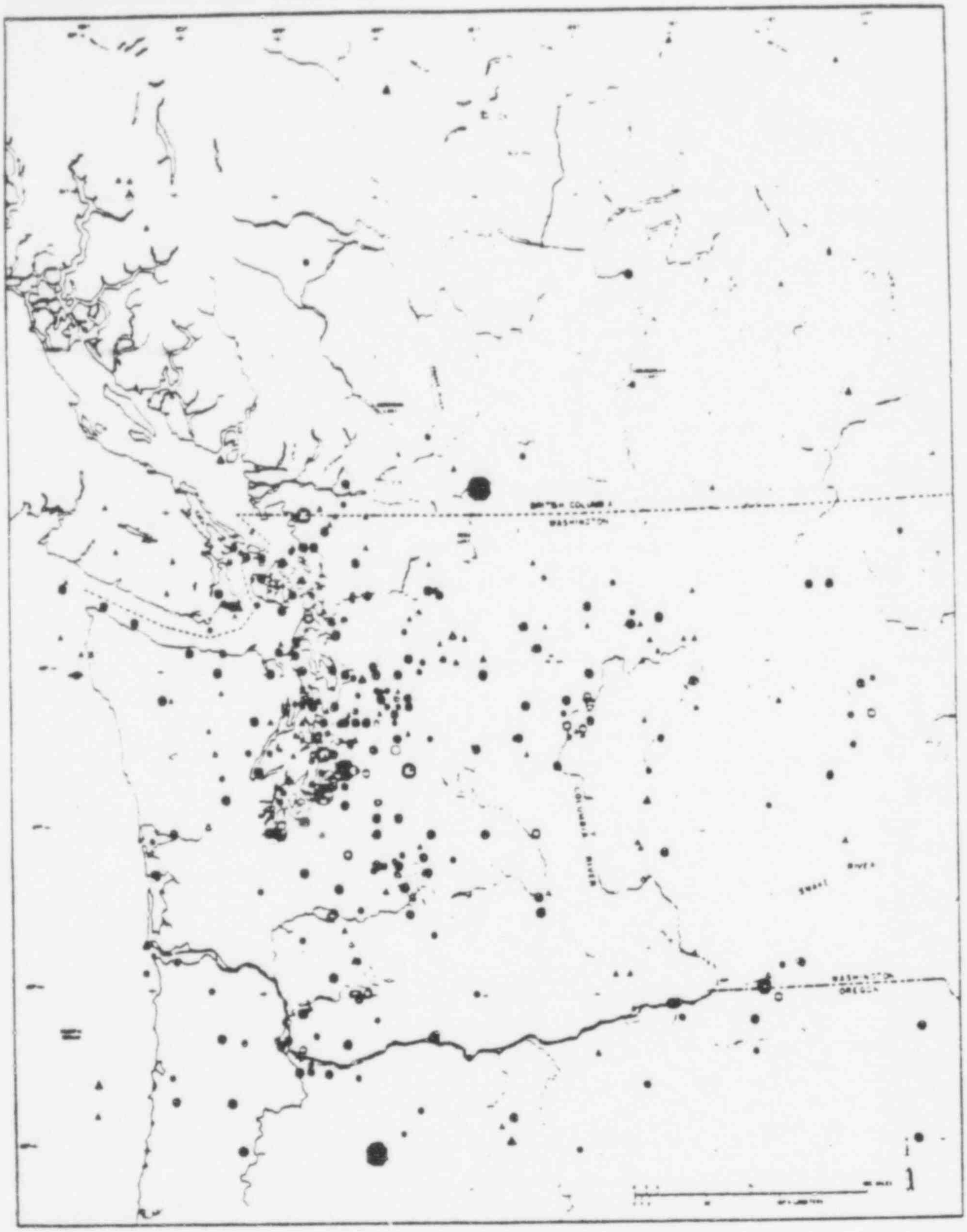


| INTENSITY | MAGNITUDE |
|---|---|
| ≥ IX | ≥ 7 |
| ≥ VIII | ≥ 6 |
| ≥ VII | ≥ 5 |
| ≥ V-VI | ≥ 4 |
| ≥ IV | > 3 |

FIGURE 4-1

PACIFIC NORTHWEST SEISMICITY
(FROM WPPSS, 1977)



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instrumental data. Examination of isoseismal maps in the historical record indicates (Table 4-1) that over a 150 year interval, the site has experienced one MM site intensity VI and perhaps as many as nine MM site intensity IV earthquakes. While this data must be used qualitatively since both the historical record and isoseismal maps may be incomplete, the results serve to suggest a relatively low risk at the site. This is because first, the large historical earthquakes have occurred in distant source regions and second, the seismicity of the nearby source regions is such that large earthquakes infrequently, if ever, occur. In the following sections we analyze the historical seismic record statistically to provide a quantitative basis for these statements.

## SEISMIC SOURCE REGIONS

As discussed earlier, various geologic, geophysical and seismological data suggest an intuitively appealing seismic zonation of the area around the site. Figure 4-2 presents the source zones considered to be appropriate for this analysis; the superposed seismicity demonstrates the relationship between the historical seismic record and the selected source regions, but gravity, aeromagnetic and geologic data were also employed in their selection.

For example, Figure 4-3 presents the physiographic zonation of the region and Figure 4-4 shows how surface geology results in a similar zonation. As discussed in Section 4, these are important data in our assessment of the seismic zonation of the region. However, because major earthquakes are a result of deep-seated stresses, we rely most heavily on the results of geophysical gravity surveys. Because a gravity anomaly is indicative of a stress differential, the anomalous area can, therefore, be readily associated with a capability for earthquakes. In Figure 4-5 we present a comparison between the best available Bouquer Gravity map and the seismicity. Note first that there is a broad relationship between the gravity anomalies and the geologic and physiographic zones, thus reasonably suggesting a correlation between deep-seated and surface structure. Also note that the concentrations of seismicity occur along gravity gradients. This association of seismicity with gravity gradients is not only intuitively appealing, but also builds on the research and observations of Kane (1977) who has noted such correlations at seven major zones of seismicity elsewhere in the United States.

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TABLE 4-1

HISTORICAL RECORD OF MM SITE INTENSITIES
(ADAPTED FROM WPPSS, 1976)

| Date | Location | Epicentral Intensity | Maximum Site Intensity |
|---|---|---|---|
| 14 December 1872 | Lake Chelan Area | VIII | VI |
| 1 November 1918 | 46.7 N 119.5 W | V-VI | IV-V |
| 15 July 1936 | 46.0 N 118.5 W | VII | IV |
| 23 April 1943 | 47.8 N 120.6 W | V | IV |
| 29 April 1945 | 47.8 N 121.8 W | VII | IV |
| 14 February 1946 | 47.5 N 122.5 W | VII | IV |
| 13 April 1949 | 47.3 N 122.5 W | VIII | IV |
| 7 August 1959 | 47.5 N 120.0 W | VI | IV |
| 17 August 1959 | 44.5 N 111.1 W | X | IV |
| 29 April 1965 | 47.4 N 122.4 W | VIII | IV |

