REVIEW-LEVEL EARTHQUAKE EVALUATION:

RECOMMENDATIONS FOR IPEEE IMPLEMENTATION AT THE PALO VERDE NUCLEAR GENERATING STATION NEAR WINTERSBURG, ARIZONA

FINAL REPORT

Prepared for

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Section 1

INTRODUCTION

1.1 GENERAL BACKGROUND AND PURPOSE OF STUDY

This report presents the basis and methods for evaluating an appropriate earthquake review-level for the Palo Verde Nuclear Generating Station (PVNGS) located in Arizona (2 miles south of Wintersburg). The resulting recommended review-level earthquake (RLE) is intended for use as a screening and reporting basis in implementing the seismic portion of the Individual Plant Examination of External Events (IPEEE) at the PVNGS site, in response to NRC Generic Letter 88–20, Supplement 4 (1). Specific guidance on use of the RLE in seismic-IPEEE implementation can be found in NUREG–1407 (2) and EPRI NP–7498 (3).

Generic Letter (GL) 88–20, Supplement 4 specifies an RLE value (or review bin) for each nuclear power plant licensed for commercial operation in the United States. In that context, PVNGS is described as a "Western United States site whose default bin is 0.5g unless the licensee can demonstrate that the site hazard is similar to those sites east of the Rocky Mountains that are found in the 0.3g bin." Without the benefit of a consistent set of site-specific seismic hazard results, one would be unable to ascertain a definitive RLE value for the PVNGS site; therefore, in the absence of further analysis, a RLE value of 0.5g would, by default, be considered generally conservative.

Information and results from the Final Safety Analysis Report (4) and a preliminary seismic hazard study (5), however, imply a very low seismic hazard at the PVNGS site. Furthermore, the actual ground-motion spectrum used in the seismic design of the plant substantially exceeds that required as a Safe Shutdown Earthquake (SSE) for plant licensing. These points suggest that a RLE value of 0.5g may not be clearly warranted for IPEEE implementation at the PVNGS site, but rather, a RLE value of 0.3g may be appropriately justified.

Consequently, for the purpose of better defining the site-specific hazard and the seismic input appropriate for IPEEE implementation and safety evaluation, Arizona Public Service (APS) has undertaken a seismic hazard study and uncertainty investigation (6) for the Palo Verde station. The primary application of the present study is to make use of these seismic hazard results (together with hazard results, derived similarly, for plant sites in the central and eastern U.S.) in determining a consistent RLE value (0.3g or 0.5g) that is appropriate for IPEEE implementation at the PVNGS site.

In addition to developing a basis for establishing a recommended RLE for the PVNGS site, a second purpose of this study is to develop general recommendations on an appropriate scope of effort to undertake in seismic-IPEEE implementation of each of the three nuclear reactors at the Palo Verde station.

1.2 BACKGROUND ON OBJECTIVES OF THE IPEEE

The IPEEE program is being conducted in response to NRC's Severe Accident Policy Statement (7). That statement describes the motivation, understanding, and formal policy basis to be considered in resolving issues related to potential severe reactor accidents; key highlights of the Commission's statement are noted as follows:

- Based on currently available information, the Commission concludes that existing nuclear power plants pose no undue risk to public health and safety;
- Based on NRC and industry experience with plant-specific PRAs (Probabilistic Risk Assessments), however, systematic plant examinations are beneficial in identifying plant-specific vulnerabilities to severe accidents for which safety improvements may be justified;
- Each existing plant should, therefore, perform a systematic examination to identify any plant-specific vulnerabilities, and report the results to the Commission.

Hence, a fundamental objective of severe accident policy is to verify the widely held belief that plants pose no "undue risk" and that "all reasonable steps are taken to reduce the chances of occurrence of a severe accident involving substantial damage to the reactor core and to mitigate the consequences of such an accident should one occur." The Individual Plant Examination (IPE) is a key element of the implementation program developed by the NRC Staff for meeting this objective and for developing a plan for integrated closure of severe accident issues (8). The IPEEE is that facet of the overall IPE effort which specifically addresses the potential for severe reactor accidents due to external causes. As outlined in the NRC documents for IPEEE guidance, the specific objectives of the IPEEE are, for each utility in charge of operating an existing plant, to (2):

- "Develop an appreciation of severe accident behavior,"

- "Understand the most likely severe accident sequences that could occur at the licensee's plant (under full power operating conditions),"
- "Gain a qualitative understanding of the overall likelihood of core damage and fission product releases, and"
- "If necessary, to reduce the overall likelihood of core damage and radioactive material releases by modifying, where appropriate, hardware and procedures that would help prevent or mitigate severe accidents."

In its Severe Accident Policy Statement, the NRC clarifies the level of effort the IPEs should involve:

> "licensees of each operating reactor will be expected to perform a limited-scope, accident safety analysis designed to discover instances (i.e., outliers) of particular vulnerability to core melt or to unusually poor containment performance, given core-melt accidents."

Hence, a limited-scope plant investigation, that makes effective use of insights yielded by past detailed investigations, aimed at effectively identifying cost-effective mitigations of plant-specific vulnerabilities, is the course intended by the NRC Commissioners for implementation of IPEs in severe accident policy resolution. The recommendations in this report for plant seismic review level and overall scope of seismic IPEEE implementation are consistent with this "limited-scope" intent of systematic evaluations as described in the NRC Severe Accident Policy Statement.

1.3 ROLE OF THE RLE IN IPEEE IMPLEMENTATION

It is generally recognized that seismic margin assessment (SMA) methodology and walkdown procedures are quite thorough and efficient at identifying "outliers" (or "weak-links") when directed by a well-qualified Seismic Review Team (SRT). In fact, many knowledgeable engineers believe that such a well-focused, well-directed, thorough plant walkdown is the single-most important aspect of plant examination for identifying potential severe-accident vulnerabilities. Hence, the SMA approach (with recommended enhancements) has been endorsed by the NRC (2) as a basis for conducting the seismic IPEEE.

In this context of seismic margin assessment (viz-à-viz the context of a PRA analysis), the role of the RLE in IPEEE implementation is most meaningful. In particular, the RLE serves to fix the limits for SMA screening of potential outliers in the seismic IPEEE review and also delineates the ground-motion spectrum to be used in response and capacity analyses (HCLPF calculations). Generally speaking, the RLE simply defines a uniform "reporting limit" for component capacities and potential vulnerabilities. In other words, components with computed HCLPF capacities less than the RLE (i.e., with capacities that would not meet or exceed the level of seismic demand imposed by the RLE spectrum) would need to be reported as potential vulnerabilities and would need to be addressed for further evaluation.

The RLE ground motion specified for IPEEE implementation by the NRC (2) is the 5%-damped, median NUREG/CR-0098 (9) spectral shape [for the appropriate site condition (soil or rock)] anchored to the RLE peak ground acceleration (PGA) value (0.3g or 0.5g). Hence, the RLE ground motion is not a site-specific basis for plant evaluation (i.e., its shape is not based explicitly on expected earthquake characteristics and its amplitude is not determined from considerations of plant-specific hazard or risk); rather, the RLE is a standard or reference ground-motion demand for plant evaluation.

The advantage of a standardized RLE ground motion is to ensure that capacity calculations are performed on a consistent, uniform basis from plant to plant. This advantage facilitates one-to-one comparisons of plant-level capacities and clarifies industry-wide insights on general understanding of plant capacities (without any specific influence of the seismic hazard).

For decisionmaking purposes, however, considerations of site-specific seismic hazard and risk (in addition to plant capacity alone) are required for a consistent and meaningful decision process. For this reason, therefore, the RLE is unsuitable as a decision criteria; hence, the NRC has clarified that the RLE should not serve as an ultimate acceptance level (2).

As a result, whether a plant is reviewed at a level of 0.3g or 0.5g would be immaterial in terms of bottom-line plant safety and in terms of any actual modifications undertaken for safety enhancement, provided the selected RLE is of sufficient amplitude to reveal the set of potential meaningful safety enhancements. Consequently, the RLE should be large enough to screen-in components and systems for which meaningful potential safety enhancements, if any, may be found. On the other hand, if the selected RLE is too large, unnecessary analyses will be performed and unnecessary expenses will be incurred with no added benefit in terms of plant safety. In this case, no additional safety enhancements that are meaningful in terms of cost-effectiveness will be found to justify the additional effort.

Because a review-level of 0.5g would generally imply a substantially greater effort in plant evaluation costs than would a 0.3g review level, there should be a clearly definitive basis for expecting that the additional cost in plant analysis is necessary in discovering a more complete set of meaningful, cost-effective potential safety enhancements.

1.4 RELEVANCE AND ASPECTS OF IPEEE CLOSURE

The aspect of IPEEE implementation that deals with bottom-line decisionmaking is IPEEE closure. NRC severe accident policy specifies that backfit criteria (i.e., cost-benefit comparisons) serve as the ultimate basis for deciding whether or not potential safety enhancements are justified. Industry guidelines, criteria, and a decisionmaking framework have been developed for the purpose of achieving systematic seismic IPEEE closure [see Reference (3)]. The closure criteria employ risk-based screening and decision elements for evaluation of alternative safety enhancements based on cost-benefit analyses. The present study does not specifically address such decision-based criteria; however, it is important to emphasize the critical significance of these criteria in establishing the link between IPEEE implementation and the objectives of severe accident policy. For perspective, the RLE (as a screening and reporting level) does not serve as a criteria for satisfying severe accident policy objectives of delineating cost-effective enhancements. For an optimal, efficient IPEEE implementation, the RLE would be selected so that only the truly viable safety enhancements, as respects IPEEE closure, are screened in for evaluation in the IPEEE closure process. Determining whether or not an effective (and efficient) IPEEE implementation can be accomplished at a review level of 0.3g for the Palo Verde station is a primary consideration in this study.

1.5 REPORT ORGANIZATION AND OVERVIEW

In the following section, additional background on IPEEE implementation and on the use of the RLE is presented to introduce the notation, concepts and basis for the RLE evaluation approach. The primary inputs required for RLE evaluation are site-specific seismic hazard results; Section 3 summarizes the results of the seismic hazard analysis for the PVNGS site. A brief description of the hazard results used for characterizing the seismic threat at central and eastern U.S. plants is also provided to establish the basis for subsequent hazard comparisons. Section 4 outlines the approach for the RLE evaluation, and describes the procedures and methods for the seismic hazard comparisons.

It is important to note that the RLE general evaluation procedure, including use of hazard measures, frequency-dependent weighting criteria, and overall binning philosophy, as described in Appendix A of NUREG–1407, were employed on a consistent basis in this study for the RLE evaluation at PVNGS. All comparisons of seismic hazard measures, however, are here based on EPRI seismic hazard results, as the hazard analysis for the PVNGS site was conducted in a manner similar and consistent with the EPRI hazard methodology. Results and comparisons of computed spectral hazard measures (as a function of vibration frequency) are provided in Appendices A, B and C [whereas Section 5 summarizes the weighted (or composite) results used in developing the RLE recommendations]. All hazard comparisons are relative (plant-to-plant), and the relative binning results should be similar to those obtained if LLNL hazard methods were implemented. As opposed to performing a formal binning analysis (for instance, using the clustering methodology described in Appendix A of NUREG–1407), simple comparisons of various seismic hazard-based measures are made with central and eastern U.S. plants falling in the 0.3g full-scope and focused-scope bins (i.e., the hazard bounds for plants in these bins were assumed to denote general references for assessing whether or not the PVNGS site would belong in these bins).

Considering this basis, Section 5 presents the comparisons of seismic hazard measures for the PVNGS site with those for the 0.3g full-scope and focused-scope sites in the central and eastern United States. Then finally, Section 6 develops general recommendations for the selection of an appropriate seismic IPEEE review level at PVNGS and presents general suggestions for the scope of IPEEE implementation at the three reactor units. To provide here a quick synopsis of the results and recommendations prior to further discussion, the following conclusions are highlighted:

- For the PVNGS site, weighted/composite probabilities of exceeding the NUREG/CR–0098 (median, 5%-damped) spectrum anchored to 0.3g PGA lie substantially within the central range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. Comparative rankings for the PVNGS site vary from 13-of-51 (for median hazard results) to 27-of-51 (for mean hazard results), where a ranking of 51 would indicate the lowest probability of exceedance of all plants. Therefore, the composite probabilities for the PVNGS site are effectively indistinguishable from the body/population of results observed for the 0.3g plants.

- For the PVNGS site, weighted probabilities of exceeding the seismic design basis are indistinguishable from the population of results for the 0.3g focused-scope plants. The comparative rankings (ranging from 27-of-51 to 36-of-51) are, however, somewhat more favorable than those obtained above (for probabilities of exceeding the NUREG/CR–0098 spectrum) because of the comparatively greater level of conservatism in the seismic design basis for PVNGS.

- In most cases, the mean and 85th-fractile hazard-based measures demonstrate a somewhat more favorable comparison, relative to results for the 0.3g plants, than do the median hazard-based measures. On an absolute basis, the mean and 85th-fractile composite probabilities of exceeding the 0.3g NUREG/CR-0098 (median, 5%-damped) spectrum are both considerably less than the 10^{-4} level, whereas the median composite probability is notably less than 10^{-5}. Criteria in NUREG-1407, related to these absolute comparisons, demonstrate that an RLE assignment of 0.5g would not be supported at the PVNGS site.

- Based upon the set of relative (plant-to-plant) comparisons and binning procedures used in NUREG-1407, the results of the present study support placing the PVNGS site into the 0.3g review bin.

- In addition, implementing the approach described in NUREG-1407 for delineating among full-scope and focused-scope 0.3g plants, PVNGS would apparently qualify as a 0.3g focused-scope site. NUREG-1407 precludes the exclusive use of focused-scope procedures in the IPEEE analysis of PVNGS. It is considered worthwhile, however, that the use of focused-scope procedures (on a non-exclusive basis) be pursued where found to be appropriate. In particular, results of the first IPEEE analysis, based on 0.3g full-scope SMA application for a single reactor unit, would be used as a basis for judging the applicability and adequacy of focused-scope procedures at the remaining two reactor units, and such procedures would be implemented as appropriate at these units.

The detailed basis for these statements and tentative recommendations, together with related results, are the subject of the remaining sections of this report.

1.6 REFERENCES

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8. USNRC. *Policy Issue (Information): Integration Plan for Closure of Severe Accident Issues.* SECY-88-147, May 25, 1988. USNRC Memorandum from Victor Stello, Jr. to Commissioners.

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Section 2
BACKGROUND ON IPEEE

This section provides a brief overview of the IPEEE process from a very general perspective. The intent of this overview is to clarify the use of the RLE ground-motion spectrum in plant screening, response analysis, capacity calculations, and IPEEE reporting. Additionally, the discussion introduces fundamental notation used consistently throughout this document.

2.1 GENERAL OVERVIEW OF PROCESS

Figure 2–1 presents a general overview of the IPEEE process. The first three elements of this process are common to guidelines that are found in both reports NUREG–1407 (1) and EPRI NP–7498 (2). The other elements, which pertain to the seismic IPEEE closure process, and the framework for considering alternative actions for plant modification, are explicit steps in the seismic-IPEEE implementation approach recommended by industry in EPRI NP–7498.

As indicated in Figure 2–1, the first step in the overall process is to conduct a plant walkdown and perform a plant screening analysis. The plant screening analysis produces a set of seismic-IPEEE *outliers.* Next, response analyses (e.g., structural dynamics calculations) are performed to determine expected seismic demands for particular plant components (structures or equipment) of interest. The purpose of the response analyses is to enable HCLPF capacities to be assessed for the outlier components. Outliers with computed HCLPF capacities that do not meet the specified RLE ground-motion demand are denoted as *remaining outliers* or *potential vulnerabilities.* In accordance with NUREG–1407, these remaining outliers are reported in the IPEEE submittal and require further evaluation as to their significance.

The evaluation process for remaining outliers (i.e., closure process) identifies whether or not alternative actions, in the form of *potential safety enhancements* that mitigate the potential vulnerabilities, need to be addressed. The closure process also assesses the cost-effectiveness of potential safety enhancements and indicates any resulting *safety enhancements* found to be justified and appropriate for implementation through modification of plant hardware or procedures. Any ultimate actions (or inactions) in response to potential vulnerabilities are clearly explained and justified by documentation in the IPEEE submittal.

As discussed in Section 1, the RLE does not delimit a plant-specific acceptance level, and therefore, serves no direct purpose in closure evaluation. The primary use of the RLE pertains to the plant screening level, the seismic input for capacity evaluations, and the HCLPF reporting basis (i.e., the first three elements in the overall process of Figure 2–1); each of these aspects of the seismic IPEEE is described briefly below.

2.2 PLANT SCREENING

The guidance on the EPRI seismic margins methodology provided in the report EPRI NP-6041 (3) [1991 revision to Reference (4)], or on the NRC seismic margins methodology provided in NUREG/CR–4334 (5), may be used as a basis for screening components. In particular, Table 2–3 (for structures) and Table 2–4 (for equipment) of EPRI NP-6041 provide conservative screening criteria, for various components, associated with alternative review levels defined by a range of spectral-acceleration screening limits. For instance, distinct screening criteria are defined for the following RLE spectral acceleration ranges: S_a less than 0.8g, S_a between 0.8g and 1.2g, and S_a greater than 1.2g. For plants with a RLE value of 0.3g PGA, the screening criteria applicable for $S_a < 0.8g$ are used in IPEEE implementation, whereas screening criteria for S_a values between 0.8g and 1.2g are used for plants with an RLE value of 0.5g PGA (2). Hence, selection of an RLE value determines at what level plant screening will be performed.

Components screened-out based on the applicable screening criteria require no further evaluation, indicating that the specified S_a screening limits are conservatively satisfied. Components screened-in as outliers cannot be said, on a conservative basis, to satisfy the specified S_a screening limits, and calculations are required to ascertain whether or not the outlier-component capacities in fact meet the screening limits (and/or the RLE spectral acceleration limits). Hence, the screening criteria themselves are somewhat conservative with respect to the actual screening-limit values. In other words, even if the screening criteria are not satisfied entirely, the associated screening limits may still be shown as being met through actual calculations.

In addition to the conservatism inherent in seismic-margin screening relative to the applicable screening limits, in seismic IPEEE implementation there is also conservatism in the seismic margin screening limits relative to the RLE ground-motion spectrum. Figure 2–2 indicates this conservatism (over the vibration frequency range of interest) for both the 0.8g S_a screening limits relative to the 0.3g RLE ground-motion spectrum, and the 1.2g S_a screening limits relative to the 0.5g RLE ground-motion spectrum.

As discussed in Section 1, the RLE ground-motion spectrum for IPEEE review is defined by the 5%-damped, median NUREG/CR-0098 (6) spectral shape [for the appropriate site condition (rock or soil)] anchored to the RLE PGA value. The lower RLE spectrum in Figure 2–2 has a RLE PGA value of 0.3g, whereas the upper RLE spectrum has a RLE PGA value of 0.5g. The lower screening spectrum in Figure 2–2 consists of a S_a limit of 0.8g and a spectral velocity (S_v) limit of 20 in/sec, whereas the upper screening spectrum consists of a S_a limit of 1.2g and a S_v limit of 30 in/sec. The basis for these screening limits, and for their use in the EPRI SMA screening tables, is presented in reports EPRI NP–6041 and EPRI NP–7498. The actual screening values of 0.8g and 1.2g compare conservatively with the maximum spectral accelerations of 0.636g and 1.06g, respectively, for the 0.3g-RLE and 0.5g-RLE ground-motion inputs.

The two sources of conservatism in plant screening just noted are both important to keep in mind when evaluating an appropriate ground-motion level for seismic-IPEEE implementation. The implications of these conservatisms are that components for which HCLPF capacities substantially in excess of the RLE demand will ultimately be demonstrated, will be initially screened-in as outliers. For a plant with a 0.3g review level, it is likely that some components with actual HCLPF PGA capacities as high as 0.35 to 0.40g (or so) may be screened-in for analysis.

2.3 RESPONSE ANALYSES AND CAPACITY CALCULATIONS

Another primary purpose of the RLE ground-motion spectrum, in addition to fixing the SMA screening limits and criteria, is to characterize the ground-motion input for component response analyses and HCLPF capacity calculations. In accordance with EPRI NP–6041, the RLE ground-motion demand should be applied at the free field as opposed to the basemat of the structure. Hence, for soil sites, it may be appropriate to conduct a soil-structure interaction analysis to develop the shaking input to specific components. The RLE ground-motion would serve as a reference or control motion for this purpose. The guidance provided in EPRI NP–6041 may be used as one basis for developing in-structure response spectra, when necessary, for either rock or soil conditions. Based on the results of the response analyses, HCLPF capacities may be computed using either the conservative deterministic failure margin approach or the fragility analysis method.

2.4 HCLPF REPORTING

The RLE ground-motion spectrum delimits the level at which HCLPF capacities must be documented. In other words, components either screened-out during the plant walkdown or found to have computed HCLPF capacities in excess of the RLE, do not require further evaluation. Only components found to have a computed HCLPF capacity lower than the RLE level need be documented as requiring further attention. A complete list of the outliers screened-in during the SMA walkdown should be reported, but no additional evaluation would be indicated for those components (outliers) with computed HCLPF capacities larger than the RLE.

2.5 REFERENCES

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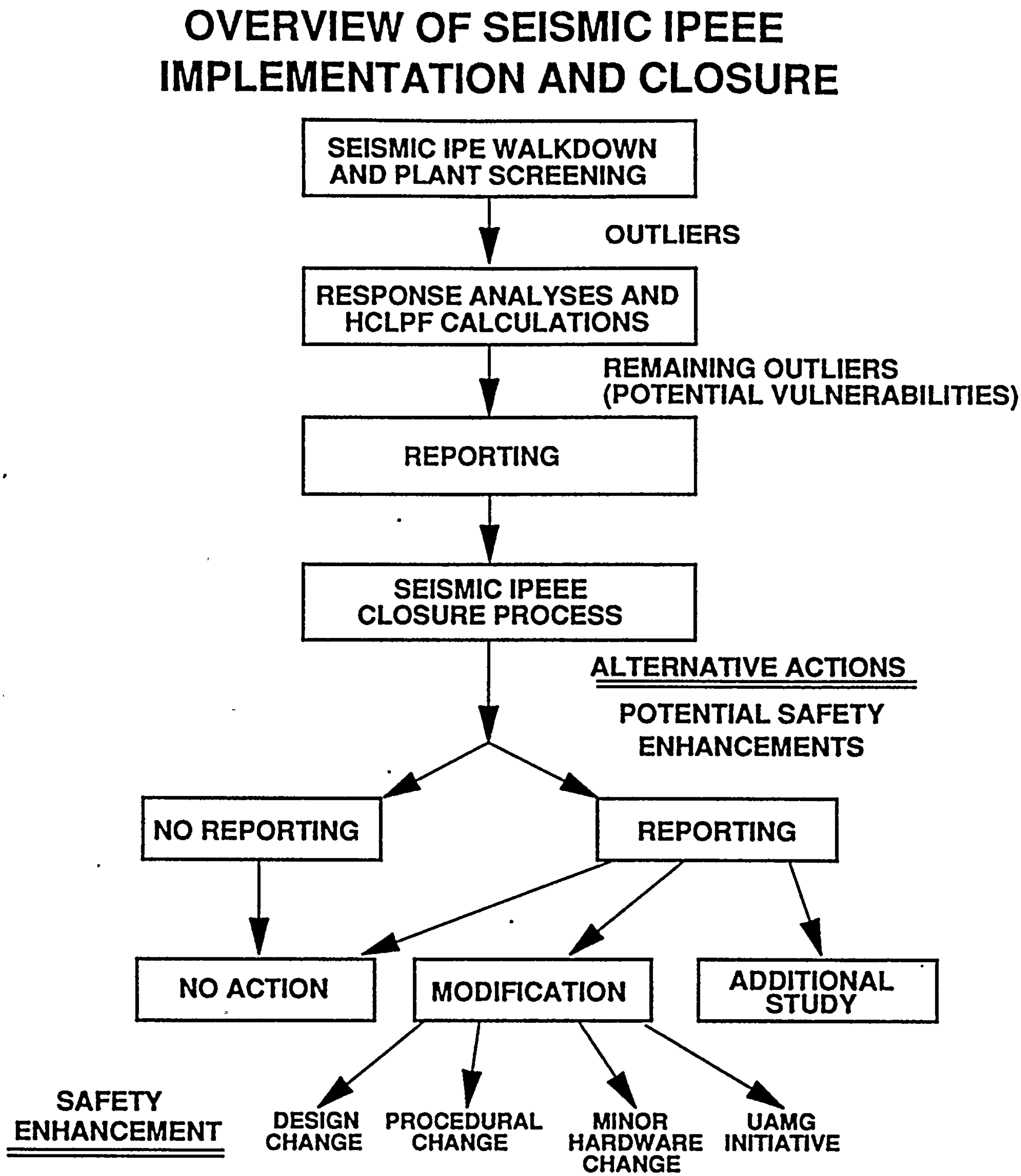

Figure 2-1. Diagram illustrating the overall seismic-IPEEE process.

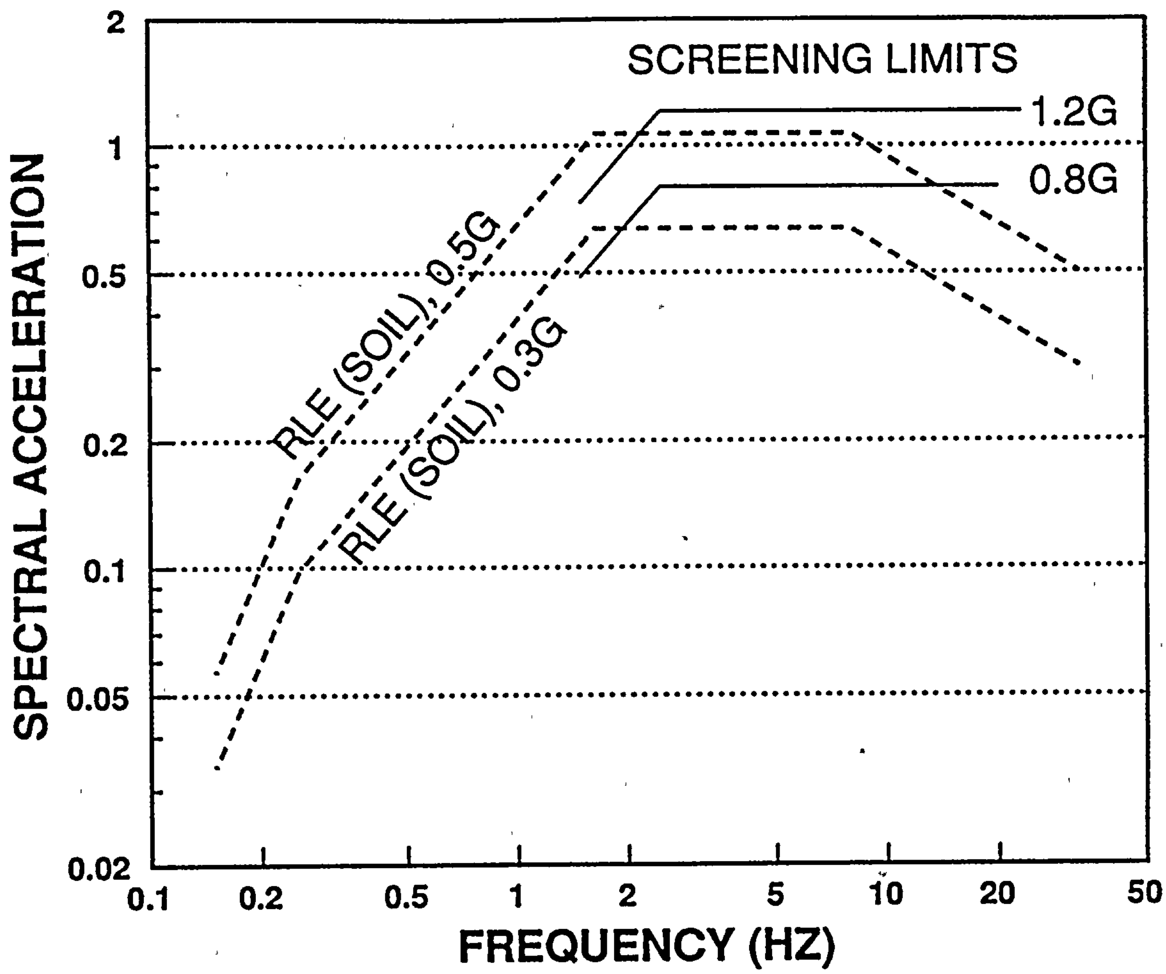

Figure 2-2. Spectral screening limits for implementing SMA screening criteria, compared with RLE spectra (at 0.3g and 0.5g) used in seismic-IPEEE implementation.

Section 3
SUMMARY OF SEISMIC HAZARD RESULTS

This section provides a quick summary of the seismic hazard results, for the PVNGS site, which are used as inputs to the comparison procedures and RLE evaluation approach described later. The fundamental results are seismic hazard curves for PGA and for spectral acceleration at vibration frequencies of 25 Hz, 10 Hz, 5 Hz, 2.5 Hz, and 1 Hz. From these curves, ground-motion spectra for uniform probabilities of exceedance (i.e., uniform hazard spectra) have been derived. Both hazard curves and uniform hazard spectra (UHS) are presented here to enable one to reproduce subsequent computations.

Complete documentation of the hazard study for the PVNGS site can be found in Reference (1). To facilitate subsequent analyses and comparisons [particularly for determining probabilities of exceedance of reference spectra (e.g., NUREG/CR-0098 and design bases)], ground-motion amplitudes have been converted, in the present study, from spectral velocities to spectral accelerations.

3.1 HAZARD-CURVE RESULTS

Data presented in Tables 3-1 to 3-6 provide the basis for constructing seismic hazard curves (annual frequencies of exceedance as a function of ground-motion amplitude) for peak acceleration and spectral acceleration at vibration frequencies of 25, 10, 5, 2.5, and 1 Hz. For various amplitudes of each of these ground-motion measures, the hazard data consist of the following statistics: mean, 15th fractile, median (50th fractile) and 85th fractile. Plots of the actual hazard curves for these statistics are shown in Figures 3-1 to 3-6.

3.2 UNIFORM HAZARD SPECTRA RESULTS

Table 3-7 presents ground-motion amplitudes corresponding to annual exceedance probability levels of 10^{-3}, 2×10^{-4}, 10^{-4}, and 10^{-5} Results are provided for the same set of hazard statistics described above.

Plots of the mean, 15th-fractile, median, and 85th-fractile UHS, for the above-referenced annual probability levels, are presented in Figures 3-7 to 3-10; separate graphs are shown for the different probability levels. In addition, Figure 3-11 shows, on one graph, the median UHS results for all probability levels.

3.3 RELEVANT ASPECTS OF THE PVNGS HAZARD ANALYSIS

For PVNGS to qualify as a 0.3g plant for IPEEE implementation, NUREG-1407 specifies that the seismic hazard at the PVNGS site should be similar to the hazard at sites in the central and eastern U.S. that belong to the 0.3g bin. For purposes of practical comparison, information from the EPRI and/or the LLNL hazard studies (2,3) should be used. It is important, therefore, that the hazard analysis procedure for the PVNGS site resemble (as closely as possible) the methodology developed in one of these major studies.

As discussed in Reference (1), the procedures employed in the hazard analysis are substantially similar to those comprising the EPRI seismic hazard methodology (4). The analysis was conducted in such a manner to establish a consistent basis for comparison of the PVNGS hazard results with the EPRI results for plants in the central and eastern United States. The soil amplification factors used in the PVNGS hazard analysis were different from those used (based on very general soil categorizations) in the EPRI hazard study of 58 sites (2); this difference was necessary as the general soil categorizations were judged to be inadequate (inapplicable) in characterizing the conditions at the PVNGS site. Nonetheless, the methods and format used in developing and describing site-specific soil amplification factors for the PVNGS site are very similar to those implemented in the EPRI hazard study.

Because the EPRI hazard study was undertaken specifically for plants east of the Rocky Mountains, but the PVNGS site is located in the Western U.S., one would expect some inherent differences in characterization of certain parameters in the analyses. For instance, the models and parameters for attenuation of ground motion differ necessarily to account for expected differences in ground-motion propagation for locations in the western versus eastern U.S. Despite these unavoidable differences, however, the hazard analysis for the PVNGS site is a state-of-the-art study representative of an EPRI analysis. In other words, it is believed that if the Palo Verde site were included in the original EPRI study, results would have been subtantially comparative to those obtained in Reference (1) [i.e., those used in this study].

Generally speaking, the LLNL hazard results for plants in the central and eastern U.S. are notably greater than those obtained from the EPRI hazard study. It can be expected, therefore, that (comparatively speaking) the PVNGS hazard results will be generally lower relative to the LLNL hazard values than to the EPRI hazard numbers. Consequently, it would be inappropriate to compare the present PVNGS results with the LLNL hazard results.

