JUSTIFICATION FOR REDUCTION IN IPEEE PROGRAM BASED ON REVISED LLNL SEISMIC HAZARD RESULTS

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EXECUTIVE SUMMARY

The NRC recently issued draft NUREG-1488, "Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains," for public comment. Revisions of the Lawrence Livermore National Laboratory (LLNL) seismic hazard methodology over the past fifteen years have resulted in a continuous decrease in the assessed annual probability of exceeding the Safe Shutdown Earthquake (SSE) for ***all*** Eastern U.S. (EUS) plants. These revised LLNL hazard results corroborate those previously developed by the Electric Power Research Institute (EPRI) and have confirmed that the seismic hazard at most EUS plants is low, comparable to the 1989 LLNL seismic hazard results at 10 sites which were binned as reduced scope plants in NUREG-1407. This information along with quantitative core damage values based on conservative plant capacity factors support the position that focused scope plants should perform a reduced scope seismic review. A summary of the conclusions of this paper are as follows:

- Revisions of the LLNL seismic hazard methodology over the past 15 years have resulted in a continuous decrease in the estimated annual probability of exceeding the Safe Shutdown Earthquake for Eastern U. S. plants.

- The revised LLNL results (NUREG-1488) confirm the validity of the 1989 EPRI seismic hazard analyses.

- The revised LLNL results confirm that the mean seismic hazard at most EUS plants is low, lower than the 1989 LLNL seismic hazard estimates for the group of 10 plants which were originally designated as reduced scope.

- There is consensus that the most cost-effective and beneficial aspect of the IPEEE Seismic Margin Assessment Programs is obtained through detailed plant walkdowns.

- Based on studies and evaluations conducted to date, plant walkdowns have effectively captured the seismically weaker elements which required modifications.

- Utilities are committed to performing detailed plant walkdowns regardless of binning classification.

- The mean probability of exceeding the SSE at each site using the 1993 LLNL results is generally less than the mean probability of exceeding a 0.30g NUREG/CR-0098 spectrum using 1989 LLNL results.

- A mean core damage frequency seismic criterion of 5.0×10^{-5} is an appropriate upper bound value to use with the conservative core damage estimates based on SSE capacities below which plants should commit to no more than a reduced scope seismic review.

- All of the comparisons confirm the appropriate classification of only a handful of plants for either a full scope margins or Seismic Probabilistic Risk Assessment (SPRA) review - while also confirming that the remaining EUS plants should be doing no more than the reduced scope seismic review.

- It is estimated that a cost savings of approximately $250,000 per plant can be achieved by changing the seismic review from focused scope to reduced scope. Past studies have shown that there is little value gained through the additional analysis required under the focused scope program, since these analyses have produced no adverse surprises that the seismic walkdown/review teams did not already identify.

Based on the significant reduction in LLNL seismic hazard results at EUS sites, along with the large number of seismic review programs conducted at nuclear plants over the past 15 years which have demonstrated plant seismic safety and ruggedness, any further effort by utilities should only be that which has proven cost-effective. The real seismic concerns deal with the potential for a limited number of seismically weaker elements which might impair the seismic safety of specific plants. There is consensus that the most cost-effective and technically optimum method of finding these potential weak links is to perform a detailed plant specific walkdown by experienced engineers which is the nucleus of the reduced scope program and is of the same high quality as the focused and full scope reviews.

It is imperative that utilities and the NRC keep in perspective that the commitments made to resolve IPEEE are based on a "Request for Information" contained in Generic Letter 88-20, Supplement 4 and are not mandated by regulation. It is up to a utility to make commitments (or to change commitments) to address and resolve the issue. Accordingly, the new LLNL hazard results support a position that most EUS plants should be conducting a reduced scope seismic review; and the additional analyses/effort required under a focused scope program are not cost justified for these units.

INTRODUCTION - IMPACT OF NEW INFORMATION

The NRC recently issued draft NUREG-1488, "Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains," [1] for public comment. NRC staff memorandum SECY-93-311, "Progress in Programs to Resolve Differences Between Probabilistic Seismic Hazard Estimates in the Eastern United States," [2] places in context the draft NUREG relative to the Commission's program to resolve differences between the Lawrence Livermore National Laboratory (LLNL) and Electric Power Research Institute (EPRI) probabilistic seismic hazard estimates.

Revisions of the LLNL seismic hazard methodology over the past 15 years have resulted in a continuous decrease in the estimated annual probability of exceeding the SSE for all Eastern U.S. (EUS) plants. An example of this progressive reduction in seismic hazard at a typical pre-Appendix A EUS site is shown in Figure 1.

Figure 2 compares the mean probability of exceeding the SSE at all EUS sites based upon the 1989 LLNL (NUREG/CR-5250) [3] and 1989 EPRI (EPRI NP-6395-D) [4] results. As can be seen, the LLNL results are much higher in probability than the EPRI results. Figure 3 is a similar comparison, except now the 1993 LLNL results are used, which shows there is much closer agreement between the two studies. These later results (NUREG-1488) [1] confirm the validity of the 1989 EPRI seismic hazard analyses.

Generic Letter 88-20, Supplement 4, "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," [5] and NUREG-1407, "Procedural and Submittal Guidance," [6] provided a basis for each plant to examine seismic events. A methodology for establishing a Review Level Earthquake (RLE) was presented, along with a binning procedure to group plants according to seismic hazard levels as Reduced Scope, Focused Scope, Full Scope and SPRA. The basis of this binning procedure and the required level of effort to satisfy the IPEEE are addressed by this paper as part of the justification for changing the seismic review level from focused scope to reduced scope.

The new information in NUREG-1488 provides the basis for many utilities to adjust their commitments to a lesser scope of effort. Specifically, these revised LLNL results have confirmed that the mean seismic hazard at most EUS plants is low, lower than the 1989 LLNL mean seismic hazard estimates for the group of 10 plants which were originally designated as reduced scope. An additional plant (Farley) has subsequently been added to the reduced scope bin based on a reevaluation of its hazard level.

