SEISMIC RISK ANALYSIS FOR GENERAL ELECTRIC PLUTONIUM FACILITY PLEASANTON, CALIFORNIA

PART I

Submitted to
LAWRENCE LIVERMORE LABORATORY
P.O. Box 808
Livermore, California 94550

Attention: Mr. Don Bernreuter
Project Manager

TERA CORPORATION
Teknekron Energy Resource Analysts

2150 Shattuck Avenue
Berkeley, California 94704
415-845-5200

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ERRATA SHEET

Figure 5-1, Legend

Calaveras is mis-spelled twice as "Calavaras".

Figures 5-3 and 5-4,

ordinate scale should be labelled

r Kilometers

p. 5-5, Table 5-2,

N_o for Northern Calaveras should be 0.012, not 0.009.

p. 5-9, 4th paragraph, first two lines should read,

Our estimate of the seismic risk represents the weighted results from five classes of calculations consisting of fourteen individual calculations. These calculations represent a base case and our perturbations about this base case.

p. 5-11, first line should read,

Finally, we account for uncertainty in the background seismicity by considering it 70 percent probable that the rate will be the rate derived from the data, and that it is again 15 percent probable that the rate will be four-thirds or two-thirds, respectively.

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1.0 INTRODUCTION AND SUMMARY

In this report, TERA Corporation presents the first of a two-part study addressing the seismic risk of the special nuclear materials (SNM) facility of the General Electric Nuclear Center at Pleasanton, California. This report presents the results of a seismic risk analysis that focuses on all possible sources of seismic activity, with the exception of the postulated Verona Fault. The second report, currently under preparation, will address the risk from this particular structure.

This project was directed by Don Bernreuter of the Nuclear Test Engineering Division at the Lawrence Livermore Laboratory. At TERA, the effort was managed by Lawrence Wight.

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.

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 was established after a review of available literature, consultation with operators of local seismic arrays and examination of appropriate seismic data bases including the USGS, University of California and NEIS data bases.

The resulting seismic record, covering the period 1769-1977, was used to identify all possible sources of seismicity that could affect the site. Inadequacies and incompleteness in this record were explicitly considered in this 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 complete re-evaluation of all relevant strong motion data, with particular attention directed to the near-field environment.

To guarantee use of the best available calculational methods and input, the entire project was reviewed by two eminent seismologists with particular expertise in the local and regional seismology and tectonic setting:

Professor Thomas V. McEvilly,
University of California

Professor Stewart W. Smith,
University of Washington

The results of our analysis, which include estimates of the uncertainty, are presented in Figure 1-1. Our best estimate curve indicates that the Vallecitos facility will experience 30 percent g with a return period of roughly 130 years and 60 percent g with a return period of roughly 700 years. The curves on either side of our best estimate represent roughly the one standard deviation confidence limits about this best estimate.

These curves provide the seismic design basis for the Vallecitos facility in terms of peak ground acceleration. For those structures and equipment that could experience structural amplification, we recommend scaling the mean (50 percentile) alluvium response spectrum contained in WASH 1255 to the desired peak acceleration in Figure 1-1. The uncertainty in these spectral accelerations can be derived using a lognormal distribution of acceleration about the 50 percentile acceleration.

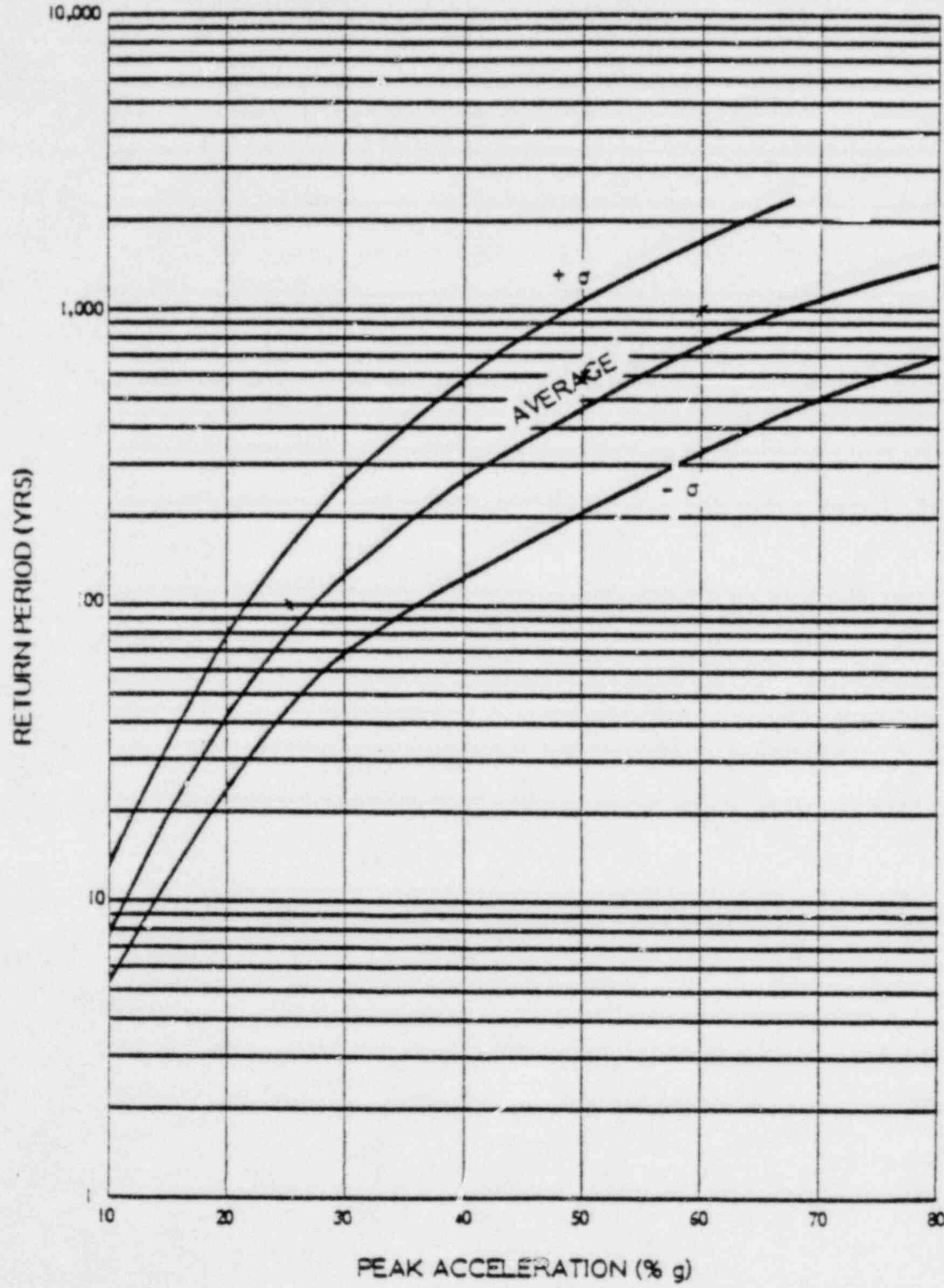

FIGURE 1-1

PEAK ACCELERATION VS. RETURN PERIOD
FOR THE VALLECITOS SITE

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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 probabilistic Poisson model for the risk assessment at the Vallecitos facility.

There are generally two distinctly different approaches to seismic risk analysis; probabilistic 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.

The probabilistic 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 probabilistic 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 (Vagliente, 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

$$P\,[A] = \int\int P\,[A/m \text{ and } r]\;\; f_M(m)\, f_R(r)\, dmdr$$

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.

In our assessment of the Vallecitos 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 β = bln10.

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.

Since the attenuation relation used in this analysis relates peak acceleration to distance from the nearest point of energy release, this program was modified to include a rupture model. The model, which is appropriate only for line sources and earthquakes that result in significant surface rupture ($M \geq 5.5$), assumes that an epicenter location is midway on the fault rupture length and that the rupture length is related to magnitude through the Mark and Bonilla relationship. Given a line source of seismicity and an epicentral location of an earthquake in that source, the model calculates the distance to the nearest point of energy release.

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.

3.0 REGIONAL GEOLOGY

The General Electric Company Vallecitos Nuclear Center is located in the San Francisco Bay Region which is bounded by mountain ranges of the Coast Range Geomorphic Province. The area is within the Diablo Range, approximately 30 miles southeast of the City of Oakland.

The site slopes gently to the south. Deformed older sedimentary materials consisting of alluvial deposits of gravel, sand, silt, and clay underlay the study area. These deposits include the Livermore gravels.

REGIONAL OVERVIEW

Regional Physiography

Regionally, the study area, Figure 3-1, is situated within the Diablo Range of the California Coast Ranges. The area constitutes the northern part of the folded and faulted Mesozoic and Tertiary sediments of the Diablo Range. The area has several northwest trending ridges separated by valleys, largely bounded by faults.

The area is now in an advanced stage in geomorphic development. However, this development is not uniform and is complicated by structural irregularities. The present landscape has also inherited many erosional features developed during earlier cycles of erosion.

Headward growth of stream valleys and canyon cutting are now the dominant processes, forming steep and narrow gullies. Most of the ridges are between 1,500 and 3,000 feet high. The flat-topped crests of many of the ridges may represent remnants of a once extensive, gently undulating erosion surface. Most streams flow north or south, the notable exception being Alameda Creek, which flows west through Niles Canyon.