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Table 3-1

ANNUAL PROBABILITY OF EXCEEDANCE FOR PEAK GROUND ACCELERATION: PALO VERDE SITE (SOIL)

Peak Ground Acceleration (g)	Annual Exceedance Probabilities for:			
		Percentiles		
	Mean	15th	50th	85th
0.010	.182E-01	.123E-02	.603E-02	.257E-01
0.020	.375E-02	.617E-03	.214E-02	.692E-02
0.051	.628E-03	.219E-03	.501E-03	.100E-02
0.071	.349E-03	.135E-03	.288E-03	.537E-03
0.102	.186E-03	.832E-04	.155E-03	.269E-03
0.153	.835E-04	.417E-04	.700E-04	.117E-03
0.204	.419E-04	.209E-04	.339E-04	.589E-04
0.306	.982E-05	.347E-05	.741E-05	.159E-04
0.509	.535E-06	.550E-07	.251E-06	.933E-06
1.019	.606E-08	.260E-09	.162E-08	.977E-08

Table 3-2

ANNUAL PROBABILITY OF EXCEEDANCE FOR 25-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.03	0.005	.159E+00	.324E-02	.248E-01	.191E+00
0.06	0.010	.281E-01	.151E-02	.851E-02	.417E-01
0.10	0.016	.824E-02	.871E-03	.372E-02	.148E-01
0.20	0.032	.178E-02	.437E-03	.123E-02	.324E-02
0.50	0.080	.325E-03	.135E-03	.269E-03	.501E-03
1.00	0.160	.820E-04	.389E-04	.676E-04	.117E-03
2.00	0.320	.875E-05	.282E-05	.646E-05	.138E-04
5.00	0.800	.398E-07	.199E-08	.129E-07	.676E-07
7.00	1.120	.396E-08	.955E-10	.813E-09	.603E-08
10.00	1.600	.234E-09	.107E-11	.275E-10	.299E-09
15.00	2.401	.591E-11	.138E-28	.211E-12	.603E-11
20.00	3.201	.329E-12	.100E-29	.398E-14	.234E-12

Table 3-3

ANNUAL PROBABILITY OF EXCEEDANCE FOR 10-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.03	0.002	.123E+00	.692E-02	.403E-01	.204E+00
0.06	0.004	.398E-01	.372E-02	.195E-01	.724E-01
0.10	0.006	.179E-01	.229E-02	.120E-01	.363E-01
0.20	0.013	.684E-02	.123E-02	.525E-02	.138E-01
0.50	0.032	.203E-02	.575E-03	.174E-02	.347E-02
1.00	0.064	.836E-03	.288E-03	.708E-03	.132E-02
2.00	0.128	.330E-03	.117E-03	.269E-03	.501E-03
5.00	0.320	.517E-04	.112E-04	.316E-04	.891E-04
7.00	0.448	.185E-04	.107E-05	.794E-05	.389E-04
10.00	0.640	.555E-05	.631E-07	.141E-05	.112E-04
15.00	0.960	.130E-05	.302E-08	.145E-06	.245E-05
20.00	1.280	.410E-06	.243E-09	.209E-07	.661E-06
30.00	1.921	.602E-07	.385E-11	.933E-09	.550E-07
50.00	3.201	.262E-08	.275E-19	.603E-11	.119E-08
100.00	6.402	.117E-10	.100E-29	.708E-15	.193E-11

Table 3-4

ANNUAL PROBABILITY OF EXCEEDANCE FOR 5-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.005	.203E+00	.525E-02	.240E-01	.269E+00
0.50	0.016	.175E-01	.162E-02	.525E-02	.275E-01
1.00	0.032	.461E-02	.813E-03	.214E-02	.851E-02
2.00	0.064	.136E-02	.437E-03	.871E-03	.229E-02
5.00	0.160	.325E-03	.144E-03	.251E-03	.501E-03
7.00	0.224	.187E-03	.891E-04	.144E-03	.269E-03
10.00	0.320	.100E-03	.513E-04	.776E-04	.144E-03
15.00	0.480	.367E-04	.138E-04	.275E-04	.550E-04
20.00	0.640	.132E-04	.111E-05	.912E-05	.240E-04
30.00	0.960	.199E-05	.129E-07	.393E-06	.372E-05
50.00	1.600	.127E-06	.178E-09	.525E-08	.140E-06
100.00	3.201	.210E-08	.355E-12	.202E-10	.871E-09

Table 3-5

ANNUAL PROBABILITY OF EXCEEDANCE FOR 2.5-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.002	.454E+00	.143E-01	.776E-01	.759E+00
0.50	0.008	.548E-01	.282E-02	.977E-02	.776E-01
1.00	0.016	.157E-01	.123E-02	.302E-02	.209E-01
2.00	0.032	.317E-02	.537E-03	.100E-02	.442E-02
5.00	0.080	.424E-03	.178E-03	.288E-03	.661E-03
7.00	0.112	.236E-03	.102E-03	.166E-03	.355E-03
10.00	0.160	.131E-03	.589E-04	.102E-03	.190E-03
15.00	0.240	.668E-04	.275E-04	.550E-04	.102E-03
20.00	0.320	.385E-04	.129E-04	.316E-04	.589E-04
30.00	0.480	.144E-04	.282E-05	.105E-04	.240E-04
50.00	0.800	.187E-05	.102E-06	.813E-06	.347E-05
100.00	1.600	.302E-07	.172E-09	.359E-08	.417E-07

Table 3-6

ANNUAL PROBABILITY OF EXCEEDANCE FOR 1-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.001	.655E+00	.224E-01	.219E+00	.933E+00
0.50	0.003	.111E+00	.302E-02	.209E-01	.219E+00
1.00	0.006	.410E-01	.966E-03	.525E-02	.631E-01
2.00	0.013	.131E-01	.355E-03	.123E-02	.170E-01
5.00	0.032	.159E-02	.923E-04	.219E-03	.132E-02
7.00	0.045	.601E-03	.550E-04	.126E-03	.537E-03
10.00	0.064	.192E-03	.266E-04	.676E-04	.234E-03
15.00	0.096	.586E-04	.851E-05	.339E-04	.891E-04
20.00	0.128	.275E-04	.302E-05	.159E-04	.479E-04
30.00	0.192	.893E-05	.309E-06	.372E-05	.170E-04
50.00	0.320	.155E-05	.881E-08	.251E-06	.263E-05
100.00	0.640	.798E-07	.143E-10	.151E-08	.803E-07

Table 3-7

SPECTRAL ACCELERATIONS FOR VARIOUS EXCEEDANCE PROBABILITIES: PALO VERDE SITE (SOIL)

		Frequency (Hz)					
		PGA	25	10	5	2.5	1
Exceedance Probability	Statistic or Percentile	Period (sec)					
		PGA	0.04	0.1	0.2	0.4	1
1×10^{-3}	Mean	0.040	0.044	0.056	0.078	0.054	0.038
	15	0.013	0.014	0.016	0.026	0.019	0.006
	50	0.033	0.036	0.049	0.058	0.032	0.014
	85	0.051	0.057	0.078	0.106	0.066	0.036
2×10^{-4}	Mean	0.098	0.102	0.164	0.215	0.124	0.063
	15	0.054	0.059	0.085	0.122	0.073	0.019
	50	0.088	0.093	0.145	0.184	0.100	0.034
	85	0.118	0.124	0.208	0.265	0.155	0.068
1×10^{-4}	Mean	0.140	0.145	0.231	0.320	0.188	0.080
	15	0.089	0.095	0.136	0.207	0.113	0.030
	50	0.127	0.131	0.196	0.277	0.162	0.051
	85	0.163	0.168	0.301	0.373	0.243	0.091
1×10^{-5}	Mean	0.304	0.307	0.538	0.679	0.526	0.184
	15	0.241	0.229	0.325	0.498	0.343	0.091
	50	0.282	0.281	0.424	0.625	0.485	0.146
	85	0.332	0.338	0.660	0.774	0.605	0.222

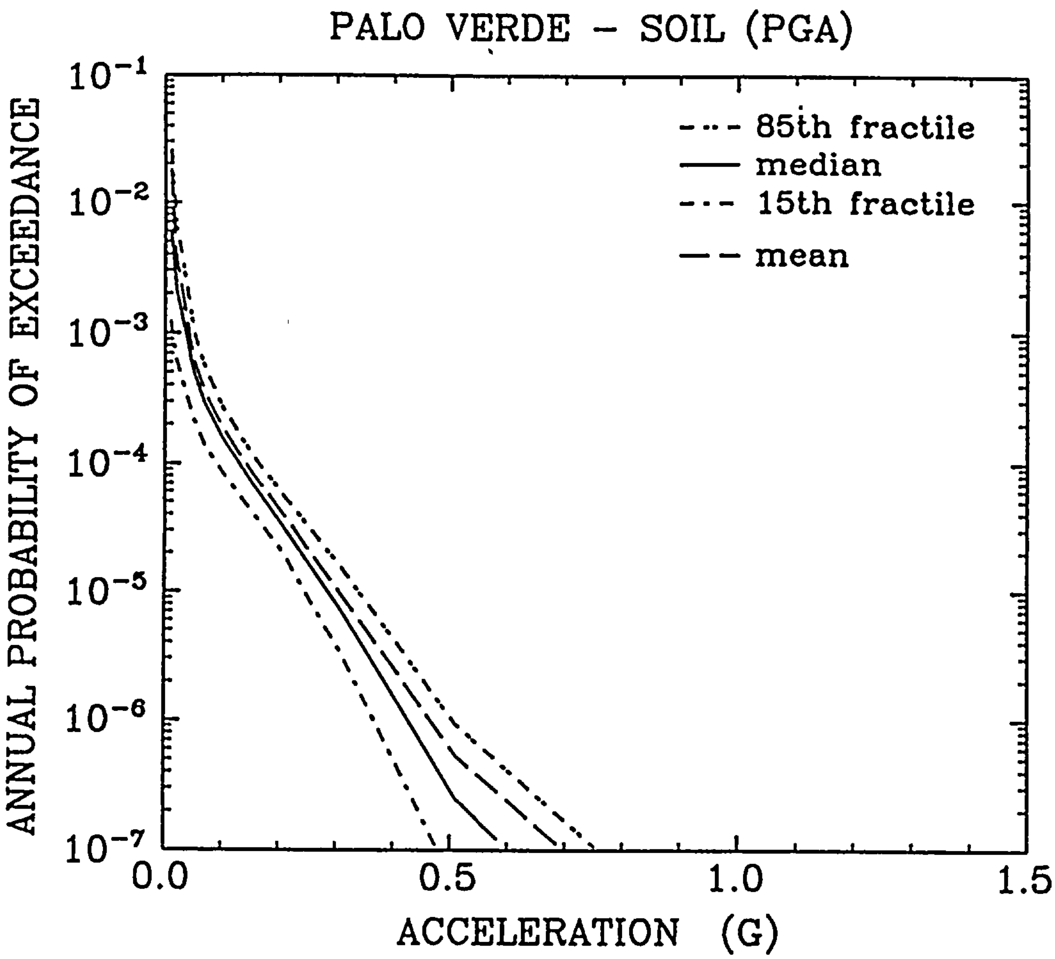

Figure 3-1. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for peak ground acceleration; Palo Verde site (Soil).

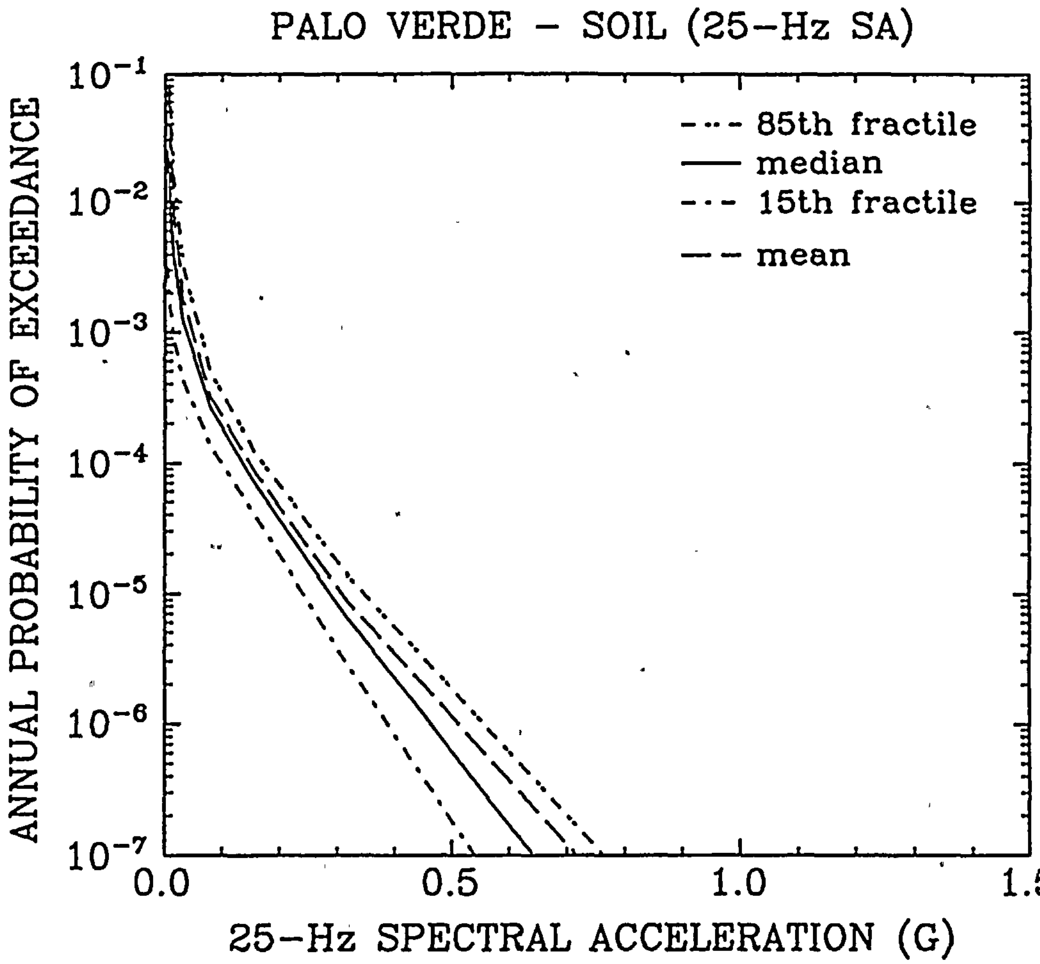

Figure 3-2. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 25-Hz spectral acceleration; Palo Verde site (Soil).

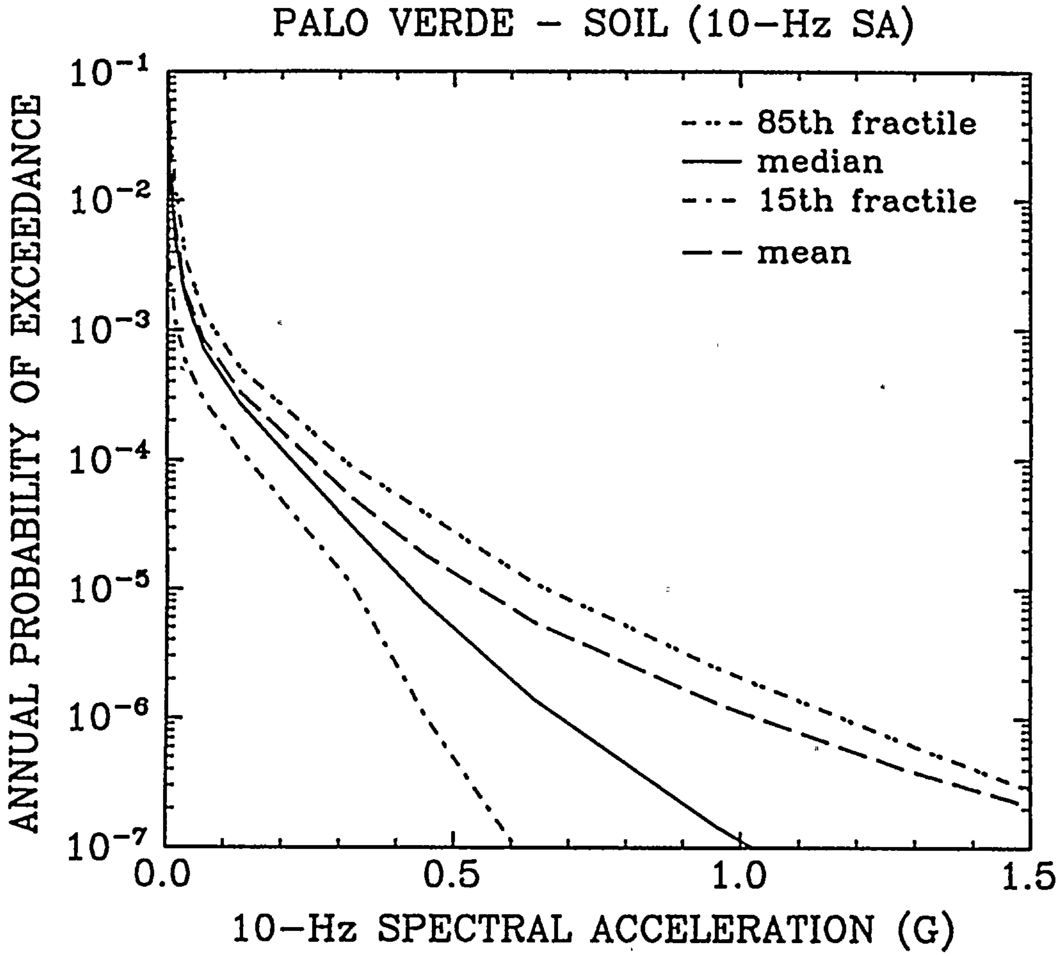

Figure 3-3. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 10-Hz spectral acceleration; Palo Verde site (Soil).

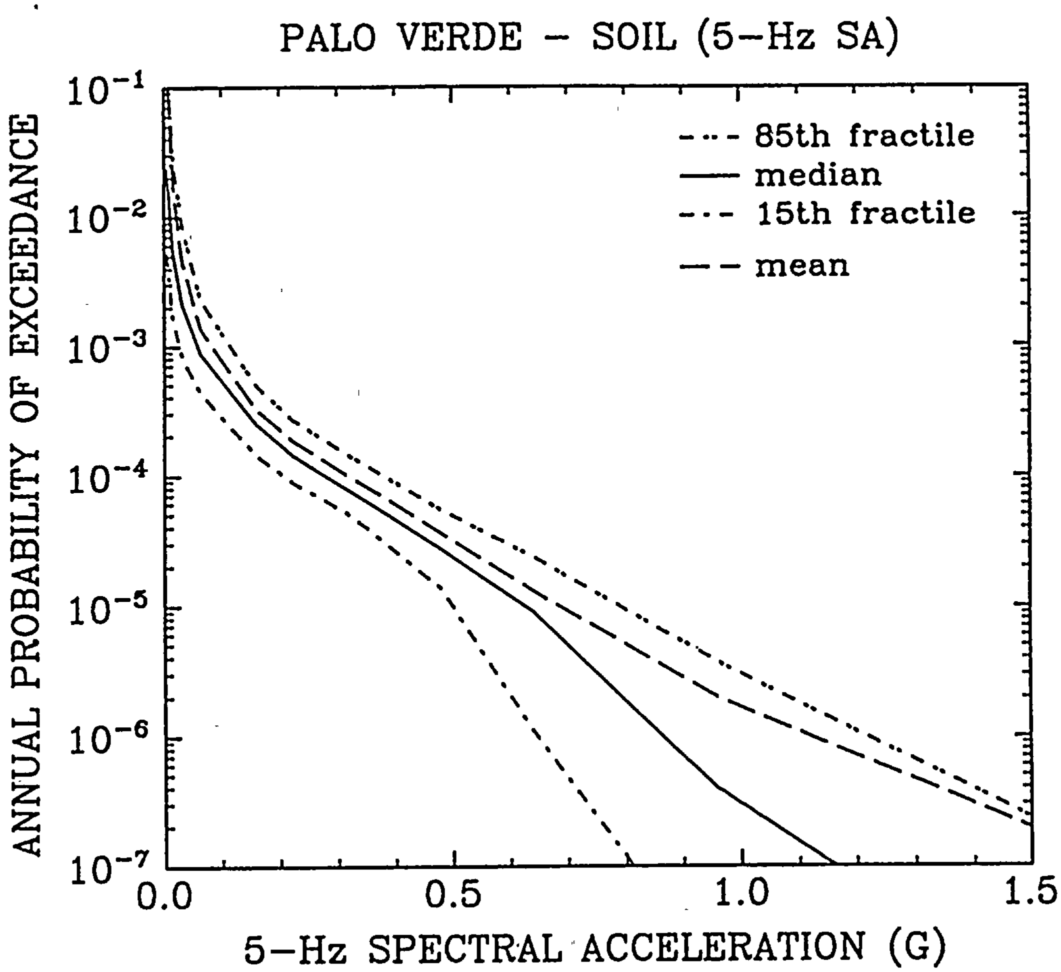

Figure 3-4. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 5-Hz spectral acceleration; Palo Verde site (Soil).

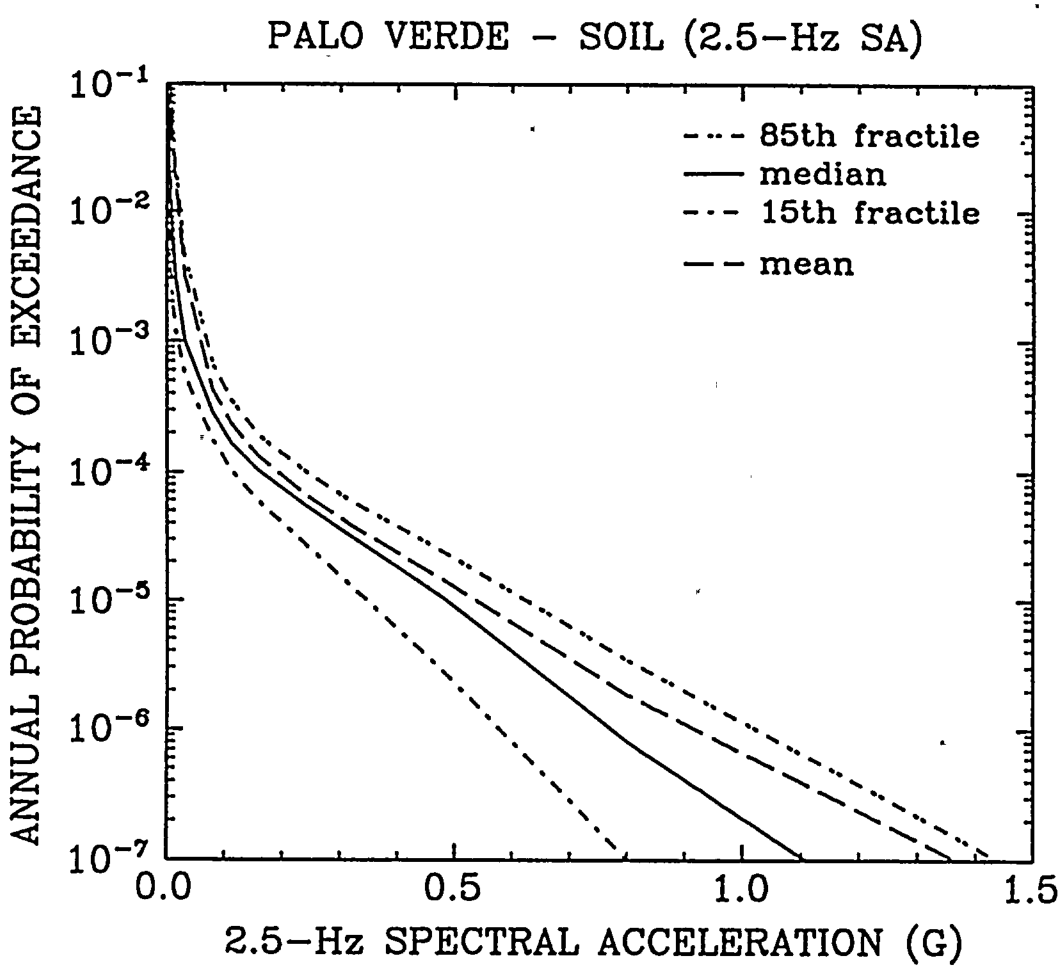

Figure 3-5. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 2.5-Hz spectral acceleration; Palo Verde site (Soil).

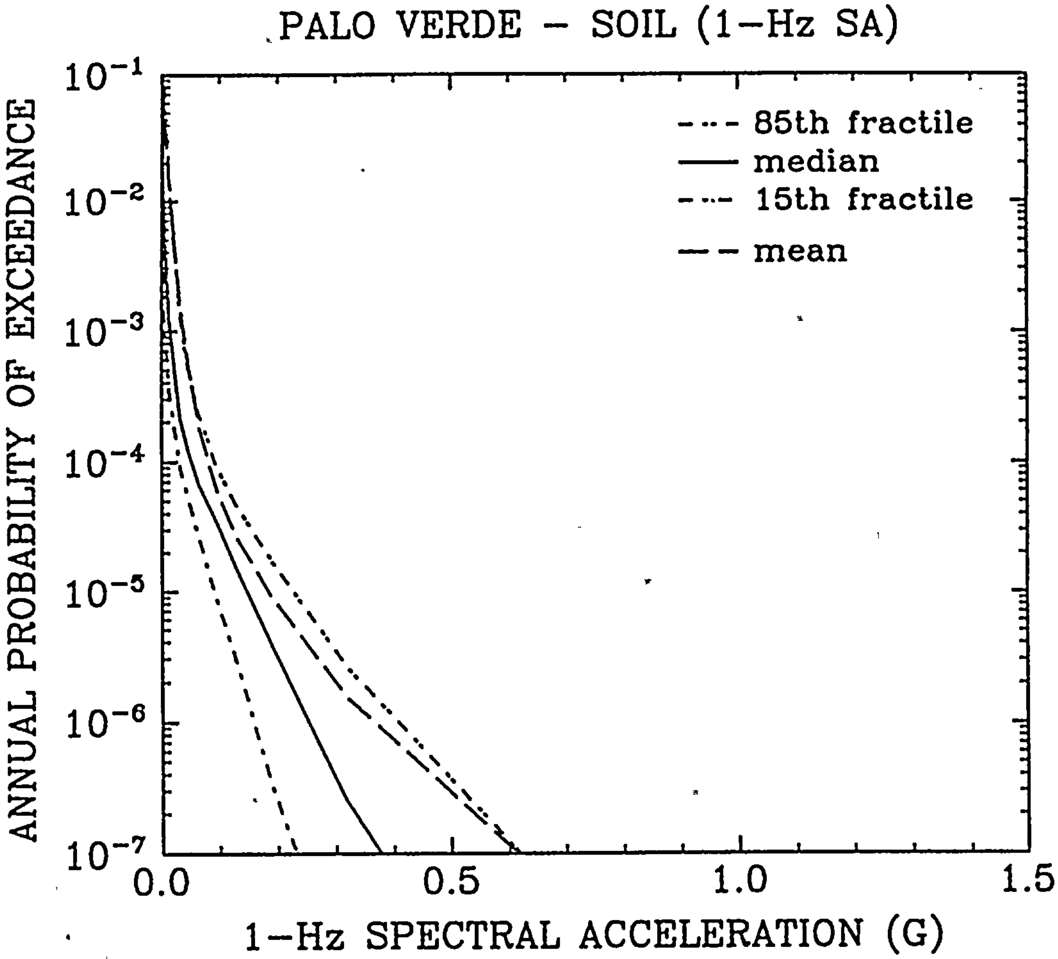

Figure 3-6. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 1-Hz spectral acceleration; Palo Verde site (Soil).

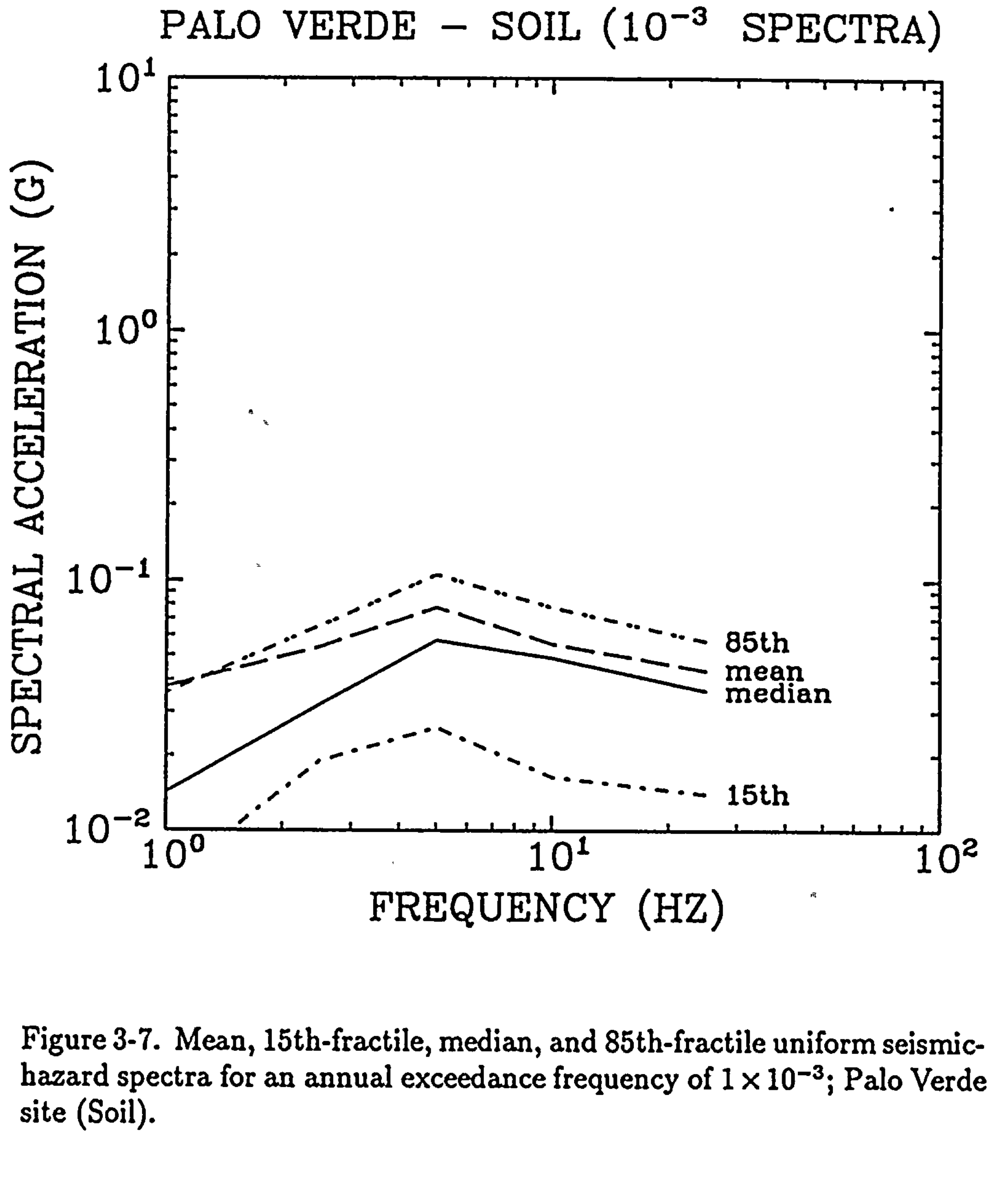

Figure 3-7. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-3}; Palo Verde site (Soil).

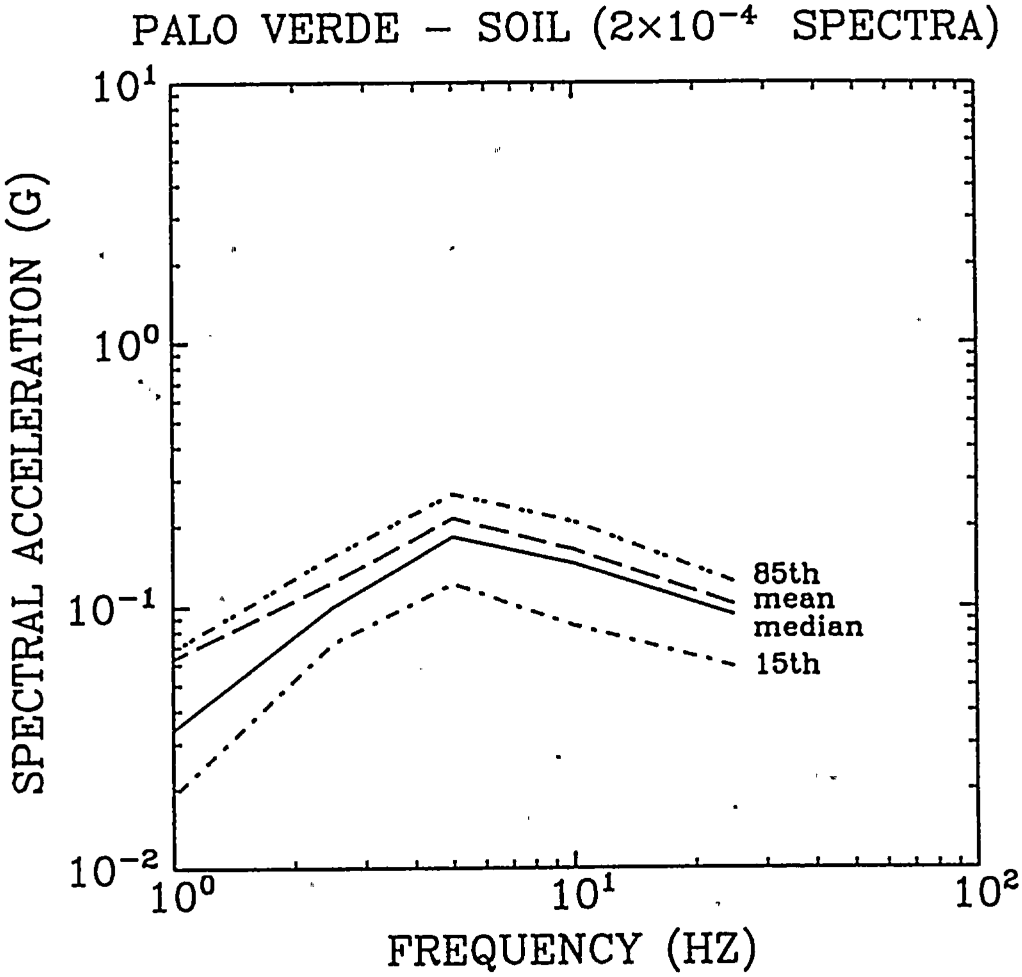

Figure 3-8. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 2×10^{-4}; Palo Verde site (Soil).

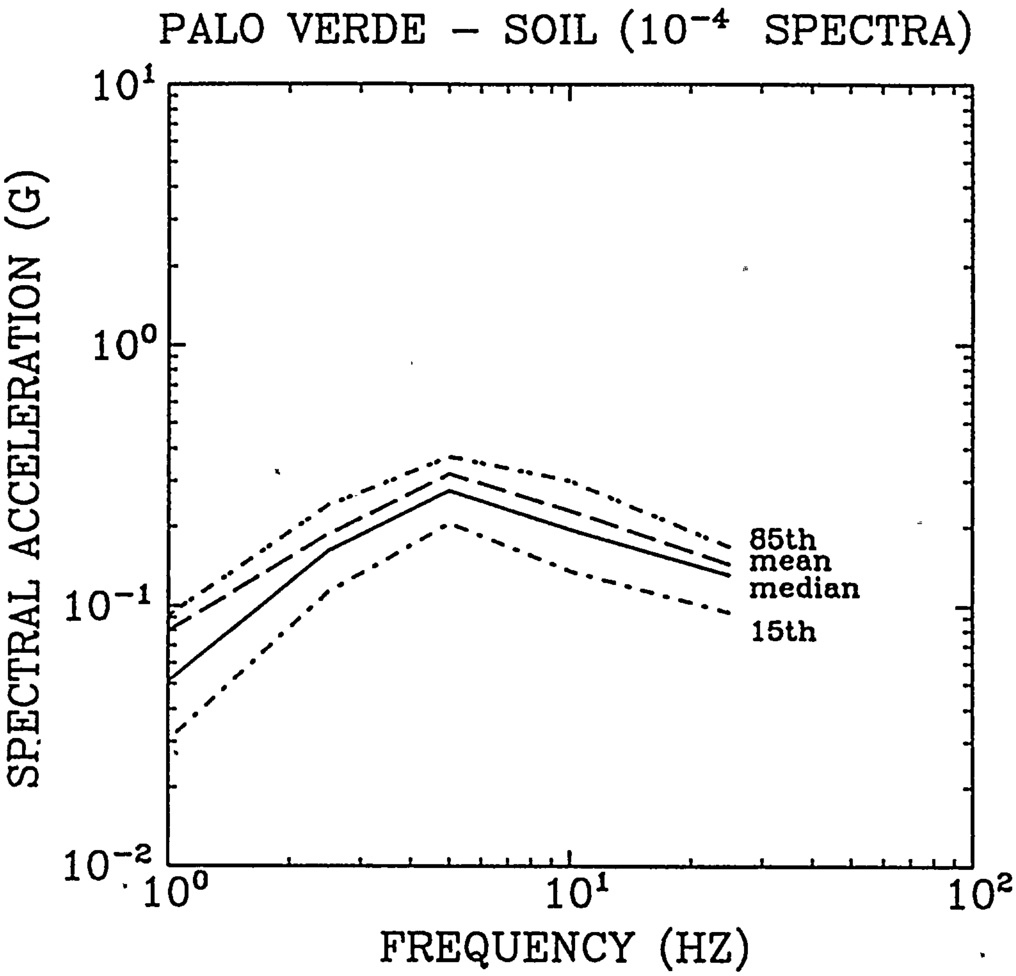

Figure 3-9. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-4}; Palo Verde site (Soil).

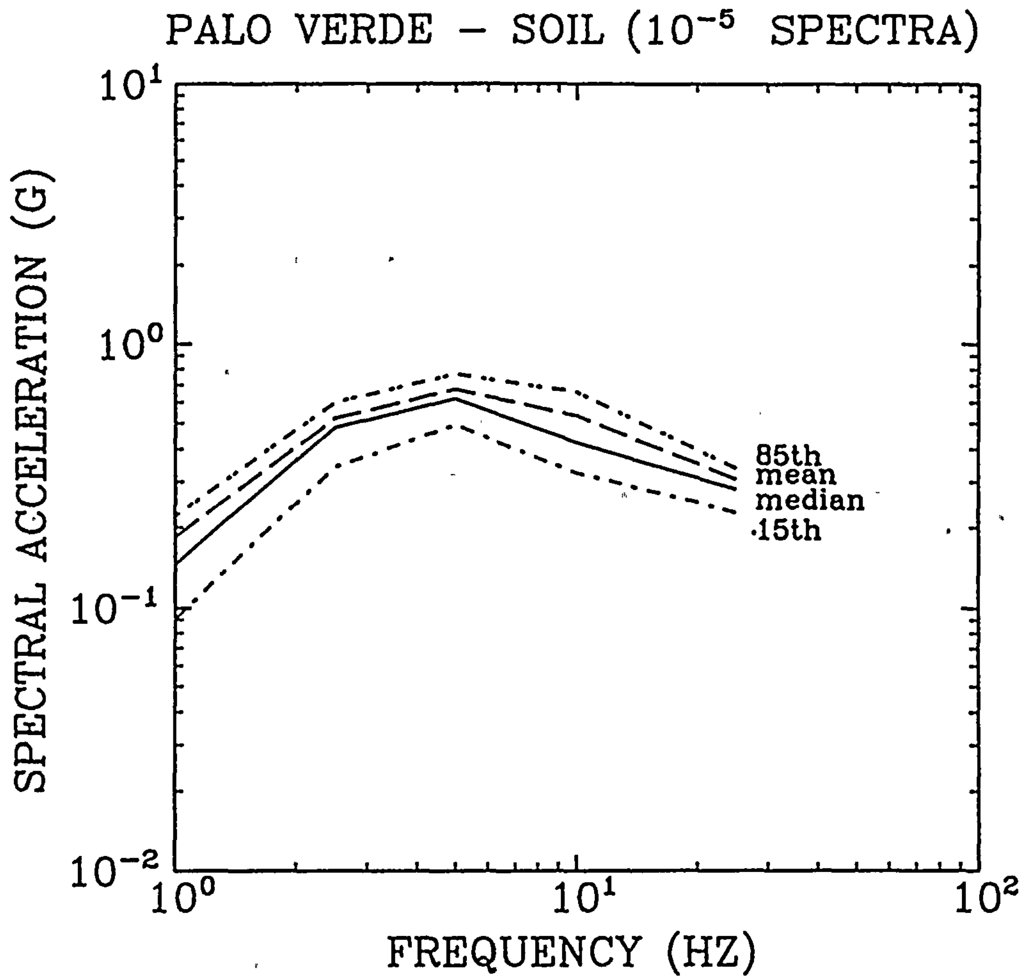

Figure 3-10. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-5}; Palo Verde site (Soil).