EVOLUTION OF THE SEISMIC HAZARD

There is a long history of LLNL seismic hazard results for EUS sites with the most recent being NUREG-1488. The purpose of this section is to summarize the LLNL analyses and describe how these results have impacted the perception of seismic hazard over time. For comparison purposes the probability of exceeding the SSE at various plants will be used as the basis for comparison. SSE spectral ordinates used are those published in NUREG-1488. The probability of exceeding the SSE spectrum is determined by calculating the probability of exceeding the 10 hz SSE spectral ordinate and the 5 hz SSE spectral ordinate and then averaging the results.

1978 - 1979

The origin of these analyses can be traced to the Site-Specific Spectrum Program (SSSP) which was performed by TERA Corporation under contract to LLNL. Originally (1978) the SSSP was started as a $50,000 research program directed at improving the EUS seismic data base, modifying a seismic hazard computer code, and illustrating the approach by assessing the seismic hazard at the Dresden Systematic Evaluation Program (SEP) site. The program was subsequently (December, 1978) expanded to include eight other EUS SEP sites. The goal of the expanded project was to perform extensive sensitivity studies on the seismic hazard, to determine the most important parameters of the problem and to, therefore, establish a basis for possibly directing the licensees to undertake specific studies that could result in licensee-proposed site-specific spectra.

The program changed emphasis in the Spring of 1979 when TERA began to incorporate the subjective input from ten expert seismologists. Consistent with the framework of any expert opinion analysis, TERA attempted to minimize the role of their own opinions and, instead, replace those opinions with either an expert's opinion or a consensus. Using these expert inputs, TERA calculated the 1,000 year spectra at the SEP sites and published these results in an August 24, 1979 [7] report. Dr. C. A. Cornell commented [8] on these results in November 1979, stating that these results were substantially at odds with existing studies. TERA Corporation also proposed that a review of these analyses be performed to provide a partial explanation for the unusually large accelerations reported in their August report. TERA Corporation also sent a letter to LLNL dated May 30, 1980 [9], which states that the results published in the August 1979 report were substantially higher than what TERA calculated if their preferred inputs were used.

1980 - 1981

In 1980 SEP plant licensees were sent a letter [10] describing the ground response spectrum to be used for seismic evaluations. These 1,000 year SEP spectra were based upon the TERA Corporation August 1979 report and additional sensitivity analyses. The SEP synthesis spectra are based on a weighted average which represents a median or somewhat higher than median representation of the individual spectra computed for each expert. Also in the letter sent to SEP licensees is a memo from Robert Jackson (NRC Geosciences Branch Chief) to J. Crutchfield (Acting Chief, SEP Program) [10]. A quote from the Jackson memo follows:

> "It is unlikely that there will be further changes in the return periods associated with the recommended spectra for the various sites. These return periods will still be able to be demonstrated as 'of the order of 1,000 or 10,000 years', *which is the present description of the spectra and the level implicitly accepted by NRC in recent licensing actions*".

The words, *will still*, were meant to imply that even as refinements were made in the LLNL methodology and inputs, that the SEP spectra *will still* presently be described as 'of the order of 1,000 or 10,000 years' return periods. It is also important to note that, for the Staff to make the above statements about implicit acceptance levels, the LLNL results available to them during this time frame were used (NUREG/CR-1582 [11] sensitivity studies by LLNL).

Several important concepts and outcomes can be associated with the SEP probabilistic analyses which are documented in NUREG/CR-1582. They are:

- The implicit level of acceptance for SSE spectra was of the order of 1,000 to 10,000 years,
- The return period perception for the design earthquake at pre-Appendix A plants was low (100 to 1,000 years),
- Post-Appendix A return period perception for the SSE was between 1,000 and 4,000 years (Seabrook and Wolf Creek, analyses by D. Bernreuter),
- The concept of 'relative use of probabilities' was developed by the Staff,

- LLNL/TERA results plus 'Charleston Issue' spawned years of heightened sensitivity about seismic adequacy of EUS NPPs.

A fundamental regulatory concern was that the safe shutdown earthquake (SSE) used for the design of plants could be exceeded with relatively low, but still unacceptably high probability. Therefore, the basis for the adequacy of the seismic design of plants could not rest on the size of the SSE alone, but requires demonstration of adequate seismic margin. In other words, if the probability of exceeding the SSE is high (10^{-2} to 10^{-3}) then there is a greater need for margin beyond the SSE.

1982 - 1984

In 1984 LLNL published NUREG/CR-3756 [12]. This study was an outgrowth of NUREG/CR-1582 and presented interim results at ten test sites. The purpose of this study was to:

- Develop a methodology for application at all EUS sites and evaluate the USGS position on the 'Charleston Issue',

- Present results as an estimate of the distribution (15th - 50th - 85th percentiles) of the seismic hazard rather than just a point estimate as was done in NUREG/CR - 1582 [11].

Three important conclusions can be drawn from the results of NUREG/CR-3756. They are:

- SEP 1,000 year synthesis spectra are comparable to median estimates of 1,000 year return period spectra at 5 and 10 hz (see Figure 5.9 and 5.10 of NUREG/CR-3756),

- Only the use of median hazard results presented in NUREG/CR-3756 support the statement that an implicit level of acceptance for recently licensed plants is of the order of 1,000 to 10,000 years,

- For post-Appendix A plants, return period perception for SSE spectra is about 1,000 to 5,000 years (Braidwood, River Bend, Wolf Creek, Vogtle, Shearon Harris, Limerick, and Watts Bar) using median results (See Figure 4).

The above conclusions are important, because to compare the progressive change in LLNL results relative to an implied acceptance criteria, a consistent statistical measure must be used, and that statistical measure is the median of LLNL results as described above.

1985

In 1985 LLNL published UCID-20421 [13]. These are the final results for the ten test sites used in NUREG/CR-3756. These results are based on updated responses by panel members from both the Seismicity and Ground Motion Panels. Based upon median results the following conclusion can be made:

- For post-Appendix A plants, return period perception for SSE spectra is about 1,000 to 10,000 years (Braidwood, River Bend, Wolf Creek, Vogtle, Shearon Harris, Limerick, and Watts Bar). See Figure 4.