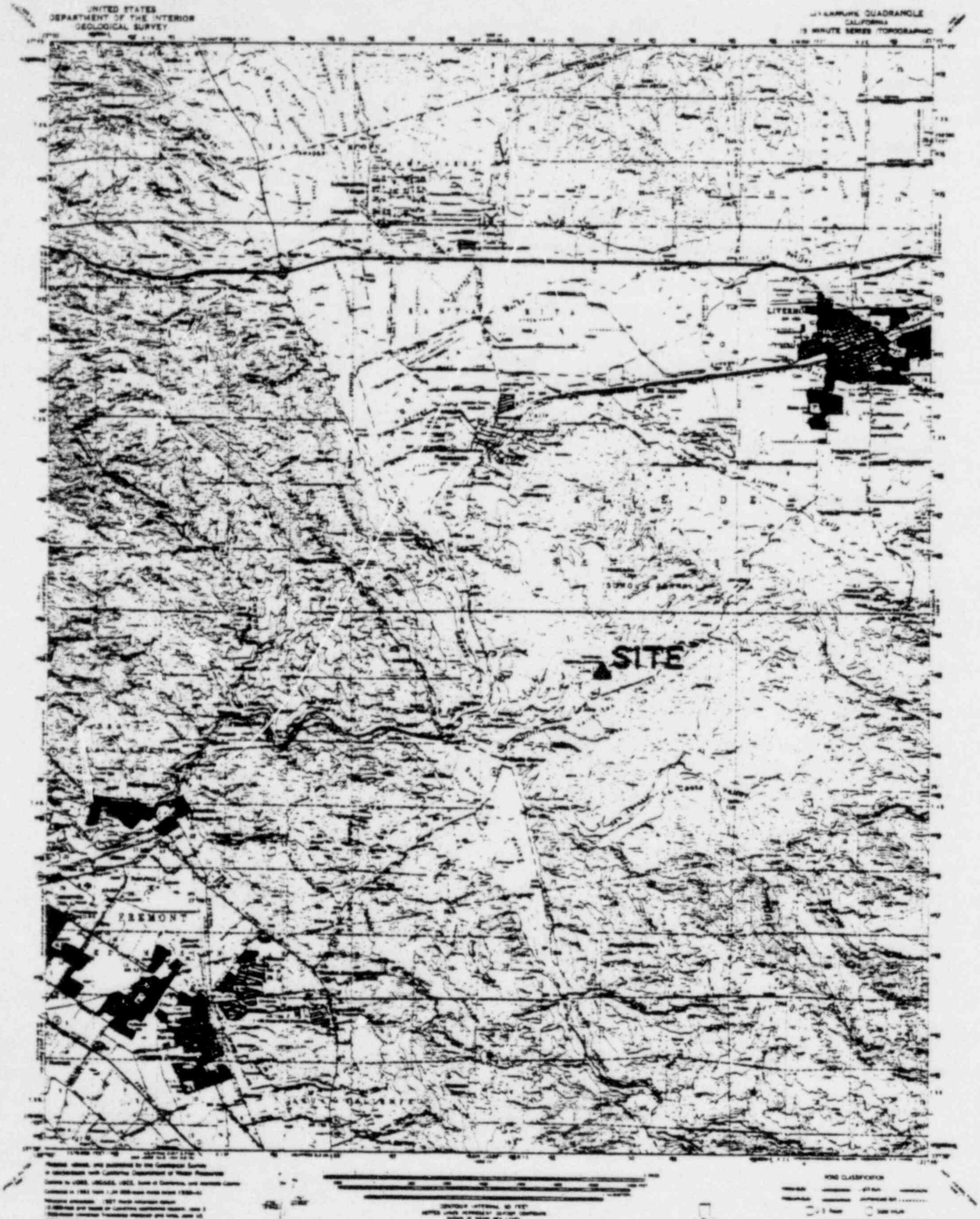

FIGURE 3-1

TOPOGRAPHY OF THE
SITE VICINITY

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The geomorphic history is complex, each fault-bounded block a distinct unit with a history differing in part from that of the adjoining blocks. Resistant formations form crests and add ruggedness to the mountains. These features are subordinate to the larger forms such as ranges and valleys, upland surfaces, and basins. The prominent old land surfaces indicate that many of the mountains in the western and southern parts of the area have been elevated twice within relatively recent geologic time. The thick section of Livermore gravels suggests that the magnitude of these uplifts is large.

Old land surfaces may be recognized throughout the area by the nearly accordant summits and nearly level ridge surfaces. The name Oak Ridge surface was applied by Crittenden (1951) to the old land surface extending from Oak Ridge in the San Jose quadrangle northward into the Pleasanton area along Valpe Ridge and Maguire Peaks to Vallecitos Valley. Across this surface much of the Livermore gravels were transported. Another surface, or a part of the Oak Ridge surface, is east and north of Mission Peak at the 1,200-foot level.

North of La Costa Valley an erosional surface is at the 750-foot level on the south side of the Verona fault and at the 1,100- or 1,200-foot level north of the fault. North of the town of Livermore nearly all the hills have been eroded to an approximate 680-foot elevation indicating still another old land surface.

The general drainage pattern of the area is dendritic with larger streams parallel to the main structural trends. Headward growth of stream valleys with little lateral cutting is now taking place.

The major topographic features are as follows: (1) the strike ridges called Walpert, Sunol, and Pleasanton ridges underlain by Cretaceous rocks; (2) Divide Ridge (or "The Knife") consisting of Miocene rocks and separating part of Alameda County from Contra Costa County; (3) Mission Peak, which is separated from the strike ridges by Niles Canyon; (4) Sunol and Amador valleys, paralleling the Calaveras-Sunol fault; (5) Livermore Valley, a broad structural depression which crosses the Mount Diablo Range diagonally; (6) Maguire Peaks-Valpe Ridge-Wauhab Ridge area, the highest part of the region, with elevations as high as 3,109 feet; and (7) the small valleys of La Costa, Vallecitos, and a part of the Arroyo del Valle (Hall, 1958).

Regional Geology

During the Jurassic, this area was apparently part of a slowly sinking geosyncline in which several thousand feet of sandstone, shale and minor amounts of conglomerate were accumulated. Following uplift and erosion, deposition of Cretaceous sediments occurred. From the close of the Cretaceous to Late Eocene, land areas may have persisted in the area.

Warping, tilting and erosion must have occurred between the Oligocene and Middle Miocene followed by deposition of the Pliocene Orinda Formation (Hall, 1958). After deposition of the Orinda Formation, the Middle and Late Pliocene were marked by intense folding and faulting that destroyed the Pliocene basins and resulted in tight or overturned folds. Faulting, erosion and alluviation continue to the present and uplift in the Quaternary has caused several levels of terraces to form along some of the prominent streams (Hall, 1958).

Regional Stratigraphy

The sedimentary rocks in the area range in age from Jurassic to Recent. The Cretaceous rocks consist of the Lower Cretaceous Oakland conglomerate conformably overlain by shale and siltstone beds of the Lower Cretaceous Niles Canyon formation. The youngest Cretaceous rocks are the Del Valle formation of Late Cretaceous age (Hall, 1958).

The oldest Tertiary rocks in this area are the Eocene Tolman formation. The younger Tertiary formations, which are more extensive, are the Sobrante sandstone, Claremont shale, and Oursan sandstone of Middle Miocene age and the Tice shale and Hambre sandstone of lower Upper Miocene age. The Briones, Cierbo, and Neroly sandstones are upper Upper Miocene. The Orinda formation, Livermore gravels, and Irvington gravels are Pliocene and Pleistocene in age.

Regional Structure

The most intensive faulting and folding occurred sometime between the Pliocene and Late Pleistocene. Recent movement along the Hayward fault is shown by a variety of rift features. The major faults within the area are the Calaveras-Sunol and Hayward, both of which are right lateral faults.

The area is here divided into three structural blocks that will be designated the Bay, Sunol, and Livermore-La Costa. The Bay block is in the western part of the area and is separated from the Sunol block by the Hayward fault. The Sunol block is in the central part of the area and is separated from the Livermore-La Costa block to the east by the Calaveras-Sunol fault. Each of these blocks contains several folds and faults with a prevailing northwest trend. Most of the folds within this area commonly make an angle of 15° to 20° with the trends of the faults, except in the Divide Ridge area where the angle between the axes of the folds and the Calaveras fault is 40°. All the folds involve Tertiary as well as older rocks.

Generally the folds are flexural-slip structures with trends of approximately 30° to 50° west of north. The axial planes of the overturned folds dip to the northeast. Most of the folding took place after the Pliocene Orinda formation was deposited and before the deposition of the Plio-Pleistocene Livermore gravels. The folds are commonly truncated by faults (Hall, 1958).

The major faults in the area commonly show post-Miocene strike-slip displacement of large magnitude. Possible pre-Miocene faulting was of the normal or high-angle reverse type (Hall, 1958).

The strike-slip faults in the area probably developed in response to north-south maximum compressive stress. These faults are commonly characterized by an alignment of valleys and by transverse or tributary streams that are actively adapting to continued horizontal movement.

Folding and faulting in the area range from pre-Miocene to Recent. The folding is considered to be older than, or in part contemporaneous with, the faulting. The pattern of stresses has varied, as the strike of the beds roughly parallels the trend of the faults, yet the latter are not thrusts, which would suggest contemporaneous folding and faulting. The principal time of regional deformation is believed to have been post-Orinda, possibly Early Pleistocene. Evidence that much of the faulting occurred after folding is shown by the axes of folds that are offset by the smaller cross faults.