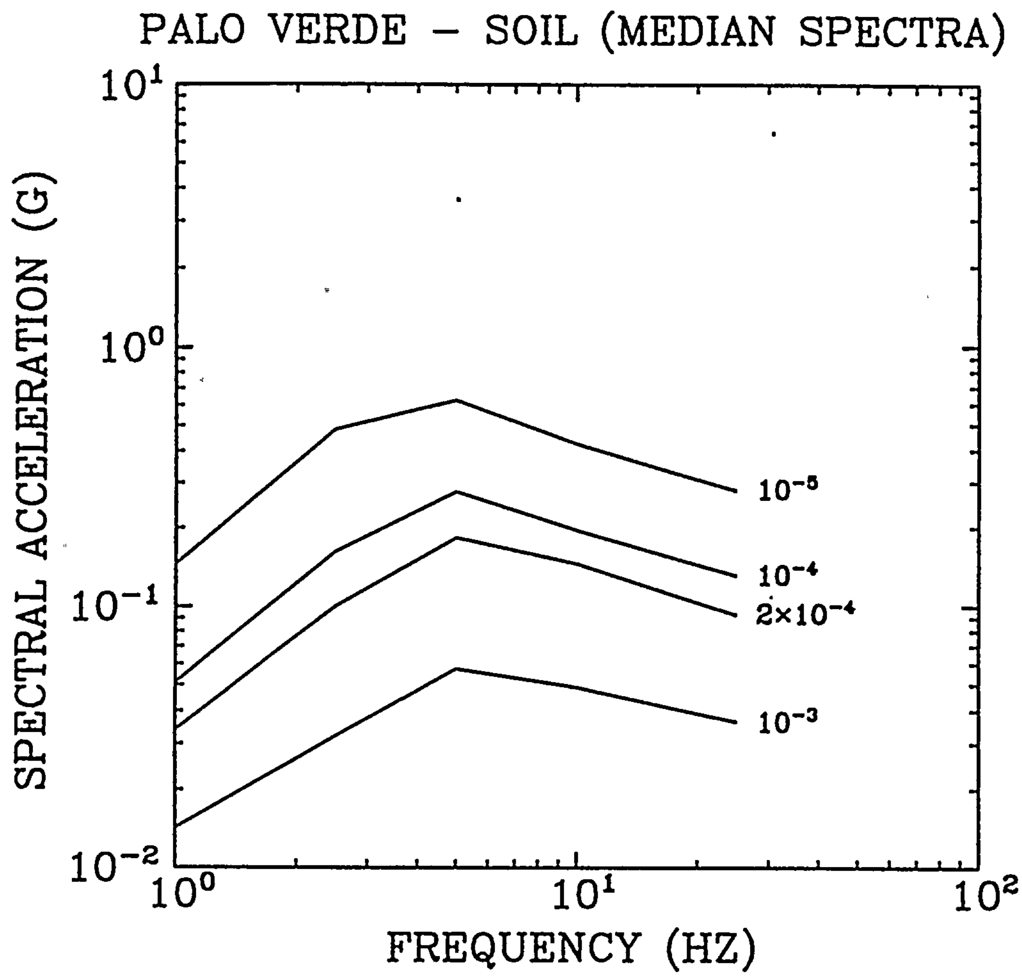

Figure 3-11. Median uniform seismic-hazard spectra for annual exceedance frequencies of 1×10^{-3}, 2×10^{-4}, 1×10^{-4}, and 1×10^{-5}; Palo Verde site (Soil).

Section 4
RLE EVALUATION APPROACH

This section summarizes the approaches, used for comparing seismic hazard results, which serve as a basis in developing a recommended RLE value at the PVNGS site. The justification for the procedures and comparisons employed is provided. An overview of specific aspects in NUREG–1407 (1) which pertain to plant binning is presented to demonstrate a consistent approach and basis in this report. The technical methods for computing hazard-based measures are clearly explained, to enable one to reproduce this study's results. And, the appropriate role of alternative hazard comparisons in developing RLE-related assessments is explained.

4.1 OVERVIEW OF RECOMMENDATIONS IN NUREG–1407

The general RLE evaluation approach discussed here follows closely the binning rationale and bases adopted in NUREG–1407 for RLE assessment. For the PVNGS site to be reassigned in the 0.3g review-level bin, NUREG–1407 requires simply that it be shown that the site hazard is similar to that at plants east of the Rocky Mountains that are found in the 0.3g bin.

Because, however, there are a variety of hazard statistics and an infinite set of combinations and comparisons that can be made with these, specific guidance on the comparison process proves useful in practical assessment. To achieve the greatest level of consistency with the basis for binning the central/eastern U.S. plants, the specific hazard statistics, weighting criteria, and binning philosophy used in NUREG–1407 are considered here. These aspects of the RLE evaluation process (characterized as they are presented in Appendix A of NUREG–1407) are discussed below:

- Comparison Procedure. Hazard comparisons are made using the mean, median, and 85th-fractile hazard statistics. Although both EPRI and LLNL hazard results were used in the binning of the 0.3g plants, for the reasons discussed in Section 3, the EPRI hazard results form the basis here for comparison with the PVNGS results. NUREG–1407 does not specify that a particular analysis procedure (EPRI, LLNL, or other) must be used to demonstrate similarity in seismic hazard. It is anticipated that the binning results achieved will be substantially robust with respect to the hazard methodology considered, so long as comparisons are made on a consistent and relative basis.

- Weighting Criteria. To facilitate developing conclusions from hazard comparisons, it is useful to establish a reasonable weighting of results for various vibration frequencies. In this manner, ambiguities related to variations in comparisons across spectral frequencies are removed. NUREG–1407 specifies that unit weights of 2/7th each should be assigned to the likelihoods of exceeding spectral response ordinates at 2.5, 5, and 10 Hz, whereas one-half unit weight should be assigned to the likelihood of exceeding the PGA. (Note, the weightings are applied to exceedance frequencies as opposed to ground-motion ordinates). The present study makes no representation that this method of frequency-dependent weighting is the most reasonable [numerous studies would suggest giving no weight to PGA, but perhaps some (small) weight to frequencies between 10 and 25 Hz]. Nonetheless, to establish comparisons that are consistent with the basis used in defining the 0.3g bin, it has been considered most appropriate to adopt the same weighting criteria here as used in NUREG–1407.

- Spectral Shape. Comparisons of a single uniform hazard spectrum will not account for the range of exceedance frequencies, and variations with vibration frequency, that are expected to be meaningful to plant risk. A variety of UHS may be compared, or alternatively (to facilitate comparison), a relevant transformation of the hazard surface (a three-dimensional function of vibration frequency and ground-motion amplitude) may be performed which does achieve an appropriate comparison that is roughly meaningful in terms of contribution to plant risk. Selection of an appropriate ground-motion spectrum provides a simple basis for performing such a transformation.

  Because the seismic design process is used to establish capacities of major plant components, and because the probability of exceeding plant capacity is relevant to plant risk, it would appear appropriate that the seismic design-basis spectrum be chosen for the hazard transformation. In fact, such a means for characterizing hazard results has been proposed (2,3). An alternative viewpoint is that the seismic design level may generally have little significance on plant capacity (and risk) due to dominance of spurious conditions and unanticipated outliers that are not directly impacted by the magnitude of the design level. In this case, a target plant HCLPF capacity may be considered to be a more appropriate hazard-transformation basis. Although plant-specific target HCLPFs or acceptance levels have not been proposed in NUREG–1407, the NUREG/CR-0098 (median, 5%-damped) spectrum anchored to 0.3g serves as a preliminary basis for characterizing a target and/or expected plant capacity. In fact, NUREG-1407 does specify that this spectrum be used for performing hazard transformations in developing probability of exceedance characterizations used as a basis for the major grouping of plants into 0.5g and 0.3g bins. For the plants that fall within the 0.3g bin on this basis, however, the design-basis spectrum is subsequently used for hazard transformation in developing exceedance-probability characterizations for sub-grouping the plants into full-scope and focused-scope categories.

A similar approach is taken in this study. That is, similarity in comparisons of probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum is used as a basis for delineating whether or not a 0.3g RLE assessment at the PVNGS site would be appropriate. Provided that a favorable basis for the 0.3g RLE evaluation is indicated, then similarity in probabilities of exceeding plant design basis is used to decide whether or not a focused-scope categorization is justified. NUREG-1407 does not allow the implementation of focused-scope procedures, on an exclusive basis, for IPEEE review at the Palo Verde station. Yet, if a favorable comparison for focused-scope categorization is indicated, certain applications of focused-scope methods may be appropriate, as so judged by the IPEEE Seismic Review Team after performing a full-scope analysis of one of the reactor units.

- Specific Binning Procedure. Nine separate hazard measures (three hazard statistics each for the LLNL five-expert, LLNL four-expert, and EPRI studies) were used in NUREG-1407 as binning criteria. Conditional binnings were obtained for each of these nine measures based on a grouping/clustering methodology employed in NUREG-1407. Final binning was based on a consistency analyses of the nine distinct groupings; consistency criteria considered agreement among all of the three hazard studies and agreement between the median and either the mean or 85th-fractile statistic. For a final binning assignment of 0.5g, all consistency criteria had to be satisfied. For instance, if a 0.5g conditional binning assignment was indicated for all criteria except the EPRI median, a plant would remain in the 0.3g bin; conclusions on binning had to be clearly supported by all hazard studies.

  For the present case where results of EPRI hazard analyses are compared, the above binning approach would imply that conditional assignments of 0.5g must be indicated for all three criteria (mean, median, and 85th-fractile results) in order for a final RLE binning of 0.5g to be clearly supported. In other words, if only one of the criteria indicated a 0.3g conditional assignment, then that assignment would govern the final binning (of 0.3g).

In the present study, a formal conditional binning assessment (as that used in NUREG-1407) is not undertaken. Although including the PVNGS results in the original binning procedure would have effected the basis for clustering or grouping plants, no such explicit impact on the binning delineations is considered here. As a surrogate (and simpler) approach to the conditional binning based on clustering, this study assumes that the range of composite exceedance probabilities defined by the 0.3g plants defines general reference limits for making conditional assignments to a 0.3g or 0.5g bin. Hence, if a composite exceedance probability for a particular hazard statistic fell above the upper limit of similar results for the 0.3g plants, then a conditional assignment of 0.5g would be indicated for that hazard statistic. Because (for a variety of reasons) the binning delineations are not precise, a variation on the order of a few percent above the upper limit would not be considered significant.

- Subsequent Binning Evaluations. To confirm that the absolute level of hazard was sufficiently high to warrant inclusion in the 0.5g bin, a subsequent "sanity check" was included in the NUREG-1407 binning evaluation. In this confirmation check, it was assumed that a 0.5g binning assessment would be supported if: (1) the mean or 85th-fractile (composite) annual likelihood of exceeding the 0.3g spectrum from all hazard studies was 10^{-4} or greater, and (2) the median (composite) annual likelihood of exceeding the 0.3g spectrum from all hazard studies was 10^{-5} or greater.

  For the present RLE evaluation approach, this check implies that the median composite probability of exceeding the 0.3g NUREG/CR-0098 spectrum must be greater that the value of 10^{-5} and either the corresponding mean or 85th-fractile composite probability must also exceed the value of 10^{-4} to confirm a 0.5g assignment. Stated in an alternative way, if both the mean and 85th-fractile values are less that 10^{-4}, but the median value is greater than 10^{-5}, then an RLE assessment of 0.5g is not clearly supported.

The above aspects of the NUREG-1407 procedure help to better define consistent avenues to follow in performing seismic hazard comparisons for RLE assessment. Consideration of hazard statistics, hazard-transformation procedures, and comparison approaches beyond those just described would at best be merely superfluous for the purposes of RLE evaluation, but at worst (if relied upon) might lead to inconsistencies relative to the overall binning process.

4.2 OVERVIEW OF INDUSTRY RECOMMENDATIONS

Industry recommendations for selection of a seismic-IPEEE review type are provided in the report EPRI NP-7498. The overall approach is somewhat similar to that specified in the NUREG-1407 analyses. In particular, the use of composite probabilities of exceeding seismic design levels is recommended in selecting among full-scope and focused-scope review alternatives.

The overall philosophy and bases for review-level selection recommended in EPRI NP-7498 have influenced the guidelines developed in NUREG-1407 and have served as background for the present study. The approach does not describe specific methods that would be applicable for distinguishing a 0.5g review level. Hence, no further specific consideration of these guidelines is required.

4.3 CALCULATION OF HAZARD-BASED MEASURES

As identified above, the primary hazard-based measures required for subsequent comparisons and RLE evaluation consist of composite probabilities of exceeding the 0.3g NUREG/CR-0098 spectra and composite probabilities of exceeding plant seismic design levels. As illustrated in Figures 4-1 and 4-2, the calculation of these measures is straightforward. Whether the 0.3g NUREG/CR-0098 spectrum, the design-basis spectrum, or some other ground-motion spectrum is used as the hazard-transformation basis, the approach for obtaining the probability measures is identical. In all cases, we assume that a reference spectrum has been obtained for converting to probabilities.

As shown in Figures 4-1, the first step in obtaining probabilities is to overlay a set of uniform hazard spectra (mean, median, or 85th fractile) on the reference spectrum and interpolate between UHS curves for ground-motion ordinates at various vibration frequencies. The vibration frequencies to consider include the union of frequencies defining the UHS curves and the reference spectrum, to insure that all distinct segments of the subsequent probability spectra are defined. (Although not shown in Figure 4-1, the interpolation of probabilities should also be performed for PGA). In addition, the interpolation (at given vibration frequency) assumes a linear variation in the logarithm of hazard versus the logarithm of ground-motion ordinates.

The next step is to construct a probability spectrum from the interpolated results at the various vibration frequencies. By obtaining such probability spectra for several sites, comparisons can be readily made (as indicated in Step C of Figure 4-1). These comparisons are useful in indicating variations in hazard-based measures with vibration frequency. For purposes of binning comparisons and RLE evaluation, these spectral results must be converted to scalar or composite probabilities. The procedure for weighting the probability spectra to obtain composite-probability values is indicated in Figure 4–2.

The transformation of ground-motion spectra to composite probabilities occurs separately for mean, median, and 85th-fractile hazard statistics. For comparison purposes, the results are three plots for each type of ground-motion transformation: each plot presents (based on results for several sites) plant-to-plant values of composite probabilities for a given hazard statistic.

4.4 RLE EVALUATION RELATIVE TO FULL-SCOPE PLANTS

The process for determining whether or not an RLE evaluation of 0.3g full scope would be appropriate for a particular site that is initially assigned, by default, to the 0.5g bin, requires plant-to-plant comparisons of mean, median, and 85th-fractile composite probabilities of exceeding the NUREG/CR–0098 spectrum (median, 5%-damped) anchored to a PGA value of 0.3g.

It is appropriate to first evaluate whether the median composite probability of exceeding the 0.3g spectrum is greater than 10^{-5} or whether the mean and 85th-fractile composite probabilities are greater than 10^{-4}. If either of these two conditions is not demonstrated, then their would not be a clearly supported basis for the 0.5g RLE assignment; on the other hand, if the test of the two conditions are both affirmative, then it is unlikely that a 0.3g RLE evaluation would be justifiable.

Given that the former case has been demonstrated, it would be appropriate to next make conditional RLE binning assignments for each of the three hazard statistics. For instance, if the composite hazard measure fell near or below the upper range of composite values comprising the set of 0.3g plants, then a conditional RLE binning assessment of 0.3g would be indicated; otherwise, a conditional RLE assignment of 0.5g would be required.

Consistent with the approach in NUREG–1407, conditional RLE binnings for all three hazard statistics would be required to clearly justify a 0.5g RLE assessment; if any one of the conditional binnings indicated a 0.3g RLE, then a final RLE evaluation of 0.3g would be supported.

4.5 RLE EVALUATION RELATIVE TO FOCUSED-SCOPE PLANTS

Presuming that a supportable basis for a 0.3g RLE assessment can be made, it would be of interest and worthwhile to test if a plant meets criteria to implement focused-scope procedures. The process for determining whether or not such criteria are met requires plant-to-plant comparisons of mean, median, and 85th-fractile composite probabilities of exceeding seismic design-basis spectra. This process is consistent with the approach in NUREG–1407 for categorizing plants east of the Rocky Mountains into full-scope and focused-scope groups.

To categorize a 0.3g plant as full-scope or focused-scope, a conditional sub-grouping analysis similar to that described above (for conditional binning) could be conducted. For instance, if results for a particular composite (design-basis) hazard measure fell near or below the upper range of composite values comprising the set of 0.3g focused-scope plants, then a conditional RLE categorization of focused-scope would be indicated.

If comparisons for all three hazard statistics were favorable for focused-scope assessment, there would be a clear basis for considering the implementation of focused-scope procedures (even if on a limited basis) as would be deemed appropriate in the expert judgment of the Seismic Review Team responsible for plant review.

The procedures described above for RLE evaluation and review-scope determination are implemented in the next section to develop relevant observations and recommendations for the Palo Verde Nuclear Generating Station.

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3. R. T. Sewell, T. F. O'Hara, C. A. Cornell, and J. C. Stepp. Selection of Review Method and Ground-Motion Input for Assessing Nuclear Power Plant Resistance to Potential Severe Seismic Accidents. In Symposium Proceedings: *Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping.* North Carolina State University., December 1990. (Supplement).

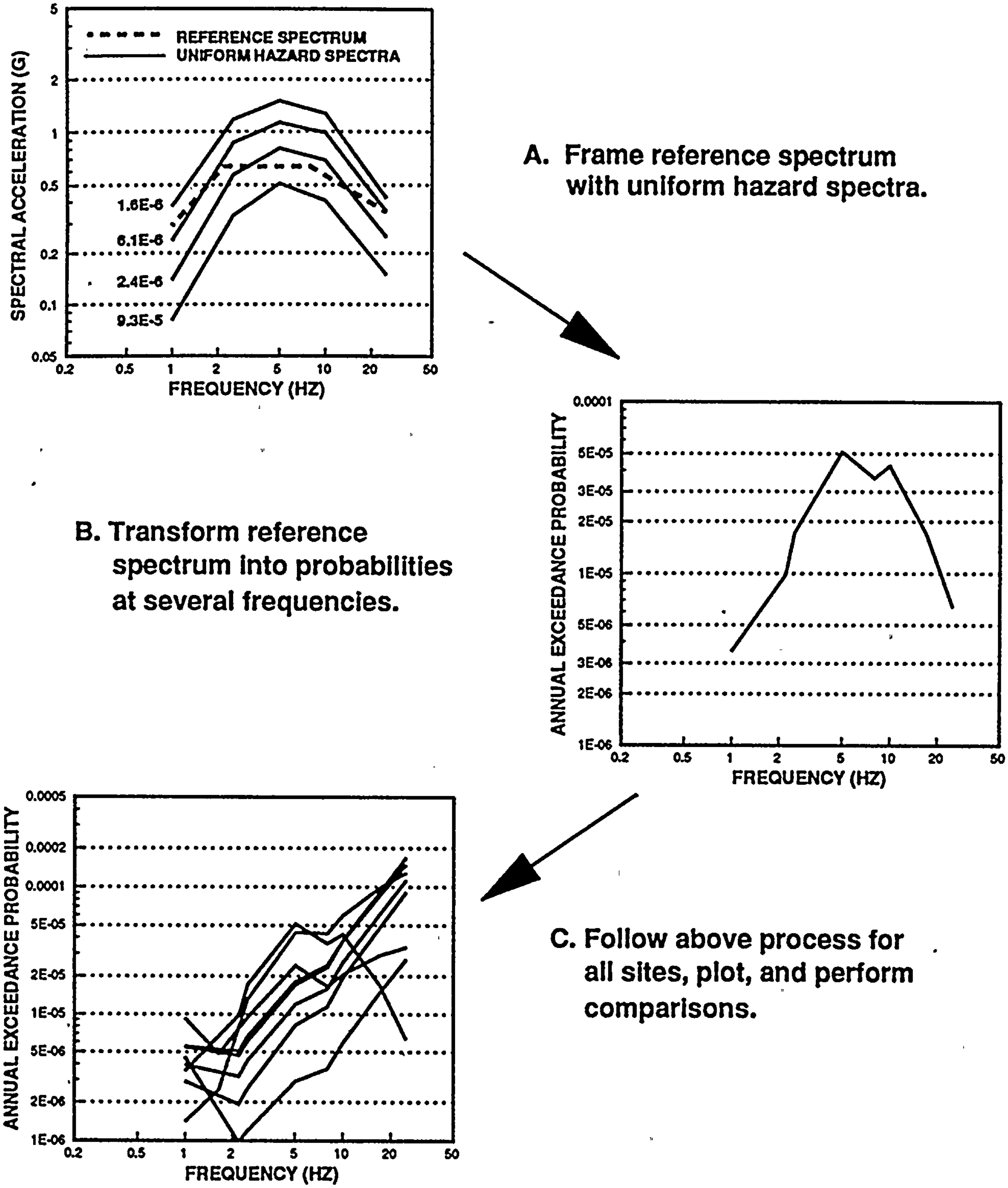
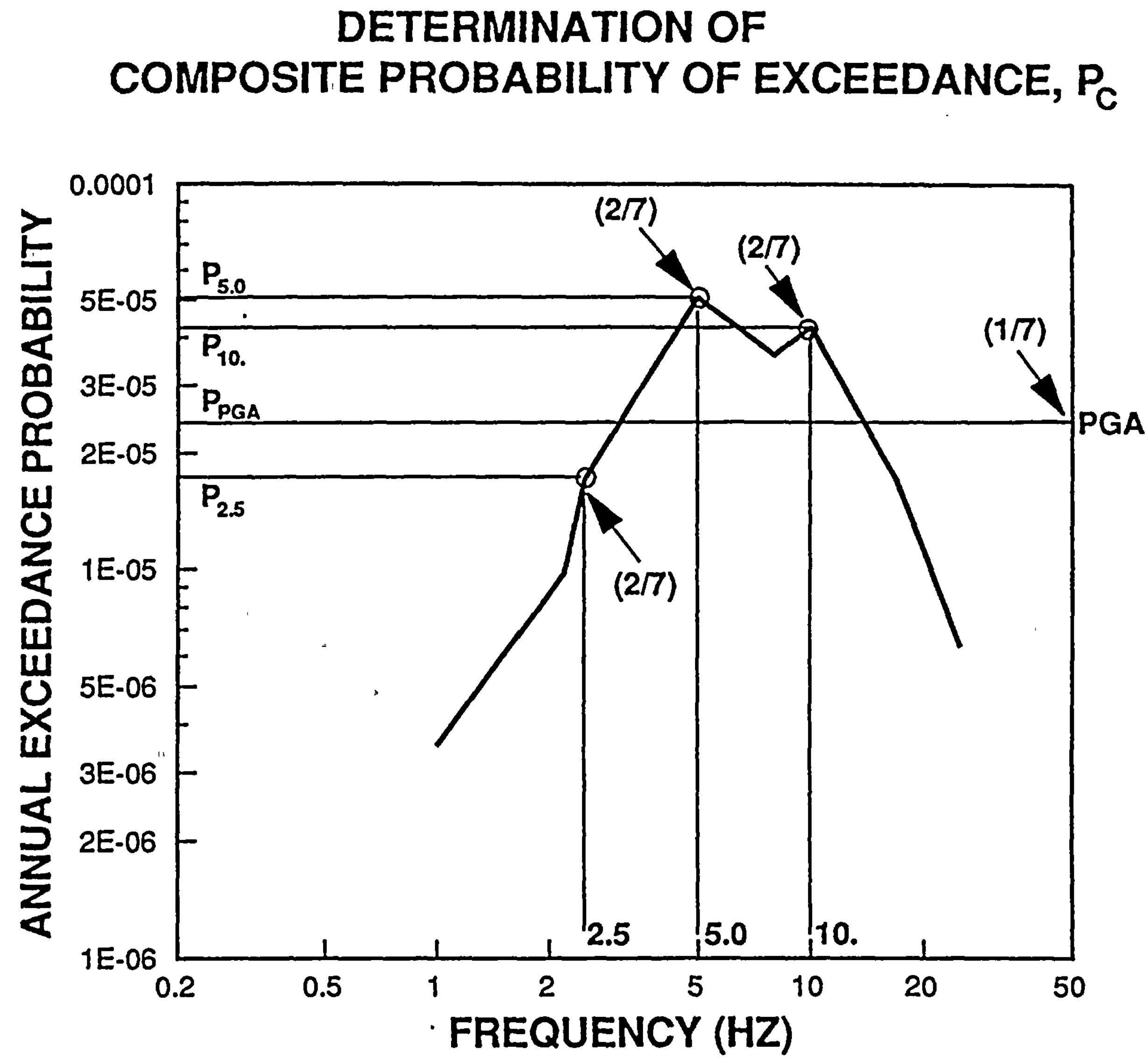


Figure 4-1. Illustration of process to convert a reference ground-motion spectrum to probabilities, through transformation of site-specific uniform seismic hazard spectra.



$$P_C = (2/7)(P_{2.5} + P_{5.0} + P_{10.}) + (1/7)(P_{PGA})$$

Figure 4-2. Illustration of weighting procedure to convert a spectrum of probabilities to a scalar, composite probability measure.

Section 5

COMPARISONS OF SEISMIC HAZARD MEASURES

This section implements the approaches described in Section 4 to obtain results of hazard-based measures, and to develop comparisons with central/eastern U.S. (CEUS) plants in the 0.3g full-scope and focused-scope bins. The hazard measures used or developed for comparison are of three primary forms: (1) uniform hazard spectra, (2) probabilities of exceeding NUREG/CR-0098 spectra, and (3) probabilities of exceeding seismic design spectra.

The detailed computational results of these hazard-based measures, including PGA-based results and spectral results, are provided in Appendices A, B, and C. Brief discussions of these results are provided. In addition, composite hazard measures, based on the weighting criteria described in Section 4, are presented in this section; these composite measures are the primary basis for formulating or clarifying conclusions relevant to an appropriate RLE assessment for the PVNGS site. General observations pertaining to the comparisons of the composite hazard measures are summarized. The potential implications of these comparisons, together with relevant conclusions and recommendations, are themselves provided in Section 6.

5.1 GENERAL DESCRIPTION OF COMPARISONS

Hazard measures are computed for 50 nuclear power plant sites in the central and eastern U.S., in addition to computations for the PVNGS site; hence, results for a total of 51 sites are considered as the basis for the hazard comparisons. The 50 CEUS sites comprise the set of 0.3g plants (full-scope or focused-scope) for which EPRI hazard results have been published (1). Table 5-1 lists the names of the 51 sites considered in the hazard comparisons. It is noted that there are 7 full-scope plants and 43 focused-scope plants among the set of 50 CEUS sites.

Results in the appendices show plots of both probability of exceedance spectra (51 curves on each graph) and PGA-based exceedance probability measures (51 points on each graph). The results distinguish between full-scope plants, focused-scope plants, and the PVNGS site. The spectral comparisons allow one to determine which range of vibration frequency dominates the value of composite probability of exceedance.

The composite probability results summarized in this section are presented as plots of weighted annual exceedance frequency versus re-ordered site number (51 points on each graph), where the ordering is performed so that results are presented from highest composite value to lowest. It was considered unimportant to identify the specific plant associated with a particular result. Hence, a re-ordered site number does not pertain consistently (from hazard measure to hazard measure) to a specific plant, but rather, pertains to rankings of composite probabilities within the set of 0.3g plants (for a particular hazard measure).

5.2 COMPARISONS OF UNIFORM HAZARD SPECTRA

Uniform hazard spectra themselves are not used in the RLE evaluation approach. But nonetheless, comparisons of UHS are useful in checking with subsequent results. Appendix A presents spectral and PGA-based comparisons of ground-motion ordinates at uniform hazard levels of 10^{-3}, 10^{-4}, and 10^{-5}. For each uniform hazard level, results are provided for mean, median, and 85th-fractile hazard statistics; hence, a total of 9 plots each for spectra and for PGA may be considered.

From the PGA results (Figures A–1 to A–9), it may be observed that the values for PVNGS fall clearly within the hazard limits defined by the full-scope plants or the focused-scope plants for all uniform-hazard levels and for all hazard statistics. Rankings for the PVNGS site range from 16 to 29 out of 51 for the 10^{-3} comparisons (where 1 is the ranking for highest hazard and 51 for lowest); 20 to 33 (out of 51) for the 10^{-4} hazard comparisons; and 19 to 38 for the 10^{-5} results. In all cases (i.e., three hazard levels), the rankings for the median statistic are highest (i.e., the median produces the lowest ranking number and the highest comparison value, relative to results for the mean or 85th-fractile statistic).

From the spectral results (Figures A–10 to A–18), it is observed that the plots for the PVNGS site fall within (or very nearly within) the range of curves defined by the 0.3g plants for the mean and 85th-fractile hazard statistics (regardless of the uniform-hazard level). Generally speaking (for vibration frequencies of interest), the PVNGS results are highest, comparatively, over the frequency range of 2.5 to 5 Hz; this observation is associated with the expected difference in spectral-shape characteristics between the PVNGS site and the CEUS sites. Whereas the PVNGS spectra peak at 5 Hz, they become very low (comparatively) at a frequency of 25 Hz. The severest comparisons for the PVNGS site are seen in the median 10^{-4} and 10^{-5} UHS results, where UHS ordinates lie slightly above the limits for CEUS site over the frequency range of 1 to 5 Hz.

As a consequence of these observations, one may generally expect that subsequent comparisons of the mean and 85th-fractile results will be well within the limits defined by the CEUS 0.3g sites, whereas the median comparisons (for spectra) may be somewhat less favorable in the 1- to 5-Hz range.

5.3 COMPARISONS OF PROBABILITIES OF EXCEEDING 0.3G AND 0.5G NUREG/CR-0098 SPECTRA

Comparisons of probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum are key factors in the RLE evaluation process. Spectral results and PGA-based results are provided in Appendix B; composite/weighted probabilities are shown later in this section. Although not used in the RLE evaluation approach, probabilities of exceeding the NUREG/CR-0098 spectrum at a level of 0.5g are also presented to convey the impact of the ground-motion transformation basis on the conditional binning assessments.

5.3.1 Frequency-Dependent Probabilities

For PGA-based results (Figures B-1 to B-6), it is observed that probabilities of exceeding the 0.3g spectrum for the PVNGS site are well within the range of results defined be either the full-scope plants or the focused-scope plants, for all hazard statistics. Rankings range from 19 of 51 (for median results) to 34 of 51 (for mean results). Probabilities of exceeding the 0.5g NUREG/CR-0098 spectrum demonstrate an even more favorable comparison for the PVNGS site. Rankings for the PVNGS site based on these probabilities range from 46 of 51 (for the median results) to 50 of 51 (for the mean and 85th-fractile results).

For spectral values (Figures B-7 to B-12), comparisons of plots of probabilities of exceeding the 0.3g spectrum again reveal that mean and 85th-fractile values for the PVNGS site are well within the bounds defined by the full-scope and focused-scope plants. As was the case for the UHS comparisons, however, the median results lie somewhat above these bounds, over the frequency range of 1 to 5 Hz. Probabilities of exceeding the 0.5g spectrum produce more-favorable comparisons; not only are the mean and 85th-fractile results well within the bounds of the 0.3g CEUS plants, but the PVNGS median results (for all vibration frequencies) are bound within the highest results defined by all other plants.

5.3.2 Composite Probabilities

The composite/weighted probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum are shown in Figures 5-1 to 5-3. These plots reveal that the mean and 85th-fractile composite probabilities for the PVNGS site lie near the center of the range of results for the 50 CEUS 0.3g sites; the median composite probability lies somewhat higher, yet still well within the range of results for the body of plants (24% of the other plants have a higher median composite probability). (The rankings for the PVNGS site based on these hazard measures are 27-of-51 based on the mean, 13-of-51 based on the median, and 23-of-51 based on the 85th-fractile).

Considering the RLE evaluation approach outlined in Section 4, these results produce 0.3g conditional binnings based on the mean, the median, and the 85th-fractile hazard measures; a 0.5g conditional binning is not indicated for any hazard measure. Hence, a final binning (unconditional on hazard measure) of 0.3g would be suggested by these results.

As an additional verification that a 0.5g binning assignment is not supported for the PVNGS site, the mean and 85th-fractile composite probabilities are compared with a threshold of 10^{-4} and the median composite probability with a threshold of 10^{-5}. The binning approach in NUREG–1407 would require that the median composite probability exceed 10^{-5} and either the mean or 85th-fractile probability exceed 10^{-4} for a 0.5g binning assignment to be supported. Because, however, as indicated in Figures 5–1 and 5–3, both the mean and 85th-fractile composite-probability measures fall below the 10^{-4} threshold, and the median composite-probability measure falls below the 10^{-5} level, a 0.5g binning assessment would not be supported for the PVNGS site.

These observations all indicate a 0.3g RLE binning assignment for the Palo Verde Nuclear Generating Station.

Figures 5–4 to 5–6 show mean, median, and 85th-fractile composite probabilities of exceeding the 0.5g NUREG/CR–0098 spectrum. The plots in these figures show that the PVNGS site lies substantially within the lower range of probability results defined by the 0.3g CEUS sites, for all three hazard measures. The rankings for the mean, median, and 85th-fractile hazard measures are, respectively, 35 of 51, 34 of 51, and 31 of 51. In this case, the median hazard measure shows a more favorable relative comparison than previously. These results provide further support for the conclusion that the hazard at the PVNGS site is most similar to seismic hazards at plants in the 0.3g bin (as opposed to plants binned as 0.5g).

5.4 COMPARISONS OF PROBABILITIES OF EXCEEDING PLANT-SPECIFIC SEISMIC DESIGN SPECTRA

Comparisons of probabilities of exceeding seismic design-basis spectra are important elements in deciding whether or not the application of focused-scope methods in IPEEE implementation is justified. For this aspect of the RLE evaluation of the PVNGS site, spectral results and PGA-based results are provided in Appendix C; composite/weighted probabilities are presented in this section.

The seismic design-basis spectrum for the PVNGS site is the Reg. Guide 1.60 spectrum anchored to a peak ground acceleration of 0.25g, whereas the SSE level for licensing purposes (based on seismological studies described in the safety analysis report) is 0.2g (2).

Because the actual design basis acceleration, as opposed to the lower (minimum required) SSE acceleration, impacts component capacities, the 0.25g spectrum is the appropriate one for transforming hazard results to probabilities of exceeding seismic design. The seismic design bases for the 50 CEUS plants were derived from data provided by LLNL; it is believed that these data are the same as those used in the NUREG–1407 studies.

5.4.1 Frequency-Dependent Probabilities

For PGA-based results (Figures C–1 to C–3), it is observed that probabilities of exceeding the design spectrum for the PVNGS site are well within the lower range of results defined by the focused-scope plants, for all hazard statistics. Rankings range from 37 of 44 focused-scope plants (for median hazard-based results) to 42 of 44 focused-scope plants (for 85th-fractile results).

For spectral results (Figures C–4 to C–6), comparisons of plots of probabilities of exceeding design-basis spectra reveal that mean and 85th-fractile values for the PVNGS site are within the bounds defined by the focused-scope plants. Similar to the trend noted previously, the median results lie closer to the upper bounds of focused-scope-plant results, over the frequency range of 1 to 5 Hz (although the median results are clearly below the bounds defined by the full-scope plants for all vibration frequencies).