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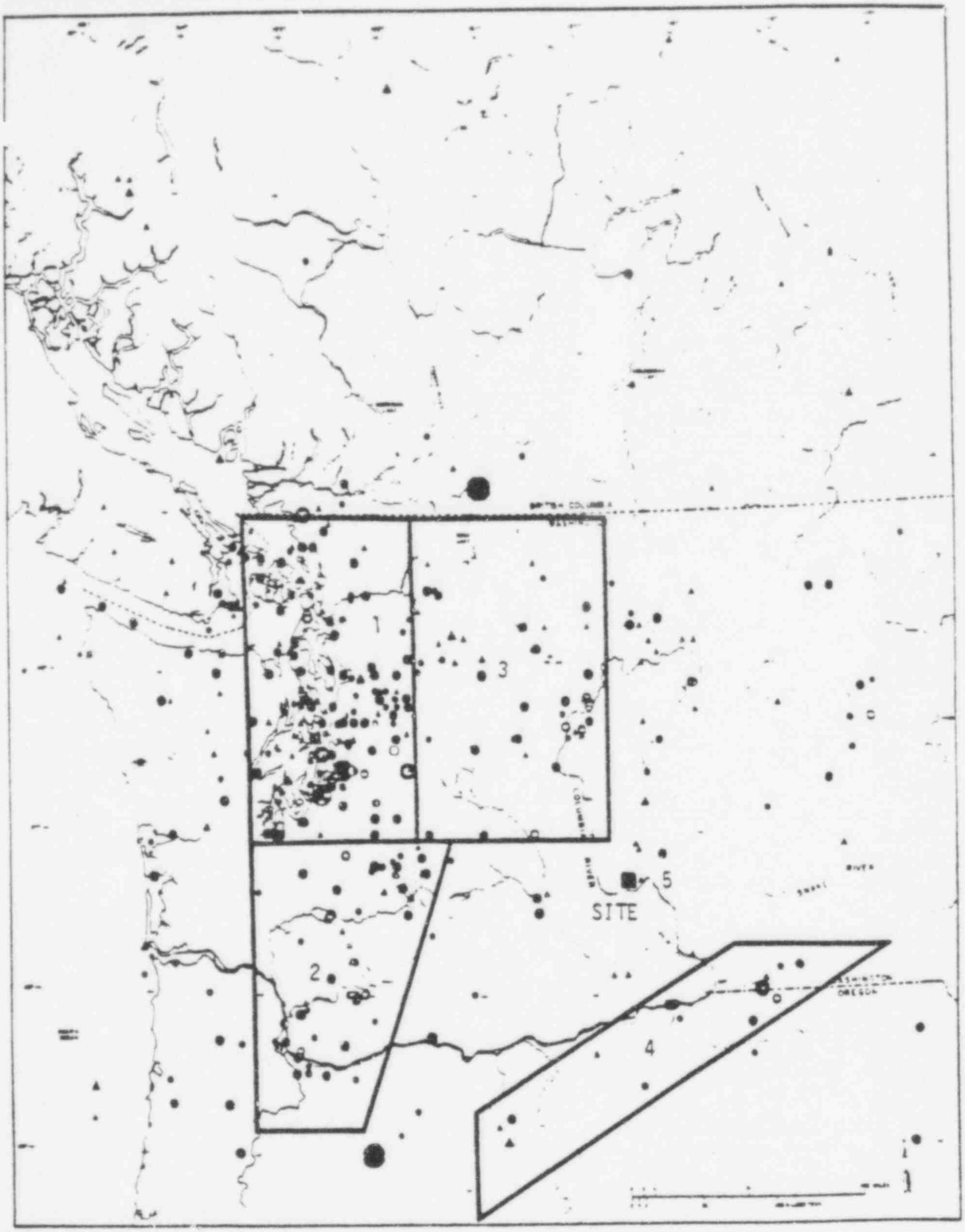


INTENSITY | MAGNITUDE
≥ IX | ≥ 7
≥ VIII | ≥ 6
≥ VII | ≥ 5
≥ V-VI | ≥ 4
≥ IV | > 3

FIGURE 4-2

SEISMIC SOURCE REGIONS USED IN THE SEISMIC RISK ANALYSIS





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FIGURE 4-3

PHYSIOGRAPHIC PROVINCES OF THE PACIFIC NORTHWEST
(FROM WPPSS, 1977)

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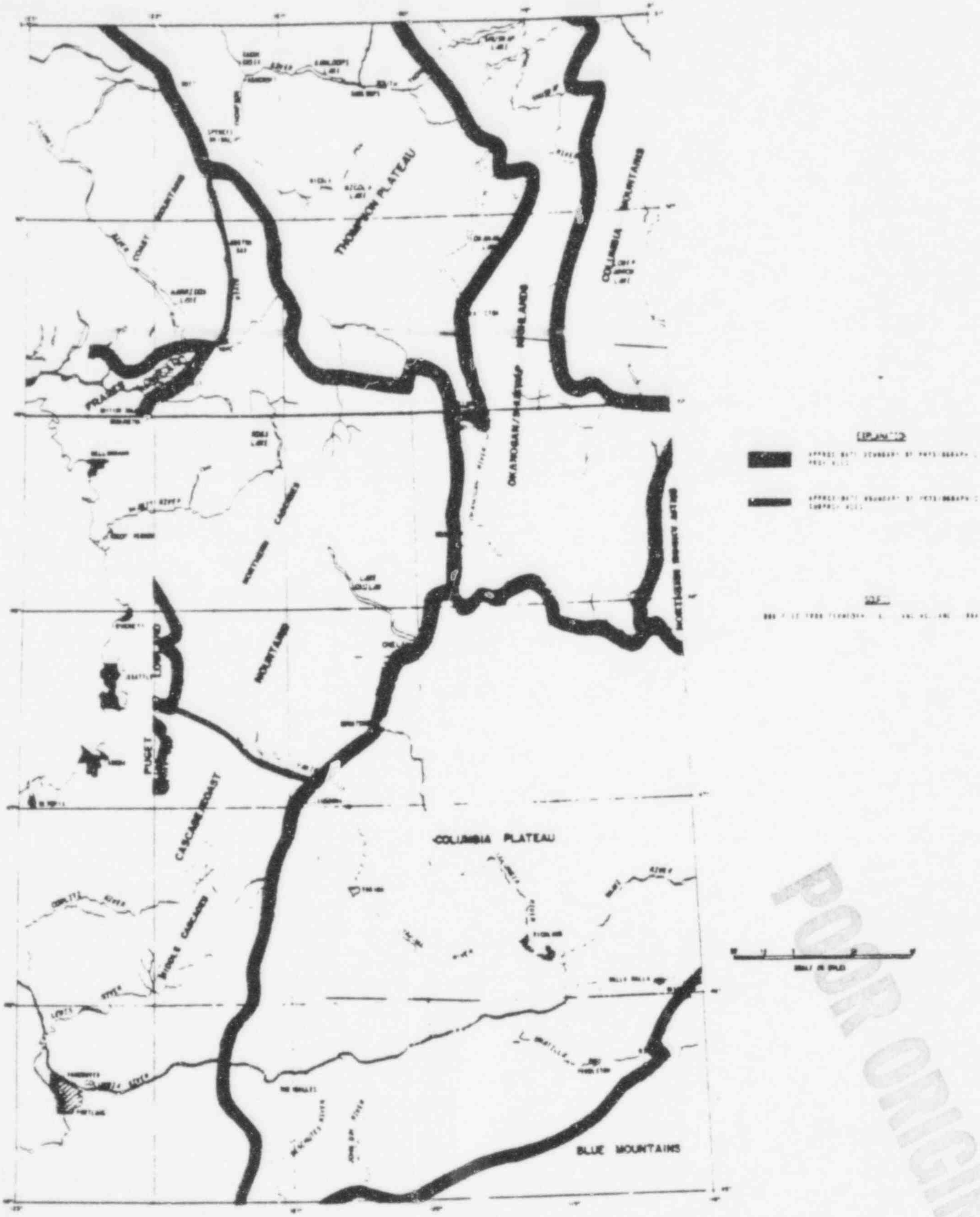