Regional Ground Water

The Vallecitos Nuclear Center lies in the Vallecitos ground water subbasin, which is one of the three subdivisions of the Sunol Valley ground water basin (Department of Water Resources, 1974). Both water-bearing and nonwater-bearing geologic formations occur within the Sunol and Vallecitos Valley areas. In the Vallecitos Valley, water-bearing alluvial deposits comprise the valley floor, and the Livermore Formation, which is exposed in the adjacent uplands, underlies the valley alluvium. Nonwater-bearing rocks occur on all sides of the valley and underlie the valley floor.

Unconsolidated deposits of upper Pleistocene to Recent age are grouped together as the Quaternary alluvium which consists of stream and lake deposited sediments including various mixtures of gravel, sand, silt and clay (Department of Water Resources, 1966). Available well log evidence, the small size of the Vallecitos ground water subbasin, and the known presence of the Livermore Formation underlying the valley all suggest that the alluvium does not exceed 100 feet in thickness.

The Livermore Formation is of Pliocene-Pleistocene age and consists of massive beds of rounded gravel cemented by an iron-rich sandy clay matrix. Sediments of this formation are divided into two facies; a clay facies found only in Livermore Valley, and a more predominant gravel facies. The gravel facies are more typical of the Livermore Formation which is found at depths ranging from a few tens of feet to over 400 feet.

Nonwater-bearing rocks of Jurassic-Cretaceous age exist under Vallecitos Valley. These rocks consist of hardened marine sandstone, shale and conglomerate, associated with smaller amounts of greenstone, chert and serpentine. Where sufficiently fractured, jointed or bedded, these rocks may yield minor quantities of water that is of poor quality and probably unsuitable for most beneficial uses.

SITE GEOLOGY

The General Electric Vallecitos Nuclear Center is located near Pleasanton in Alameda County, California. This site has an approximate area of 1,534 acres and is situated on the north side of Vallecitos Valley. The geographical coordinates of the property are 37°37' N and 121°50' W with elevations in the building area from 420 to 600 feet above sea level. All the structures and facilities on the site are located in the southwest corner of the property.

<u>Topography</u>

The Vallecitos Valley is a small westerly draining valley that lies on the western slope of the Diablo Range at its northern end. The floor of the valley is approximately three to four miles in length and a mile wide. It is separated from the larger Livermore Valley to the north by a range of hills with elevations of 1,000 to 1,300 feet. The site is located on the northern side of the valley near its western end. The elevations in the portion of the site occupied by the Center range from 420 to about 600 feet above sea level. This inner site area includes the various buildings, laboratories, GETR, and has a general slope downward toward the southwest. Above the 600-foot contour line, the terrain changes to steeper, rolling hills and canyons, which characterize the topography of the larger unoccupied north and northeast portions of the site.

Stratigraphy

The Vallecitos Valley, in which the center is located, is blanketed by alluvial deposits of material washed down from the surrounding hills. This alluvium consists of sandy and clayey soils with varying amounts of gravel and rock fragments (Dames and Moore, 1955). The low hills surrounding the valley consist of Livermore gravels, which generally have a low dip to the east or north. The gravel formation is covered by recent alluvium of the Livermore Valley about four miles north of the site and overlaps Tertiary and older rocks, which crop out about two miles south of the site. The total soil thickness at the site is probably several hundred feet.

The Livermore gravels consist of rounded clasts of Franciscan debris in a brown or buff sandstone matrix. Sand, clayey sand, and clay are present and appear to be more abundant in the lower part of the formation. The gravels are flat lying or very low dipping and rest with angular unconformity upon older rocks. A tuff bed near the base of the formation is estimated to be of Plio-Pleistocene age, approximately 4.5 million years old.

Soils within the property boundaries of the General Electric Nuclear Center are representative of several soil associations that occur on terraces, alluvial fans and uplands throughout Sunol, Amador and Livermore Valleys (USDA SCS, 1966). Soils of the hills to the north and northeast of the nuclear facilities are generally of the Diablo soil series. These soils have considerable slope and are not suitable for most methods of irrigation.

Five soil series are represented within the selected area of less than 30 percent slope with a combined acreage of approximately 434 acres. Generally, the soils are shallow or fine-grained, characterized by slowly permeable subsoils, and are subject to severe erosion if they are cultivated and not protected. Major uses for these soils throughout Alameda County include pasture, range, dry-farmed grain and grain hay.

Structure

The Vallecitos Nuclear Center is surrounded by three earthquake faults, Calaveras, Verona and the Las Positas Fault (Herd, 1977). The Calaveras Fault is a major structural feature of this part of California (Department of Water Resources, 1974). In the immediate area this fault extends along the entire western side of Livermore Valley and southerly along the west side of the canyon formed by Arroyo de la Laguna to Sunol Valley. The existence, capability and location of the Verona and Las Positas Faults are currently quite controversial (General Electric Company, 1977) but the seismic risk assessment described in the following sections explicitly addresses such uncertainties. For this particular situation, we account for the uncertainty by including a background seismicity representing earthquakes that can occur anywhere in the region on either undiscovered faults or those faults whose capability is questionable. We have not addressed in our risk analysis the hazard associated with surface rupture through the facility. Based on the results of detailed site investigations, the probability of this presently appears to be very remote.

Ground Water

The Vallecitos Nuclear Center is located within the Vallecitos subbasin of the Sunol Valley ground water basin. The five major streams entering Livermore Valley are Arroyo las Positas, Arroyo Mocho, Arroyo Valle, Alamo Creek and Tassajara Creek (Department of Water Resources, 1974). The Arroyo de la Laguna, the only surface stream flowing from the Livermore basin, drains the Livermore-Amador Valley and empties into Alameda Creek. Alameda Creek flows westward through Niles Canyon and empties into San Francisco Bay. The Vallecitos ground water subbasin is a relatively unimportant source of ground water being used primarily for stock watering and secondarily for domestic supply for a few ranches.

Surface Water. Vallecitos Creek, which drains Vallecitos Valley, is an intermittent stream which rises in the eastern portion of the Vallecitos ground water subbasin and flows in a generally northeast-southwest direction to enter Arroyo de la Laguna just above its confluence with Alameda Creek. The discharge from the Vallecitos Nuclear Center enters Vallecitos Creek about two miles above the confluence with Arroyo de la Laguna. Vallecitos Creek flows primarily during the winter but due to ground water seepage there may be continuing flow throughout the year (General Electric Company, 1975).

Water from the South Bay Aqueduct of the State Water Project is provided to Zone 7 of the Alameda Flood Control and Water Conservation District and to the Alameda County Water District (ACWD) via the surface streams within the Livermore Valley. At those times when only the ACWD is taking water, a more direct route of water transportation is provided to the District through the utilization of Vallecitos Creek. However, this latter release is both intermittent and dependent upon varying conditions not readily predictable (General Electric Company, 1975).

Ground water. Ground water in the Vallecitos subbasin is present under both confined and unconfined conditions. Although the Livermore Formation is one of the principal water-bearing formations in the Livermore Valley, it assumes far less importance in Vallecitos Valley where the sediments are considered unproductive. As of 1950, only six wells were present in the subbasin and these were all low producing wells.

Four well logs are available from the Vallecitos subbasin (Department of Water Resources, 1974). These logs indicate that ground water is contained in zones of sandy clay and cemented gravels of the Livermore Formation. Depth to water at three of the wells ranged from 48 to 71 feet. Within the Nuclear Center, depth to water in the vicinity of Building 102 has been observed at 6 to 19 feet below the surface, but borings 800 feet directly south of this location show no water. At the site of the sewage treatment plant, seepage was observed in an excavation at a depth of about 10 to 15 feet below the surface (General Electric Company, 1975).

The thinness of the alluvium contributes to its relative unimportance as a ground water source in the Vallecitos subbasin. Recharge to the subbasin occurs by infiltration of surface water draining from the rolling terrain along Vallecitos Creek and its tributaries.

The combined potentiometric slope of the ground water roughly follows the ground surface as it slopes toward the center of Vallecitos Valley (Department of Water Resources, 1974). From this point, slope is westward toward the lower end of the subbasin. The west side of the subbasin is delineated by the Maguire Peaks Fault which seperates the Vallecitos and Sunol subbasins. Due to the impermeability of this fault zone, there is probably little outflow from the Vallecitos subbasin into the Sunol subbasin. It may be possible, however, that during its southwestern movement ground water may surface in the lower end of Vallecitos Creek. Similarly, subsurface inflow of ground water from other directions into the Vallecitos subbasin also is considered to be negligible due to the nature of the subbasin boundaries.

Recent data on the chemical quality of ground water in the Vallecitos subbasin were not available. Past data for four wells within the subbasin for the years 1957-59 were obtained and as shown by the data, ground water quality at that time ranged from a calcium bicarbonate and magnesium bicarbonate to a sodium chloride water (Brown and Caldwell, 1977). Generally, the results do not show any significant changes in ground water quality over the past 20 years.

Perched ground water was encountered between depths of 24.5 and 25.5 feet. A deeper ground water table was encountered at a depth of 46 feet (possibly a perched water table also). During a previous investigation, ground water was measured at depths of about 23 feet, again, this probably corresponded to the perched ground water level. It should be noted that all of the borings done for this study (Kaldveer et al., 1976) were backfilled within an hour after drilling which may not have allowed the ground water to reach an equilibrium level. Also, it must be noted that fluctuations in the ground water level may occur due to variations in the rainfall and other factors.