5.4.2 Composite Probabilities

The composite/weighted probabilities of exceeding seismic design-basis spectra are shown in Figures 5–7 to 5–9. These plots reveal that the mean composite probabilities for the PVNGS site lie clearly within the central-to-lower range of probability results for the 43 CEUS 0.3g focused-scope plants. The rankings for the PVNGS site (based on these composite probabilities) are 30 of 44 focused-scope plants based on the mean and 85th-fractile hazards, and 21 of 44 based on the median.

Considering the RLE evaluation approach outlined in Section 4, these results would indicate a focused-scope conditional sub-grouping based on each of the three hazard statistics. Because all three hazard measures here indicate a focused-scope sub-grouping, a focused-scope categorization is clearly supported for the PVNGS site. Although NUREG–1407 does not allow for the use of focused-scope procedures on an exclusive basis at the PVNGS site, it would be reasonable to consider the appropriate use of specific focused-scope techniques that may be found to apply depending upon the lessons learned from full-scope investigation of one of the three reactor units at the PVNGS site.

These considerations favor the application of focused-scope techniques, on an as-appropriate basis, for seismic-IPEEE review of the Palo Verde Nuclear Generating Station.

The observations summarized in this section, concerning comparisons of composite probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum and composite probabilities of exceeding design spectra, form the basis for conclusions and recommendations discussed in Section 6.

5.5 REFERENCES

1. R. K. McGuire, G. R. Toro, J. P. Jacobson, T. F. O'Hara, and W. J. Silva. *Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue.* Technical Report NP-6395-D, Main Report, Electric Power Research Institute, April 1989.

2. Arizona Public Service. *Palo Verde Nuclear Generating Station: Final Safety Analysis Report.* Volume 3, Updated March 1991.

Table 5-1

LIST OF PLANTS USED IN HAZARD COMPARISONS

Plant Name	Review Type	Plant Name	Review Type
Arkansas	Full Scope	Monticello	Focused Scope
Beaver Valley	Focused Scope	Nine Mile Point	Focused Scope
Bellefonte	Focused Scope	North Anna	Focused Scope
Braidwood	Focused Scope	Oconee	Full Scope
Browns Ferry	Focused Scope	Oyster Creek	Focused Scope
Brunswick	Focused Scope	Palo Verde	—
Byron	Focused Scope	Peach Bottom	Focused Scope
Calvert Cliffs	Focused Scope	Perry	Focused Scope
Catawba	Focused Scope	Point Beach	Focused Scope
Clinton	Focused Scope	Prairie Island	Focused Scope
Davis Besse	Focused Scope	Quad Cities	Focused Scope
Dresden	Focused Scope	Robinson	Full Scope
Farley	Focused Scope	Salem	Focused Scope
Fermi	Focused Scope	Sequoyah	Full Scope
Fitzpatrick	Focused Scope	Shearon Harris	Focused Scope
Ginna	Focused Scope	Summer	Focused Scope
Haddam Neck	Focused Scope	Surry	Focused Scope
Hatch	Focused Scope	Susquehanna	Focused Scope
Hope Creek	Focused Scope	Three Mile Island	Focused Scope
Indian Point	Full Scope	Vermont Yankee	Focused Scope
Kewaunee	Focused Scope	Vogtle	Focused Scope
La Salle	Focused Scope	Watts Bar	Focused Scope
Limerick	Focused Scope	Wolf Creek	Focused Scope
Maine Yankee	Full Scope	Yankee Rowe	Full Scope
McGuire	Focused Scope	Zion	Focused Scope
Millstone	Focused Scope		

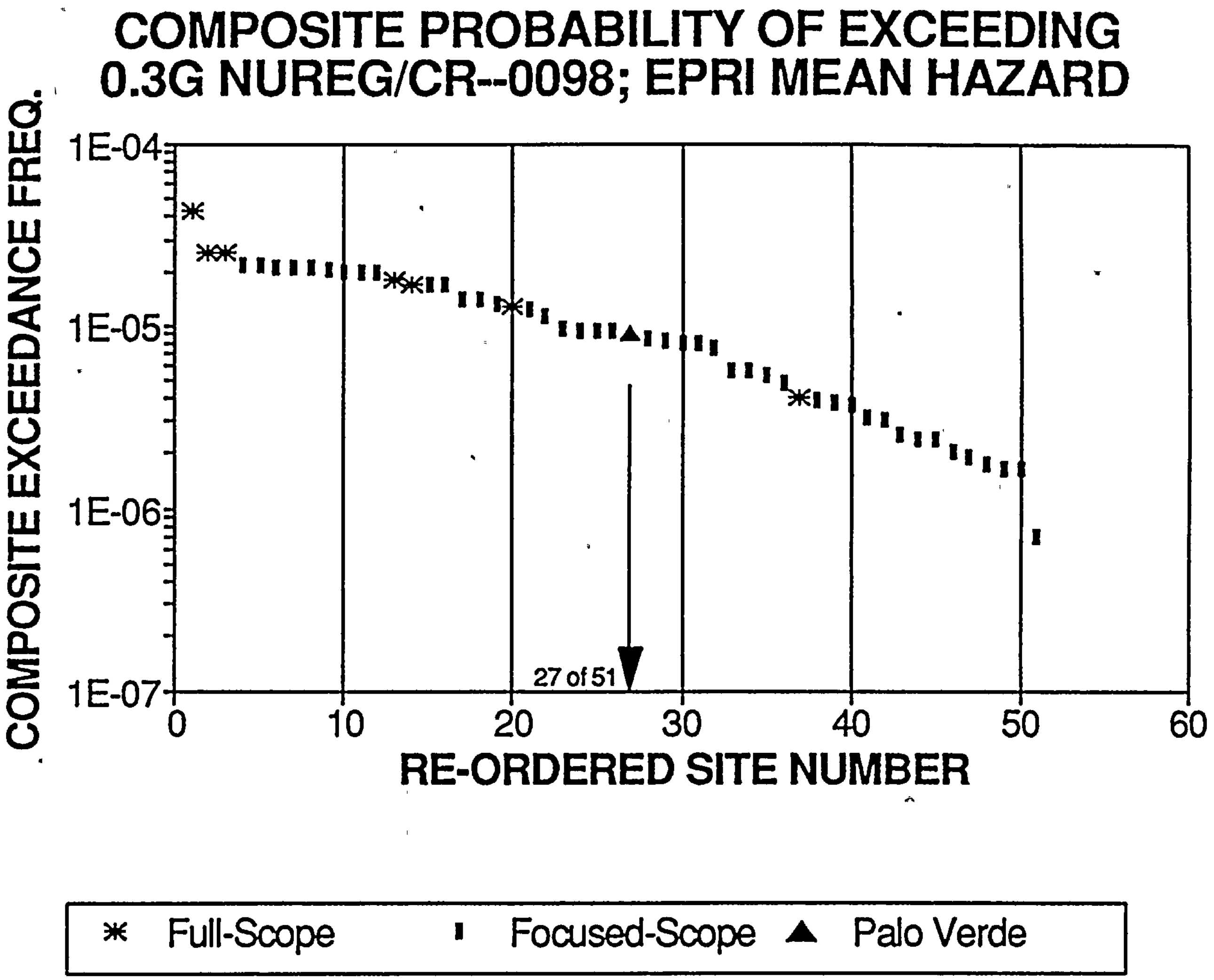


Figure 5-1. Mean composite probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

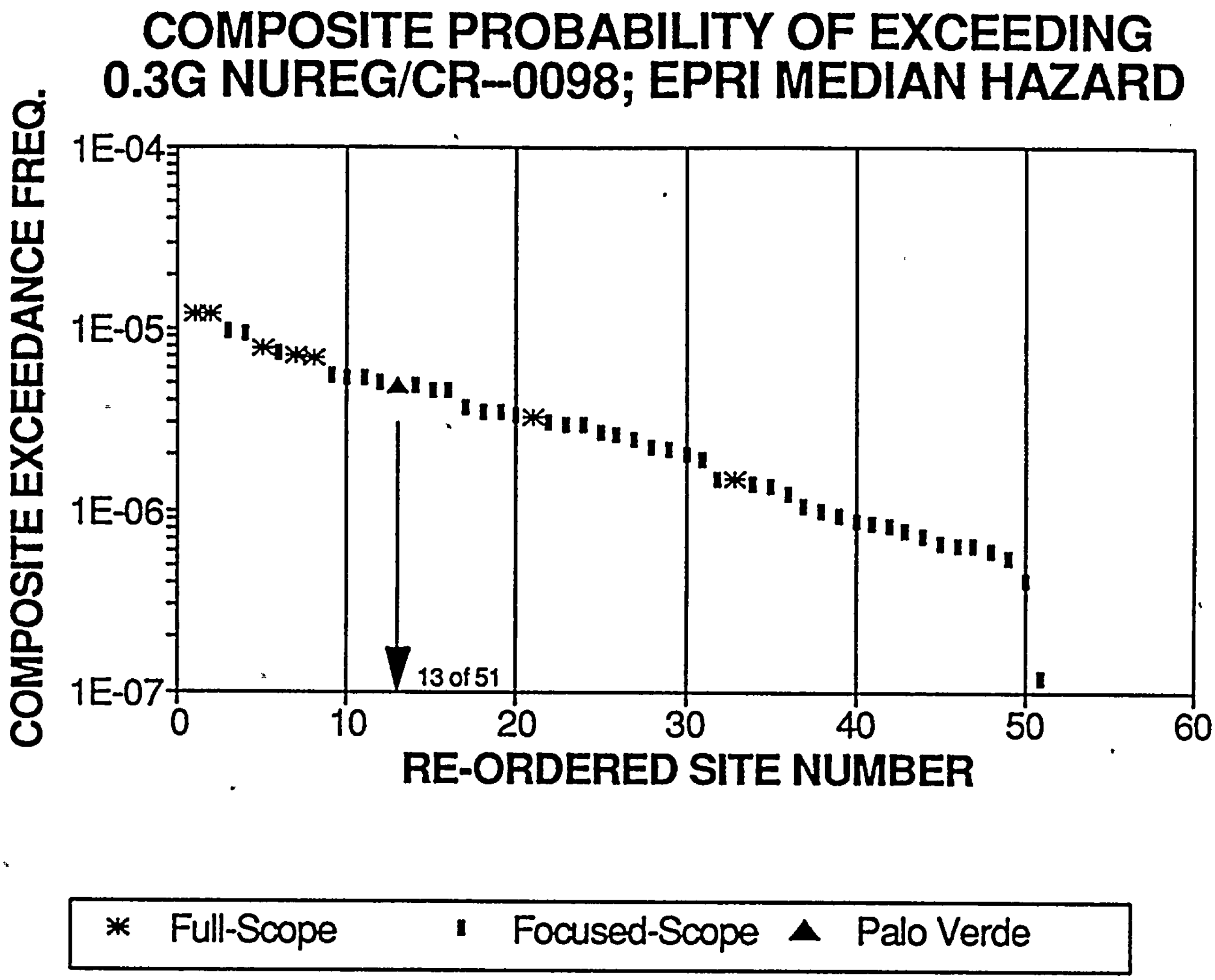


Figure 5-2. Median composite probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

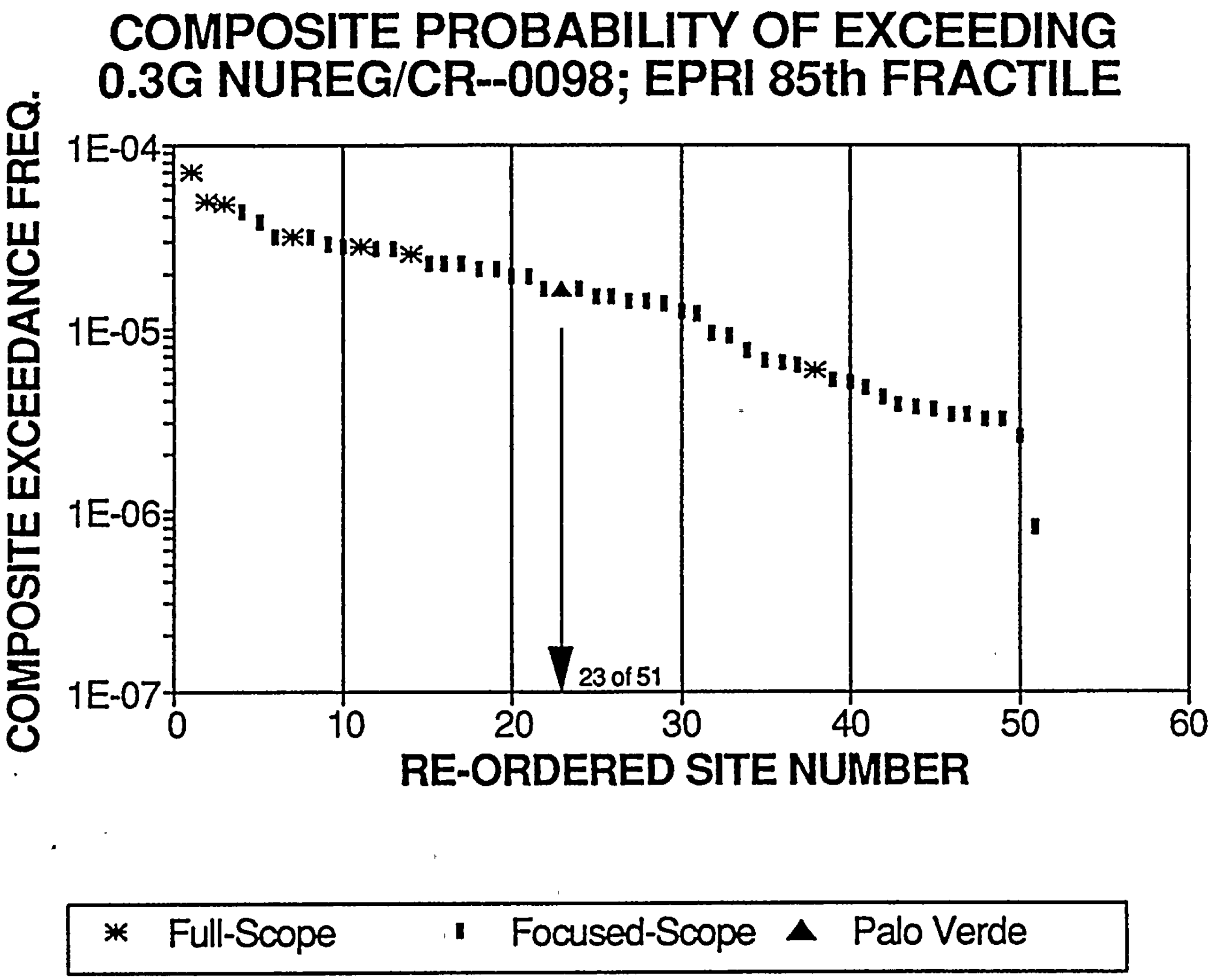


Figure 5-3. 85th-fractile composite probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

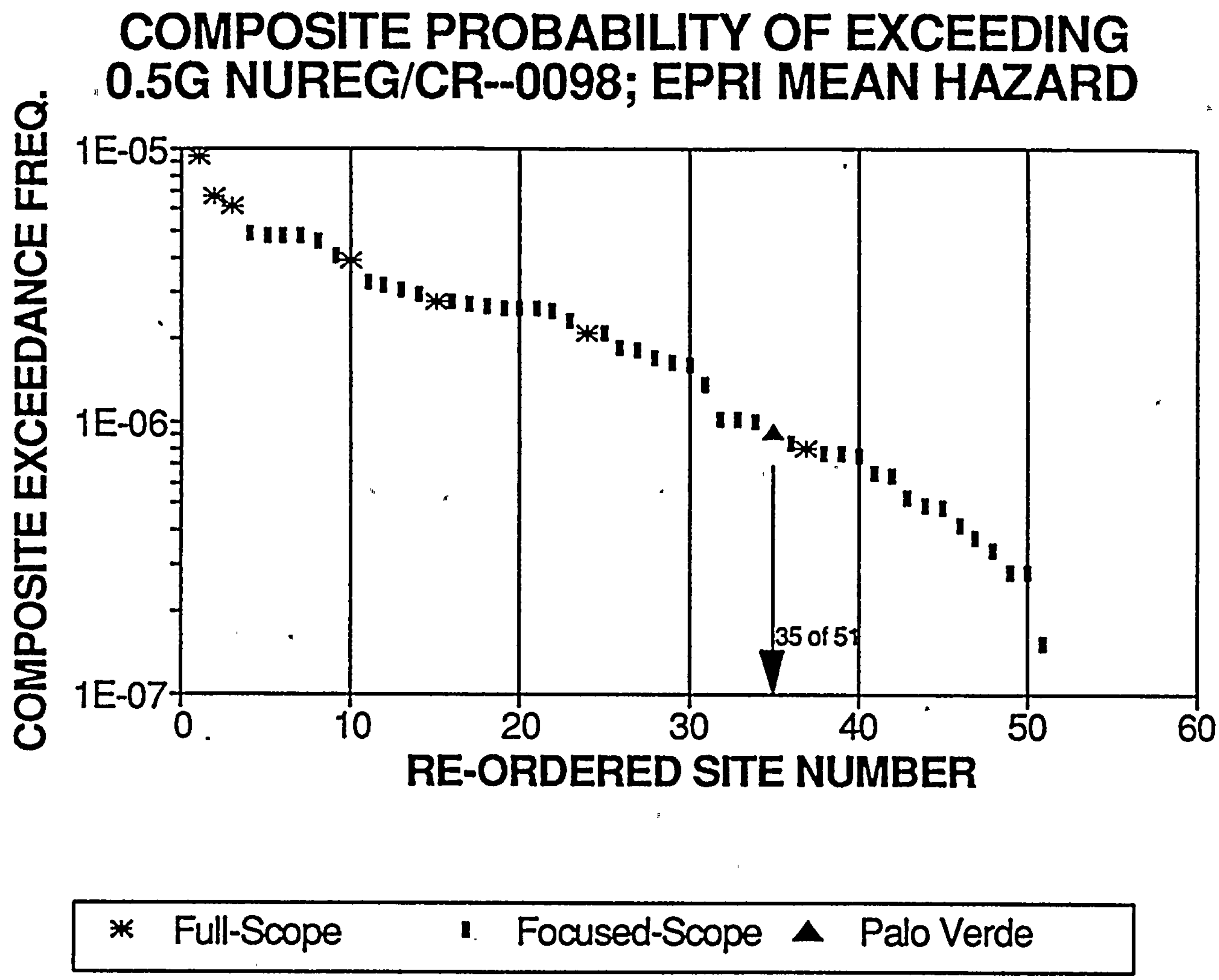


Figure 5-4. Mean composite probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

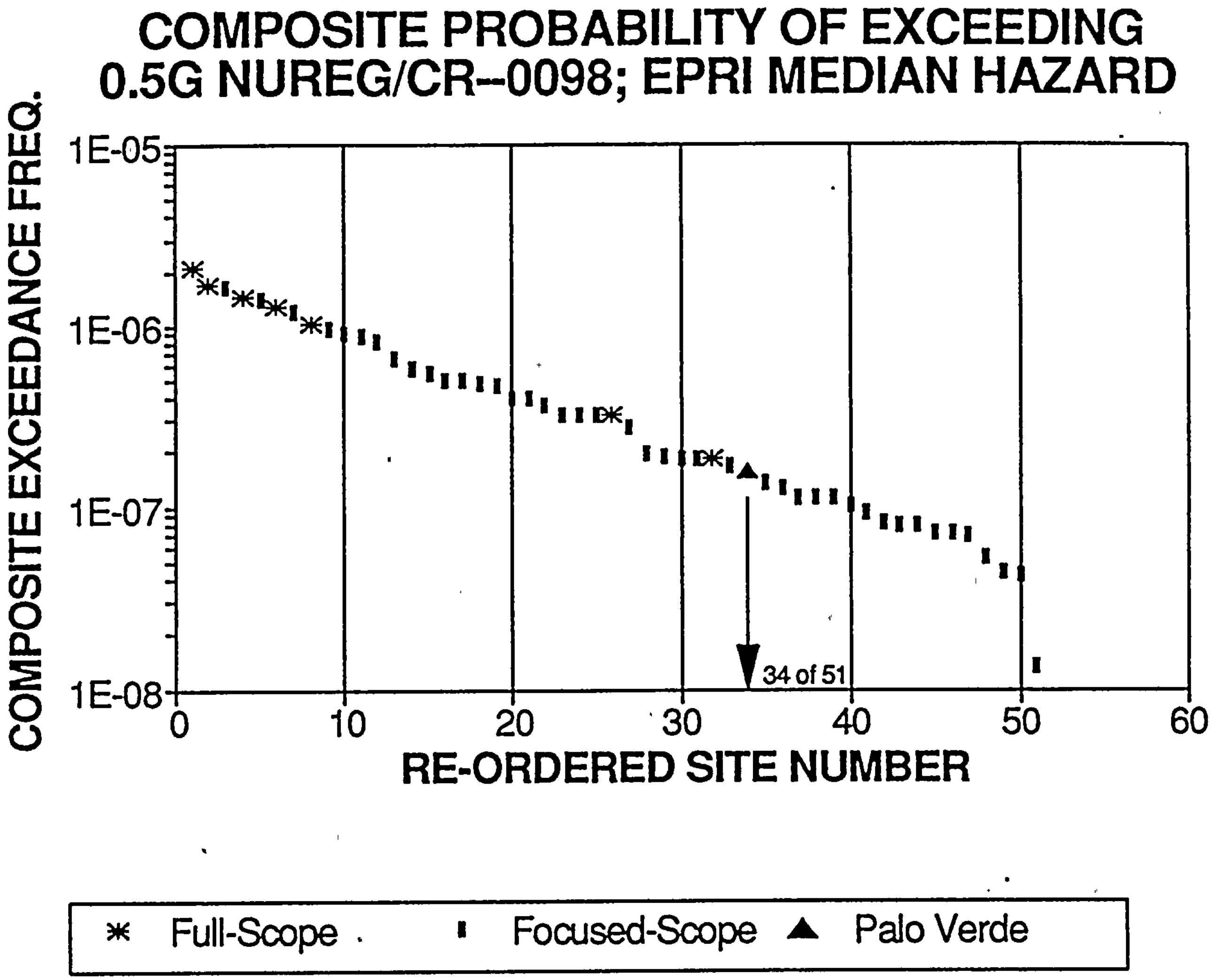


Figure 5-5. Median composite probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

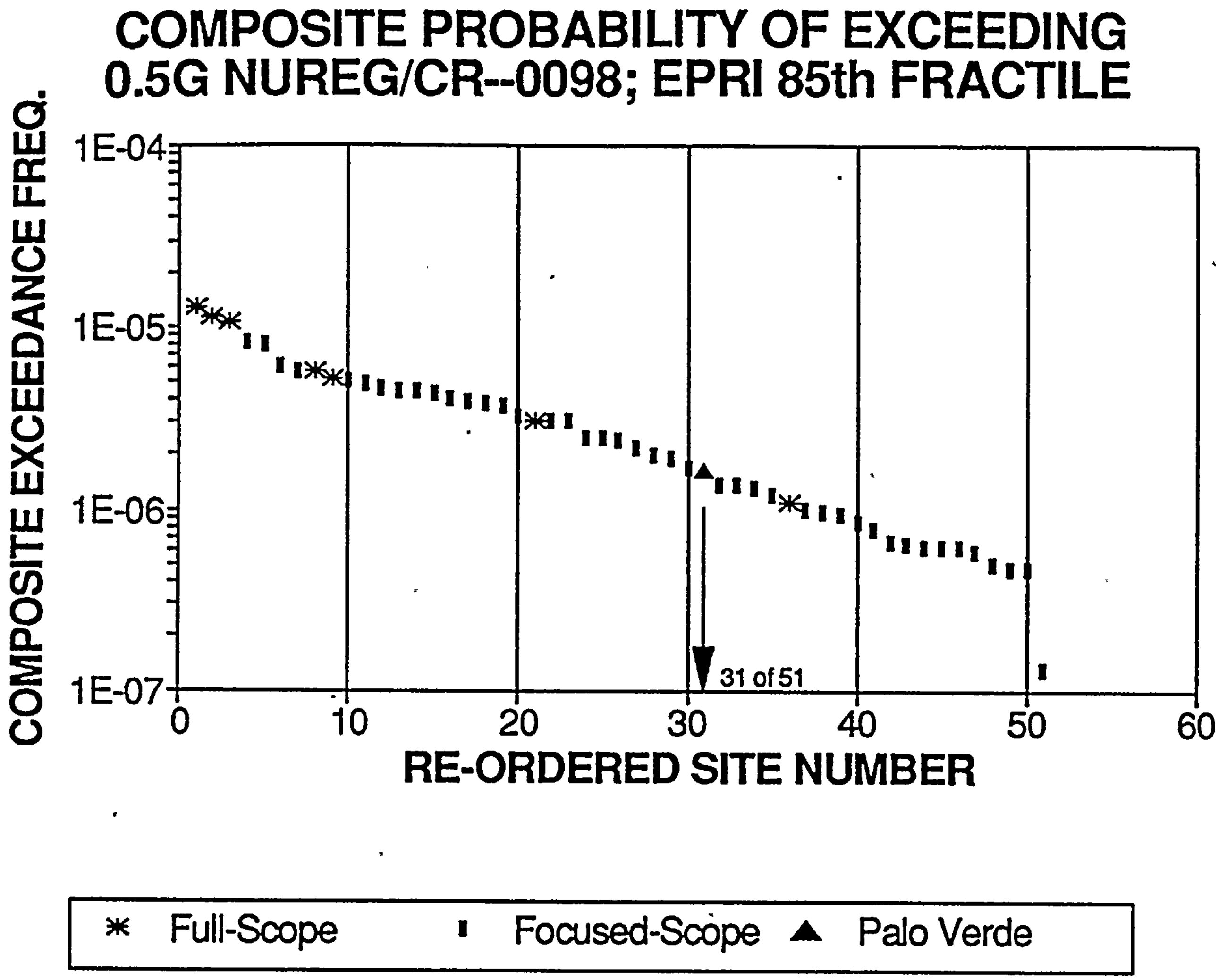


Figure 5-6. 85th-fractile composite probabilities of exceeding the NUREG/CR–0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

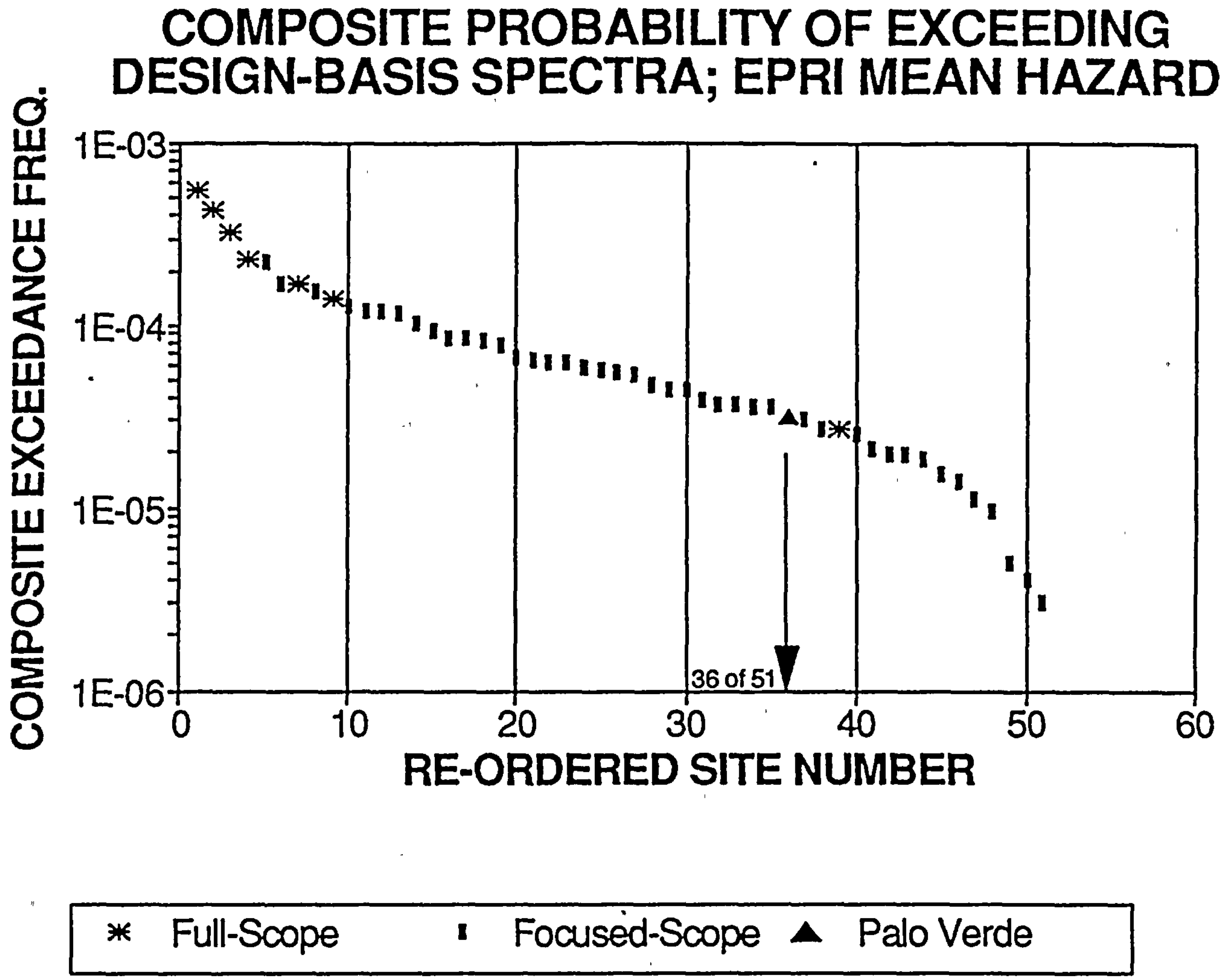


Figure 5-7. Mean composite probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

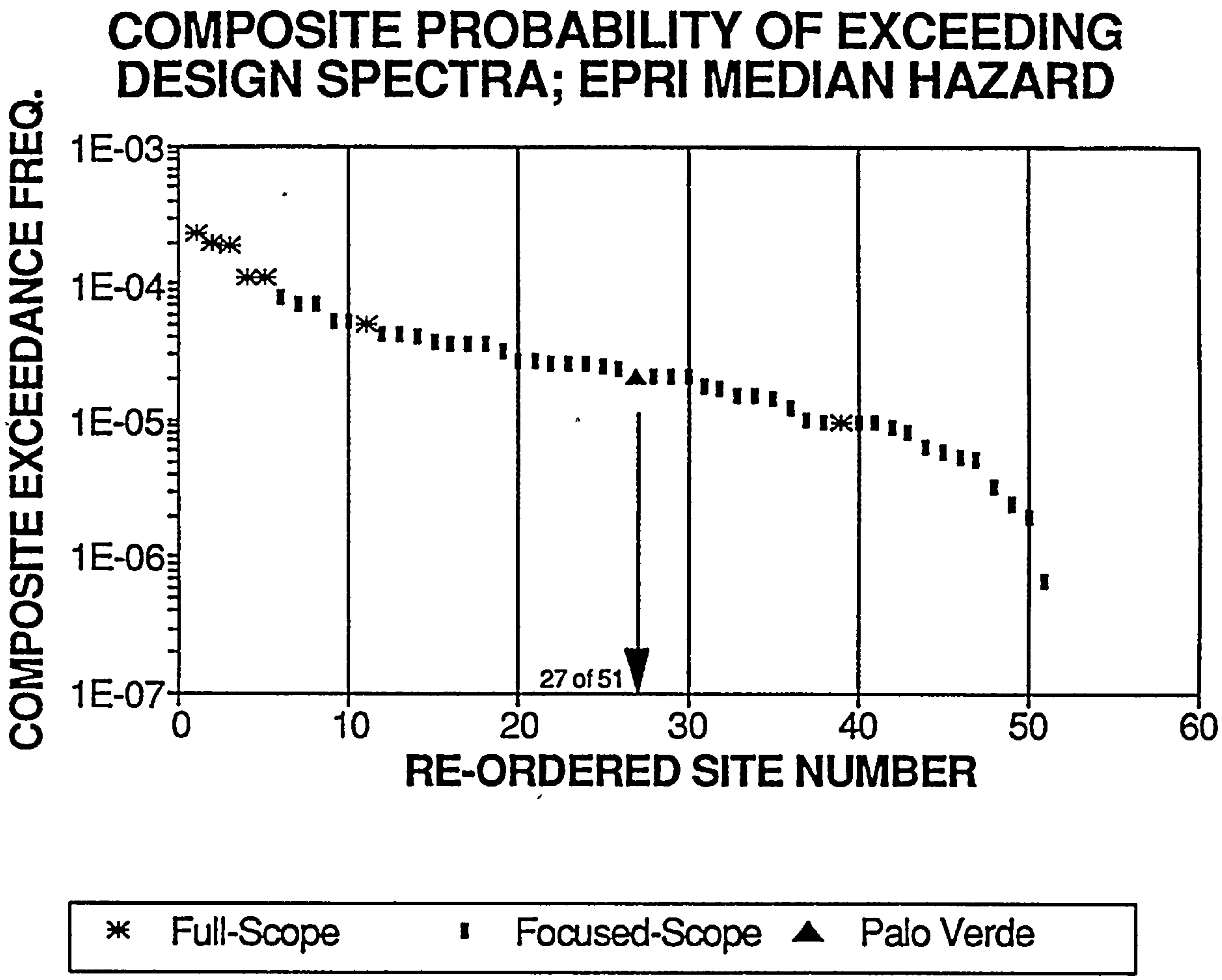


Figure 5-8. Median composite probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

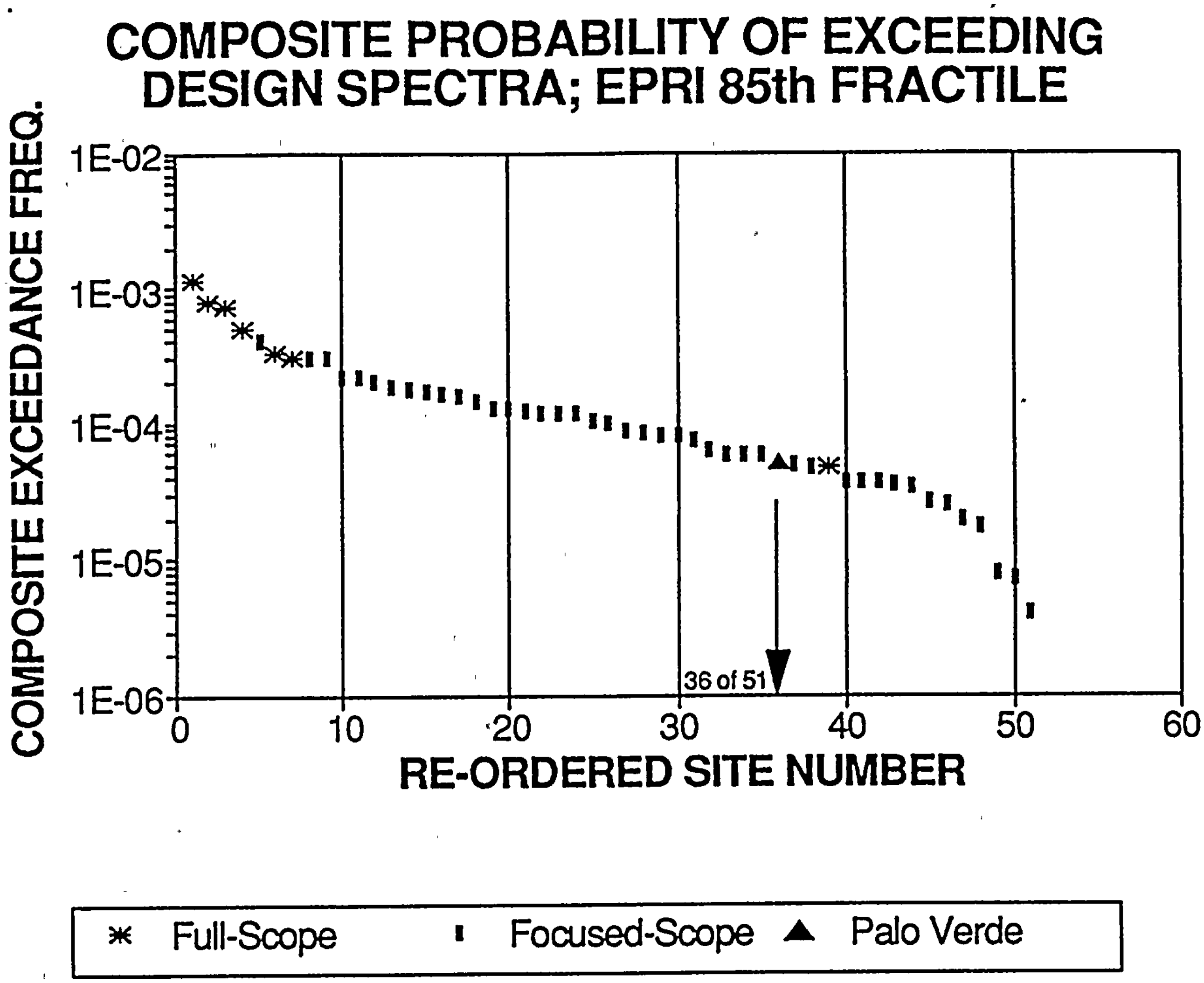


Figure 5-9. 85th-fractile composite probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Section 6
CONCLUSIONS AND RECOMMENDATIONS

This section highlights the important points of this study. Implications of the results and observations noted in the study are presented in the form of conclusions. The conclusions provide the basis for the development and discussion of general recommendations. It is anticipated that these recommendations will be used as guidelines in selecting an appropriate RLE value for the PVNGS site and for delineating an appropriate scope of effort in IPEEE implementation.