These results suggest that these post-Appendix A plants are within the implied acceptance criterion.

1986 - 1989

In 1989 LLNL published NUREG/CR-5250 [3] which presented the final seismic hazard results for 69 sites East of the Rocky Mountains. The results of this analysis are based upon the methodology developed in prior LLNL studies and are also based upon additional feedback meetings with experts to finalize inputs and methodology. Based upon median results the following conclusion can be made:

- For post-Appendix A plants, return period perception for SSE spectra is about 10,000 to 100,000 years (Braidwood, River Bend, Wolf Creek, Vogtle, Shearon Harris, Limerick, and Watts Bar). See Figure 4.

These results suggest that the return period for post-Appendix A plants are in some cases well beyond the implied acceptance criterion.

1990 - 1993

In 1993 NRC published NUREG-1488 [1] which presented revised LLNL seismic hazard results for 69 sites East of the Rocky Mountains. The basis for this revision is significant new insights gained in terms of expert elicitation. Based upon median results the following conclusion can be made:

- For post-Appendix A plants, return period perception for SSE spectra is about 30,000 to 300,000 years (Braidwood, River Bend, Wolf Creek, Vogtle, Shearon Harris, Limerick, and Watts Bar). See Figure 4.

These results suggest that the return periods for post-Appendix A plants are significantly above the implied acceptance criterion.

Figure 4 summarizes the progression of LLNL results at 9 of the test sites evaluated in the LLNL studies since 1984. The probability of exceeding the 5 and 10 hz SSE spectral ordinates is based upon median hazard results. As can be seen, the perception of the hazard has been progressively declining over time. The EPRI results are also included to show the general agreement between the 1989 EPRI results and the 1993 revised LLNL results. Figure 5 shows the 1984 results at the nine test sites relative to the 1993 results at all EUS sites. As can be seen, the trend between the 1984 and 1993 results is similar. Therefore, if the remaining sites were evaluated in 1984, the trend in the results would be similar to the 1993 results, but higher by a factor of 10 to 100. Figure 6 is similar to Figure 5 but the EPRI results are compared to the 1993 LLNL results. As can be seen there is excellent agreement between the 1993 LLNL median results and the 1989 EPRI median results. In addition, an assumption of the SEP program was that even as refinements were made to the hazard methodology, the 1,000 year SEP spectra would still fall within the 1,000 to 10,000 year return period range. The 1,000 year SEP synthesis spectrum for the Millstone site, using 1993 LLNL median results, is about a 30,000 year spectrum.

Previous comparisons in this section were based on the use of median hazard curves. Median hazard curves were used because it was shown that the 1,000 year SEP synthesis spectra presented in NUREG/CR-1582 [11] were approximated by median spectra presented in NUREG/CR-3756 [12]. In addition, only use of median results presented in NUREG/CR-3756 satisfy the implied acceptance criterion for recent licensing actions. As can be seen on Figure 6, the SSE at all EUS plants satisfy the implied NRC acceptance criterion. Subsequent comparisons and calculations of mean core damage will be based on mean hazard results.

Lastly, conclusions from early margin studies imply significant margin beyond the SSE. The comfort of additional margin beyond the SSE was important in the early 80s due to the high perceived likelihood of exceeding the SSE. Even though the hazard has been significantly reduced over time, the margin beyond the SSE still exists, hence the need to demonstrate the existence of significant margin beyond the SSE is now reduced.

BASIS FOR NRC BINNING PROCESS

All nuclear plants east of the Rocky Mountains were binned according to seismic hazard using the composite probability of exceeding a 0.3g NUREG/CR-0098 spectrum at 2.5 hz, 5.0 hz, 10.0 hz and PGA. Consistency criteria were used which included agreement among the 1989 LLNL 5-expert, 1989 LLNL 4-expert and the 1989 EPRI hazard study results using the median and either the mean or 85th percentile statistics. These criteria provided for comparisons of 9 separate hazard groupings for binning each plant. Consistency in grouping, either high or low, provided the binning basis for the EUS plants which resulted in two 0.5g bin plants, ten reduced scope plant sites and all other plants in the 0.3g bin.

Subsequent binning, which factored in plant design basis, was used to further subdivide the 0.3g bin into focused scope and full scope bins but did not alter the initial 0.5g, 0.3g, or reduced scope bins. This resulted in 7 full scope plant sites, most of which are Charleston Issue sites (i.e., relatively higher hazard sites).

The relative ranking process used by the NRC did not take into consideration the absolute value of the calculated probabilities for each plant. High hazard sites could be on the order of 10^{-2} using mean LLNL results, or less than 10^{-4} using mean EPRI results. Thus the NRC binning was done on a relative basis, mainly because of large differences in hazard estimates between the LLNL and EPRI hazard studies. The probability of exceeding plant design (SSE) was not a factor in the binning (0.5g, 0.3g and reduced scope). Reduced scope plants were described by their low seismic hazard.

EVALUATION OF 1993 NRC REVISED SEISMIC HAZARD RESULTS

The revised seismic hazard results presented in NUREG-1488 represent significant new information. Of particular interest are changes that have led to more reasonable mean hazard estimates. The LLNL mean hazard estimates have in the past been at odds with the mean estimates presented in EPRI and other studies. Figure 2 compares the mean probability of exceeding the SSE at all EUS sites based upon the 1989 LLNL and 1989 EPRI results. As is shown, the 1989 LLNL results are much higher in probability than the 1989 EPRI results. As stated earlier, this large difference in seismic hazard estimates led to the NRC use of relative rankings in the IPEEE binning process. Figure 3 compares the mean probability of exceeding the SSE at all EUS sites based upon the 1993 LLNL and 1989 EPRI results. As can be seen, there is excellent agreement between the two studies. Draft NUREG-1488 results confirm the validity of the 1989 EPRI seismic hazard analyses.