GEOLOGIC HAZARDS

Although this report emphasizes the seismologic hazards at the site, we also consider associated geologic hazards that could occur during an earthquake. The analysis of these less direct but nevertheless significant hazards is based on an extensive literature search, several site visits and discussions with experts.

One of the most damaging phenomena associated with earthquakes is surface displacement. The displacement can be either faulted displacement or landslide displacement. This particular point cannot be conclusively defined at this time owing to the continuing investigations at the site. It has been postulated (Herd, 1977) that the Verona Fault trace, discussed earlier, passes through the site within 1,000 feet of the SNM facility rather than several thousand feet away as had been previously believed (Hall, 1958). The specific location of this fault remains very uncertain in spite of thrust-type displacements that have been observed in trenches across the postulated fault location. These particular offsets may well be landslide induced (General Electric Company, 1977), thus demonstrating the capability of this area for megalandslide activity.

The subject of surface displacements and associated accelerations resulting from earthquakes on the postulated Verona Fault is treated separately in the second part report.

Other hazards associated with strong shaking include soil liquefaction and flooding.

Soil Liquefaction

Soil liquefaction is a phenomenon in which a saturated cohesionless soil layer located close to the ground surface loses strength during cyclic loading, such as imposed by earthquakes. During the loss of strength, the soil acquires a mobility sufficient to permit both horizontal and vertical movements. Soils that are most susceptible to liquefaction are clean, loose, saturated, uniformly graded, fine grained sands that lie within 50 feet of the ground surface.

Even under the conservative assumption that the soils are saturated to a depth of 20 feet, it presently appears that liquefaction does not represent a hazard for the site. This conclusion is based on grain-size analysis and standard penetration test results for materials under the nearby General Electric Test Reactor. The underlying soils at the GETR site are predominantly clays and gravels with occasional pockets of sandy, silty clay and sandy clay. These sands, whose possible mobility could induce liquefaction, are of such density and grade that their mobility is very unlikely.

On the basis of the data available, it would appear that liquefaction is not a problem. However, the uncertainty in the data and the possible intensity of excitation make this a most tentative conclusion.

Inundation Due to Dam or Embankment Failure

San Antonio Reservoir, about two miles south of the site and Del Valle Reservoir, about six miles east of the site are the only major bodies of water in the vicinity of the site (Kaldveer et al., 1976). Reference to the inundation maps prepared by the owning agencies (San Francisco Water Department and the State of California Department of Water Resources) indicate that the site would not be affected in the event of a dam failure at either of these reservoirs. Reasons include: existing drainage ways, elevation differences and volume of water available.

Other water sources include rupture of the 500,000-gallon water storage tank on the site. In view of the fact that the Vallecitos site facilities are located on a broad, sloping hillside, tank failure would not result in appreciable flooding of facilities. A large portion of the water would probably drain into Lake Lee. Any drainage from the lake discharges into a large drainage ditch, which leads to Vallecitos Creek, which is off-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.

Local coverage of earthquakes was started in 1887 when the Berkeley, Mt. Hamilton and Chabot stations were installed by the University of California. The quality and quantity of data available was improved in the 1930's when Berkeley initiated a significant expansion of the network and subjected the data to routine seismological analysis. The pre-1930 record is a very valuable supplement to the more recent data but due to poor station coverage, much of these data cannot be reliably used in developing earthquake statistics for structures in the site area. Our general approach is to use only the recently recorded data to determine the statistics for small earthquakes (magnitude 3.0-5.0) and to include the entire historical record in determination of statistics for larger earthquake magnitudes.

We have collected and integrated the data from several seismic data bases to ensure the most complete coverage. The primary source of data was the University of California (1975) seismic data base containing the earthquake history of Northern California through 1975. The data for the site area were checked and extended to 1977 by comparing them with the unpublished records of the seismograph station. The expertise of Professor McEvilly was particularly valuable in establishing the representativeness of these data. Other data bases for seismicity that were examined for consistency checks included those of the California Division of Mines and Geology, the USGS Central California Network and NOAA/NEIS.

The resulting integrated earthquake magnitude data base for the relevant area around Vallecitos is plotted in Figure 4-1. Because of the large numbers of small magnitude earthquakes, Figure 4-1 shows only those of magnitude greater than 5; earthquakes as low as magnitude 3.0 were, however, included in the statistics and analysis. Figure 4-2 presents the historical Modified Mercalli (MM) intensity record around the site; although this portion of the data base is of less quantitative value, it supports the temporal distribution of the very large earthquakes.

There are several important features of the historical data that must be included in any risk assessment. The most important is the obvious clustering of seismicity in several localities.

The most obvious and well known source of seismicity in the site area is the San Andreas Fault. The 1906 earthquake (M 8.3) on this fault, which resulted in a surface rupture from San Juan Bautista to Humboldt County, was one of the largest earthquakes ever to occur in this country. The southern sector of this fault also has experienced a major earthquake, the Fort Tejon earthquake of 1857. These two events have established the reputation of the San Andreas and associated faults, but the activity rate of the system is better determined by the large number of lesser magnitude earthquakes.

Related to the San Andreas system, but structurally unique, are the Hayward and Calaveras fault systems. These faults have also been the site of major earthquakes. In 1836 and again in 1868, slippage on the Hayward Fault resulted in intensity Rossi Forel (RF) IX-X reports and in 1861 movement on the Calaveras Fault resulted in epicentral (RF) intensities of IX north of the site near Dublin.

Each of these major earthquakes result in strong shaking at the site, but important contributions to the historical site intensity record are also made by the smaller magnitude nearby events. In an effort to provide added credibility to our results, we have reconstructed the historical acceleration record at the site using both the historical intensity data and the more recent magnitude data.