6.1 SUMMARY OF APPROACH AND RESULTS

Concerning whether or not a seismic review level of 0.3g would be appropriate for IPEEE implementation at the Palo Verde Nuclear Generating Station, this report has presented the methods and results of comparisons that develop a reasonable and technically supportable conclusion. The approach and comparisons adopted follow closely the basis for binning described in NUREG–1407; thus, it is insured that the analysis conducted here is appropriate and consistent with the manner in which plants were originally established in the 0.3g bin. Based on this analysis, the following observations are summarized:

- For the PVNGS site, weighted/composite probabilities of exceeding the NUREG/CR–0098 (median, 5%-damped) spectrum anchored to 0.3g PGA lie substantially within the central range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. Comparative rankings for the PVNGS site vary from 13-of-51 (for median hazard results) to 27-of-51 (for mean hazard results), where a ranking of 51 would indicate the lowest probability of exceedance of all plants. Therefore, the composite probabilities for the PVNGS site are effectively indistinguishable from the body/population of results observed for the 0.3g plants.

- For the PVNGS site, weighted probabilities of exceeding the seismic design basis are indistinguishable from the population of results for the 0.3g focused-scope plants. The comparative rankings (ranging from 27-of-51 to 36-of-51) are, however, somewhat more favorable than those obtained above (for probabilities of exceeding the NUREG/CR–0098 spectrum) because of the comparatively greater level of conservatism in the seismic design basis for PVNGS.

- In most cases, the mean and 85th-fractile hazard-based measures demonstrate a somewhat more favorable comparison, relative to results for the 0.3g plants, than do the median hazard-based measures. On an absolute basis, the mean and 85th-fractile composite probabilities of exceeding the 0.3g NUREG/CR-0098 (median, 5%-damped) spectrum are both considerably less than the 10^{-4} level, whereas the median composite probability is notably less than 10^{-5}.

6.2 CONCLUSIONS AND GUIDELINES FOR REVIEW LEVEL AND SCOPE

Based upon the set of binning procedures outlined in NUREG-1407, the results of this study support placing the PVNGS site in the 0.3g RLE bin, for the following reasons:

- As discussed in Section 5.3.2, relative (plant-to-plant) comparisons of the PVNGS composite probability of exceeding the 0.3g NUREG/CR-0098 spectrum indicate that the PVNGS hazard is consistent with the hazards for plants found within the central-to-upper range of the existing 0.3g bin.
- As shown in Figures 5-1 to 5-3, the mean and 85th-fractile composite probabilities of exceeding the 0.3g spectrum are both considerably less than the absolute level of 10^{-4}, and the corresponding median composite probability is notably lower than the 10^{-5} threshold.

Binning approaches based on uncertain hazard results cannot generally be used to make delineations with precise clarity. To provide a perspective that somewhat offsets this lack of clarity, however, it is important to keep in mind that conservatisms are built into the seismic review process. These conservatisms generally insure that, in a 0.3g seismic margins study, components with HCLPF capacities in excess of this level (perhaps on the order of 0.35g or greater) will be screened in for further evaluation (see the related discussion in Section 2).

Added to the relatively clear support indicated by the above observations, therefore, these facts provide additional margin of comfort in placing PVNGS in the 0.3g RLE bin.

On the present basis, implementation of the default 0.5g RLE would not be justified and would introduce an unwarranted level of conservatism in the review process.

These conclusions are based on considerations of similarity in probabilistic hazard results. Deterministic judgment, however, would also appear to support these conclusions. In particular, guidelines for selecting seismic margin earthquake (SME) levels in the EPRI seismic margins methodology (1) specify that "for plants with safe shutdown earthquake (SSE) levels of about 0.2g or lower, it is recommended that the trial SME level be set at about 0.3g." Based on extensive seismological studies of the PVNGS site, the SSE value has been determined as 0.2g. On an independent basis, therefore, an earthquake review level selection of 0.3g would be confirmed.

In addition, implementing the approach described in NUREG–1407 for delineating among full-scope and focused-scope 0.3g plants, PVNGS would apparently qualify as a 0.3g focused-scope site. NUREG–1407 precludes the exclusive use of focused-scope procedures in the IPEEE analysis of PVNGS. It is considered worthwhile, however, that the use of focused-scope procedures (on a non-exclusive basis) be pursued where found to be appropriate. In particular, results of the first IPEEE analysis, based on 0.3g full-scope SMA application for a single reactor unit, would be used as a basis for judging the applicability and adequacy of focused-scope procedures at the remaining two reactor units, and such procedures would be implemented as appropriate at these units.

These above recommended guidelines are sensitive to a number of factor, most substantially, the seismic hazard results and procedures for weighting these results. Therefore, this study's conclusions should be considered as contingent upon these factors.

6.3 REFERENCES

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Appendix A

COMPARISONS OF UNIFORM HAZARD SPECTRA

This appendix presents uniform-hazard ground-motion results for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. Both uniform-hazard peak ground accelerations and uniform hazard spectra are presented for annual exceedance frequencies of 10^{-3}, 10^{-4}, and 10^{-5}. Comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures A–1 to A–3 present, respectively, the 10^{-3} uniform-hazard peak ground acceleration results for the mean, median, and 85th-fractile hazards; The sets of graphs in Figures A–4 to A–6 and Figures A–7 to A–9 present similar results, respectively, for the 10^{-4} and 10^{-5} hazard levels.

Figures A–10 to A–18 present uniform hazard spectra results that correspond to the respective PGA-based cases just described for Figures A–1 to A–9.

The plots in this appendix support the comparisons and observations made in Section 5 of this report.

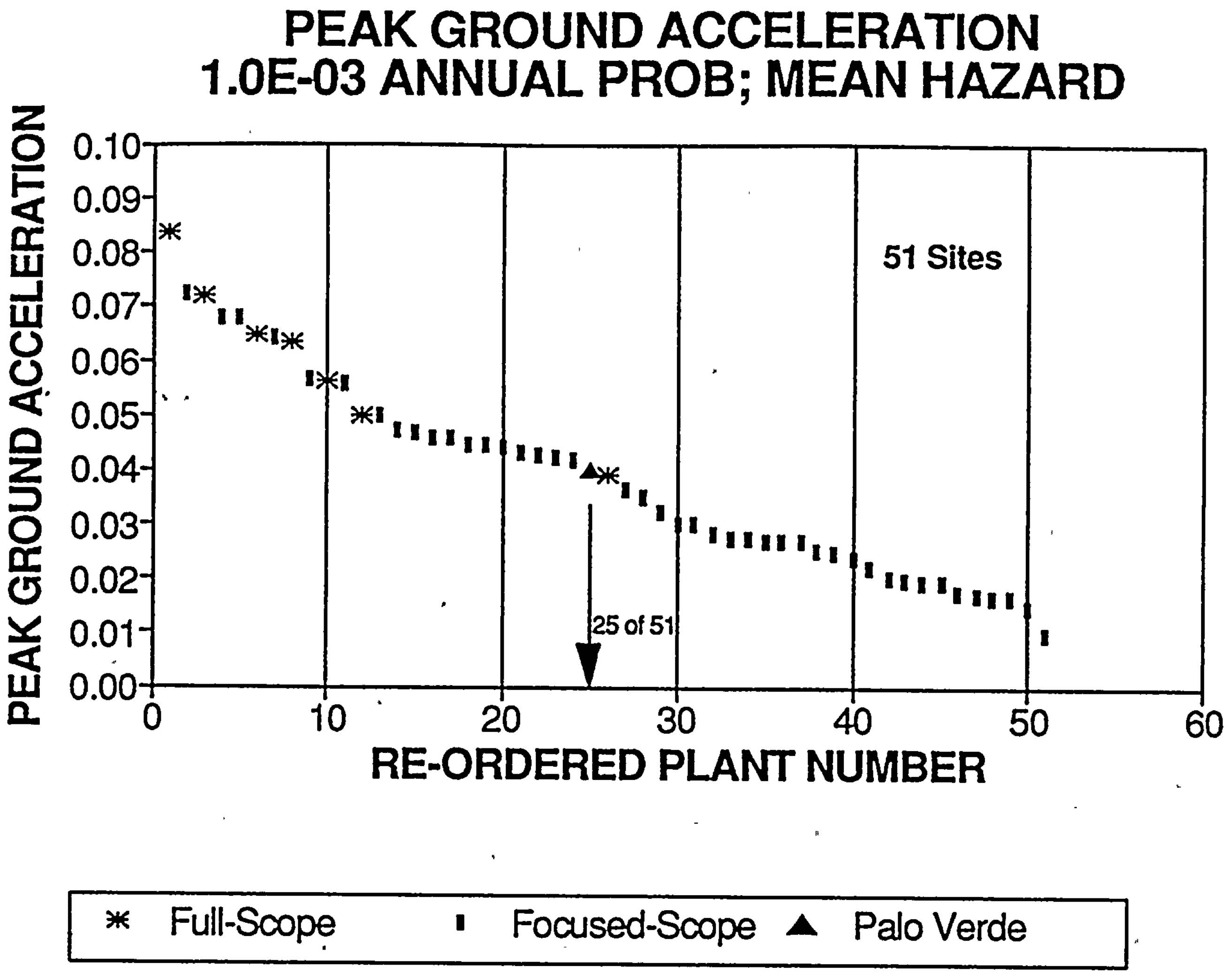

Figure A-1. Comparison of the 10^{-3} mean peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

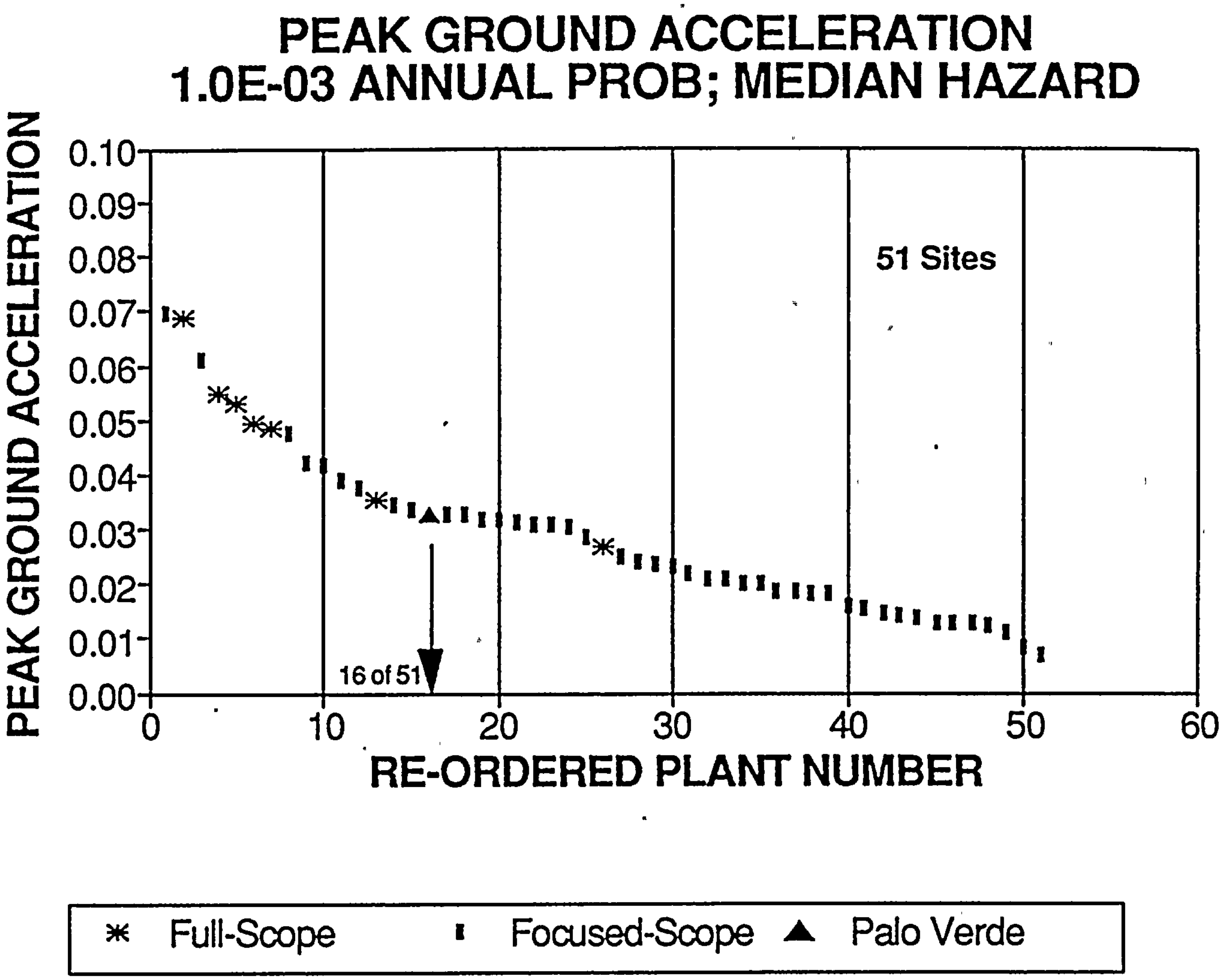

Figure A-2. Comparison of the 10^{-3} median peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

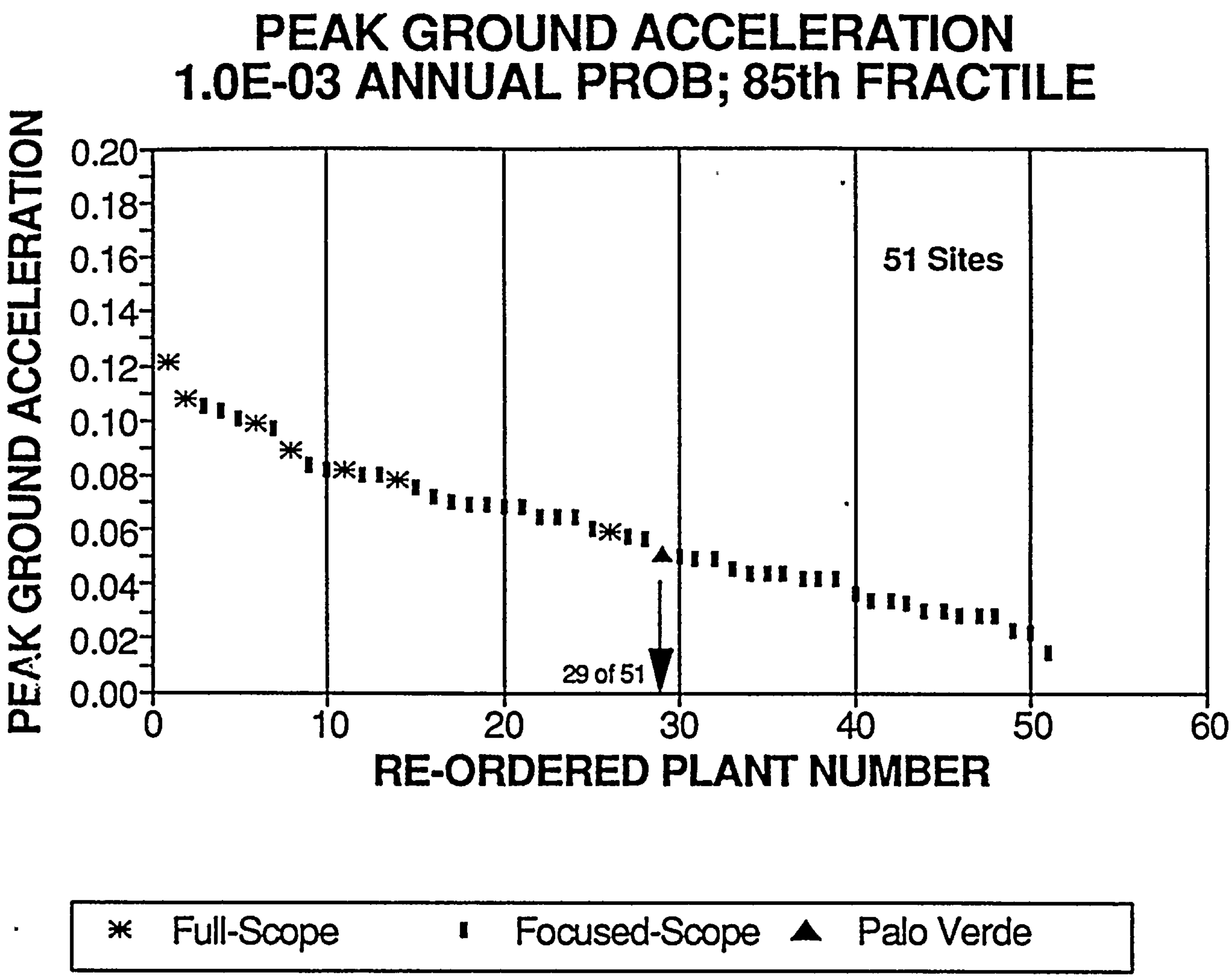

Figure A-3. Comparison of the 10^{-3} 85th-fractile peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

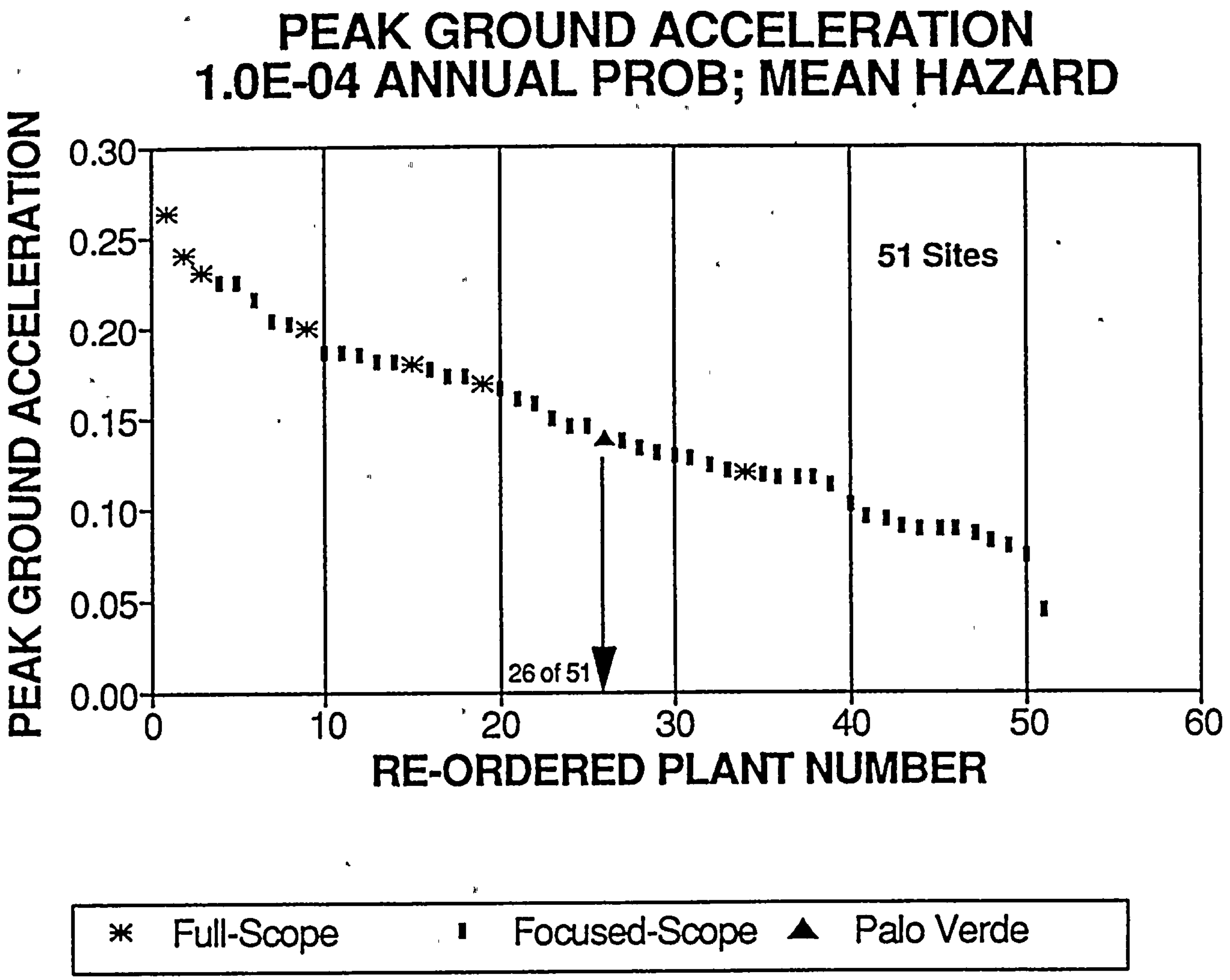

Figure A-4. Comparison of the 10^{-4} mean peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

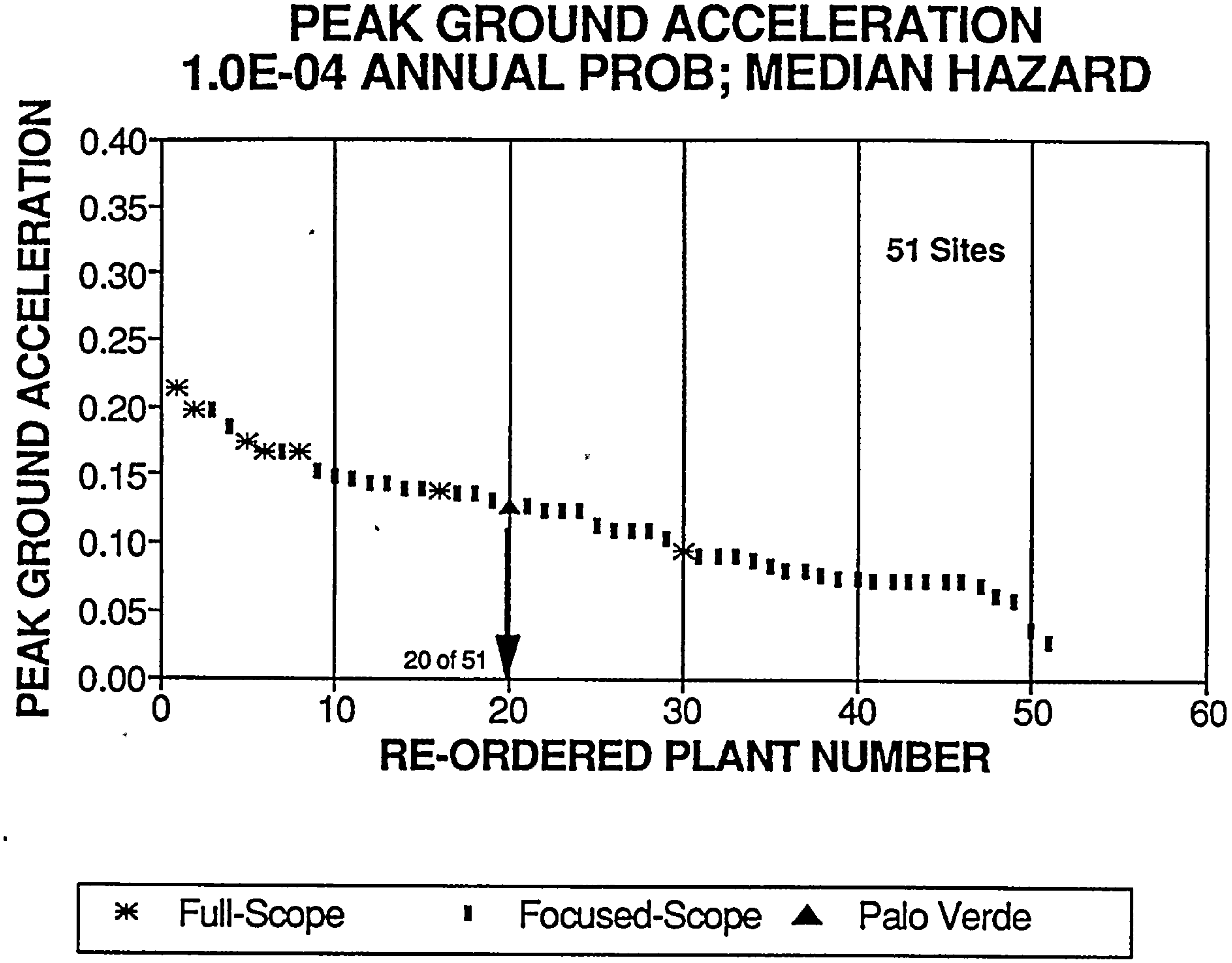

Figure A-5. Comparison of the 10^{-4} median peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

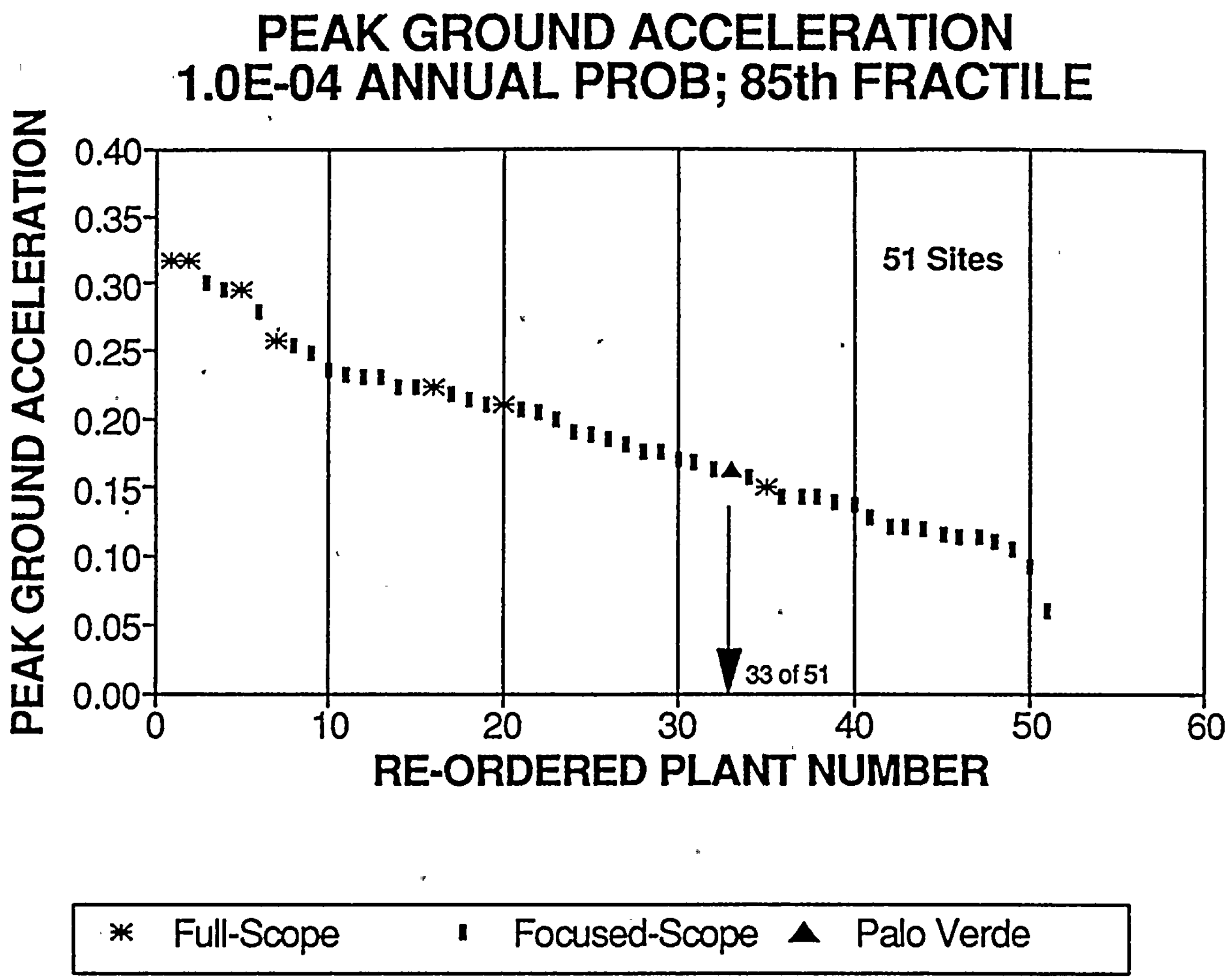

Figure A-6. Comparison of the 10^{-4} 85th-fractile peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

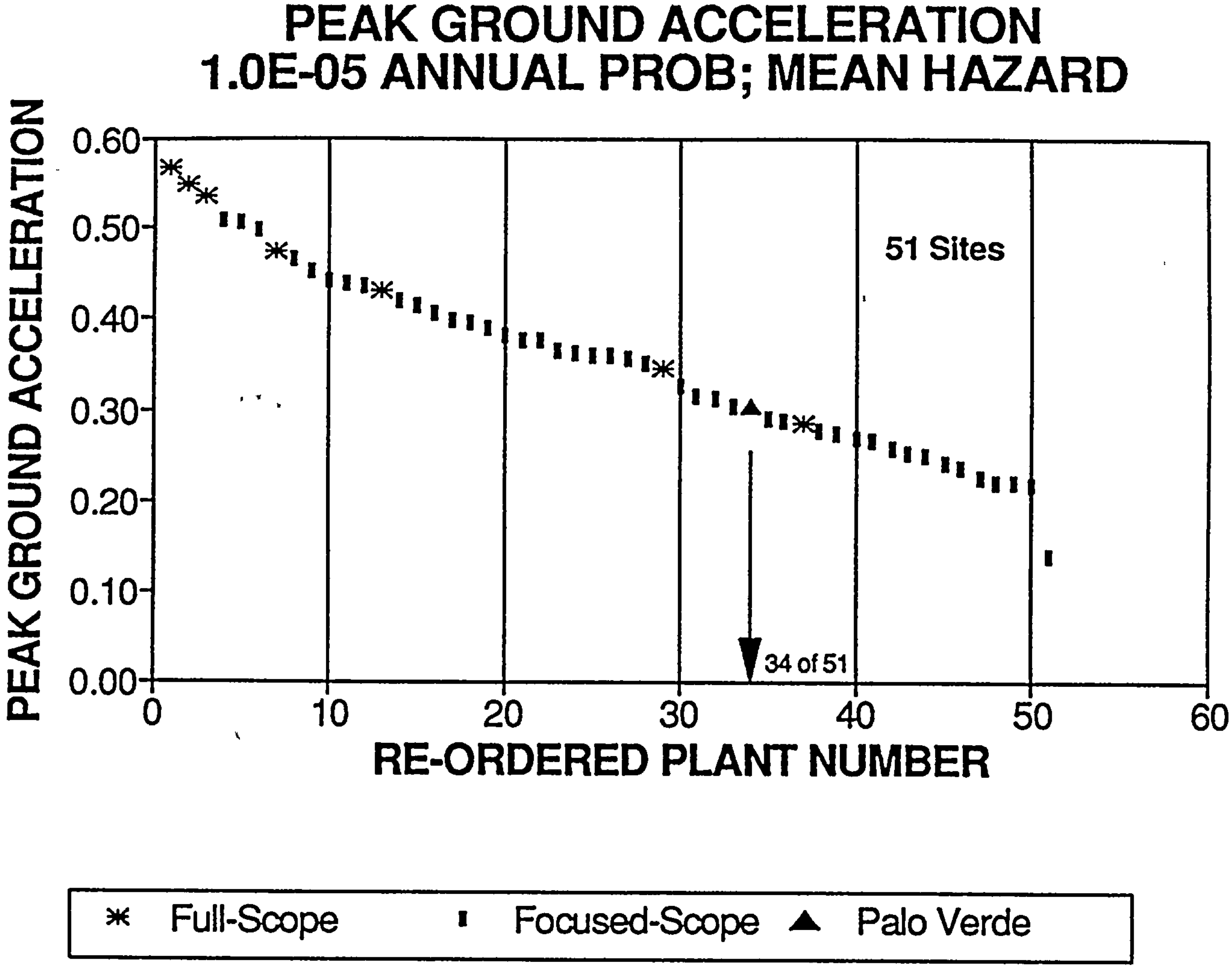

Figure A-7. Comparison of the 10^{-5} mean peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

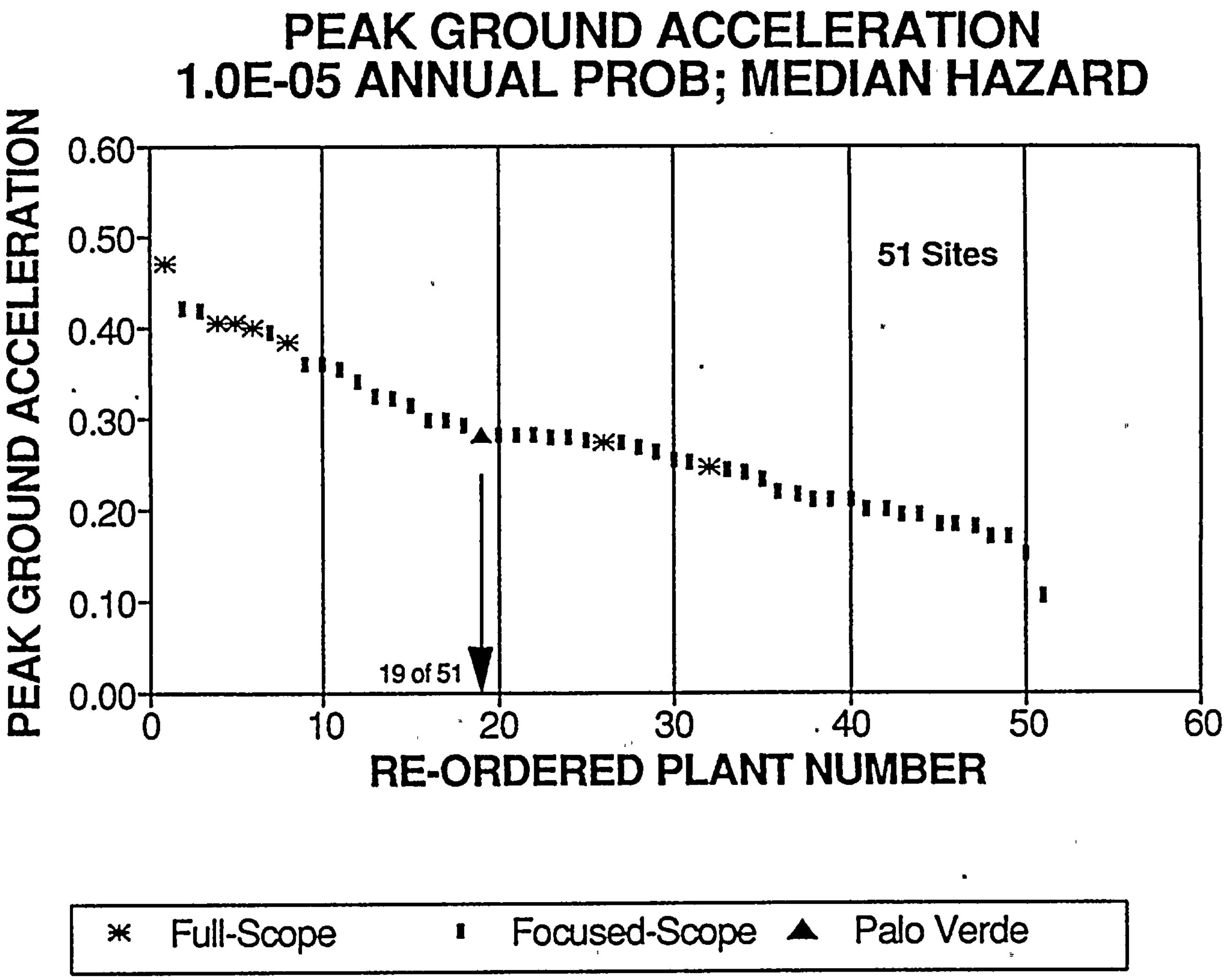

Figure A-8. Comparison of the 10^{-5} median peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