FIGURE 4-3

PHYSIOGRAPHIC PROVINCES OF THE PACIFIC NORTHWEST
(FROM WPPSS, 1977)

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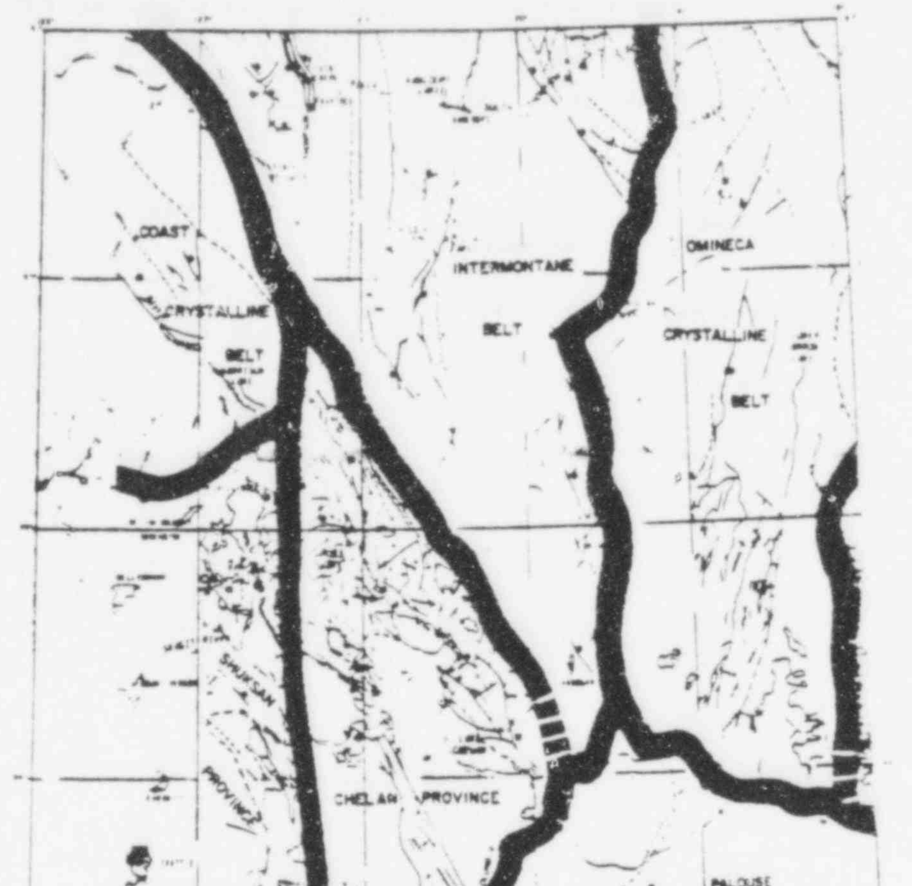


FIGURE 4-4

GEOLOGIC PROVINCES OF THE PACIFIC NORTHWEST





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FIGURE 4-5

BOUGUER GRAVITY AND EPICENTERS IN THE PACIFIC NORTHWEST (FROM WPPSS, 1977)



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In consideration of these data, we therefore judge that a most reasonable portioning of seismicity in the region is as presented in Figure 4-2.

## EARTHQUAKE STATISTICS

In this section, we analyze the seismicity in each of the source zones in Figure 4-2 to estimate the recurrence relationship for earthquakes in each zone. This relationship is one of the keystones to a probabalistic seismic risk assessment, and is usually characterized by the two parameters, a and b, in

$$\log N = a - bM$$

where N is the cumulative annual number of earthquakes greater than earthquake magnitude M. Where we require conversion of an epicentral MM intensity to magnitude, we employ the correlation presented by Toppozada (1975):

$$M = 1.85 + 0.49I$$

In our analysis of the recurrence relationship, we direct particular attention to the stability of the activity rate, b, of earthquakes. The parameter b, of the two parameters, is the most significant because it logarithmically determines the recurrence of large earthquakes.

Instability in b can arise when the subinterval of time within which earthquakes are considered is either too long, in which case the data are incompletely reported, or is too short, such that the mean activity rate is unstable. The overall approach in this report is to calculate, for each source region, the average annual number of earthquakes in a specified magnitude interval, and to then sum these over magnitude to provide an estimate of the cumulative number of earthquakes greater than a given magnitude.

A linear least squares fit of log N = a - bM results in best estimates of a and b. Within this procedure, it is the estimates of the average annual number of events in a specified magnitude interval that can introduce significant errors in the earthquake parameters. We use the method developed by Stepp (1974) to minimize these errors.

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Following Stepp, we first group earthquakes in each source zone into magnitudes intervals of 0.5. For each magnitude interval, we calculate the average annual number of earthquakes, $\lambda$ for several subintervals of time, T. The standard deviation of $\sigma$ is given by

$$\sigma = \sqrt{\frac{\lambda}{T}}$$

and therefore $\sigma$ must behave like $T^{-1/2}$ if, as we have assumed, $\lambda$ is constant. Plotting the subinterval values of $\sigma$ allows one to readily determine over what interval $\sigma$ begins to behave like $T^{-1/2}$. This is, therefore, the subinterval of data that is long enough to give a good estimate of the mean activity rate, but short enough that it does not include intervals with incomplete data.

The results of this analysis are presented in Table 4-2 where we indicate that a and b values that are developed from the regression analysis, as well as the coefficient of determination for the fit.

Because preliminary analysis showed that the seismic risk at the site was dominated by the risk due to local earthquakes in source zone five, we use this zone to illustrate the details of our statistical analysis and to further elaborate on the technique.

It is apparent from Figure 4-2 that zone five is relatively aseismic compared to surrounding source zones. Because of the significance of this zone and its macro-aseismicity we rely heavily on data from the University of Washington microseismic array centered on the Hanford Reservation.

Applying the stability techniques described above to the historical record of earthquakes in zone five results in the data indicated in Figure 4-6. Figure 4-7 indicates how the annual activity rates for each magnitude interval are defined, and Table 4-3 summarizes these rates and the interval of time appropriate for each magnitude interval.

Because these results are supported by only 48 earthquakes in the magnitude range of 3.5-5.5, we turn to supplementary data from the microseismic network.