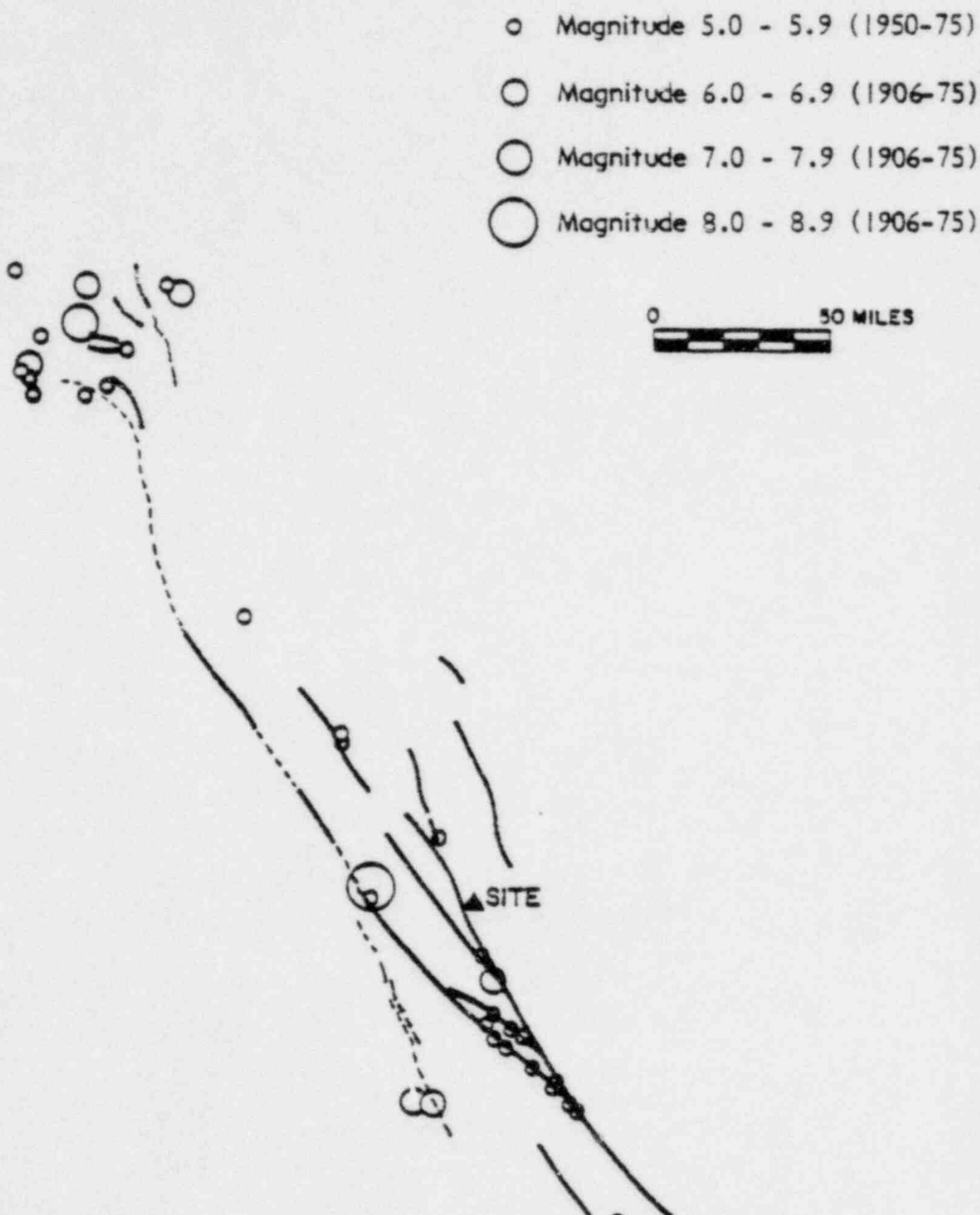

FIGURE 4-1

INSTRUMENTAL MAGNITUDES IN THE SITE VICINITY

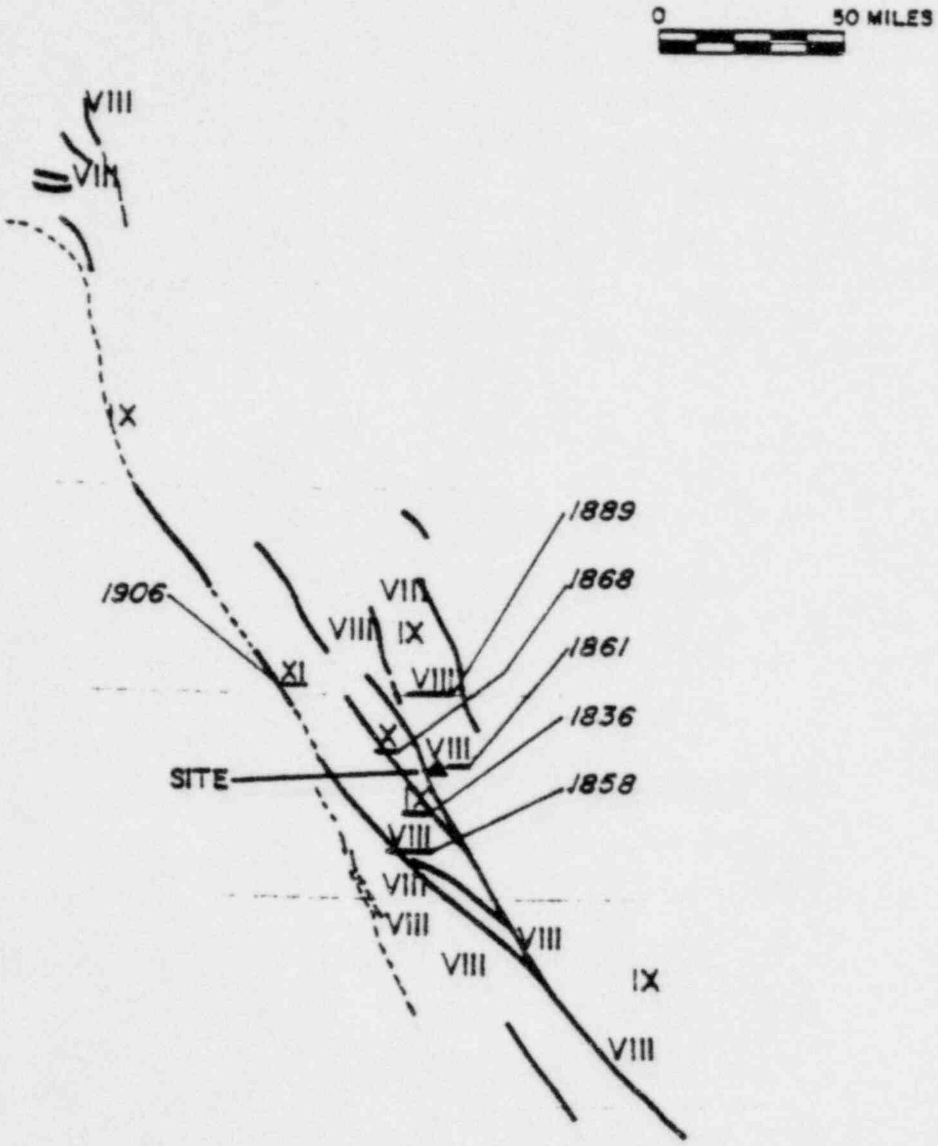

FIGURE 4-2
HISTORICAL RECORD OF
EPICENTRAL MODIFIED MERCALLI INTENSITIES
IN THE SITE VICINITY
(1813 - 1977)

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For example, using the Townley-Allen (1939) catalog as a data base, we judge that during the period 1910-75 the site experienced 11 events of intensity (MM) V and seven of intensity (MM) VI. Site intensity (RF) VIII reports have been reliably reported over a much longer time frame; we count six of these events between 1813-1975. Similarly, we believe the site has experienced two (RF) intensity IX and one intensity (RF) X over the same time. Table 4.1 provides a summary of the dates of these events. Richter (1958) has been used to convert RF intensity reports to the MM values indicated in this table. There is, of course, some uncertainty involved in inferring site intensities from isoseismal maps or surrounding intensity reports. These results, however, provide important insight into the general seismologic setting of the site.

It is evident that there are several historical earthquakes that have resulted in moderately high site intensities. Notable among these are those earthquakes listed in Table 4.1. These earthquakes are useful for estimating the seismic hazard at the site, but their location is also very important in determining the recurrence relation for specific structures. Because of this, the basis for the published locations of four significant earthquakes was carefully examined. Due to the obvious significance of the Calaveras Fault, particular attention was directed to relocating significant historical earthquakes that occurred in the vicinity of this structure. The relocation of the historical earthquakes was accomplished through examination of old newspaper reports and synthesis of these data with those available from several historical catalogs, including McAdie (1907), Holden (1898) and Townley and Allen (1939).

The overall conclusion was that in no case was there sufficient evidence for modifying the published locations of any of the earthquakes and in the case of one event the basis for the existing location was strengthened.

The earthquakes considered in the relocation analysis were those of 04 July 1861, 11 June 1903, 03 August 1903 and 01 July 1911. All the available data from these earthquakes were scrutinized and where specific historical locations had to be determined, we consulted with the Special Map Collection of the Bancroft Library, University of California at Berkeley.

TABLE 4.1

SUMMARY OF HISTORICAL SITE INTENSITIES

		Site Intensity (MM)		
V	VI	VII-VIII	VIII-IX	XI
[illegible] Nov 1914		1813*	04 July 1861	21 Oct 1868
[illegible] 1933	26 Oct 1943			
		1836*	18 April 1906	
08 March 1937	09 March 1949			
		26 Nov 1858		
15 April 1943	25 April 1954			
26 April 1943		11 June 1903		
16 Nov 1943	05 Sept 1955			
		03 Aug 1903		
27 Aug 1945	24 Oct 1955			
		01 July 1911		
22 June 1947	22 March 1957			
17 March 1962	31 Oct 1958			
10 Feb 1966				
18 Dec 1967				

*Precise dates unknown.

For the 1861 event, the key data for fixing the location and epicentral intensity were the reports that "men in the fields were thrown down" and "it opened a large fissure in the earth and a new spring of water." From other accounts, we determined that the fissure was near a house belonging to Mr. Larabie and the spring near Mr. Porter's. While we were unable to find Mr. Larabie's house, we were able to locate Mr. Porter's house on a San Ramon Rancho Map prepared in 1857. The subject house was east of Danville's present location, near the Blackhawk Ranch, thus strengthening the argument that the event was indeed located on the Calaveras and not a subsidiary fault as the Las Positas, Pleasanton or Verona.

In an effort to determine more precisely possible activity on the Las Positas Fault, we also relocated, using the Master Event Technique (Evernden, 1969), four earthquakes of magnitude 4.0-4.2 that were part of the 1943 swarm in the Livermore Valley. At that time, station coverage was sufficiently sparse to result in large uncertainties of location. We have relocated these events relative to the location of the recent June 20, 1977 magnitude 4.7 Livermore earthquake whose location was determined much more precisely. The analysis showed that the relocated epicenters were less than 4 km from the original epicenters and that the new locations did not generally align with any known structures including the Las Positas Fault.

While the results of this relocation effort are by no means conclusive, they certainly suggest that if the subsidiary faults around the Calaveras are active, their activity rates must be very low. It is on this basis that our analysis highlights the San Andreas, Hayward and Calaveras Faults and does not explicitly consider other subsidiary faulting. Activity on these minor, but possibly nearby faults is however indirectly included in the analysis; the following section presents the details of these subjects.

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 Vallecitos. In this section, we apply these concepts and data to a seismic risk analysis for the Vallecitos 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 comprises 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 Vallecitos facility analysis. Major suggestions in this regard were made by Professor T. V. McEvilly.

Source Regions

After a thorough review of the historical seismicity, tectonic slip rates, microseismic data and surface geology, we concluded that the grass source zones in the vicinity of the site defined by Algermissen and Perkins (1976) were most appropriate for this analysis. Their definition of the source zones was based on the reasonable assumption that future earthquake occurrences will have the same general statistics as historical earthquakes and that the historical variation of earthquake statistics from region to region can be used to delimit general source regions. The final definition of the source region's boundaries was based on the average separation distance for earthquakes producing the largest intensities. The representation of the source regions synthesized all the available historical seismicity data and the state of knowledge of the relationship between geologic structure and historical seismicity.

Figure 5-1 shows the source regions that are appropriate for the analysis of the Vallecitos site. These regions encompass all the significant sources of seismic activity within 200 km of the site. Their specification is generally consistent with the regionalization one would intuitively expect to be appropriate in that there is a San Andreas Zone, a Hayward-Calaveras Zone and a North County Zone.