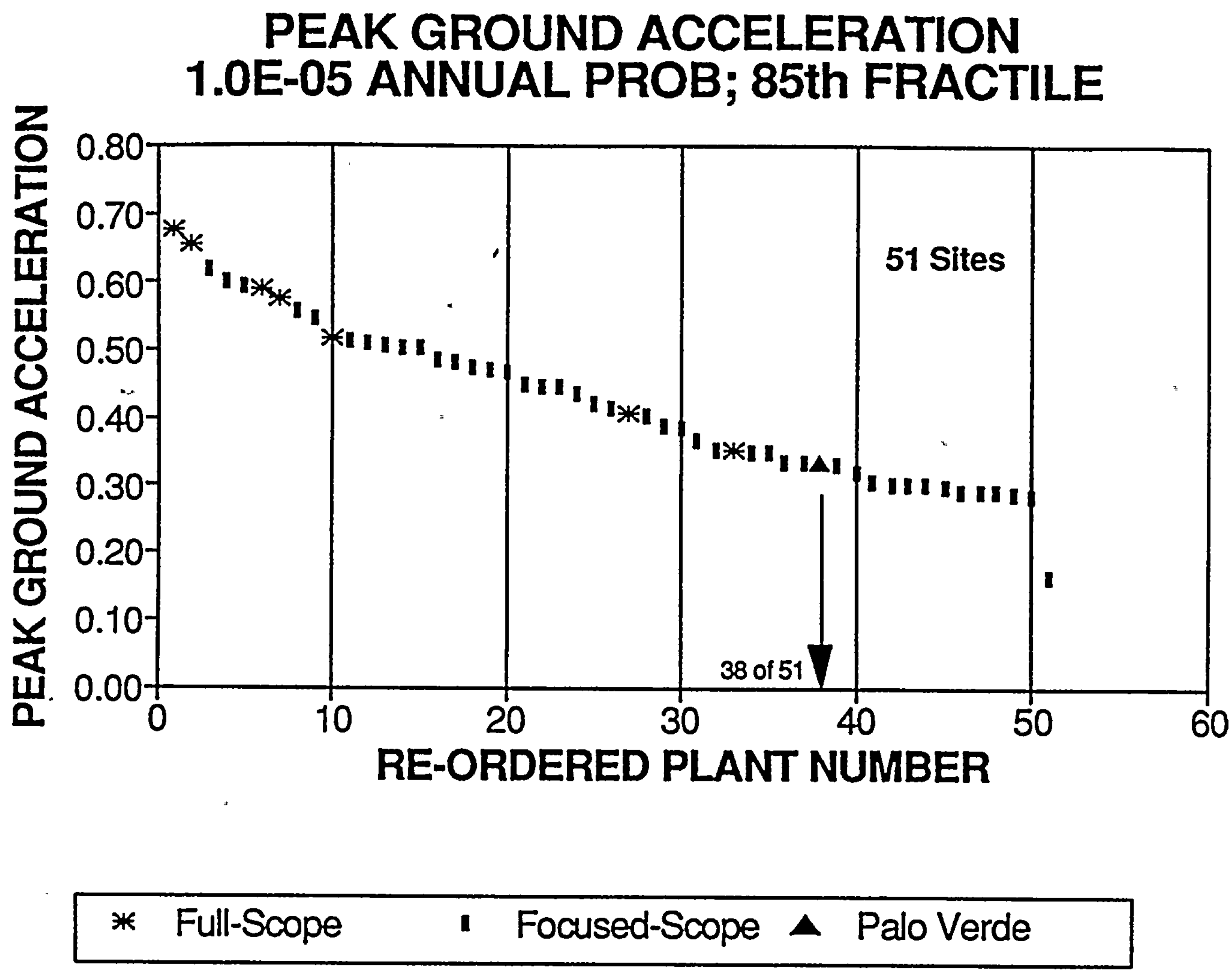

Figure A-9. Comparison of the 10^{-5} 85th-fractile peak ground acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

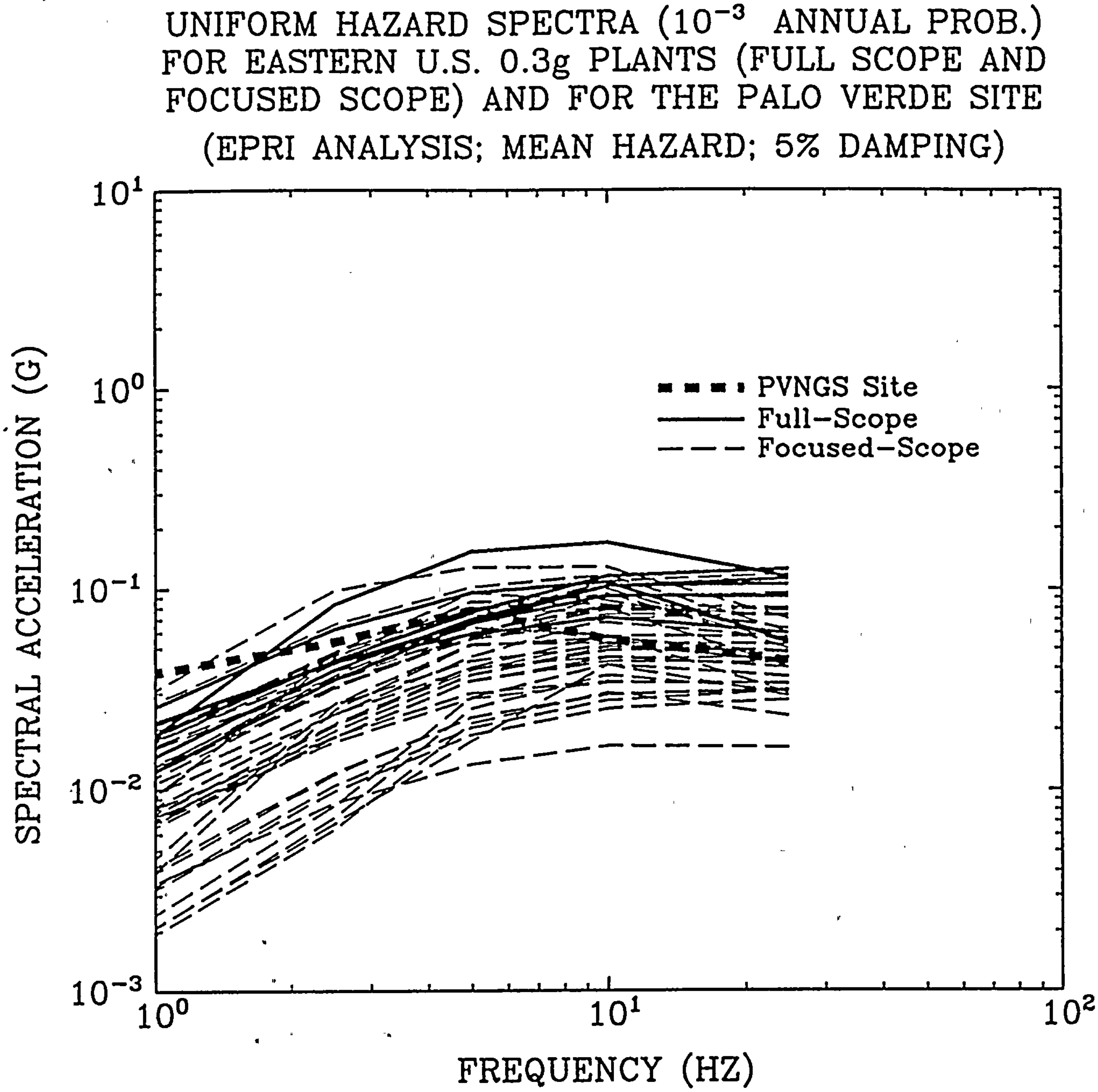

Figure A-10. Comparison of the 10^{-3} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

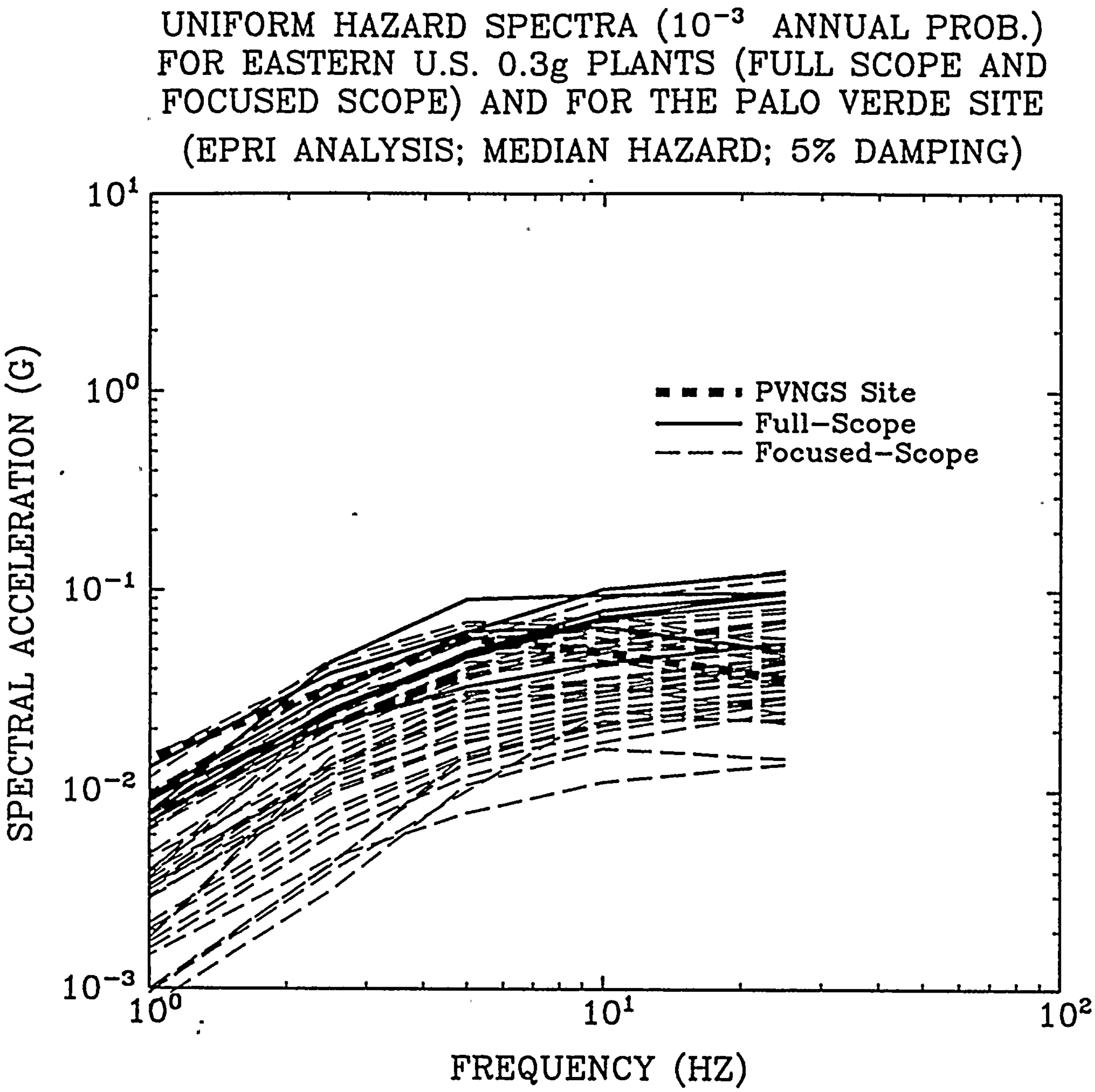

Figure A-11. Comparison of the 10^{-3} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

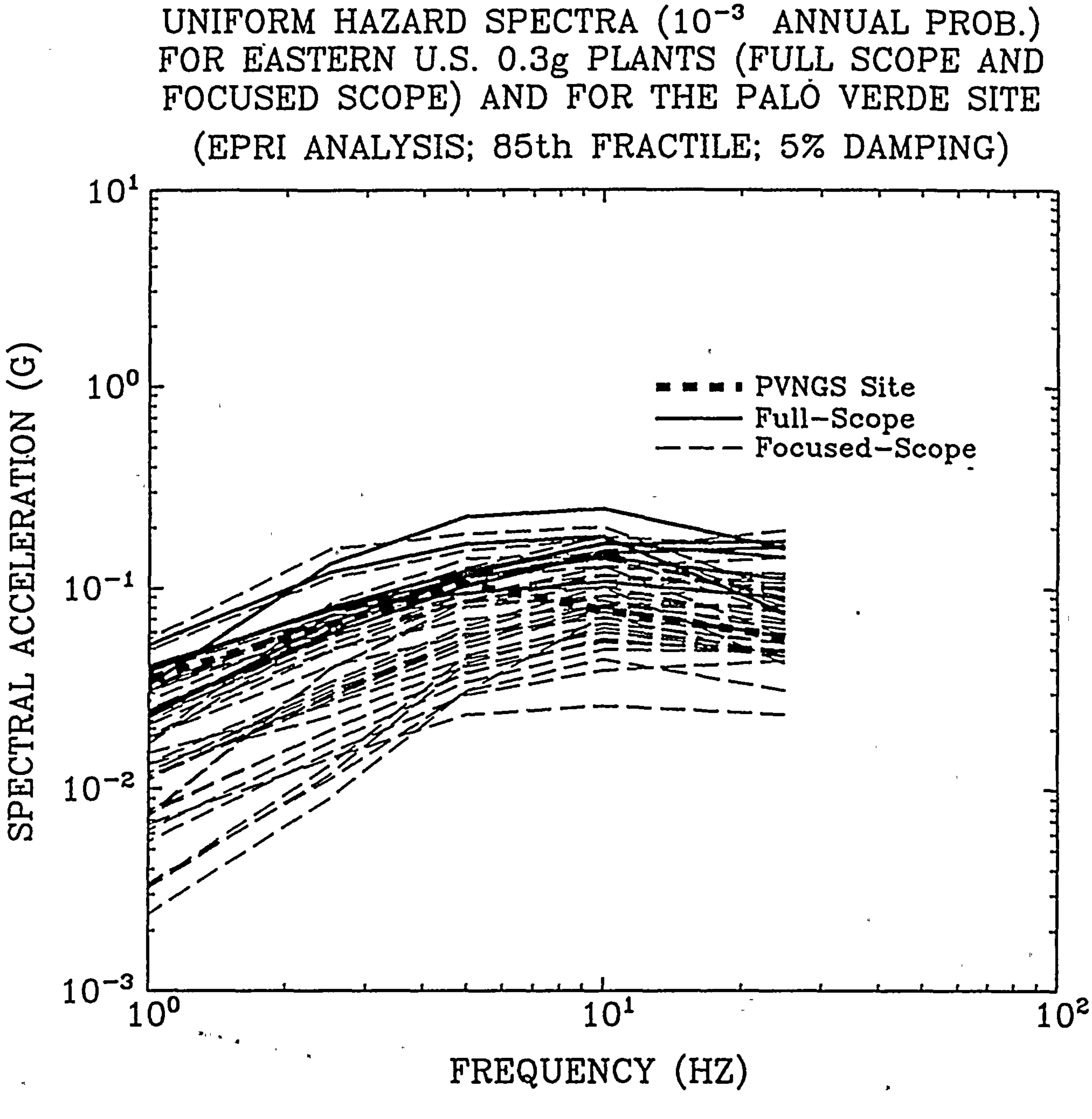

Figure A-12. Comparison of the 10^{-3} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

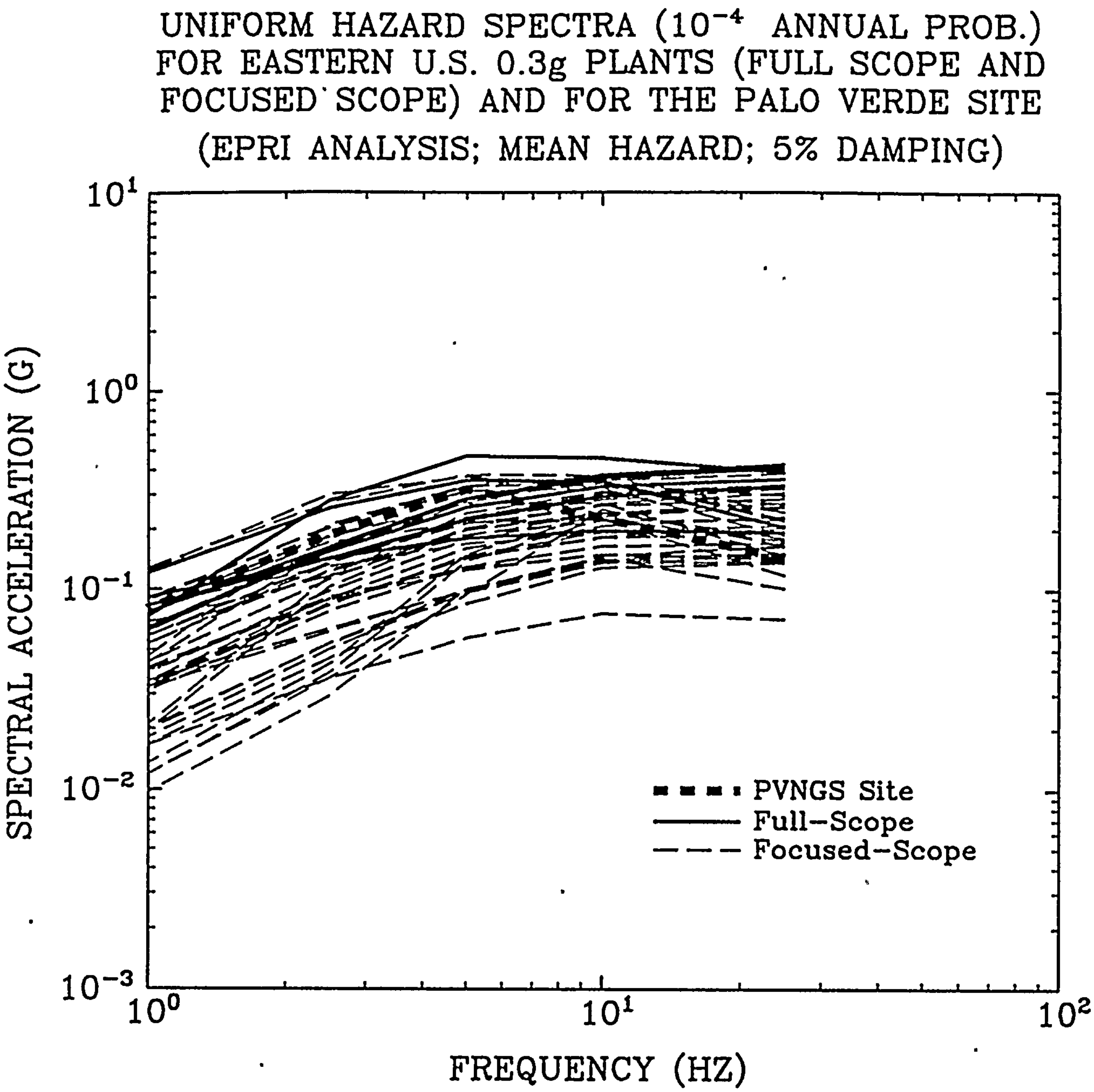

Figure A-13. Comparison of the 10^{-4} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

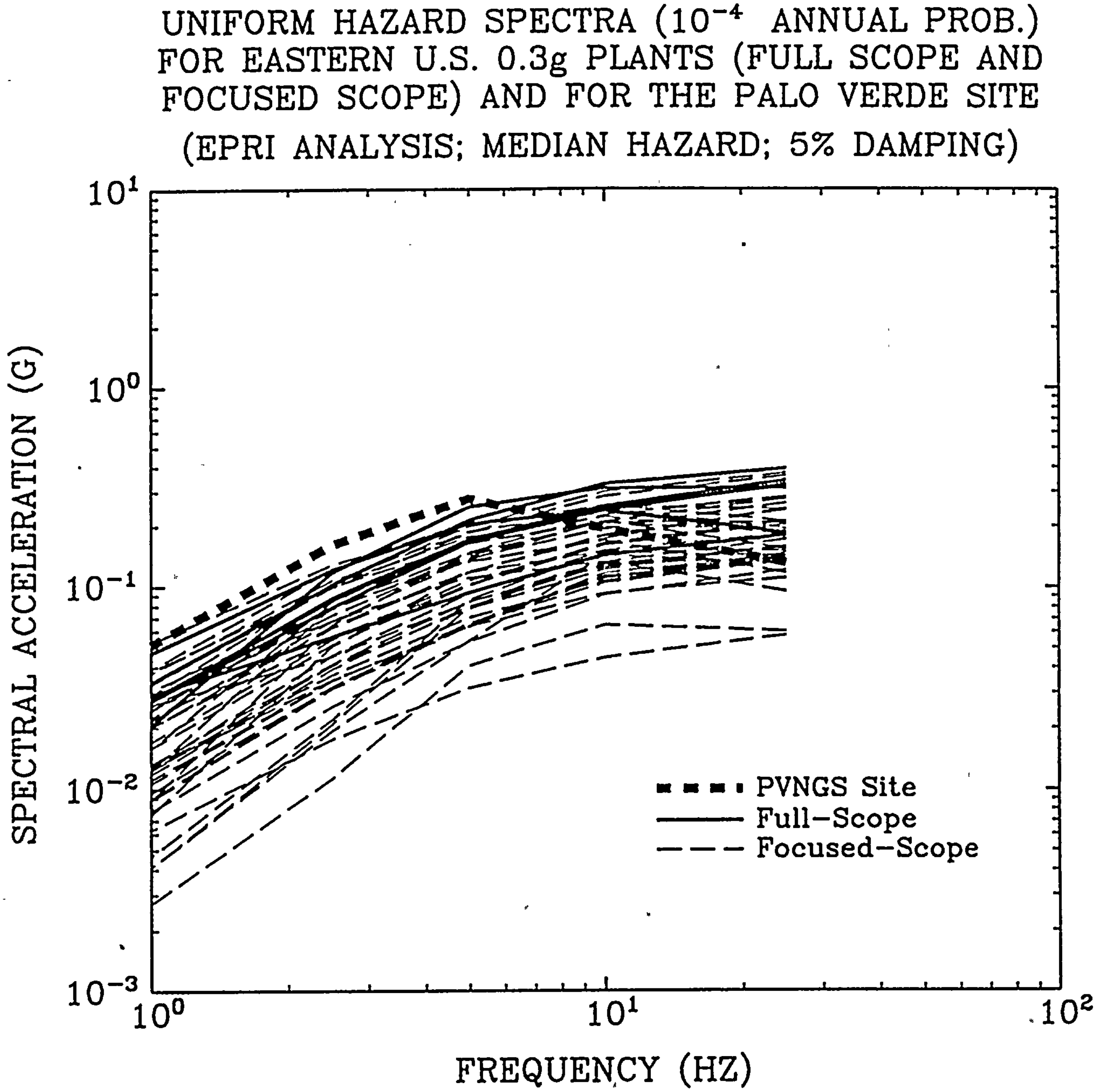

Figure A-14. Comparison of the 10^{-4} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

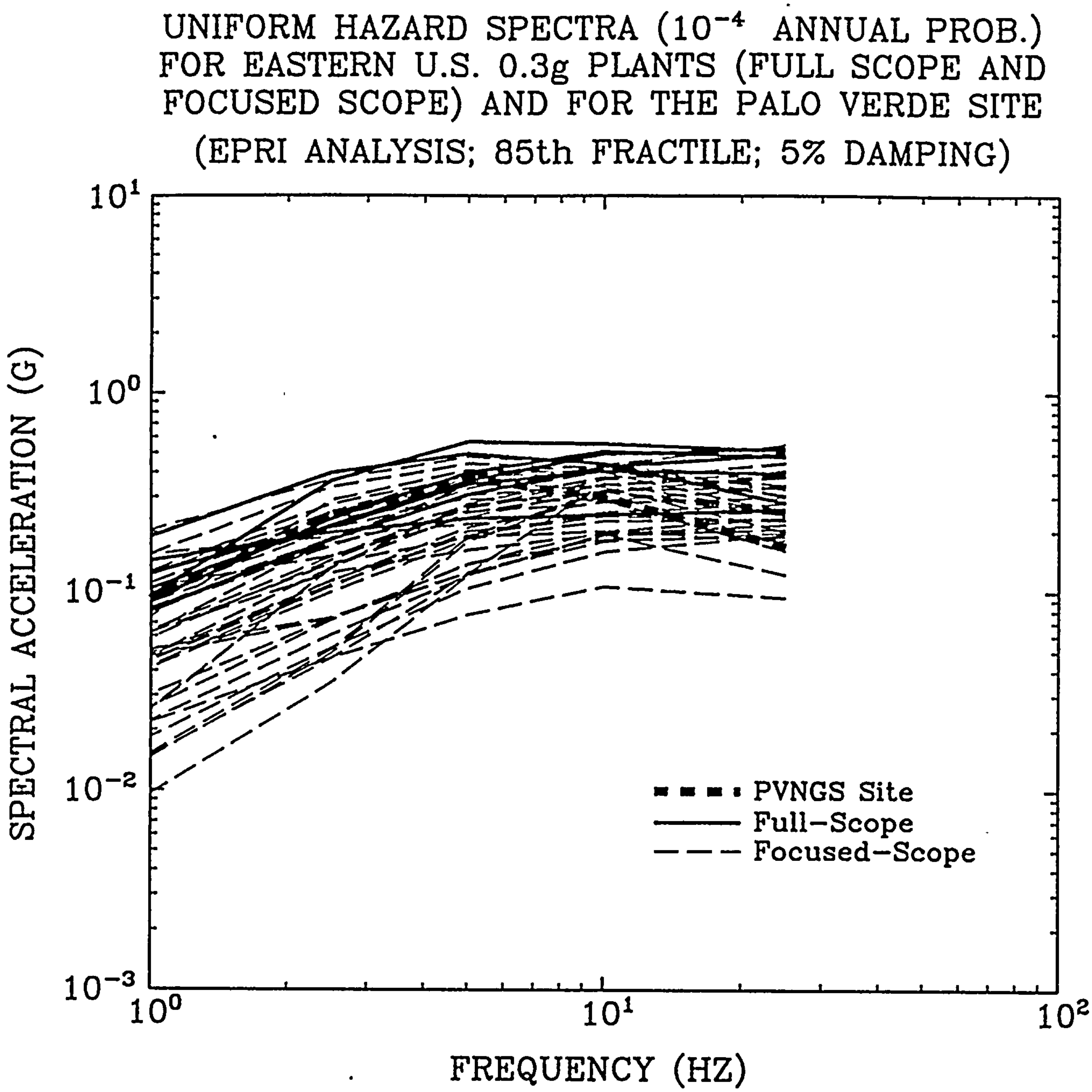

Figure A-15. Comparison of the 10^{-4} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

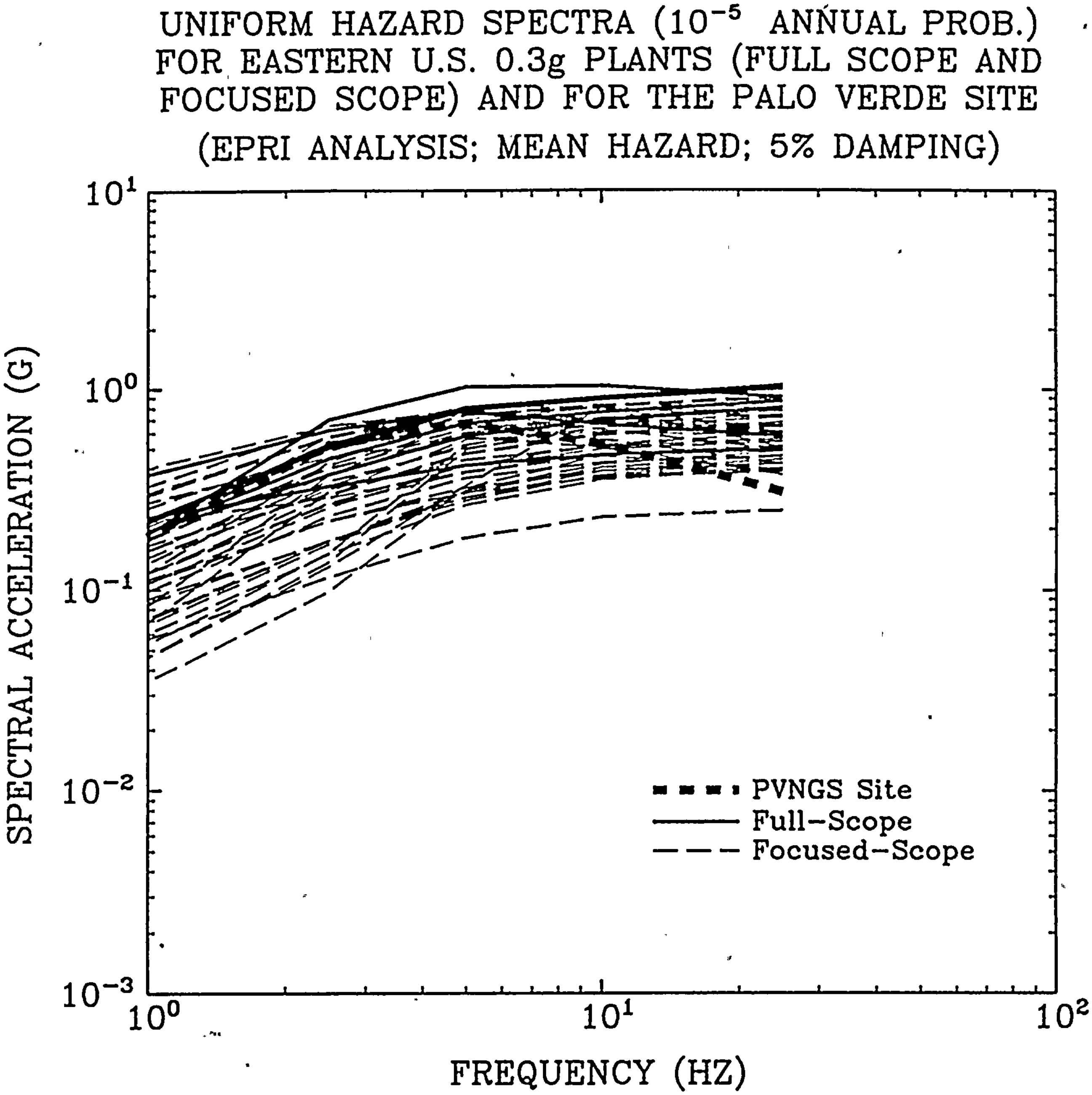

Figure A-16. Comparison of the 10^{-5} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

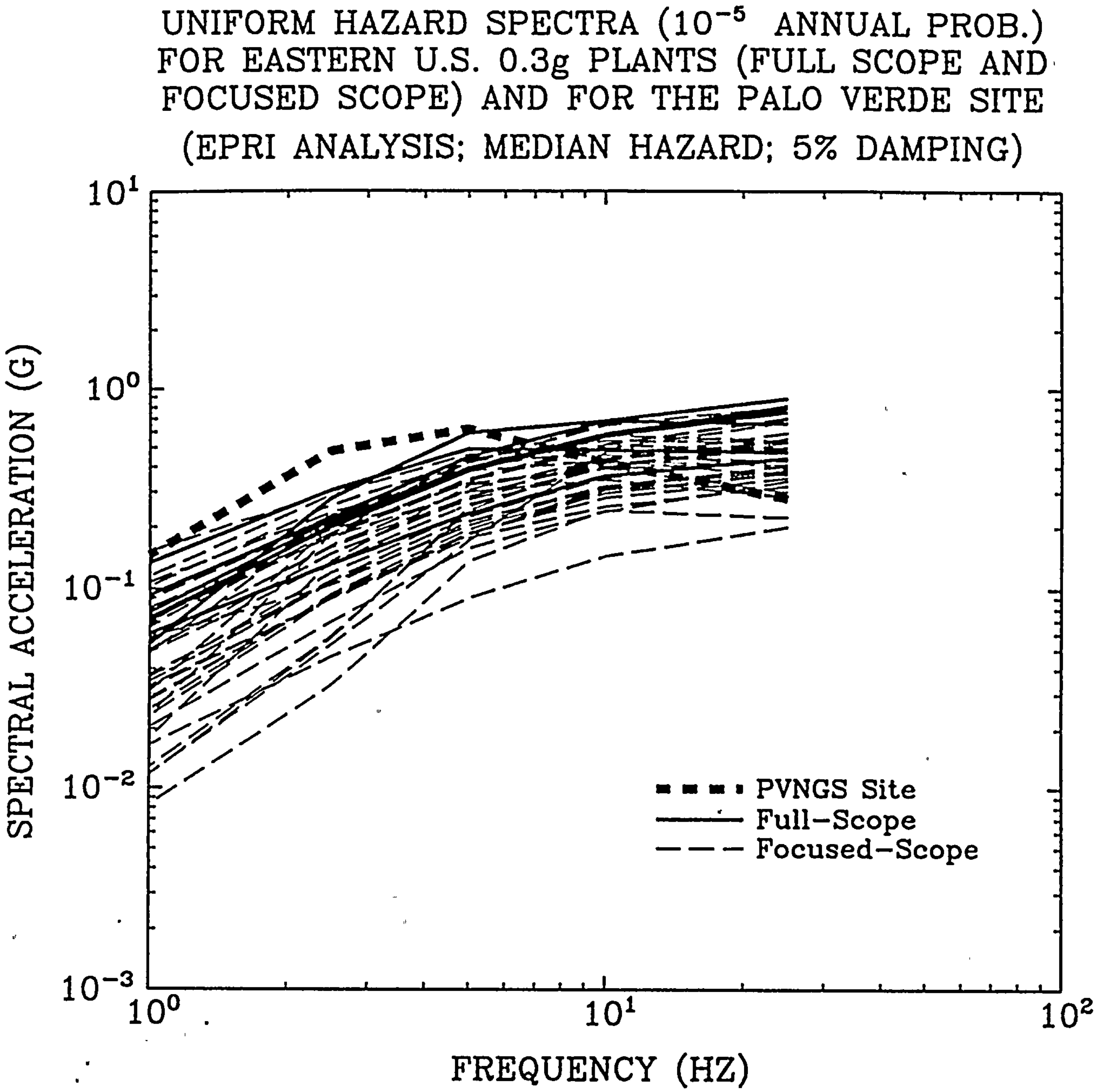

Figure A-17. Comparison of the 10^{-5} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

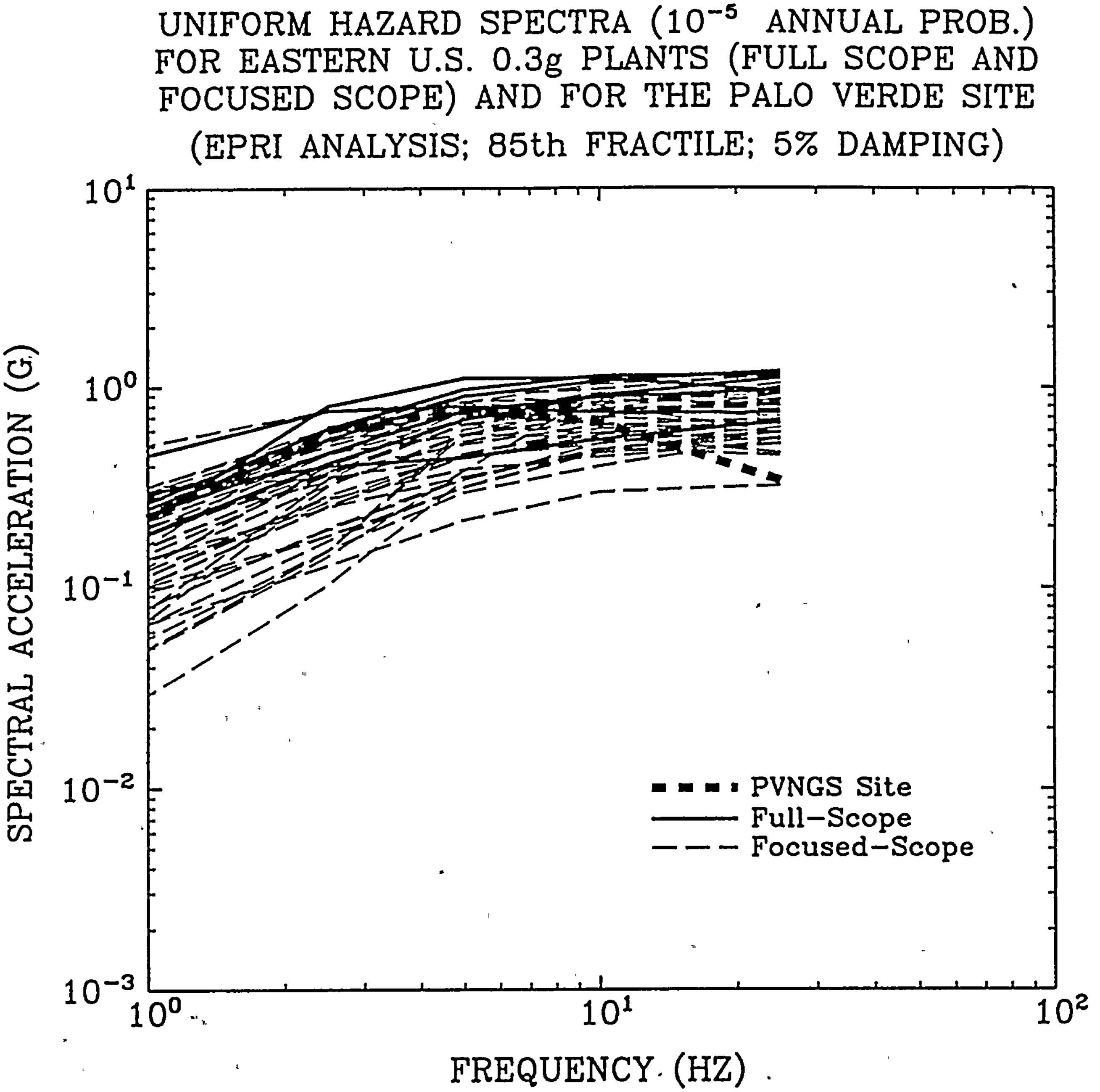

Figure A-18. Comparison of the 10^{-5} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Appendix B

COMPARISONS OF PROBABILITIES OF EXCEEDING NUREG/CR-0098 SPECTRA

This appendix presents probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum, as functions of vibration frequency. Exceedance-probability results for PGA and for spectra are provided for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. The exceedance probabilities are determined as outlined in Section 4, and are computed for the reference NUREG/CR-0098 spectrum anchored to PGA levels of 0.3g and 0.5g. Comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures A–1 to A–3 present, respectively, the mean, median, and 85th-fractile probabilities of exceeding a PGA level of 0.3g. The graphs in Figures A–4 to A–6 present similar results for a PGA level of 0.5g.