These revised LLNL results represent significant new information that should not only be used in the review of individual plant examinations of external event submittals, and early site reviews, but most importantly in a timely reassessment by utilities of the seismic level of effort for the IPEEE. This conclusion is based on the following:

- The 1993 LLNL results demonstrate that the seismic hazard at existing EUS nuclear power plants is much less than what the staff originally believed (see Figure1).

- The probability of exceeding the SSE at essentially all plants using the revised 1993 LLNL mean hazard results is less than the mean probability of exceeding the SSE at the reduced scope plants using mean hazard results from the 1989 LLNL study (see Figure 7, reduced scope sites identified as solid circles).

- The probability of exceeding the SSE based upon 1993 LLNL mean hazard results is less than the probability of exceeding the 0.3g NUREG/CR-0098 review level spectrum based on the 1989 LLNL mean hazard results at almost all plants (see Figure 8).

The following sections justify the basis for reduced scope evaluations at all but a handful of plants.

REDUCED SCOPE WALKDOWN BENEFITS

The most important aspect of any seismic review is the plant walkdown performed by a competent review team consisting of seismic and systems engineers guided by plant operations personnel. This was the conclusion of the NRC Expert Panel who developed the SMA methodology [14] and is believed to be true today by experienced seismic engineers. During SMA and SPRA studies, review teams have identified, during the walkdown process, *all* weak components that ultimately had to be fixed. Subsequent calculations for fragility and/or high confidence of low probability of failure (HCLPF) capacities were performed to confirm the concerns of the review teams. However, in no cases were weak components determined to require modification solely based on analysis. In other words, analysis has produced no adverse surprises that the seismic review teams did not already know. A plant walkdown by experienced seismic capability engineers along with plant personnel familiar with the systems and operations is the most cost-effective approach for discovering potential seismically weak elements. The industry has developed and conducted comprehensive training programs for the personnel involved in walkdowns.

The walkdown requirements for a reduced scope program are the same rigorous requirements used for the full and focused scope reviews [6]. Because of the importance of the walkdown task, the same high level of review team competence and activities were implemented into the requirements for all three types of review. The only difference is in the extent of information gathering activities that are performed. In full and focused scope reviews, where either HCLPF or fragility calculations must also be conducted, additional effort is usually required to gather data for these calculations. This information gathering process is often one of the more expensive parts of the walkdown.

A competent review team will identify the same potentially weak elements independent of the type of seismic review that is conducted. This is supported by the experience of the past 15 years which shows that seismic review teams have successfully identified all the weak elements at the time of the walkdowns which were subsequently modified or repaired. Today seismic engineers are very familiar with the limited number of classes of components and issues that lead to potential weaknesses which must be addressed during plant walkdowns. This experience is well documented in References [14-18].

There are other aspects that provide added assurance that a plant has adequate seismic capacity at the design level after completion of a reduced scope walkdown and review. All *older* plants have conducted (or are currently conducting) a USI A-46 seismic review. This NRC program addresses the seismic adequacy of safety related equipment not seismically qualified to current NRC criteria to resist the SSE input for the plant. As part of this effort seismic-spatial-systems interactions, anchorage, vertical flat-bottom tanks and heat exchangers, cable and conduit raceways, and relay functionality are reviewed. Some construction checks are also performed to verify in-situ plant conditions. For ***newer*** plants, the seismic design provisions for the SSE are more conservative than for older plants. Upon completion of a reduced scope review, and A-46 review, if applicable, the elements in the success paths can be assured of meeting the SSE design basis for both old and new plants.

NUCLEAR PLANT SEISMIC MARGIN BEYOND SSE

Results from Seismic Probabilistic Risk Assessments (SPRAs) and Seismic Margin Assessments (SMAs) over the past 15 years have demonstrated that nuclear power plants have high seismic strength. Typically, the median capacity for core damage from seismic events is in the range of **3 to 6 times the SSE level** for plants in the EUS (see Table 1) [19]. Both SPRA and SMA studies have shown that the vast majority of safety-related equipment and structures have high seismic capacity [20].

A review of early SPRAs found that structures have median factors of safety from the SSE of 4 to 12, and equipment have factors of safety between 3.5 and 20 [15]. The core damage fragility curves from past SPRAs have been dominated by a few relatively weak components, with the majority of the elements in the plant systems model possessing much higher capacity. The principal challenge in performing seismic capacity reviews has been to identify the limited number of potentially weaker elements that might impair the seismic safety of the plant. Past studies have resulted in only a very small number of seismic upgrades, and these studies have demonstrated that high capacity exists for the majority of components without the need for major modifications [20].

ESTIMATE OF CORE DAMAGE FREQUENCY (CDF)

A conservative but useful estimate of the core damage frequency can be obtained knowing that critical elements in the plant meet the SSE design basis upon completion of a reduced scope review. The procedure for establishing the plant seismic capacity using the reduced scope methodology as defined in NUREG-1407 consists of the following elements [6]:

- Selection of Assessment Team
- Identification of systems and element selection (i.e., success paths or fault trees)
- Seismic capacity walkdown and screening using guidance in NUREG/CR-4334 [14] or EPRI NP-6041 [17]
- Check of potentially vulnerable elements identified during the walkdown against the plant design basis

Once this review process is completed, the capacity of the elements in the plant systems success paths or fault trees are considered to comply with the SSE design basis. Any concerns that occurred from the walkdown process for anchorage or systems interaction issues will have been resolved as a result of the review. This resolution process will involve fixing any structural weaknesses that are discovered, or verifying that a component satisfies the SSE design basis requirements by review of existing calculations, or performing new analyses.

On this basis it is judged, as discussed below, that the plant core damage median capacity is at least a factor of 2.67 times the SSE capacity. Experience from past SPRAs indicates that this factor is at the low end of the range of past values (i.e., 3 to 6 as previously discussed and as indicated in Table 1).