In order to provide results that are more site-specific, we have subdivided the Hayward-Calaveras Zone into several subregions that model the specific faults in this zone. Thus, we model both the Hayward and the Calaveras Faults as line sources of width 1-2 kilometers on either side of the surface trace. Although the activity in the eastern sector of the zone cannot be associated with specific structures as it can in the western sector, the area east of the Calaveras appears to be capable of significant activity and thus it is considered a separate and distinct area source of gross activity. These zones are also shown in Figure 5-1. Consistent with the historical record (Figure 4-1), these line sources and the eastern area source are assumed to be the only locations in the zone that are capable of earthquakes greater than magnitude 5.5; earthquakes of lesser magnitude are, however, included in the analysis but they are not constrained to occur only upon these faults. Based on the density of subsidiary faults within the zone, the entire zone was considered equally capable of generating these smaller earthquakes.

Source Region Seismicity

Algermissen and Perkins (1976) calculated the rates at which earthquakes occur in each of their source regions based on the seismic data available at that time (1974). These rates, which are related to coefficients in the expression

$$\log N = a - b_I$$

are presented in Table 5.1.

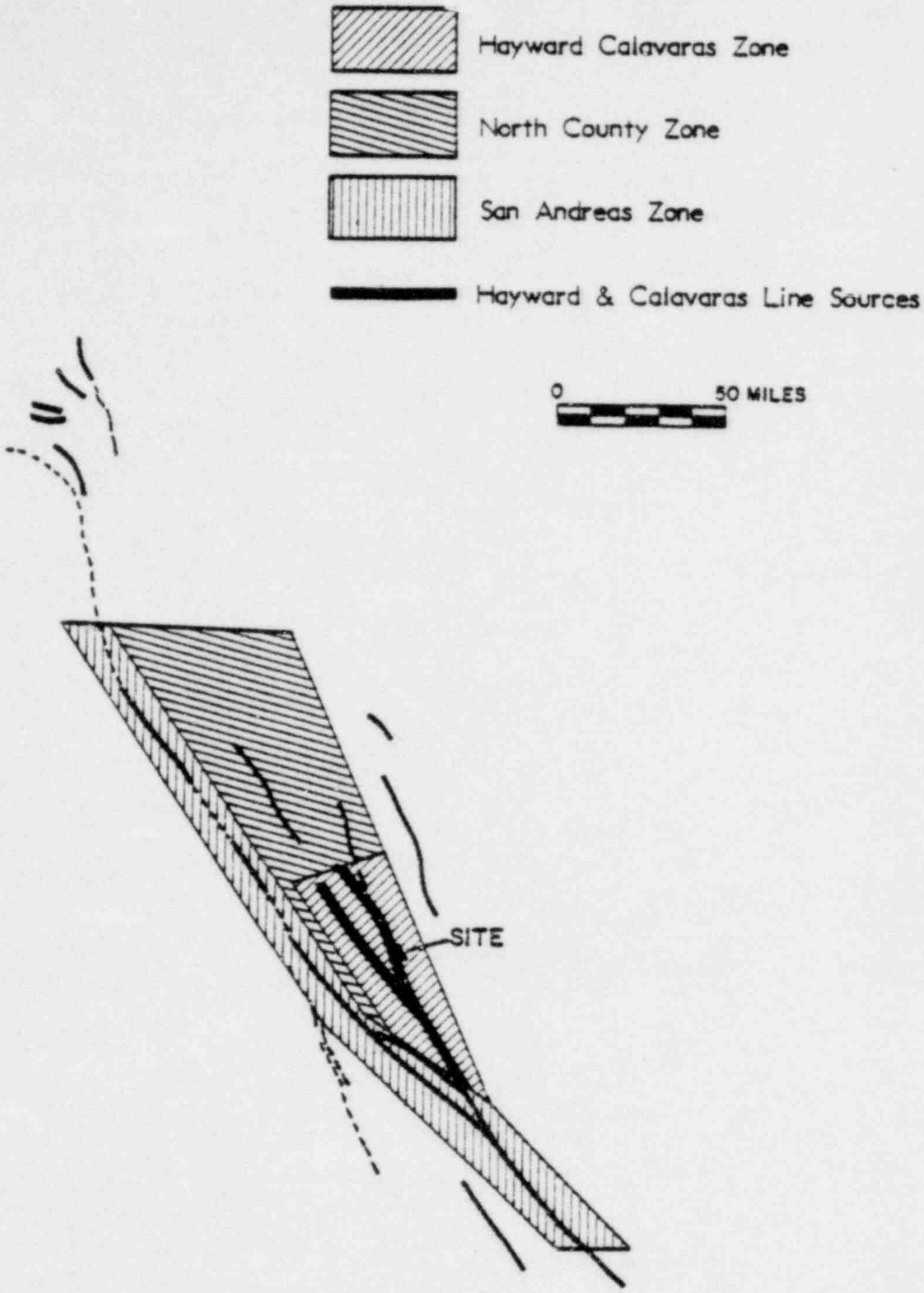

FIGURE 5-1

SEISMIC SOURCE REGIONS
USED IN THE ANALYSIS

TABLE 5.1

ALGERMISSEN AND PERKINS (1976)
EARTHQUAKE FREQUENCY PARAMETERS

Zone	Maximum Historical Earthquake (MM)	Number of MM Intensity V's per 100 years	Slope of the relation, $\log N = a - b_I$ b_I
San Andreas	XII	110	0.40
North County	IX-X	14.9	0.50
Hayward-Calaveras	X-XI	44.4	0.45

The parameters a and b_I define the incremental distribution of earthquake epicentral intensities up to an hypothesized maximum intensity. We convert these parameters to those appropriate for a cumulative distribution on earthquake magnitude by integrating the above relation over intensity and converting intensity to magnitude through Toppozada's (1975) statistically derived relationship

$$M = 1.85 + 0.49 I.$$

Toppozada's relationship is the most appropriate for this analysis since it was developed with a Northern California-Nevada data base. We recognize the uncertainty in both the fit of a log N relationship to the recurrence data and in the coefficients within Toppozada's relationship; we account for this uncertainty in the analysis by sensitivity analysis and a Bayesian combination of results.

Deferring until later the quantification of the uncertainties, the integration and conversion described above results in the earthquake frequency parameters for each source region presented in Table 5.2. The overall consistency of the results in Table 5.2 can be illustrated by comparing these results with other independent analyses. For example, Bolt (University of California, 1975) has calculated that the b-value for the Coast Range Region, which includes all the source regions in this analysis, is 1.00 and this is consistent with the average b-value from Table 5.2. Further, Evernden (1970) has determined that the b-value of the San Andreas Fault zone is approximately 0.86; we obtain 0.88. Finally, Pfluke and Steppe (1973), using microseismic data, have calculated that for earthquakes as low as magnitude 1.4 a b-value of 0.99 results for the Calaveras Fault.

We also present in Table 5.2 the earthquake activity rates for the subregions of the Hayward-Calaveras zone. The slope of the frequency relation (b) is assumed to be the same for each subregion, but the total number of events in each subregion is calculated to be proportional to the total number of magnitude 3.0-4.0 earthquakes in each subregion during the period 1965-75. The logic for this algorithm is that first, there are a sufficient number of these lower magnitude earthquakes to establish a rate for each subregion and second, the U.C. seismic

TABLE 5.2

EARTHQUAKE FREQUENCY PARAMETERS
USED IN THE CALCULATIONS

Zone	$N = N_o 10^{-bm(M-M_o)}$			Maximum Earthquake Magnitude	Largest Historical Earthquake (MM)
	N_o	M_o	b_M		
San Andreas	1.55	4.0	0.88	8.4	XII
North County	0.48	4.0	1.08	6.8	VIII
Hayward-Calaveras	1.30	4.0	0.95	See below	
Hayward-Calaveras Subregions					
Hayward	0.012	5.5	0.95	7.0	XI
Northern Calaveras	0.009	5.5	0.95	6.8	VIII-IX
Southern Calaveras	0.019	5.5	0.95	6.8	VIII
Eastern Area	0.008	5.5	0.95	6.1	VII-VIII
Background	1.250	4.0	0.95	5.5	

network became fully operational by 1965 thus providing coverage to this area that was before unavailable.

Also shown in this table is our best estimate of the largest possible earthquake in each region. Generally, this estimate is about 0.5 magnitude unit larger than the largest historical earthquake.

To account for the uncertainties discussed above, we consider several other values for the maximum earthquake. Table 5.3 presents the full range of magnitudes we consider in the calculations.

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 in the past 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 at this site, a very careful re-evaluation of all the data was performed in order to ensure state-of-the-art interpretation and maximum credibility (Boore, 1977).

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:

TABLE 5.3

DISTRIBUTION OF MAXIMUM MAGNITUDE
EARTHQUAKES USED IN THE ANALYSIS

Zone/Subregion	Lower Bound	Best Estimate	Upper Bound
San Andreas	8.3	8.4	8.5
North County	6.3	6.8	7.3
Hayward	6.5	7.0	7.5
Northern Calaveras	6.3	6.8	7.3
Southern Calaveras	6.0	6.8	7.3
Eastern Area	5.6	6.1	6.6

- Brune, et al., 1977
- Galanopoulos and Drakopoulos, 1974
- Hanks and Johnson, 1976
- Boore, to be published, 1977
- USGS C rculars;

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 5-2, 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, 1977a). 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 is presented in Figures 5-3 and 5-4.