Figures A–7 to A–12 present exceedance-probability spectra results, that correspond to the respective PGA-based cases just described for Figures A–1 to A–6, where the NUREG/CR-0098 median spectral shape is used as the basis for the transformation from ground motions to probabilities.

The values presented in this appendix have been used to obtain the composite probability of exceedance results discussed in Section 5.

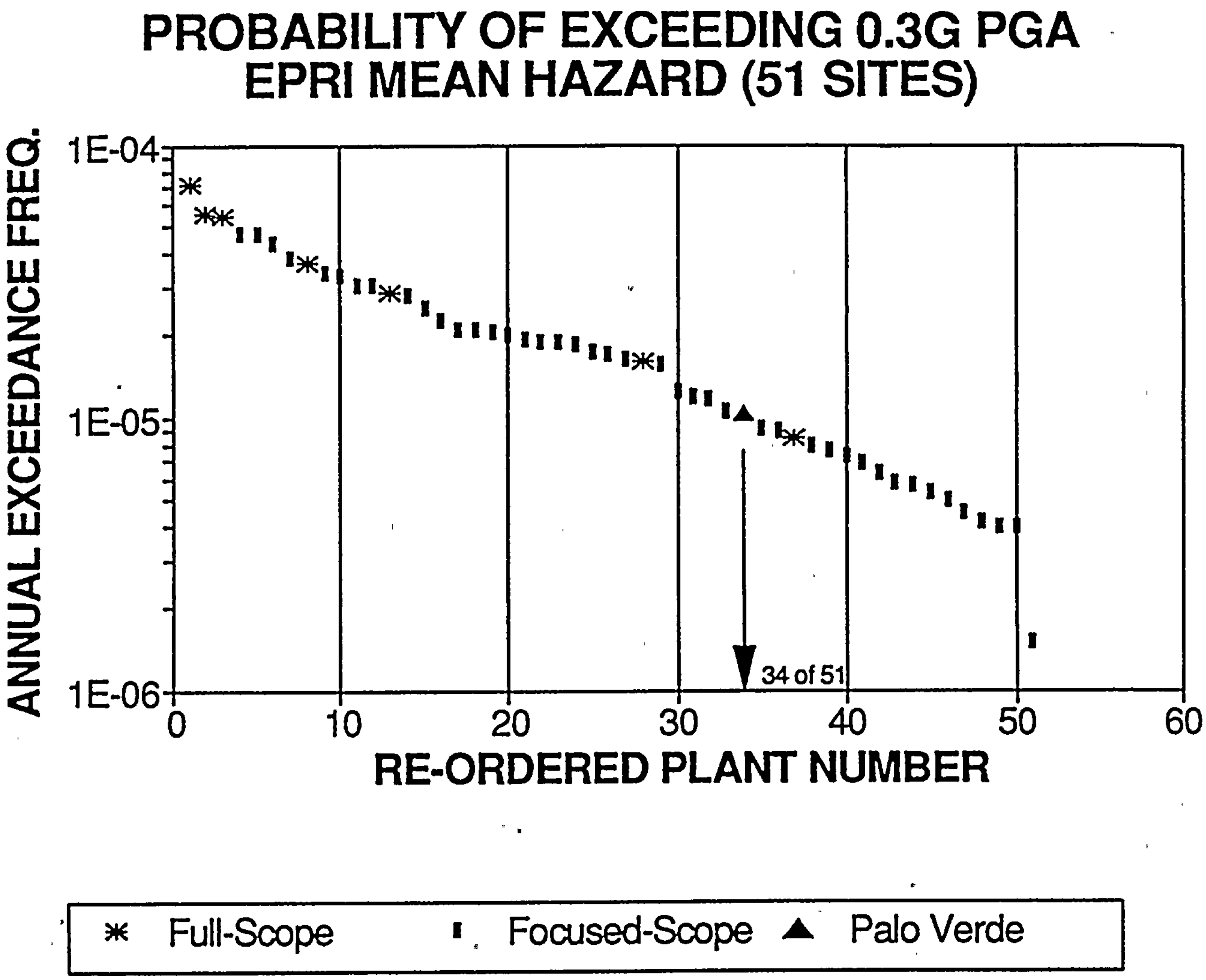

Figure B-1. Mean probability of exceeding a peak ground acceleration of 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

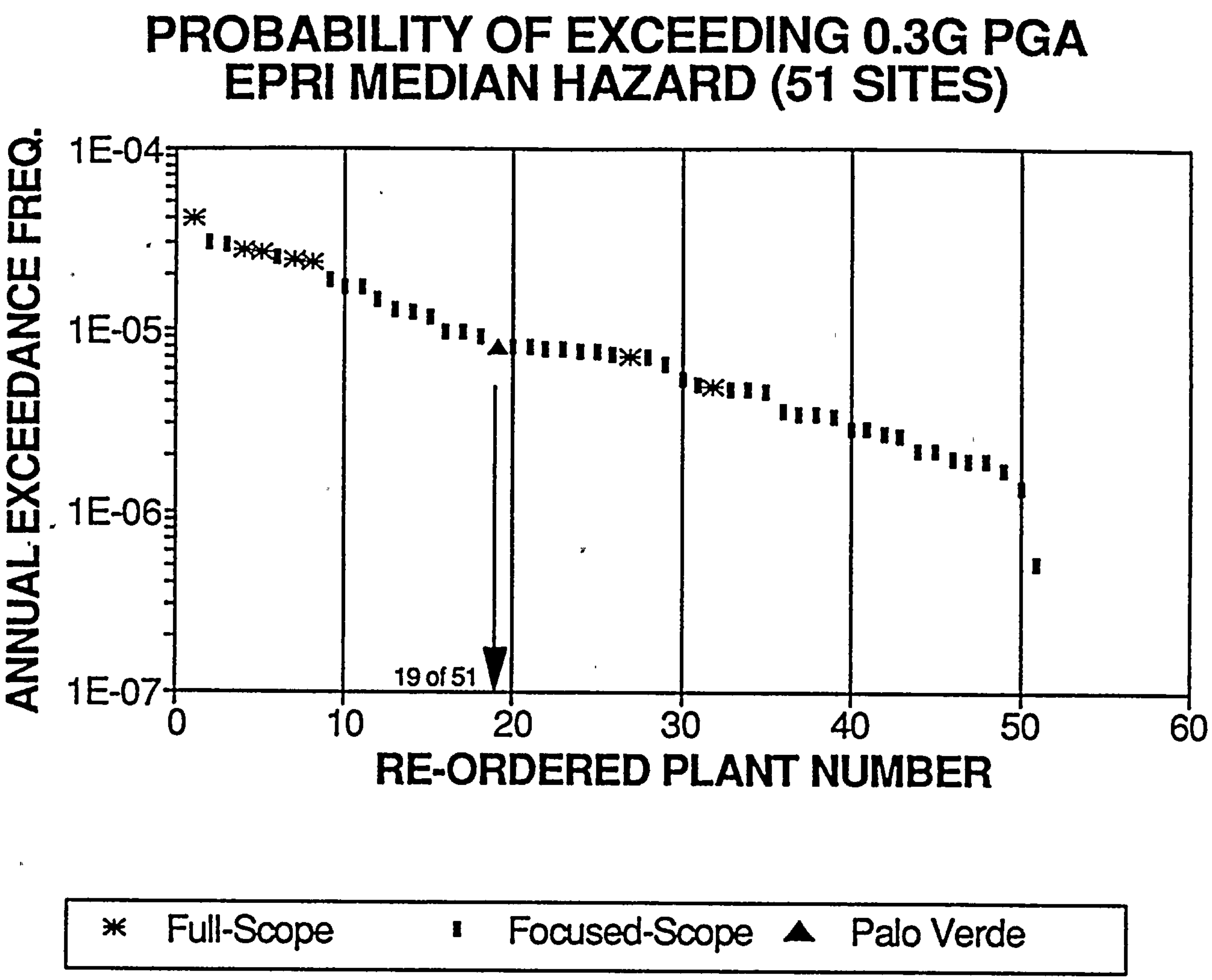

Figure B-2. Median probability of exceeding a peak ground acceleration of 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

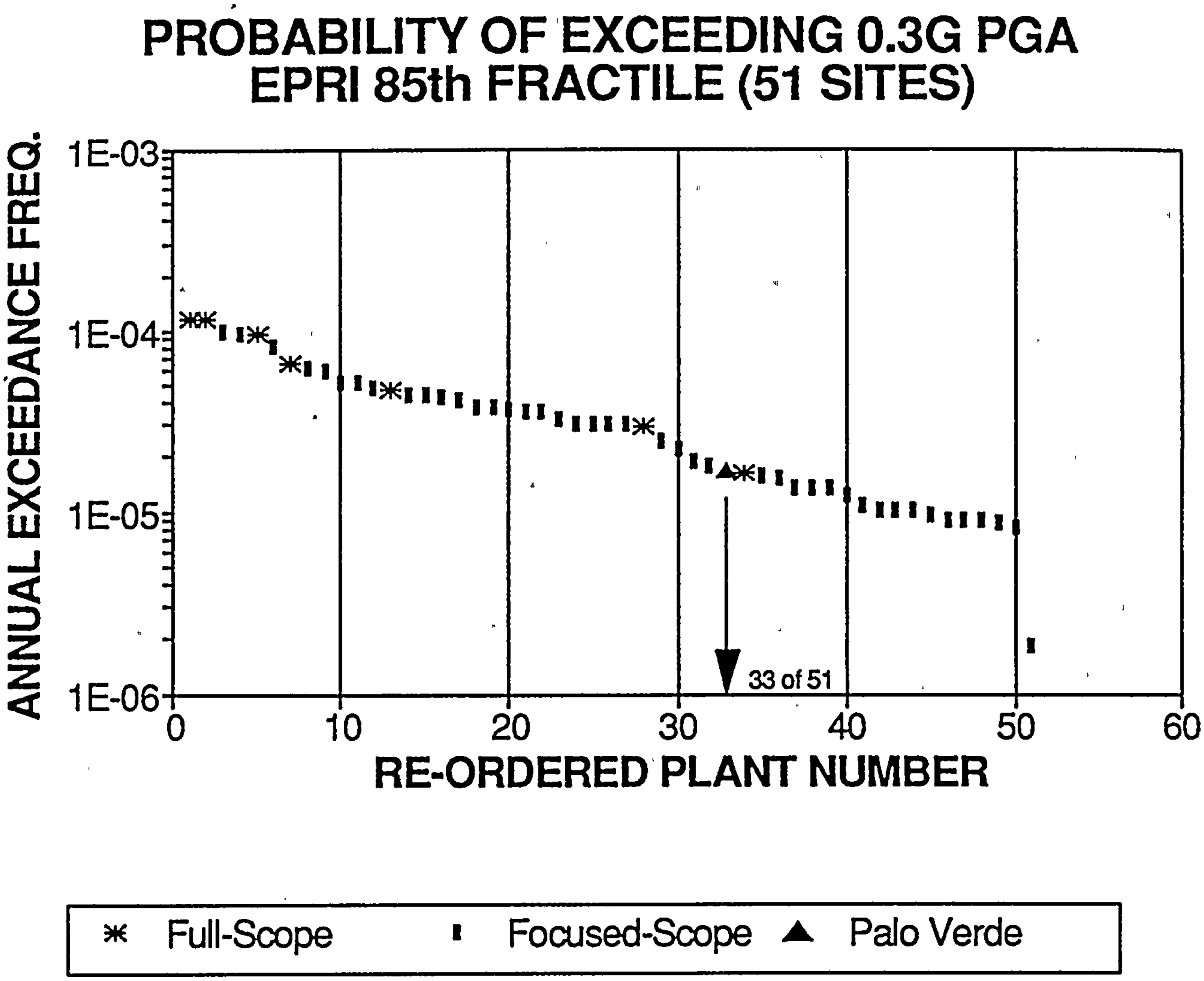

Figure B-3. 85th-fractile probability of exceeding a peak ground acceleration of 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

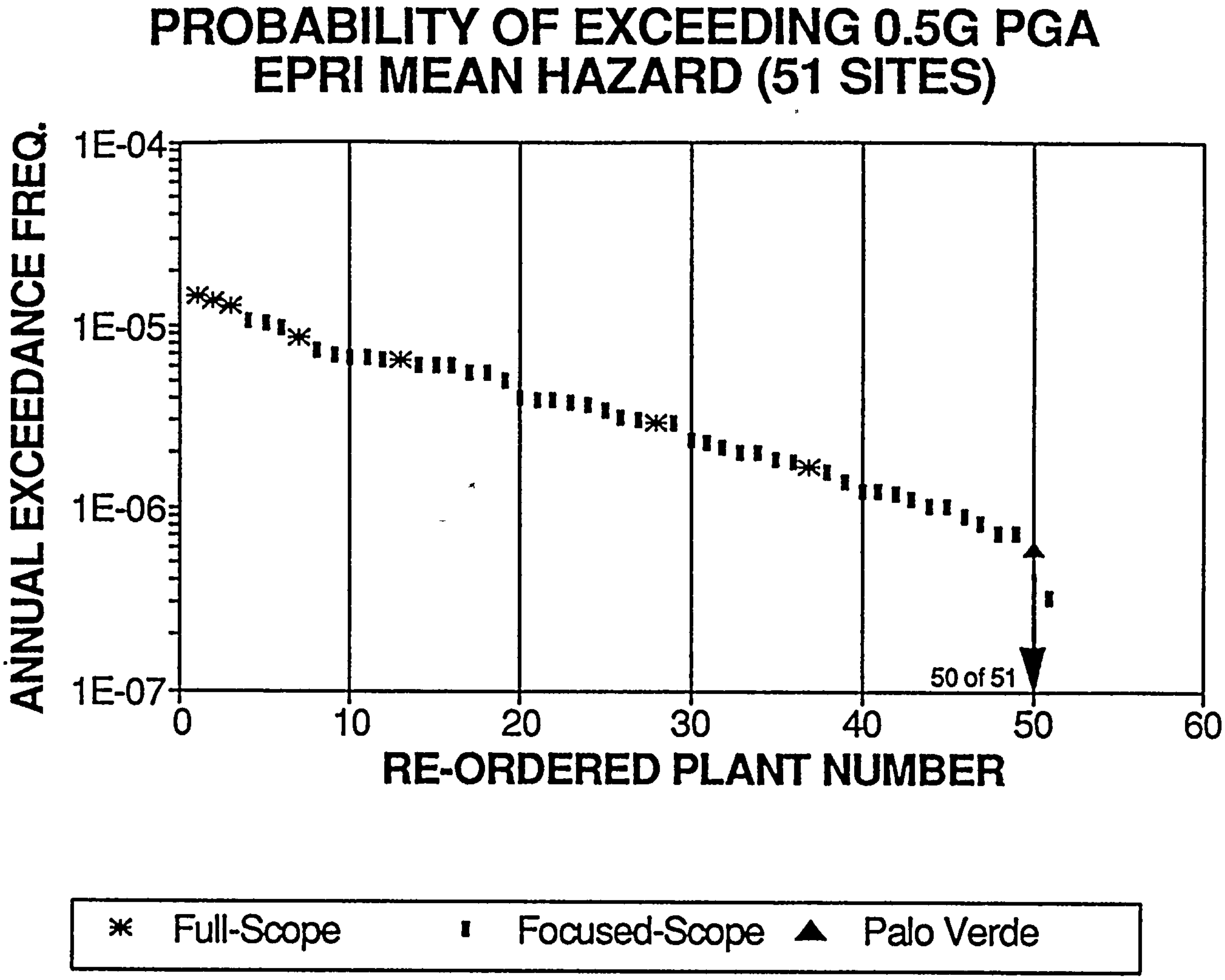

Figure B-4. Mean probability of exceeding a peak ground acceleration of 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

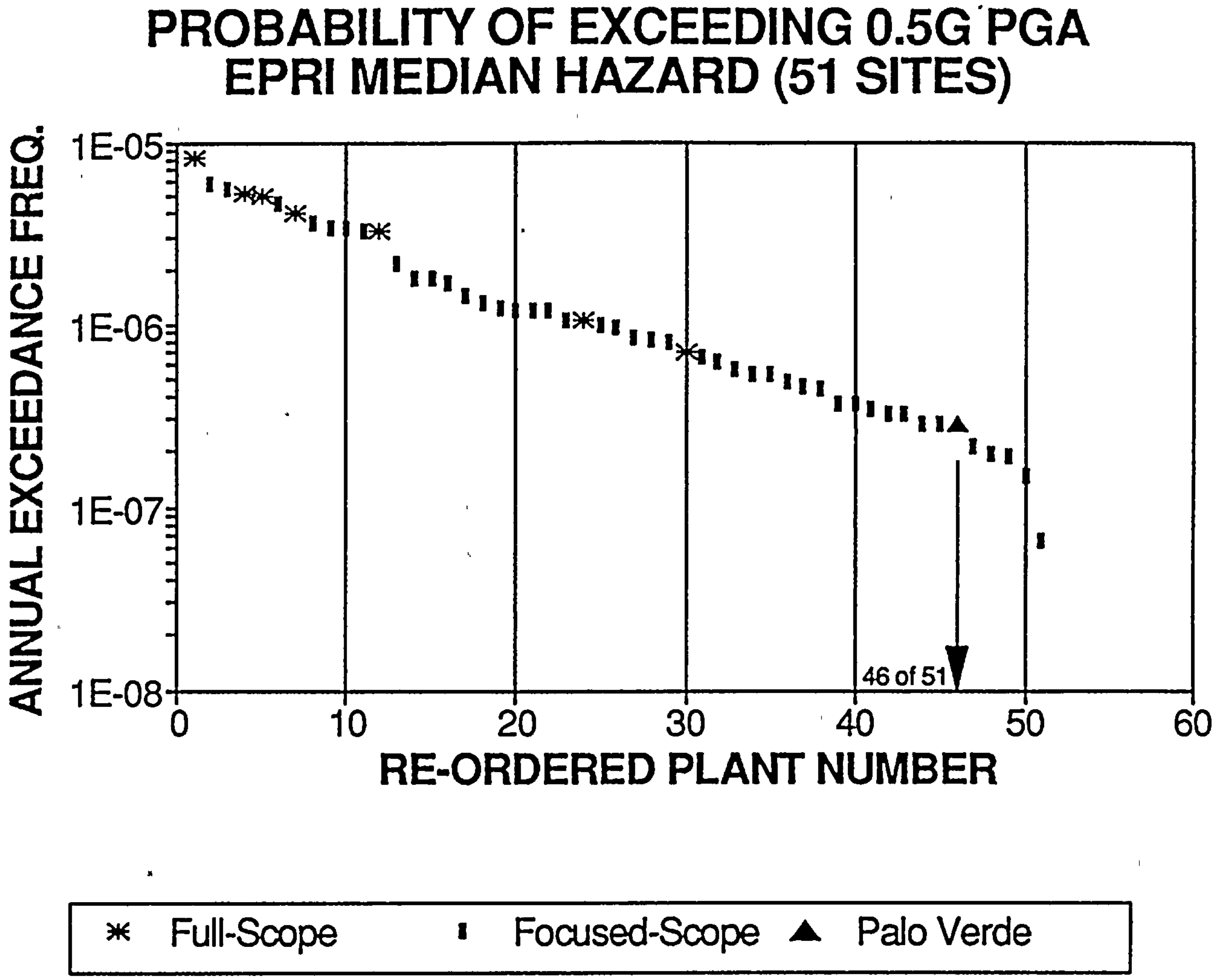

Figure B-5. Median probability of exceeding a peak ground acceleration of 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

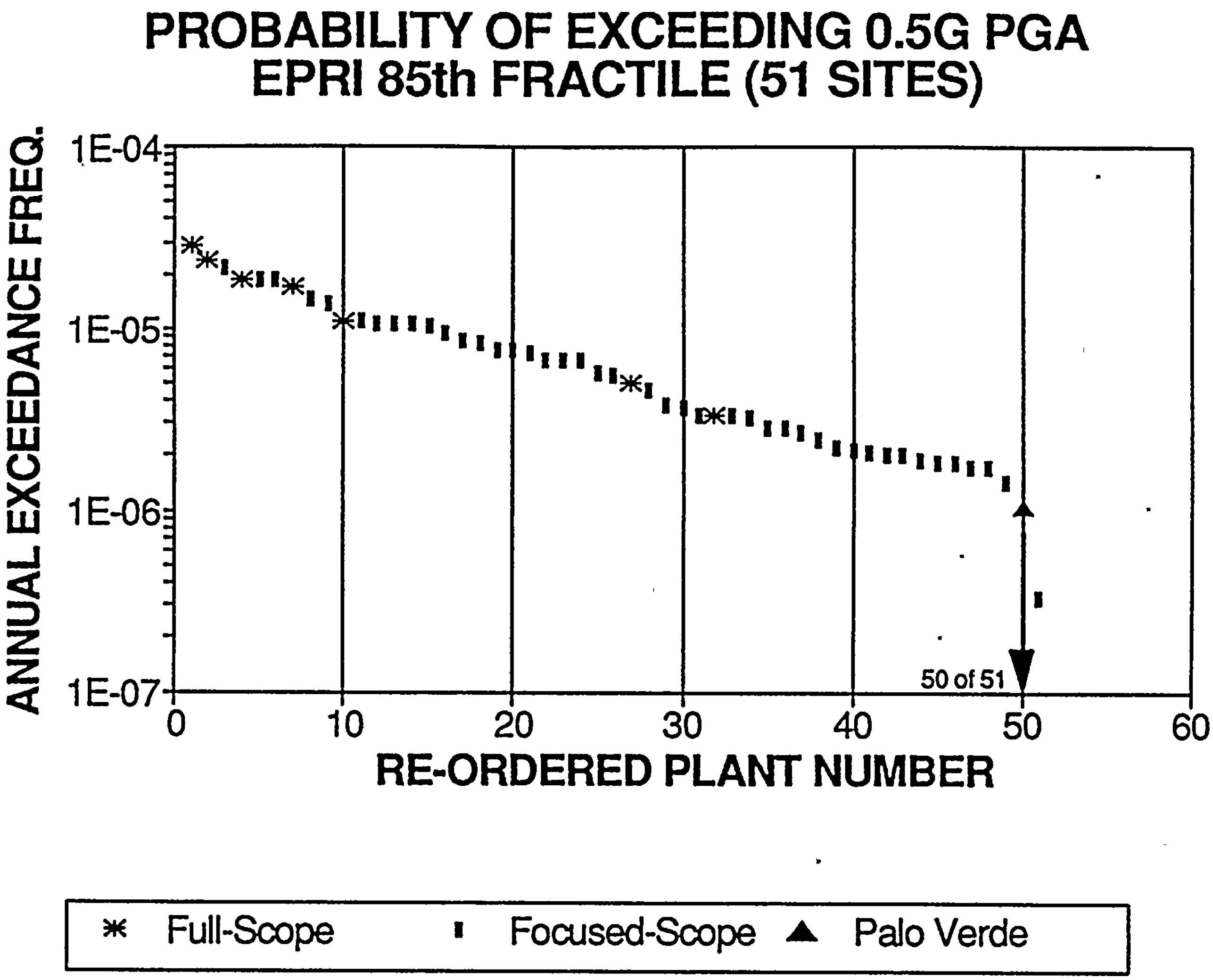

Figure B-6. 85th-fractile probability of exceeding a peak ground acceleration of 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

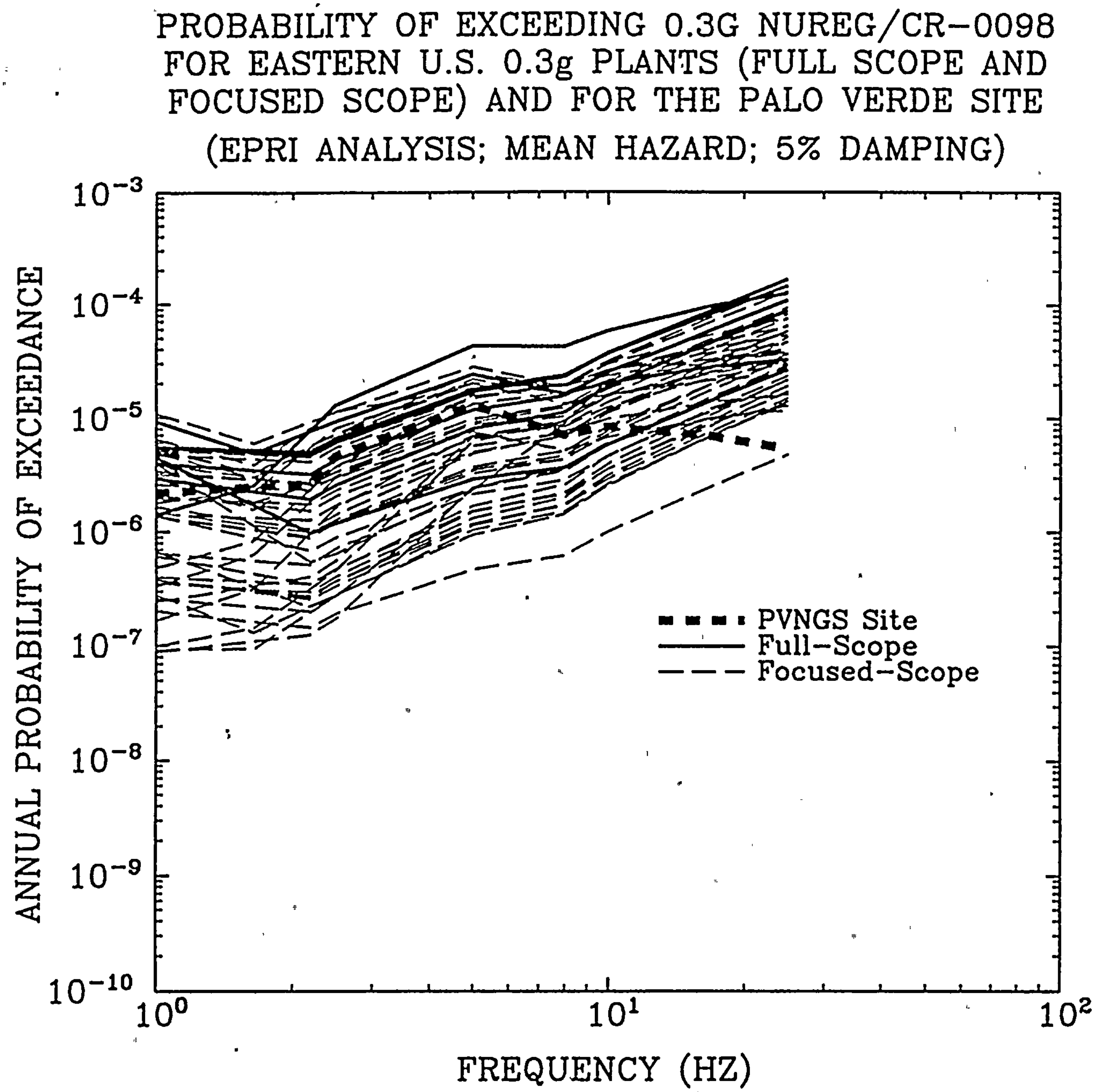

Figure B-7. Mean probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

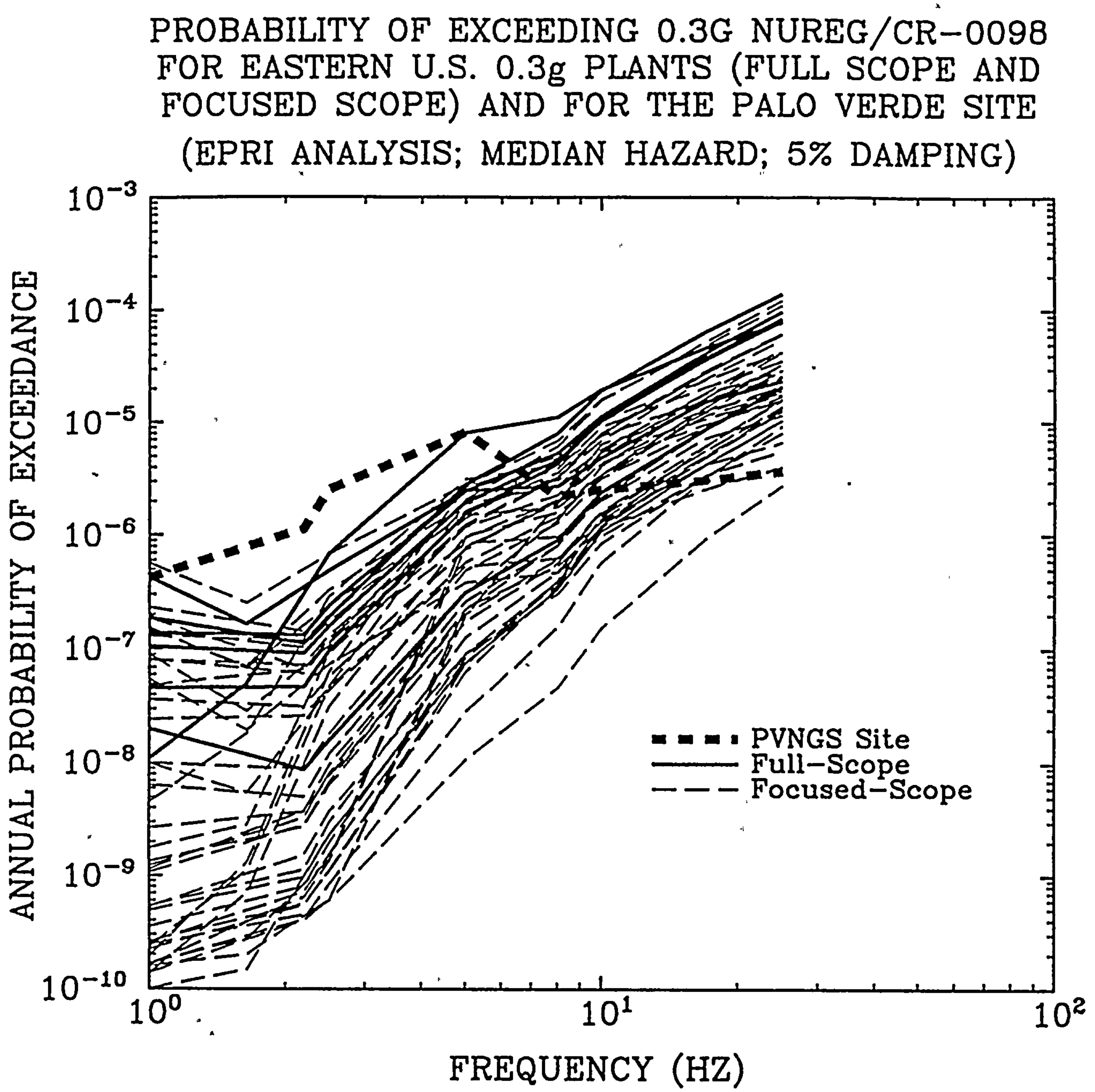

Figure B-8. Median probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

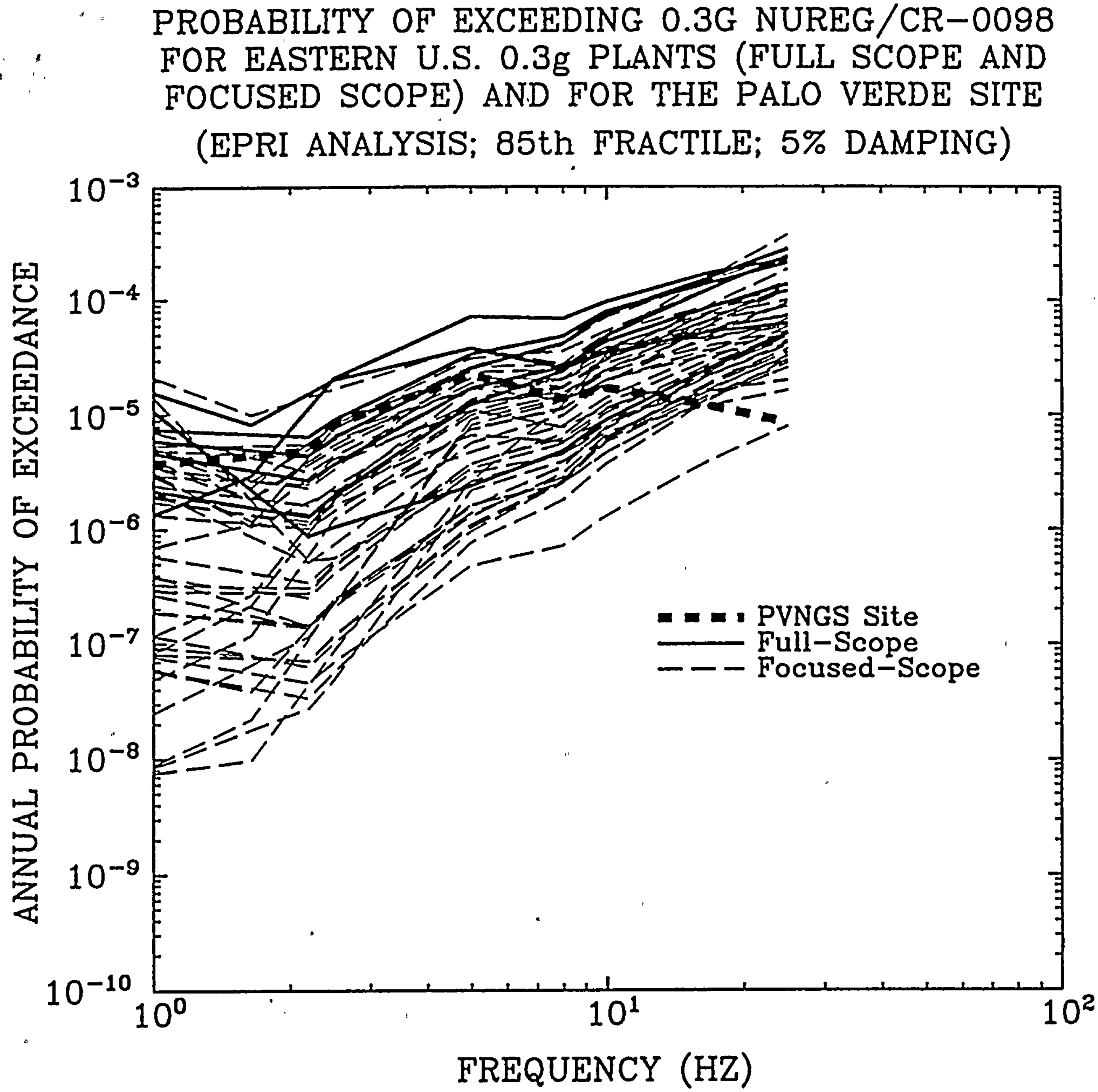

Figure B-9. 85th-fractile probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