The factor of 2.67 can be shown to be a lower limit by examining the relationship between the SSE and HCLPF capacity. Using data from Reference 4, Table 2 gives the ratio of plant core damage HCLPF capacities to corresponding SSE levels for eight plants. These ratios range from 1.2 to 2.5 with an average value of about 1.6. A value of 1.25 is recommended for determining an approximate median core damage fragility curve capacity for the purposes of estimating a conservative bound on the mean frequency of core damage. Reference 21 investigated the dispersion of core damage fragility curves using past SPRA studies and found by fitting lognormal distributions to the curves that the composite logarithmic standard deviation, β_C, averaged about 0.33 with a coefficient of variation of only 0.11 as given in Table 3.

It is noted that fragility curves for individual elements have β_C values between about 0.3 to 0.5. However, when these elements are combined through the system logic model for a plant the core damage fragility curve becomes steeper, and the β_C parameter reduces to a value in the 0.3 to 0.4 range. Using the mean value of 0.33 for β_C (which is at the conservative end of the range for the purposes of establishing a median/SSE ratio) the median capacity is given by the following equation:

$$\text{median} = \text{HCLPF}\ e^{2.3\beta_C}$$

$$= 1.25\ \text{SSE}\ e^{2.3\beta_C} \qquad \text{(eq. 1)}$$

Thus, the median/SSE ratio using a β_C of 0.33 is equal to 2.67.

There are several other approaches that can be used to demonstrate the conservatism of the 2.67 factor used for the median/SSE ratio. Again it is assumed that the elements in the success paths all comply with the SSE design requirements based on the results of the reduced scope walkdown. First, experience from SMA analysis suggests that a conservative deterministic failure margin (CDFM) HCLPF for a plant core damage state is at least 1.5 times the SSE. However, a CDFM HCLPF, which is often referred to as a HCLPF_{84}, assumes that the ground motion is reported at the 84% non-exceedance probability (NEP) level. In SPRAs the HCLPF is reported at the 50% NEP level (a SPRA HCLPF is often referred to as HCLPF_{50}) and a conversion must be made by the following equation:

$$\text{HCLPF}_{50} = \text{HCLPF}_{84}/e^{\beta_{rs}} \qquad \text{(eq. 2)}$$

where:

β_{rs} = Logarithmic standard deviation for variability in the ground motion (i.e., peak-and-valley variability)

A typical value for $e^{\beta_{rs}}$ is 1.2; thus, the resulting conservative $HCLPF_{50}$/SSE factor is again 1.25 as assumed above based on past SPRAs. This approach also supports a median/SSE factor for plant core damage of 2.67.

Another perspective for justifying the median/SSE factor can be obtained by examining seismic margins for individual components based on the requirements for SSE design. A recent report documents the basis for the seismic provisions of DOE Standard 1020 [22]. In this report, median capacity factors of conservatism relative to the design basis are reported for low-ductility and high-ductility failure modes, and for equipment qualified by testing. Design procedures that are recommended for DOE facilities are comparable to SSE requirements, except that the seismic input is defined at the median level whereas mean plus one standard deviation input is used for nuclear power plants. Median factors of safety for low and high-ductility components are reported to range from 2.40 to 4.20 and from 2.52 to 4.78, respectively. The range of values are due to assumptions on the contribution from non-seismic forces and correspond to a <u>risk reduction of 10</u> (i.e., probability of exceeding the design level divided by the probability of failure). This level of risk reduction is typical for nuclear power plants using modern hazard curves that have been developed over the last few years.

For a proper comparison to nuclear power plant designs, these factors reported for use at DOE facilities should be increased by a value of 1.2 to reflect the higher seismic input used in nuclear power plant design (i.e., at the 84% NEP level). Thus for comparison the median factors of safety for low and high-ductility components should be adjusted to range from 2.9 to 5.0 and from 3.0 to 5.7, respectively, for nuclear power plants.

For equipment qualified by testing the apparent margins are not quite as high. To achieve a risk reduction of 10 which corresponds to a median/SSE ratio of 3.0 (adjusted for the 1.2 factor for nuclear power plant seismic input), a test response spectrum (TRS) to required response spectrum (RRS) ratio of 1.4 is required. At first glance this may appear a little on the high side (i.e., too liberal) since typical nuclear power plant testing requirements only require a 10% margin. However, the development of the RRS is done very conservatively in nuclear power plant (NPP) design practice. First, RRS usually represent an envelope of many design conditions (i.e., location, elevation, seismic and hydrodynamic loads, and foundation conditions). Also, results from tests conducted for other plants are often conservatively used to qualify plant-specific equipment. On this basis the TRS/RRS ratio of 1.4 is reasonable when seismic input at specific locations is considered. Even with this interpretation, the capacities of equipment qualified by testing are still likely to be at the lower end of the range of margins compared to components that are qualified by analysis.

The margins based on Reference [22] need to be examined in light of typical design and construction practice and results from past SPRAs. These margins represent cases where a component capacity is designed and subsequently constructed just to the code criteria. In reality there are other loads and construction requirements that lead to seismic capacities that far exceed the minimum required capacities based only on code provisions. The seismic capacities at the design level of most components in nuclear power plants exceed the code required provisions. This is born out by the results of past SPRAs and SMAs [20].

On the other hand the few components that control the plant capacity are usually near the lower limit of the design requirements (note that the plant walkdown and review will assure that the SSE capacity is achieved). When these components are combined using the rules of probability through the systems model, the resulting core damage fragility curve median capacity is reduced below the median capacities of the individual components that are combined logically in series. The corresponding HCLPF capacity is reduced slightly and the overall fragility curve is much steeper than the fragility curves of the individual components. Thus, the median to SSE margins of 3 to 6 for individual elements based on the study in Reference 19 are consistent with the lower-bound core damage median capacity to SSE ratio of 2.67.

JUSTIFICATION FOR REDUCTION IN IPEEE PROGRAM

This paper provids a review of the LLNL seismic hazard results since 1979. Prior to these LLNL probabilistic studies, exceedance of the SSE was considered negligible in that the SSE was called the maximum earthquake. The perceived high seismic hazard in the late 70's and early 80's was an extreme swing from earlier deterministic perceptions and resulted in numerous NRC mandated seismic programs. In addition, these early seismic hazard results indicated an instability in the seismic licensing process in terms of the inconsistency of SSE exceedance probabilities which furthered the NRC concerns. However, recent LLNL results [1] indicate that the perceived hazard was significantly overestimated, but confirm the inconsistency of the deterministic licensing process.