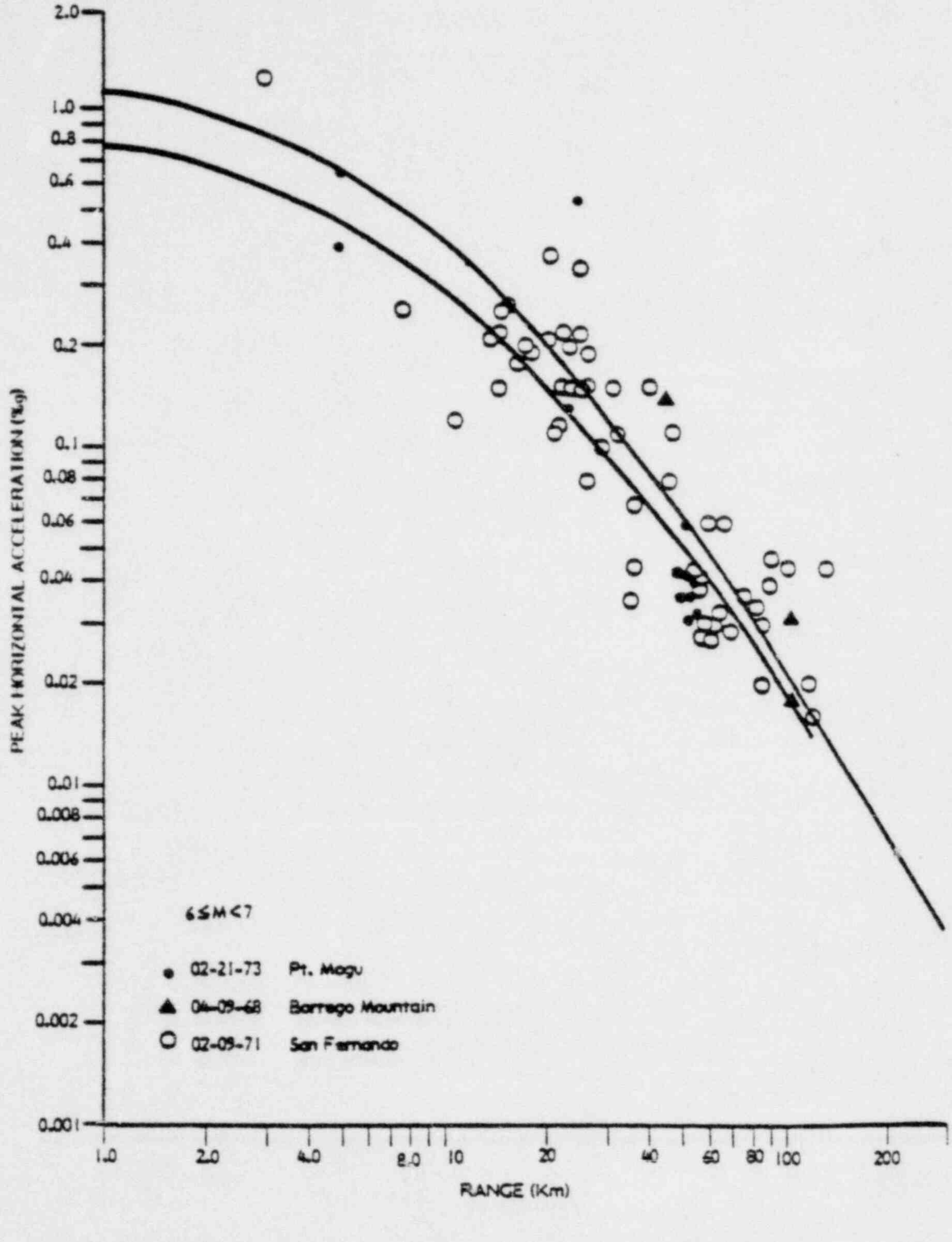

FIGURE 5-2

DATA BASE FOR THE MAGNITUDE 6.5 ATTENUATION RELATION

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ATTENUATION 1

$$A = 0.193\, e^{(2.98 - .58M + .04M^2)M} (r + 12)^{-1.75}$$

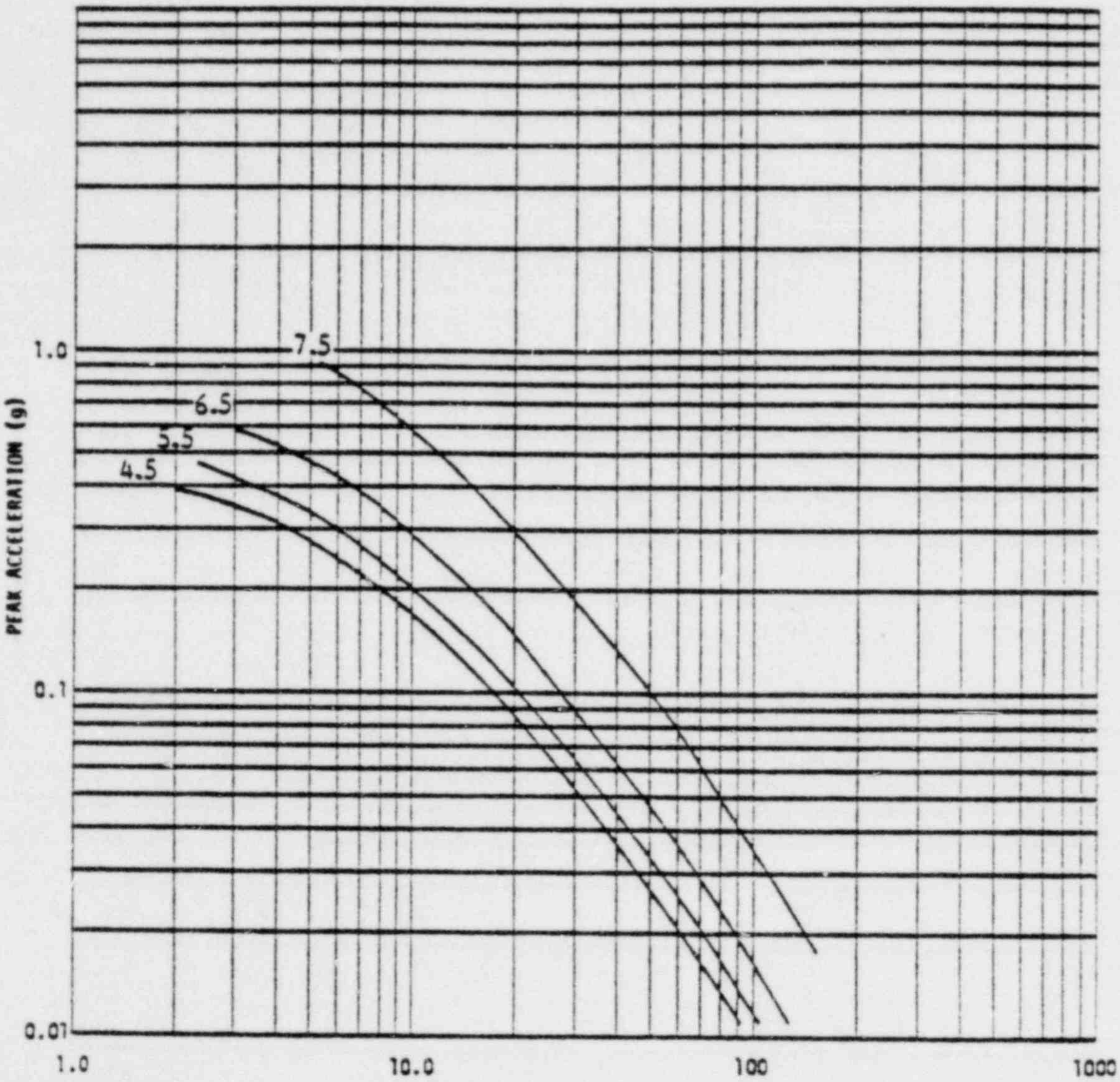

FIGURE 5-3

ATTENUATION RELATIONSHIPS

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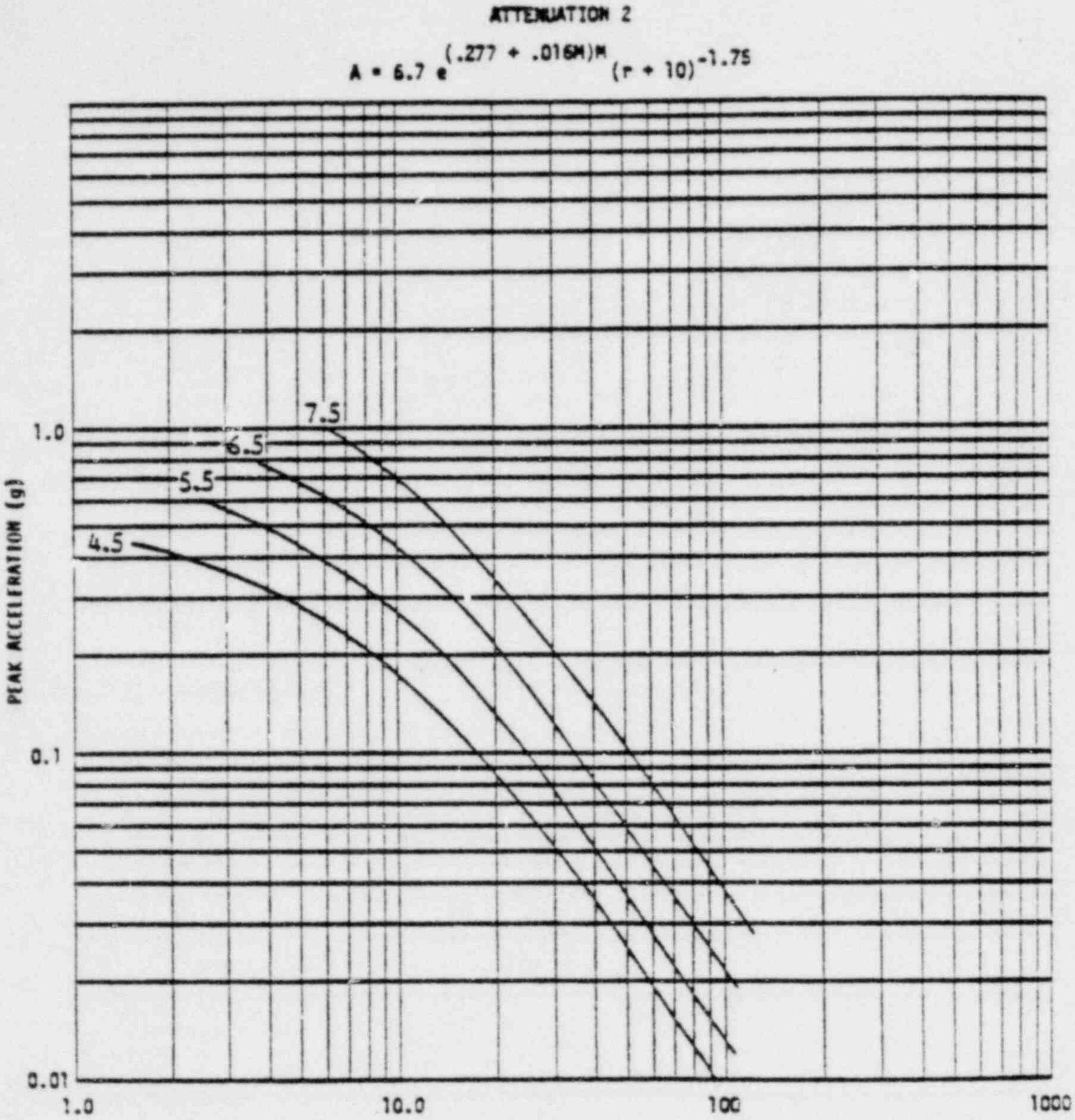

FIGURE 5-4

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

risk = 1.0 - exp(- expectec mber 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 five individual calculations. The five calculations represent a base case and our perturbations of input parameters about this base. The perturbations are weighted by subjective estimates of their probability of occurrence and thus their weighted combination results in a synthesized sensitivity study.

The parameters that are considered uncertain and which are included in this estimate of the risk are

- The maximum earthquake in each source zone
- The extent of acceleration dispersion about the mean attenutation relationships

- The seismicity that cannot be associated with known faults (background seismicity)

- The acceleration attenuation relation.

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, and the shape and level of the attenuation relation.

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

- Maximum earthquake = best estimate value from Table 5.3

- Acceleration one standard deviation dispersion, $\ln \sigma_A = 0.45$

- Background seismicity derived from the data

- Both attenuation relationships, equally weighted.

We characterize the uncertainty in these data by 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 5.3.

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 acceleration dispersion will be:

- $\ln \sigma_A = 0.55$

- $\ln \sigma_A = 0.35$

Finally, we account for uncertainty in the background seismicity by considering it 70 percent probable that the rate will be the rate derived from the data, and that it is again 15 percent probable that the rate will be double or two-thirds, respectively.

We note again that the two attenuation relationships are equally weighted.

The results from these five 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 5-5. Also shown in this figure, and derived in the same way, is our estimate of the one standard deviations about our best estimate results.

RESPONSE SPECTRUM

The above 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 have sufficiently low fundamental frequencies to experience spectral amplification.