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TABLE 4-2

EARTHQUAKE PARAMETERS FOR EACH SOURCE ZONE

| Seismic Zone | | $\log N_c = a - bM$ | | Coefficient of Determination |
|---|---|---|---|---|
| Site ID (Fig 4-2) | Descriptor | a | b | $r^2$ |
| 1 | Puget Sound | 4.30 | 1.05 | 0.99 |
| 2 | S. Cascades | 3.50 | 0.93 | 0.92 |
| 3 | N. Cascades | 3.50 | 0.93 | 0.92 |
| 4 | Milton-Freewater | 3.31 | 1.00 | 0.87 |
| 5 | Site Source Zone | 4.54 | 1.16 | 0.99 |

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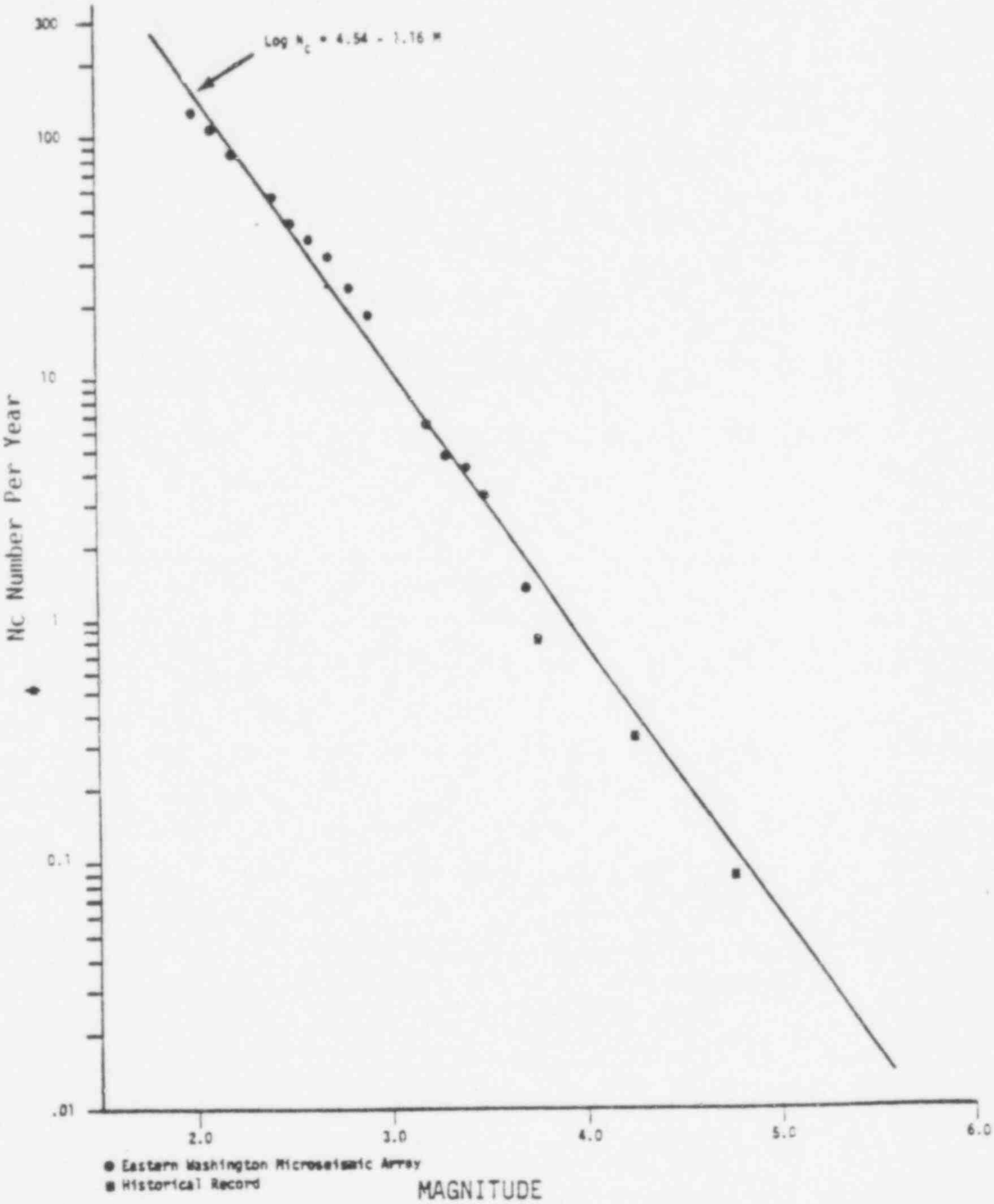


FIGURE 4-6

RECURRENCE RELATION FOR SEISMIC ZONE 5

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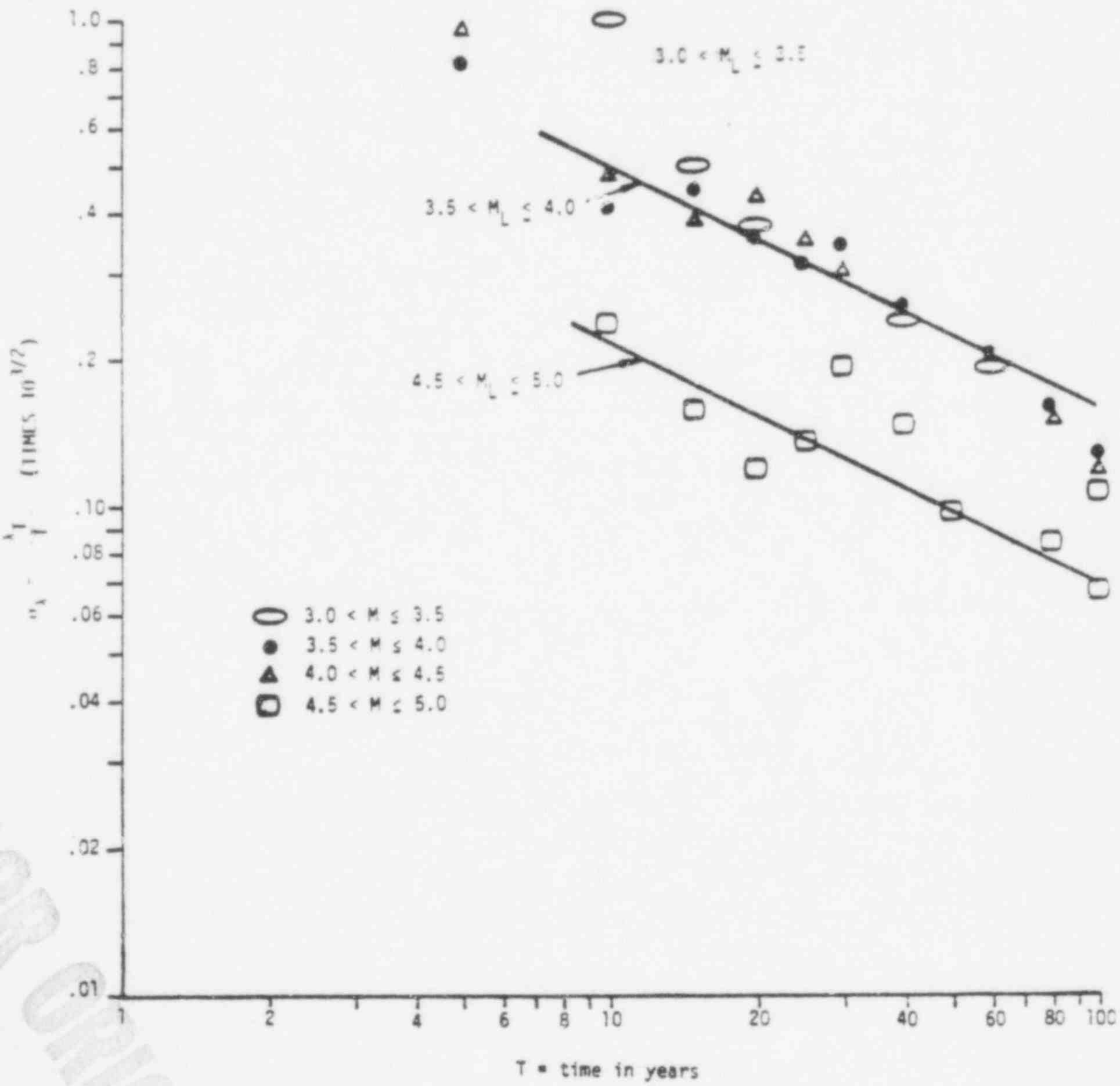