In general, the determination of acceptability is based on precedence. For the IPEEE, acceptable criteria need to be identified to justify a reduction in scope. Earlier in this paper, the acceptable seismic hazard level was shown to be a moving target. SEP plants were assigned a "so called" 1,000 year spectrum and newly licensed plants were acceptable if the probability of exceeding the design basis spectrum was between 1,000 and 10,000 years using median hazard estimates. Based on this information, one possible basis for a reduced scope plant (i.e., no design basis issues) is a median SSE hazard of 1.0×10^{-4}.

Precedent shows that acceptable core damage frequencies due to seismic have typically ranged between 10^{-4} to 10^{-5}. From NUREG-1150 [23] the mean core damage frequency using 1989 mean LLNL results for the Surry plant is 1.2×10^{-4} per reactor year, and for Peach Bottom is 7.7×10^{-5} per reactor year. In addition, from NUREG-1407 it can be seen that core damage frequencies range from a high of about 1.4×10^{-4} to a low of 3.1×10^{-6} per reactor year, with an average of about 5×10^{-5}. A preliminary review of internal IPE results indicate that the average core damage frequency is about 6.0×10^{-5}. Based on this information, a core damage frequency of 5.0×10^{-5}, as conservatively determined using the method described previously, is used as a criterion for conducting a reduced scope seismic review.

There are several other compelling reasons as to why most focused scope plants should be in the reduced scope category. First, as can be seen from Figure 6 all but a few plants have a median probability of exceeding the SSE that is greater than 10^{-4}. Secondly, based upon the 1993 LLNL results the mean probability of exceeding the SSE at most sites is comparable to the mean probability of exceeding the 0.3g spectrum using the 1989 LLNL results as is shown on Figure 8. Put differently, a seismic review to the SSE in 1994 is equivalent, in terms of probability, to a review to 0.3g based upon the 1989

LLNL results. The third reason is that a conservative analysis of mean core damage frequency (MCDF) at all EUS sites shown on Figure 9 has been calculated using the mean hazard curves from both the 1993 LLNL and 1989 EPRI analyses. These estimated MCDF values are upper bound estimates of core damage. Actual plant capacity will be significantly greater than what has been shown for this analysis. As can be seen, all but a handful of plants are below the 5.0×10^{-5} per reactor year criterion. It is important to note that the criterion level is lower than that of all but one of the reduced scope plants based on the 1989 LLNL results, and in general, only the full scope and SPRA plants now exceed this level. The last and most compelling reason for placing essentially all plants in the reduced scope category is the documented *proven value* of the plant walkdown to find essentially all seismic vulnerabilities in nuclear power plants. The following cost analysis shows that a reduction in the seismic review effort from focused scope to reduced scope can save utilities on the order of $250,000 per plant, clearly a cost beneficial licensing action, with *no* impact on plant seismic safety.

For the above reasons, all but a handful of plants should conduct the reduced scope seismic review.

COST/BENEFIT DISCUSSION

There is an industry consensus that the most cost-effective and beneficial aspect of IPEEE Seismic Margin Assessment (SMA) Programs is obtained through detailed plant walkdowns. From results of plant walkdowns to date, all discrepancies and enhancements have been picked-up during these walkdowns.

Industry is committed to performing such plant walkdowns, and these are viewed as a beneficial and cost-effective means of finding the seismically weaker elements in a plant. The added burden and costs of performing additional reviews and evaluations is no longer justified in light of the studies performed thus far.

Although many focused scope IPEEE SMA Programs are well underway, the effort involved in a reduced scope program could still result in a cost savings of over $250,000 per plant. First, evaluation is made against a plant's SSE design level versus a review level earthquake of 0.30g. In many cases SSE calculations can be easily checked to confirm the seismic adequacy of components identified as concerns. There are direct dollar savings due to the lesser effort required by reduced scope. Second, potential large savings exist by avoiding analytical evaluations of components with a High Confidence of Low Probability of Failure (HCLPF) which is less than 0.30g, but greater than the plant SSE.

An example of savings in **Contractor** costs at a single unit plant is as follows:

Reduction in Soils Evaluations	$ 40,000
Elimination of Relay Evaluation	$ 50,000
Reduction in Walkdown Effort (Data Gathering)	$ 10,000
Reduction/Elimination of HCLPF Calculations	$ 80,000
Reduction in Management of Program	$ 10,000
Reduction in Report Development/Reviews	$ 5,000
Reduction in Peer Reviews	$ 10,000
TOTAL CONTRACTOR REDUCTIONS	**$ 205,000**

When you add an estimated cost savings of over $50,000 for utility personnel, the total savings should exceed a "Quarter of a Million Dollars." This is probably a conservative estimate due to the unknown number of HCLPF calculations required.

The NRC Cost Beneficial Licensing Action (CBLA) Task Force [24] has developed definitions and criteria for determining if relief from a utility commitment is warranted. The following CBLA attributes are considered pertinent for this issue:

1. The request to change a commitment would necessarily come from the licensee since the individual plant commitments may be unique with respect to timing as well as implementation.

2. The LLNL results clearly show that the seismic hazard is substantially below the level which was presumed when the original commitments were made. Additionally, the commitment to perform a plant walkdown has not changed, and there is industry consensus that walkdowns provide the most cost-effective approach for discovering potential seismically weak elements which ultimately are to be modified or fixed. The studies conducted thus far have shown that the additional analytical efforts have discovered no weak links which would have an impact on safety.

3. As previously shown, reductions to the presently committed seismic programs will result in significant cost savings well beyond the nominal NRC staff criterion of $100K.

4. The reduction in effort is deemed to generically impact the majority of plants which were originally binned as focused scope; however, the request to change a commitment would necessarily come from the licensee as discussed in Item 1 above.