Our initial approach to the definition of a response spectrum is empirical; that is, we base our recommendation on the shape of response spectra recorded in the near-field of strike-slip earthquakes. While very sophisticated deterministic techniques exist which, through stress wave propagation calculations, can result in extremely site specific spectra, such calculations first, do not easily mesh with the probabilistic approach taken here and second, are outside the scope of this analysis.

The records chosen as most appropriate for definition of the spectra are:

1) The Cholome N 65° E component of the June 27, 1966 magnitude 5.5 Parkfield earthquake.

2) The El Centro S 00° E and S 90° W components of the May 18, 1940 magnitude 6.3 Imperial Valley Earthquake.

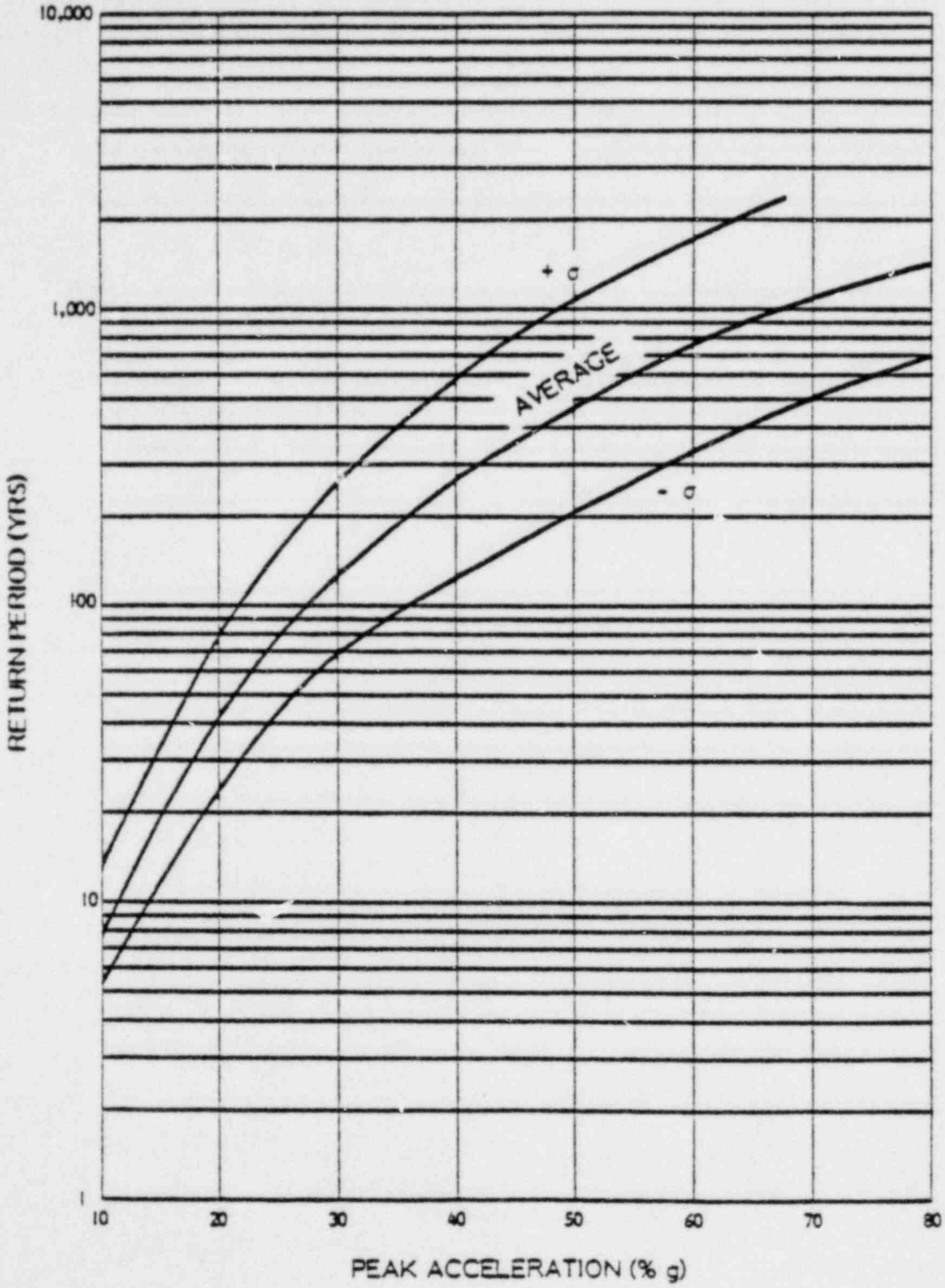

FIGURE 5-5

PEAK ACCELERATION VS. RETURN PERIOD
FOR THE VALLECITOS SITE

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The records were selected because they represent the frequency content in the near-field of a large strike-slip earthquake. The risk at the Vallecitos site is dominated by near-field events—both intermediate and large events that occur on the Calaveras, and the smaller events that we represent in the background seismicity. The records selected are the only near-field records available and, fortuitously, they also span a reasonable magnitude range. The Parkfield record represents a magnitude 5.5 event while the far-field records from the Imperial Valley Earthquake indicated a 7.0 magnitude. The event was apparently episodic with the largest single subevent being magnitude 6.3 as determined in the near-field.

When these response spectra are overlaid, the resulting envelope spectrum is closely approximated by the 50 percentile alluvium spectrum contained in WASH-1255 (USAEC, 1973). Given the broader basis for this latter spectrum and its overall credibility, we recommend use of the 50 percentile WASH-1255 alluvium response spectra for structural analysis. These spectra should be scaled by the desired peak acceleration from Figure 5-5.

CONCLUSIONS

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 Vallecitos facility. The results, shown in Figure 5-5, account for the dispersion of the data about the functional relationships used in the model. The results further account for variations in the upper magnitude cut-off. Other design response spectra can be determined by scaling the 1.0 g response spectrum in WASH-1255 to the desired peak acceleration.

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