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FIGURE 4-7

STANDARD DEVIATION OF THE ANNUAL NUMBER OF HISTORICAL EARTHQUAKES IN ZONE 5

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TABLE 4-3

RESULTS OF EARTHQUAKE STATISTICS ANALYSIS FOR ZONE 5 (SITE SOURCE ZONE)

| Magnitude Interval | Time Interval | | Annual Rate |
|---|---|---|---|
| M | Dates | Duration | |
| 3.5-4.0 | 1945-1969 | 25 | 0.508 |
| 4.0-4.5 | 1910-1969 | 60 | 0.204 |
| 4.5-5.0 | 1890-1969 | 100 | 0.092 |

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This network has been operational since 1969 and since then has been reliably reporting earthquakes over a large area that includes much of zone five. Accounting for the coverage area, a parallel analysis of the micro-earthquakes located in zone five results in the remaining indicated data in Figure 4-6. A best fit to the data of the form,

$$\log N = a - bM$$

is obtained by the values $a = 4.54$ and $b = 1.16$ (Table 4-2).

Because of the significance of this particular seismic zone, we account for the uncertainty in this relationship through the weighting of results from a parametric survey on this, and other, important parameters. The next section, RESULTS, describes these parameters, their variation, and the overall results.

# 5.0 CALCULATIONS AND RESULTS

In the previous sections, we have discussed the advantages of seismic risk analysis relative to deterministic approaches and presented a state-of-the-art calculational approach to probabalistic seismic risk. We have also described the tectonic structure and seismicity of the area around Richland. In this section, we apply these concepts and data to a seismic risk analysis for the Exxon site. The detailed input to the calculational model is described below, followed by a presentation of the results.

## INPUT

As described in Section 2.0, Seismic Risk Methodology, the input to a probabilistic seismic risk assessment is comprised of earthquake occurrence frequency relations, attenuation functions and a specification of local source regions. Because risk assessment calculations are very sensitive to the particular composition of the input, we consulted with several knowledgeable seismologists during the preparation of input for the Exxon facility analysis. Major suggestions in this regard were made by Professor S. W. Smith.

### Source Regions and Earthquake Statistics

The source regions, Figure 4-2, considered most appropriate for a seismic risk analysis were earlier described in Section 4.0. Preliminary calculations indicate that earthquakes in the source region containing the site dominate the risk at the site, and thus particular attention was directed to the validity of this region and its statistics. The basis for identification of this and the other source zones is physiography, surface geology, Bouquer Gravity data, and historical macro- and microseismicity. The other zones include the Puget Sound area, the Northern and Southern Cascades, and the Milton-Freewater area.

The recurrence relations for each zone, modelled as $\log N = a - bM$, were also developed in Section 4.0. In Table 5-1, we summarize these results and also present the maximum magnitude earthquakes for each zone. The magnitude

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TABLE 5-1

RECURRENCE RELATIONS USED IN THE ANALYSIS

| Seismic Zone | | $N=N_o e^{\beta(M-M_o)}$ | | | | Largest Historical Earthquake |
|---|---|---|---|---|---|---|
| ID | Descriptor | $N_o$ | $\beta$ | $M_o$ | $M_{max}$ | |
| 1 | Puget Sound | 1.27 | 2.42 | 4.0 | 7.5 | 7.1 |
| 2 | S. Cascades | 0.60 | 2.14 | 4.0 | 5.7 | VII |
| 3 | N. Cascades | 0.60 | 2.14 | 4.0 | 7.0 | VIII |
| 4 | Milton-Freewater | 0.20 | 2.30 | 4.0 | 6.0 | VII |
| 5 | Site Source Zone | 0.80 | 2.67 | 4.0 | 5.0 | V |

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indicated is our best estimate based on the historical record and our interpretation of the regional tectonics. Our maximum magnitude is generally one-half magnitude larger than the largest historical magnitude, which is also listed in Table 5-1. We recognize the uncertainty in this parameter, and we account for the uncertainty through a parametric survey, as described below.

## ATTENUATION

One of the keystones to any seismic analysis is the specification of decay of peak acceleration with distance from the earthquake. Credible attenuation relations have been difficult to develop for two reasons. First, the large scatter in the data makes a deterministic evaluation very difficult and second, the data are very sparse in the near-field, thus allowing for a variety of interpretations.

Because of its particular significance, a very careful re-evaluation of all the data was performed in order to ensure state-of-the-art interpretation and maximum credibility.

The overall approach to development of an attenuation relation for this analysis is as follows:

1) Use appropriate data in the range 20-100 km to estimate the far-field attenuation.

2) Focus on the acceleration data at ≈10 km to fix the trend in the near-field.

3) Rely on all available data points at ranges less than 10 km to establish the very near-field accelerations.

Peak acceleration data for development of the attenuation relation were collected from the following sources:

- Brune, et al., 1977
- Galanopoulos and Drakopoulos, 1974
- Hanks and Johnson, 1976

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- Boore, et al. to be published, 1977
- USGS Circulars;

| | |
|---|---|
| 672, 1972 | 717-D, 1976 |
| 713, 1974 | 736-A, 1976 |
| 717-A, 1975 | 736-B, 1976 |
| 717-B, 1975 | 736-C, 1977 |
| 717-C, 1976 | 736-D, 1977 |

To introduce the attenuation relationships used in this analysis, consider Figure 5-1, which shows the data in the magnitude range 6.0 to 7.0. The emphasis in this figure is on the 20-100 km ranges, but the available very near-field data (less than 10 km) are also plotted. In this plot, range is usually the distance to the nearest point on the fault or, the distance to the zone of principal energy release, if this can be determined. The data are for both rock and soil sites since there appears to be no statistically valid reason for their discrimination (Boore, et al., 1978). The relations are, therefore, for a typical site. Superimposed on the data are two alternative attenuation relations that represent equally plausible near-field accelerations. We use both of these relationships in our analysis. The scatter about these mean relationships is best characterized by a log normal one standard deviation of 0.45. This fits the data reasonably well and is consistent with the dispersion calculated by other investigators (e.g., Donovan, 1974).

These attenuation relations, while based on the most current data set available, do not represent a radical departure from previous recommendations. The acceleration spanned by these two relationships, in fact, cover all previously published attenuation relations. This overall consistency serves to further validate our recommended relations. The functional form of these relationships and their graphical representation are presented in Figures 5-2 and 5-3.