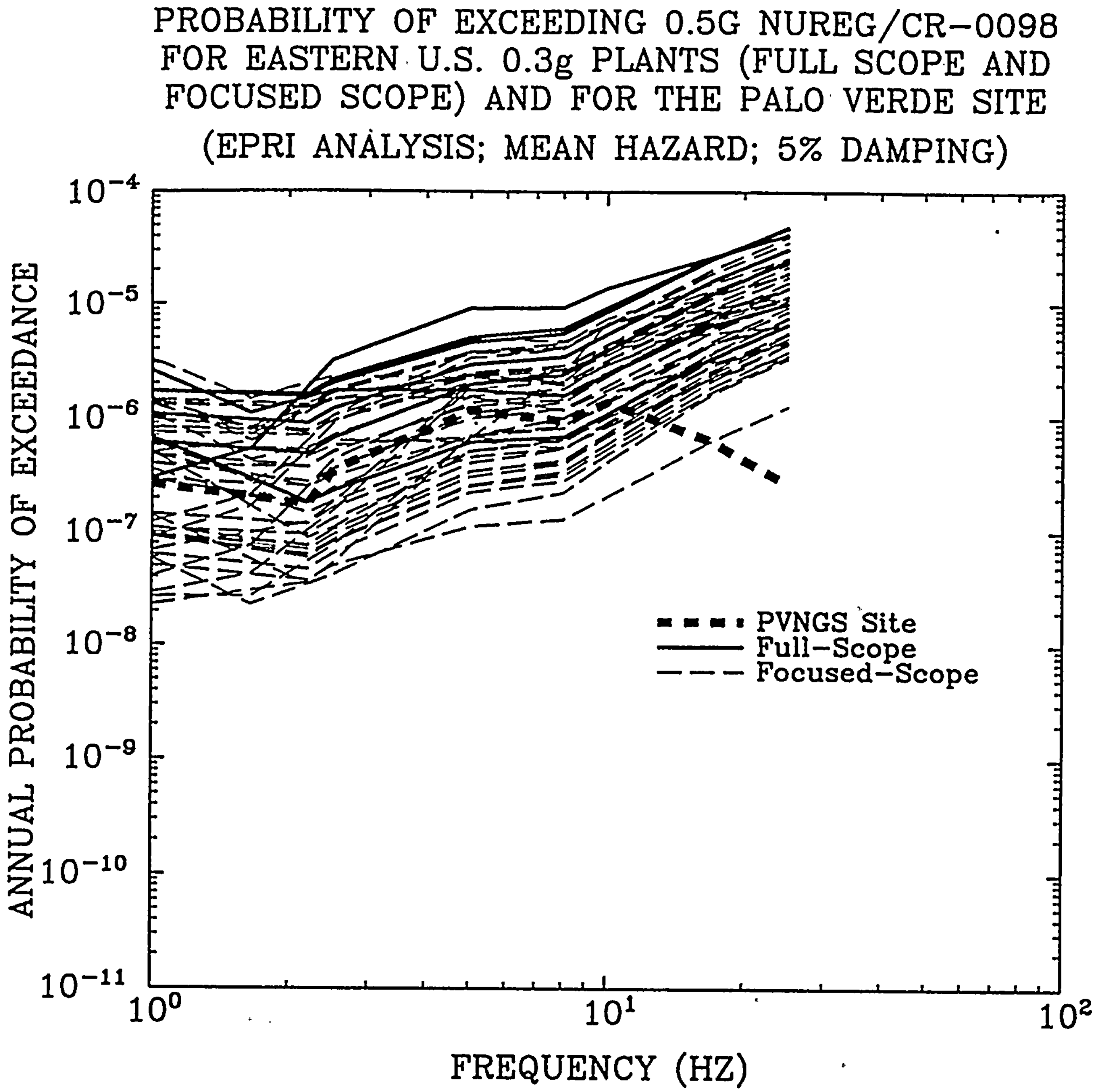

Figure B-10. Mean probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

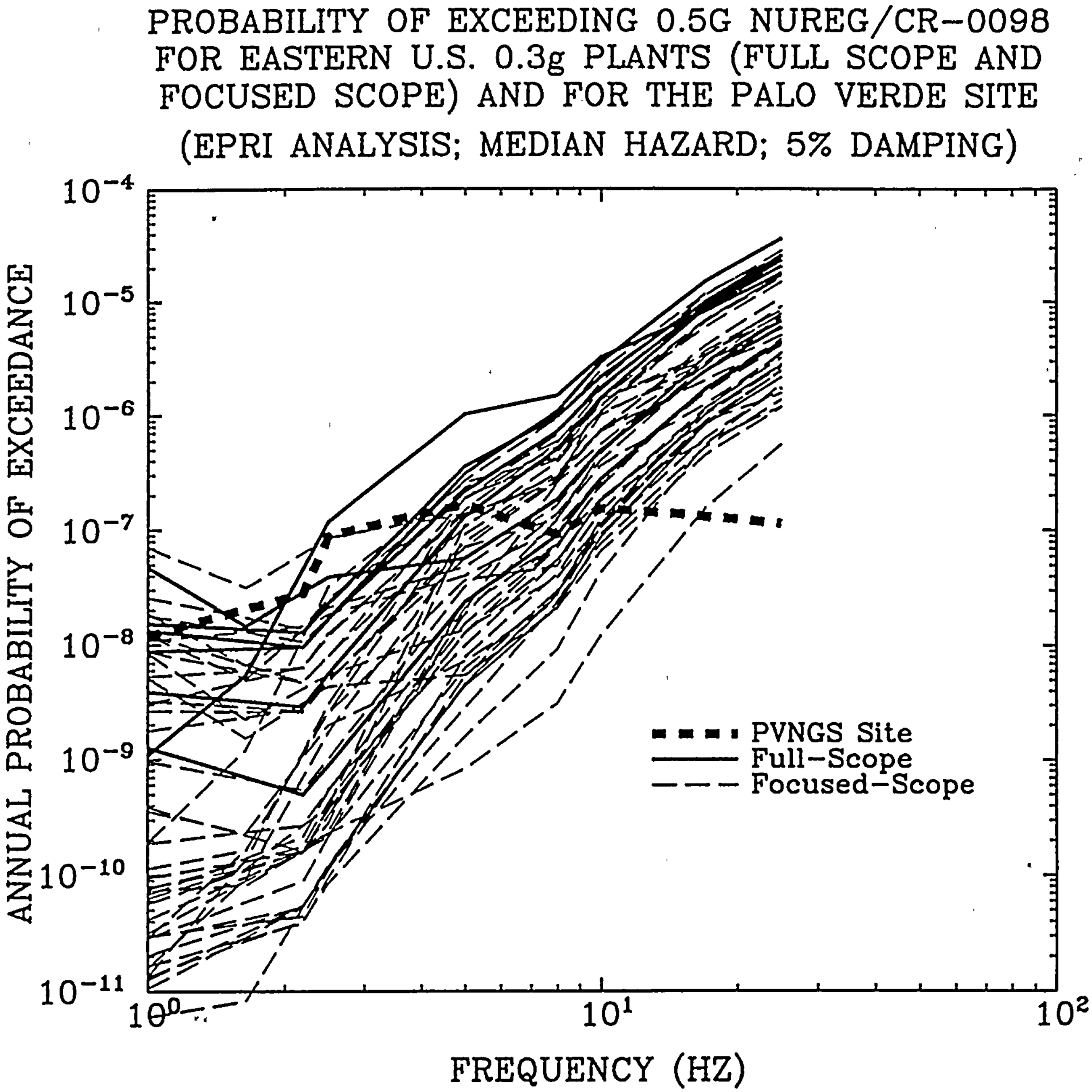

Figure B-11. Median probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

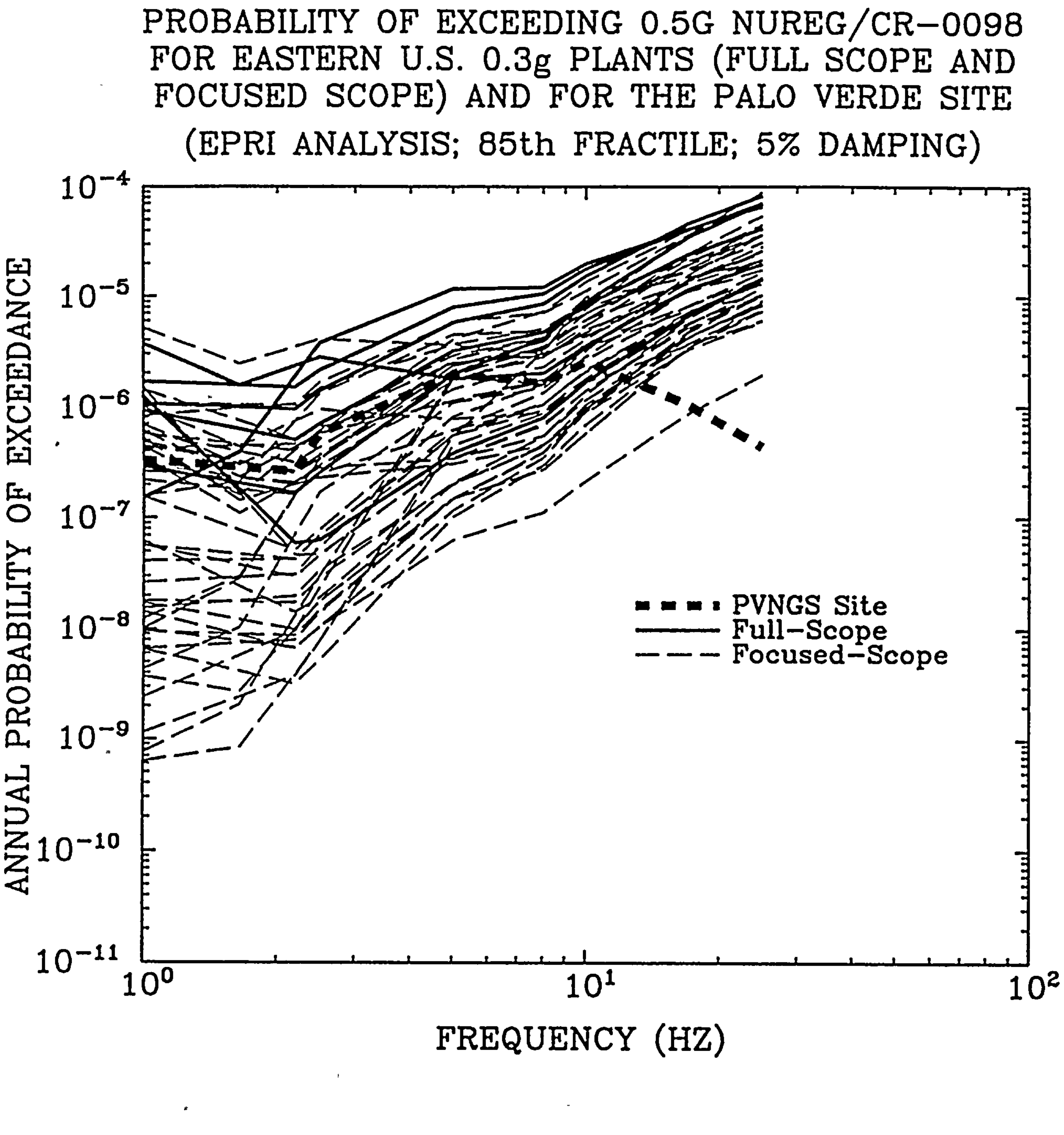

Figure B-12. 85th-fractile probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Appendix C

COMPARISONS OF PROBABILITIES OF EXCEEDING DESIGN-BASIS SPECTRA

This appendix presents probabilities of exceeding plant seismic designs, as functions of vibration frequency. Design-basis exceedance-probability results for PGA and for spectral frequencies are provided for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. The exceedance probabilities are determined as outlined in Section 4, and are computed for reference spectra defined by plant-specific seismic design (SSE) levels. Comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures A–1 to A–3 present, respectively, the mean, median, and 85th-fractile probabilities of exceeding the design PGA level. The graphs in Figures A–4 to A–6 present corresponding design-basis exceedance-probability spectra results.

The values presented in this appendix have been used to obtain composite probability of exceedance results for seismic design bases, which are discussed in Section 5.

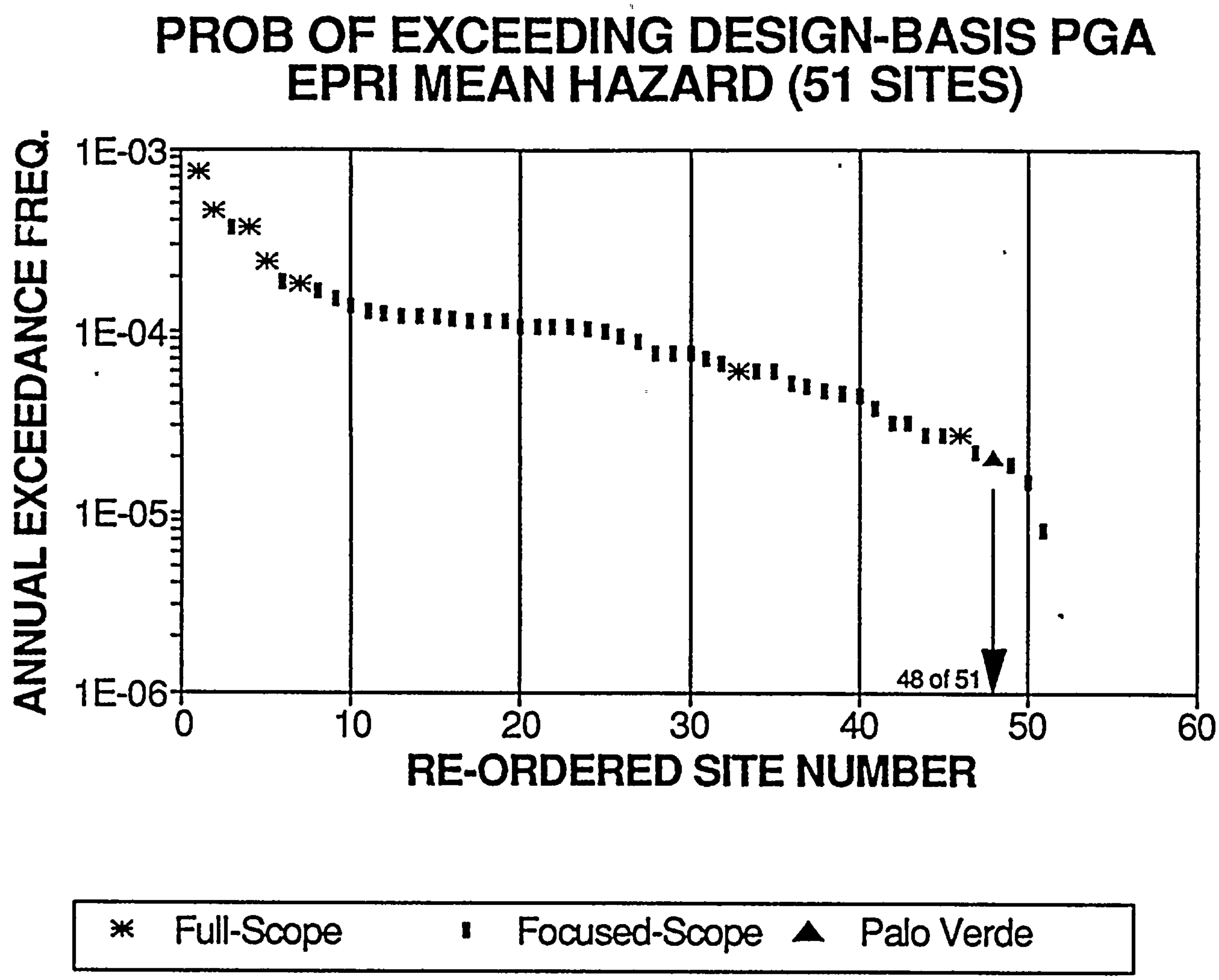

Figure C-1. Mean probability of exceeding the seismic design-basis PGA: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

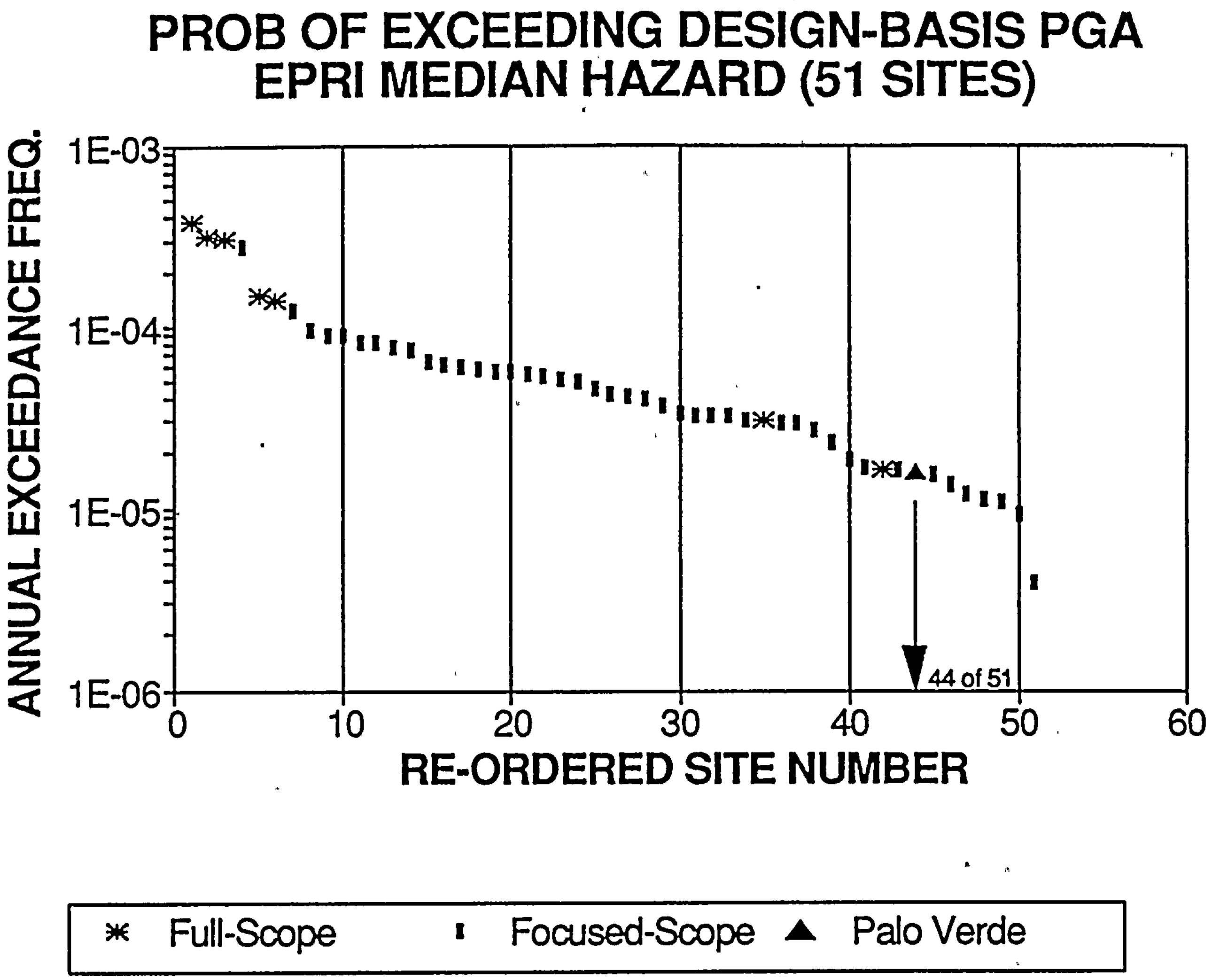

Figure C-2. Median probability of exceeding the seismic design-basis PGA: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

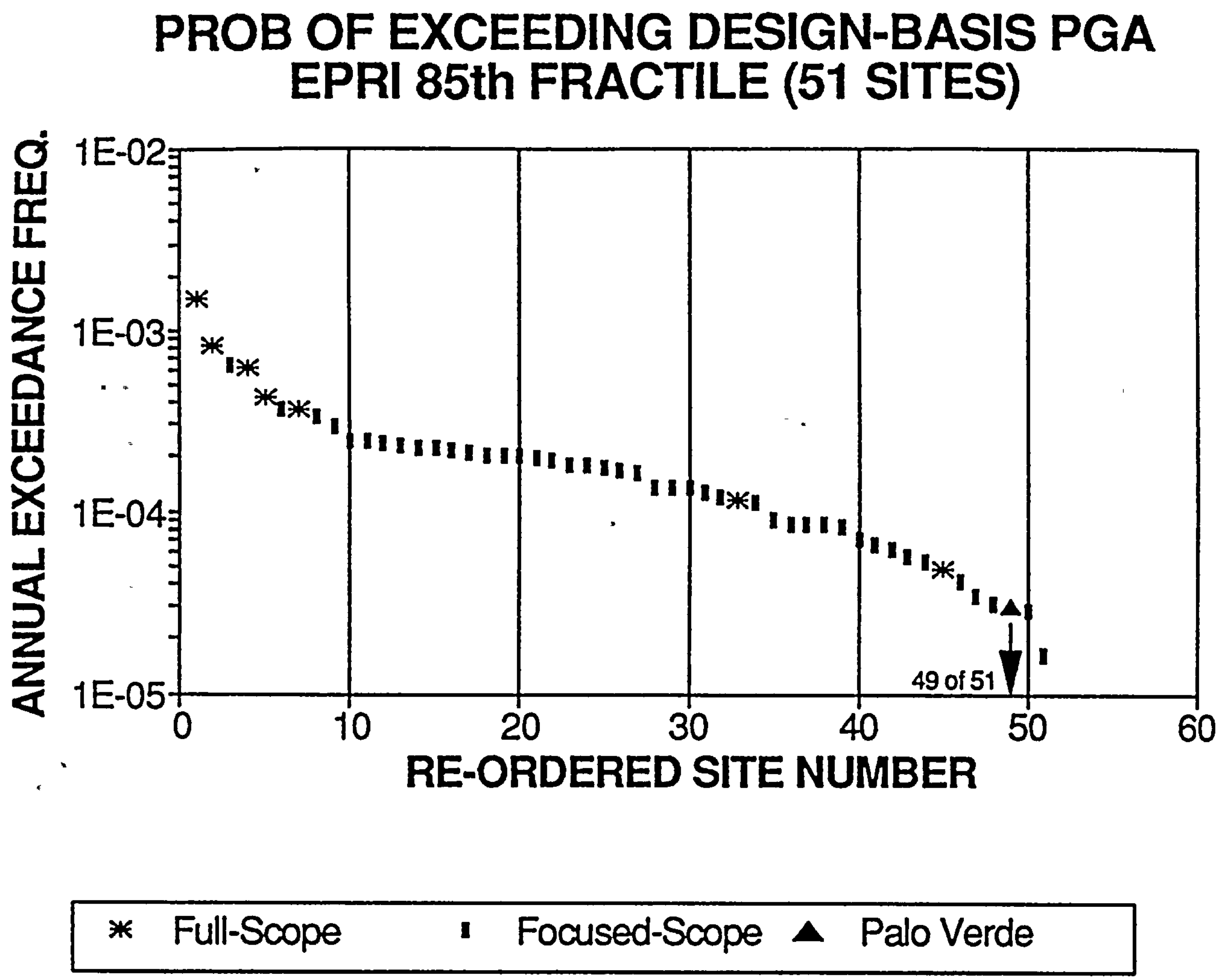

Figure C-3. 85th-fractile probability of exceeding the seismic design-basis PGA: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

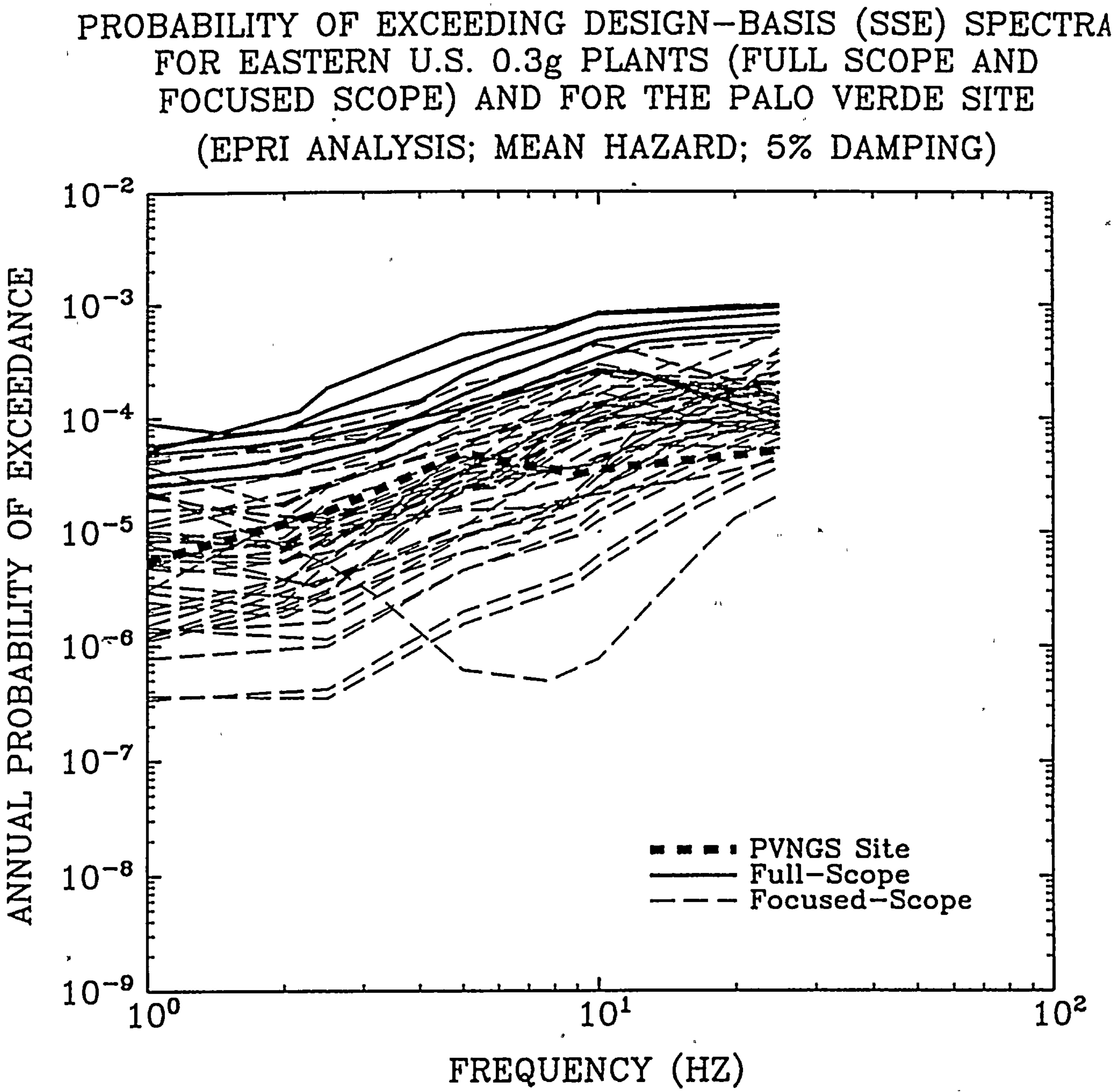

Figure C-4. Mean probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

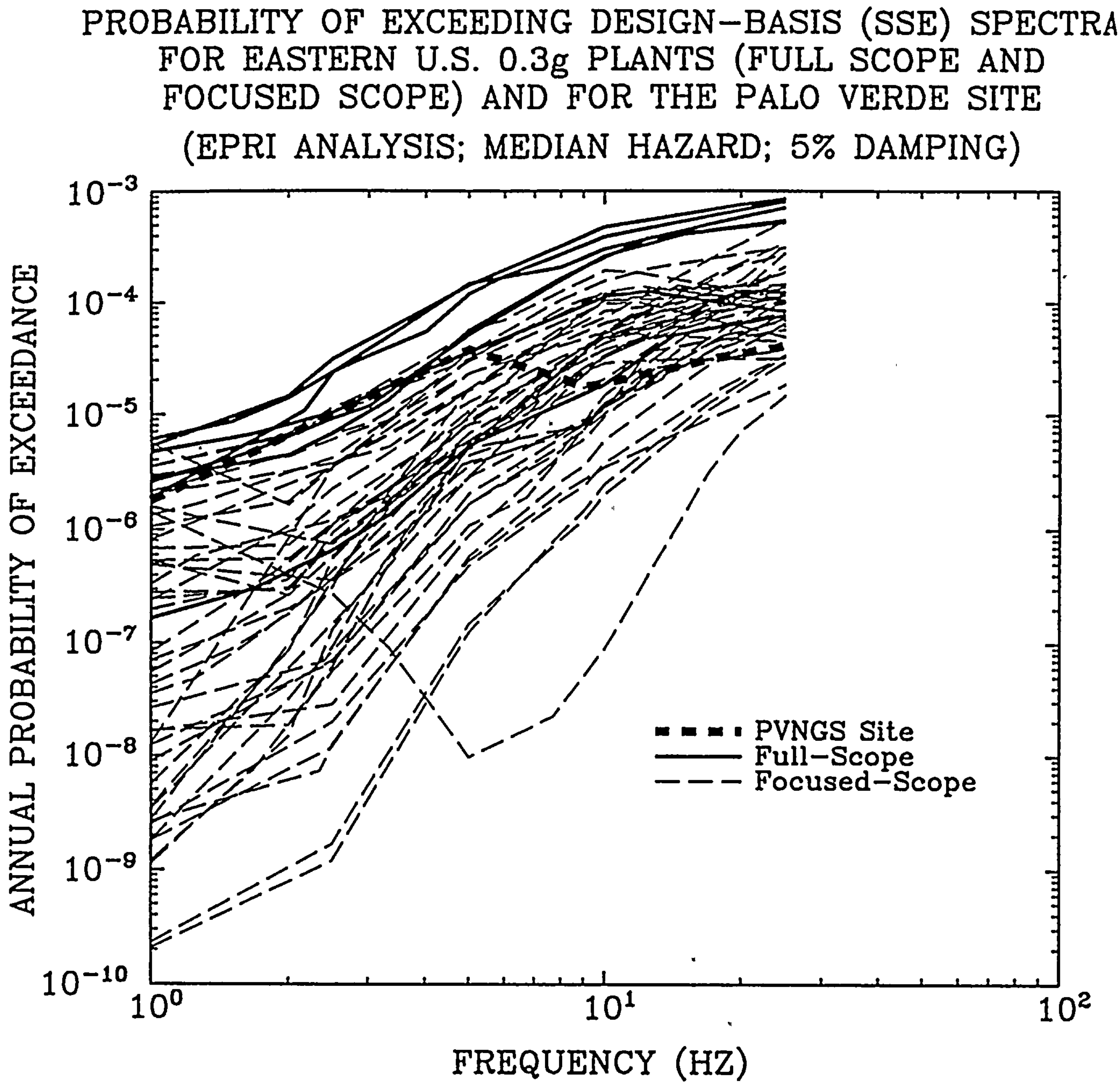

Figure C-5. Median probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

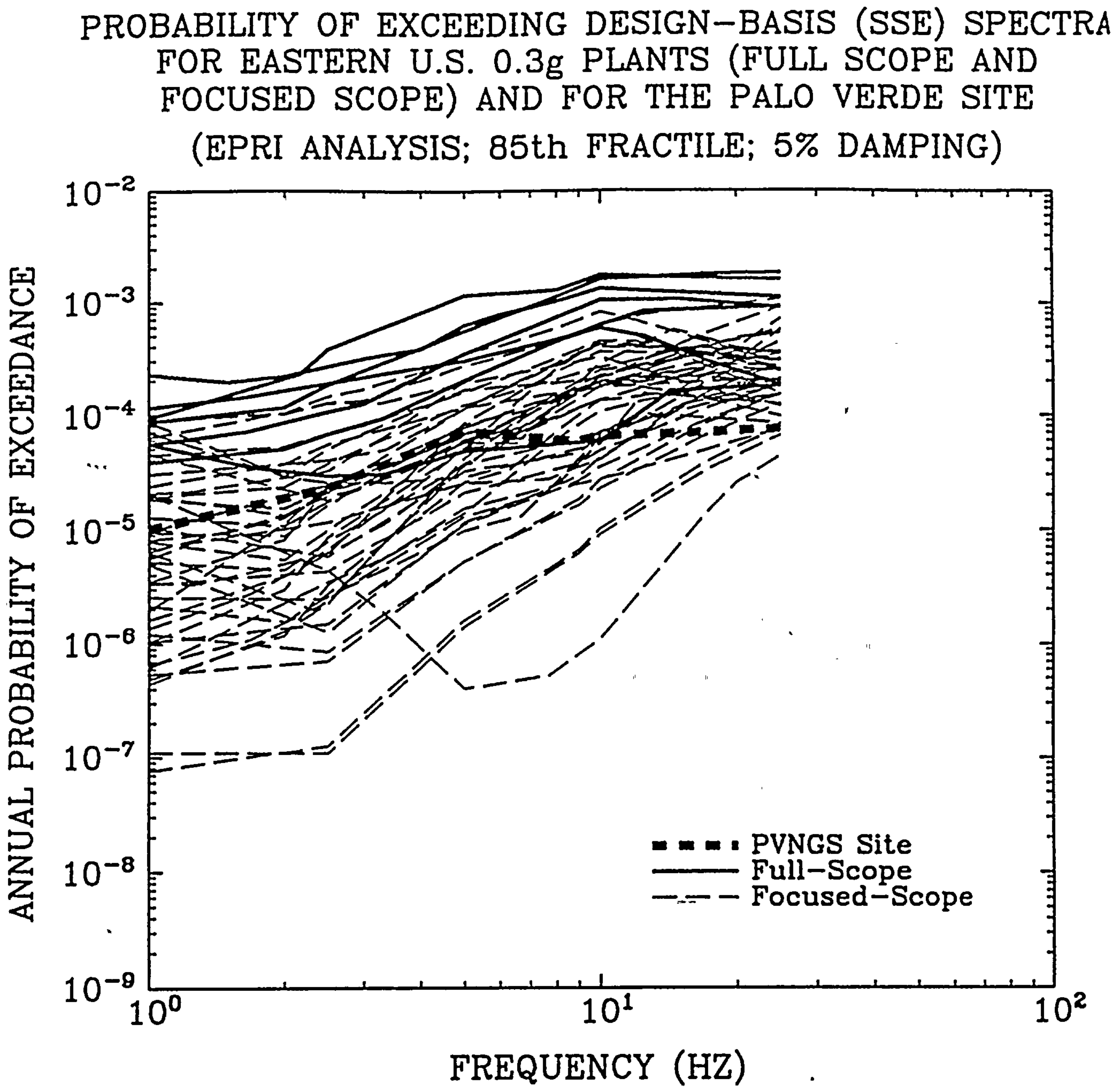

Figure C-6. 85th-fractile probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.