5. The requested changes in seismic programs will be within existing regulations and policies so that no other decision beyond agreement by the staff that the licensees request is reasonable will be required for any plant. A large number of similarly based requests could generate interest by the Commission, but no overt action is required by them.

6. Changes to the seismic programs are non-routine in regard to the substance of the issue and the changes that could be involved.

7. The requested action will involve a change in scope of the evaluations and analyses that would be performed, thereby impacting plant activities.

8. Each request will have to be individually prioritized by the licensee with respect to all of its licensing actions.

9. Each licensee is always under the obligation to provide a high quality, stand alone submittal.

The CBLA evaluation supports an industry position that studies which are not cost justified and have been shown to add no safety benefits/enhancements to the plants should not be conducted.

From a different perspective, one might ask what safety value is gained by spending an additional $250,000 per plant to conduct a focused scope seismic review. Based on previous studies, the answer is that little value is gained through the additional analyses. Analyses have produced no adverse surprises that the seismic walkdown/review teams did not already know.

CONCLUSIONS

As stated earlier, the most important aspect of any seismic review is the plant walkdown performed by a competent review team consisting of seismic and systems engineers guided by plant operations personnel. This was the conclusion of the NRC Expert Panel who developed the SMA methodology [14] and is believed to be true today by experienced seismic engineers. During SMA and SPRA studies, review teams have identified, during the walkdown process, *all* weak components that ultimately had to be fixed. Subsequent calculations for fragility and/or high confidence of low probability of failure (HCLPH) capacities were performed to confirm the concerns of the review teams. However, in no cases were weak components determined to require modification solely based on analysis. In other words, analysis has produced no adverse surprises that the seismic review teams did not already know. A plant walkdown by experienced seismic capability engineers along with plant personnel familiar with the systems and operations is the most cost-effective approach for discovering potential seismically weak elements. The industry has developed and conducted comprehensive training programs for the personnel involved in walkdowns.

The walkdown requirements for a reduced scope program are the same rigorous requirements used for the full and focused scope reviews [6]. Because of the importance of the walkdown task, the same high level of review team competence and activities was implemented into the requirements for all three types of review. The only difference is in the extent of information gathering activities that are performed. In full and focused scope reviews, where either HCLPF or fragility calculations must also be conducted, additional effort is usually required to gather data for these calculations. This information gathering process is often one of the more expensive parts of the walkdown.

Given that the critical elements in the plant meet the SSE design basis upon completion of a reduced scope review, a conservative but useful estimate of the core damage frequency can be obtained. These estimated mean core damage values are upper bound estimates of core damage. Actual plant capacity will be greater than what has been shown for this analysis. As shown, all but a handful of plants meet the 5.0×10^{-5} MCDF criterion. It is important to note that the criterion level is lower than that of all but one of the reduced scope plants based on the 1989 LLNL results, and in general, only the full scope and SPRA plants now exceed this level.

Based upon previous discussions, the following summary conclusions are made:

- Revisions of the LLNL seismic hazard methodology over the past 15 years have resulted in a continuous decrease in the estimated annual probability of exceeding the Safe Shutdown Earthquake for Eastern U. S. plants.

- The revised LLNL results (Draft NUREG-1488) confirm the validity of the 1989 EPRI seismic hazard analyses.

- The revised LLNL results confirm that the mean seismic hazard at most EUS plants is low, lower than the 1989 LLNL seismic hazard estimates for the group of 10 plants which were originally designated as reduced scope.

- There is consensus that the most cost-effective and beneficial aspect of the IPEEE Seismic Margin Assessment Programs is obtained through detailed plant walkdowns.

- Based on studies and evaluations conducted to date, plant walkdowns have effectively captured the seismically weaker elements which required modifications.

- Utilities are committed to performing detailed plant walkdowns regardless of the IPEEE binning classification.

- From Figure 8, the mean probability of exceeding the SSE at each site using the 1993 LLNL results is generally less than the mean probability of exceeding a 0.30g NUREG/CR-0098 spectrum using 1989 LLNL results.

- The MCDF criterion of 5.0×10^{-5} is an appropriate upper bound value to use with the conservative core damage estimates made based on SSE capacities below which plants should commit to no more than a reduced scope seismic review.

- All of the above comparisons confirm the appropriate classification of only a handful of plants for either a full scope margins or SPRA review - while also confirming that the remaining EUS plants should be doing no more than the reduced scope seismic review.

- It is estimated that a cost savings of approximately $250,000 per plant can be achieved by changing the seismic review from focused scope to reduced scope. From past studies there is little value gained through the additional analysis required under the focused scope program, since these analyses have not produced any adverse surprises that were not already recognized by the seismic walkdown/review teams.

Using the 1993 LLNL results, it was shown that the seismic hazard at existing EUS nuclear power plants is much less than what the Staff originally believed when GL 88-20 Supplement 4 was issued. This new information (Draft NUREG-1488) and the other insights noted above clearly provide the basis for utilities to commit to a lesser scope of effort to satisfy seismic IPEEE. Specifically, based upon this review, these revised LLNL hazard estimates confirm that the mean seismic hazard at most EUS plants is low, lower than the 1989 LLNL mean seismic hazard estimates at the 11 reduced scope plants. This information supports the position that most EUS plants should be doing reduced scope seismic margins studies.

Lastly, as stipulated by Generic Letter 88-20, Supplement 4, resolution of the IPEEE effort is based on a "Request for Information" rather than a regulation. Under such a request, it is encumbent upon the licensee to assess the request and to take the actions it deems necessary to address and resolve the issue. In light of the revised LLNL results and the evaluations presented in this paper, it is believed that the prudent action for many licensees is to focus resources in the areas that will produce the desired results, i.e., to conduct detailed plant walkdowns under a reduced scope seismic review. The additional analyses and effort required by a focused scope program are not warranted. This conclusion is borne out by the change in perceived hazard and the industry experience to date.