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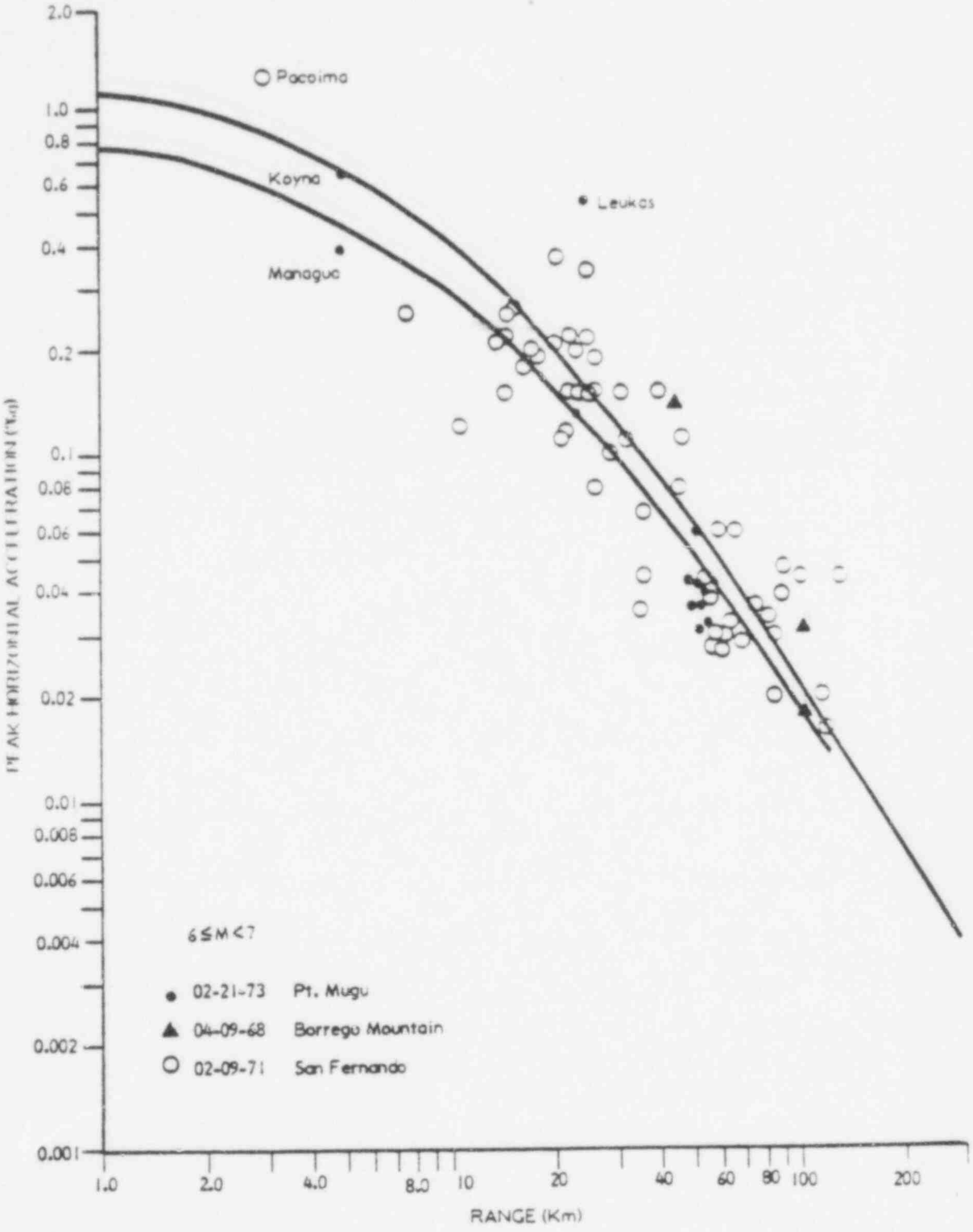


FIGURE 5-1

DATA BASE FOR THE MAGNITUDE 6.5
ATTENUATION RELATION

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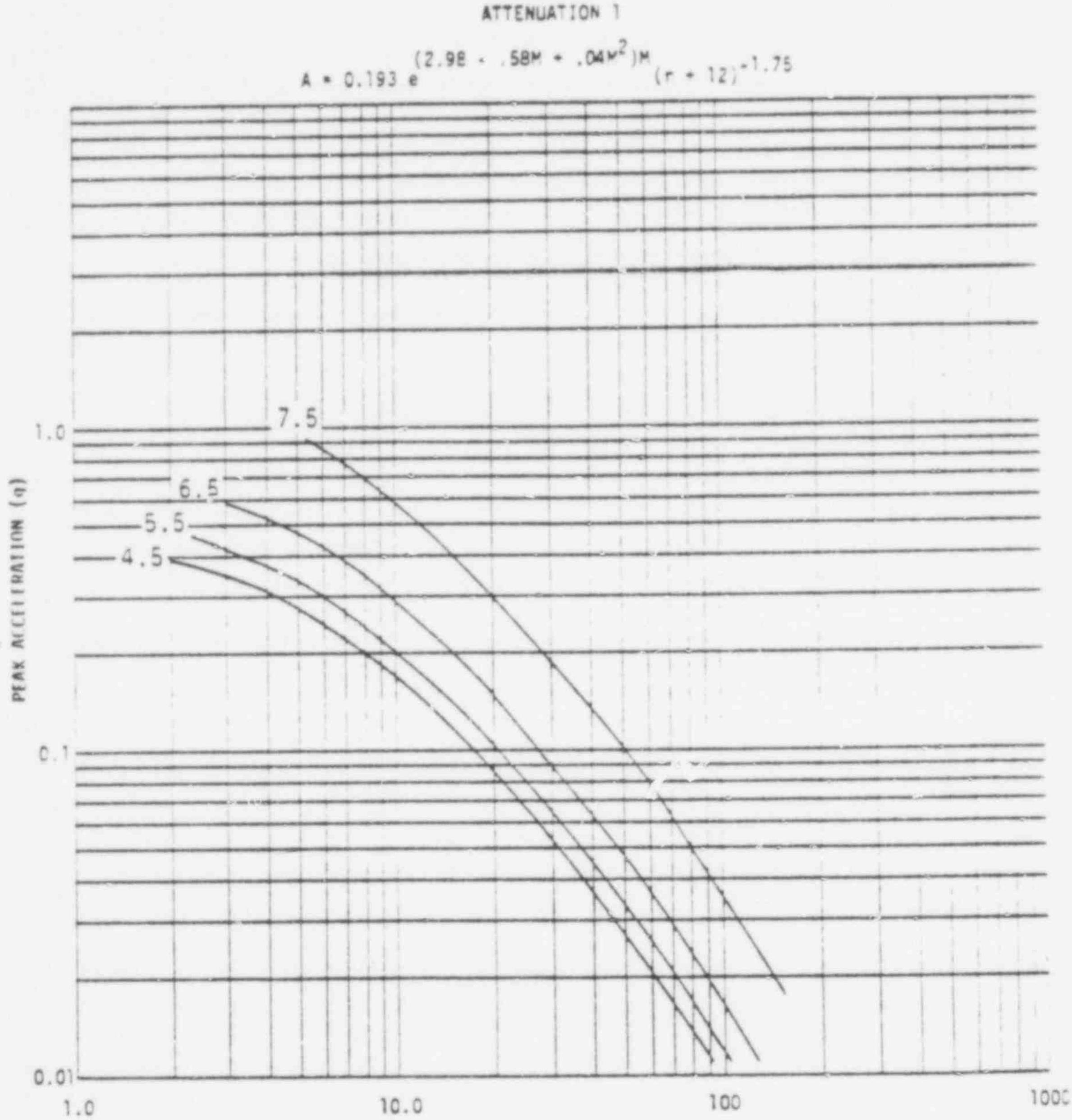






FIGURE 5-2

ATTENUATION RELATIONSHIPS

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ATTENUATION 2

$$A = 6.7\, e^{(.277 + .0\text{[illegible]}M)M} (r + 10)^{-1.75}$$

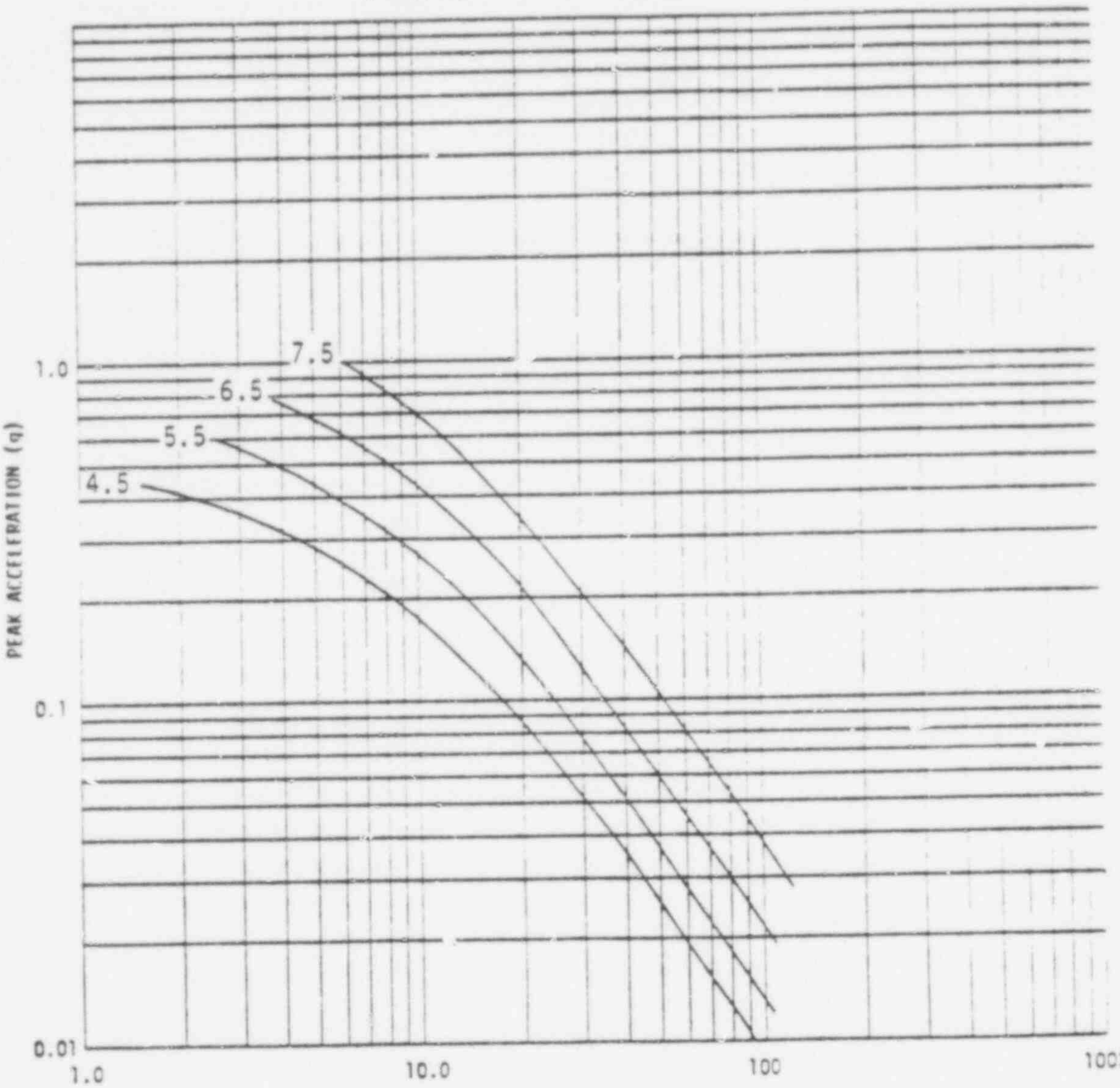


FIGURE 5-3

ATTENUATION RELATIONSHIPS



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RESULTS

The results were obtained by computer calculations with a risk analysis code (McGuire, 1976b) that is based on the work of Cornell (1968). The basis for this approach was summarized in Section 2.0.

As described in Section 2.0, the computer code calculates, for circular sectors within each source region at the site, the expected number of earthquakes per year causing accelerations greater than a specified acceleration and this is done for each source region. The expected numbers are summed for each region, and the resulting risk calculated from

$$\text{risk} = 1.0 - \exp(-\text{ expected number per year}).$$

The return period associated with the specified acceleration is the reciprocal of the expected number per year. It follows from the definition of return period that accelerations with a particular return period have a 63 percent probability of being exceeded within the return period.

Our estimate of the seismic risk represents the weighted results from seven individual calculations. The seven calculations represent a base case and our perturbations of input parameters about this base. The perturbations are weighted and combined by subjective estimates of their probability of occurrence and thus the combination can be considered a synthesis of sensitivity analyses.

The parameters that are considered uncertain and which are included in the risk analysis are the maximum earthquake in each source zone, the magnitude of the data dispersion about the mean acceleration attenuation relationship and the recurrence relation for the source region containing the site. The variations of these parameters represent the overall uncertainties in:

- Our ability to define the strain energy limit of faults around the site,
- The correlation between earthquake magnitude and intensity,

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- The shape and level of the attenuation relation, and
- The seismicity of the host seismic zone.

The base case is considered to consist of the following input:

- Maximum earthquake equal to our best estimate value (Table 5-1)
- Acceleration one standard deviation dispersion of $\sigma_{\ell nA} = .45$
- a and b values of the zone 5 recurrence relation given by a = 4.54, b = 1.16.
- Both attenuation relationships, equally weighted

Note that the value of the dispersion is based on the results of statistical analyses on the data. For example, McGuire (1974) determined that the dispersion for western data corresponded to a multiplicative factor of 1.67 in the far-field while Esteva and Villaverde (1974) obtained 1.90. The values selected for the the analysis are based not only on these calculations but also on the fact that the analysis addresses a specific site in a specific tectonic province, thus reducing the variables.

We characterize the uncertainty in all these data by first considering that it is roughly 70 percent probable that the maximum earthquake is as specified above and that it is 15 percent probable that the maximum earthquake is roughly one-half magnitude unit larger and correspondingly 15 percent probable that the maximum earthquake is roughly one-half magnitude unit smaller. The values of these parameters are presented in Table 5-2.

Similarly, we consider that it is 70 percent probable that the acceleration dispersion is as specified above and that it is respectively 15 percent probable that the dispersion will be:

- $\sigma_{\ell nA} = .55$

  and
- $\sigma_{\ell nA} = .35$

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TABLE 5-2

DISTRIBUTION OF MAXIMUM EARTHQUAKES
USED IN THE ANALYSIS

| Seismic Zone | | Maximum Earthquake | | |
| --- | --- | --- | --- | --- |
| ID | Descriptor | lower bound | best estimate | upper bound |
| 1 | Puget Sound | 7.0 | 7.5 | 7.7 |
| 2 | S. Cascades | 5.2 | 5.7 | 6.2 |
| 3 | N. Cascades | 6.5 | 7.0 | 7.5 |
| 4 | Milton-Freewater | 5.5 | 6.0 | 6.5 |
| 5 | Site Source Region | 5.0 | 5.0 | [illegible] 5 |

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Finally, we characterize the uncertainty in the zone five recurrence relation by assigning a 70 percent subjective probability to our best estimate a and b values, and assigning 15 percent to the respective values

- a = 3.45
  b = 0.94
- a = 3.99
  b = 0.93

These values represent emphasis of respectively the microseismic data and the historical record.

The results from these seven sets of parameters have been combined to produce our best estimate in accordance with the probability of the combination. These results are presented in Figure 5-4. Also shown in this figure is our estimate of the one standard deviations about our best estimate results. These were derived by assigning equal weights to the three more conservative and less conservative sets of parameters respectively.

We have also estimated the duration of strong motion associated with these risk curves. We first note that for return periods of interest the acceleration-risk curves are dominated by the effects of small, nearby earthquakes. The strong motion duration from these postulated earthquakes is very difficult to estimate in that it depends on several parameters, including the hypocentral depth, the stress drop, the azimuth, and the rupture characteristics. We attempt to cover the uncertainty in our duration estimates by considering data from two small earthquakes whose properties partly span the above parameters.

We have examined the duration function (duration as a function percentage of peak acceleration and distance) for the following two earthquakes:

April 8, 1961 M5.6 at Hollister, Calif.
June 27, 1956 M5.6 at Parkfield, Calif.

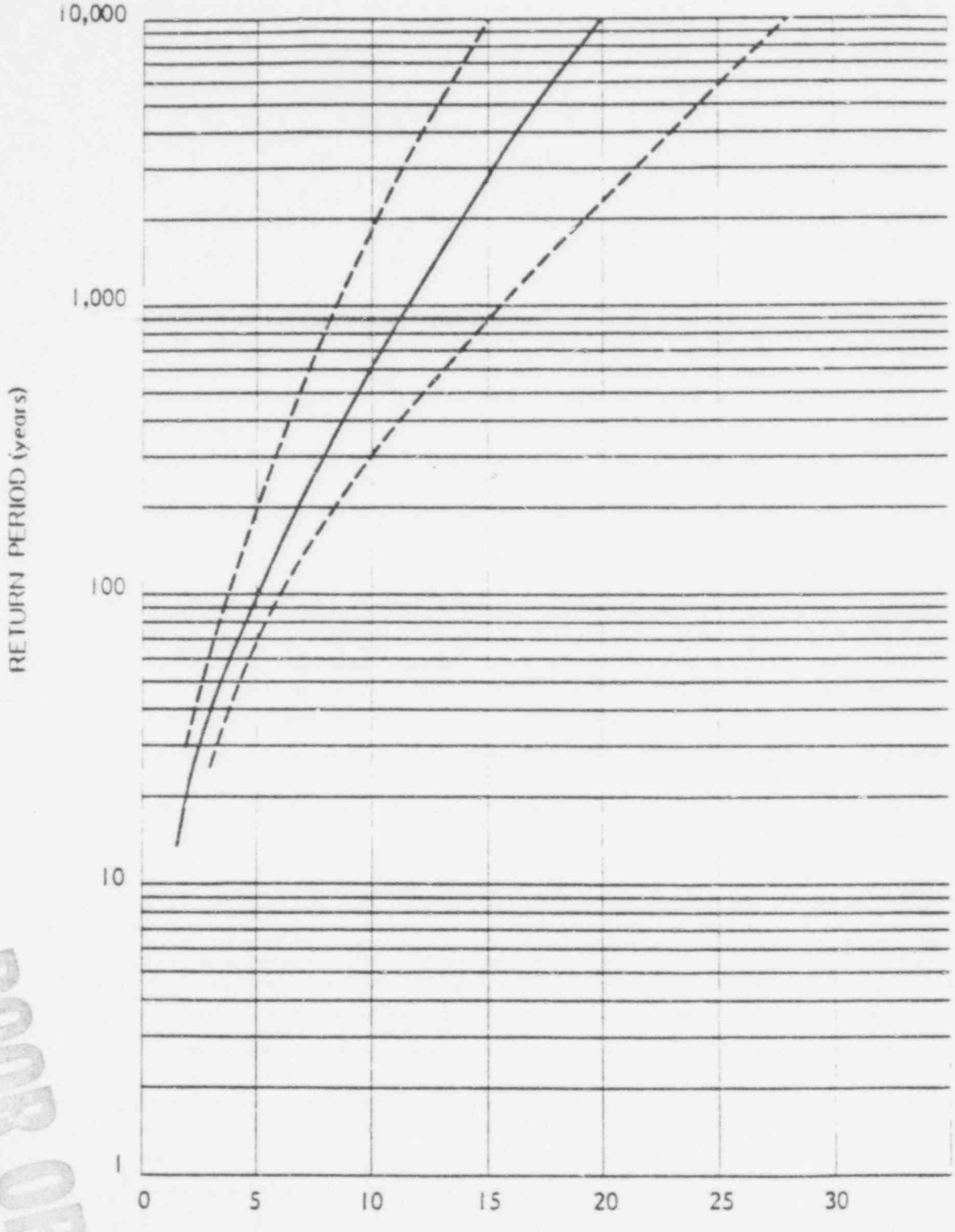






FIGURE 5-4

EARTHQUAKE RISK AT THE EXXON FACILITY

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at distances ranging from less than one kilometer to over 20 kilometers, and from this we find that a reasonable estimate of duration for the Exxon facility can be taken as follows:

| % of peak acceleration | cycles | seconds |
|---|---|---|
| 80 | 3 | 0.40 |
| 50 | 25 | 3.00 |
| 5 | 70 | 7.00 |

RESPONSE SPECTRUM

These results define the peak horizontal acceleration at the facility for various return periods. We have also determined an appropriate response spectrum for the site since some structures and equipment at the Exxon facility have sufficiently low fundamental frequencies to experience spectral amplification of the ground motion. The response spectrum for the site clearly cannot be developed in association with a specific earthquake; our return period accelerations represent an integrated effect at the site from an extraordinary variety of earthquakes and the response spectrum must reflect this. Accordingly, we judge that the <u>shape</u> of the spectrum should be similar to the Newmark-Blume statistically-based spectra from which Regulatory Guide 1.60 evolved. Accordingly, it is our judgment that the mean response spectrum for alluvium presented in WASH 1255 is the most appropriate for analysis of the Exxon facility.

In summary we have combined the best available input data with the most credible tools of seismic risk analysis to determine the return period of acceleration at the Exxon facility. The results, shown in Figure 5-4 account for all the significant uncertainties in the input. Response spectral accelerations can be determined by scaling the mean response spectrum in WASH 1255 to the desired peak acceleration.

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