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Table 1

Comparison of Median and SSE Capacities*

Plant	Peak Ground Acceleration (g) Median	SSE	Median / SSE
Indian Point 2	0.76	0.15	5.07
Indian Point 3	0.92	0.15	6.13
Susquehanna	0.70	0.15	4.67
Limerick	0.70	0.15	4.67
Maine Yankee	0.57	0.18	3.17
Millstone 3	0.57	0.17	3.35
Zion	0.56	0.17	3.29
		mean	4.34
		COV	0.26

* Based on data partially from Reference 19

Table 2

Comparison of HCLPF and SSE Capacities*

Plant	Peak Ground Acceleration (g) HCLPF	SSE	HCLPF / SSE
Indian Point 2	0.29	0.15	1.93
Indian Point 3	0.38	0.15	2.53
Limerick	0.30	0.15	2.00
Millstone 3	0.26	0.17	1.53
Oconee	0.12	0.10	1.20
Seabrook	0.30	0.25	1.20
Shoreham	0.26	0.20	1.30
Zion	0.22	0.17	1.29
		mean	1.62
		COV	0.30

* Based on data partially from Reference 25

Table 3

Logarithmic Standard Deviations for Core Damage Fragility Curves*

Reactor No.	Logarithmic Standard Deviation		
	Randomness, β_r	Uncertainty, β_u	Combined, β_c
1	0.23	0.30	0.38
2	0.28	0.27	0.39
3	0.22	0.20	0.30
4	0.22	0.20	0.30
5	0.24	0.19	0.31
6	0.19	0.24	0.31
7	0.19	0.24	0.31
8	0.19	0.24	0.31
		mean	0.33
		COV	0.11

* Data taken from Reference 21

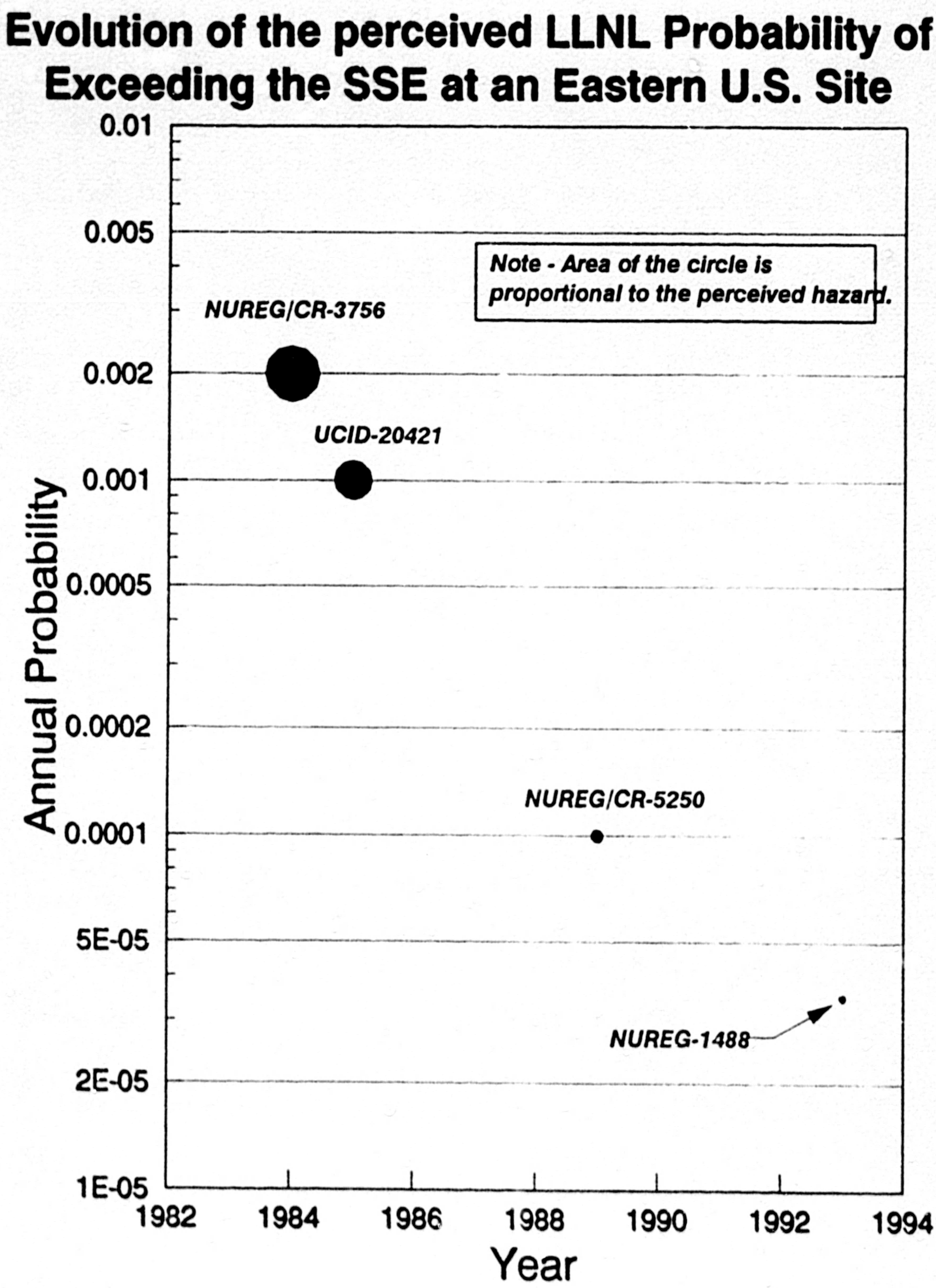
Evolution of the perceived LLNL Probability of Exceeding the SSE at an Eastern U.S. Site
Note - Area of the circle is proportional to the perceived hazard.
NUREG/CR-3756
UCID-20421
NUREG/CR-5250
NUREG-1488
Annual Probability
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
5E-05
2E-05
1E-05
1982
1984
1986
1988
1990
1992
1994
Year

Figure 1

Probability of Exceeding the 5 & 10 hz Spectral

Ordinates at EUS NPPs. Comparisons Based on LLNL and EPRI Results. NUREG-1488 Spectra.

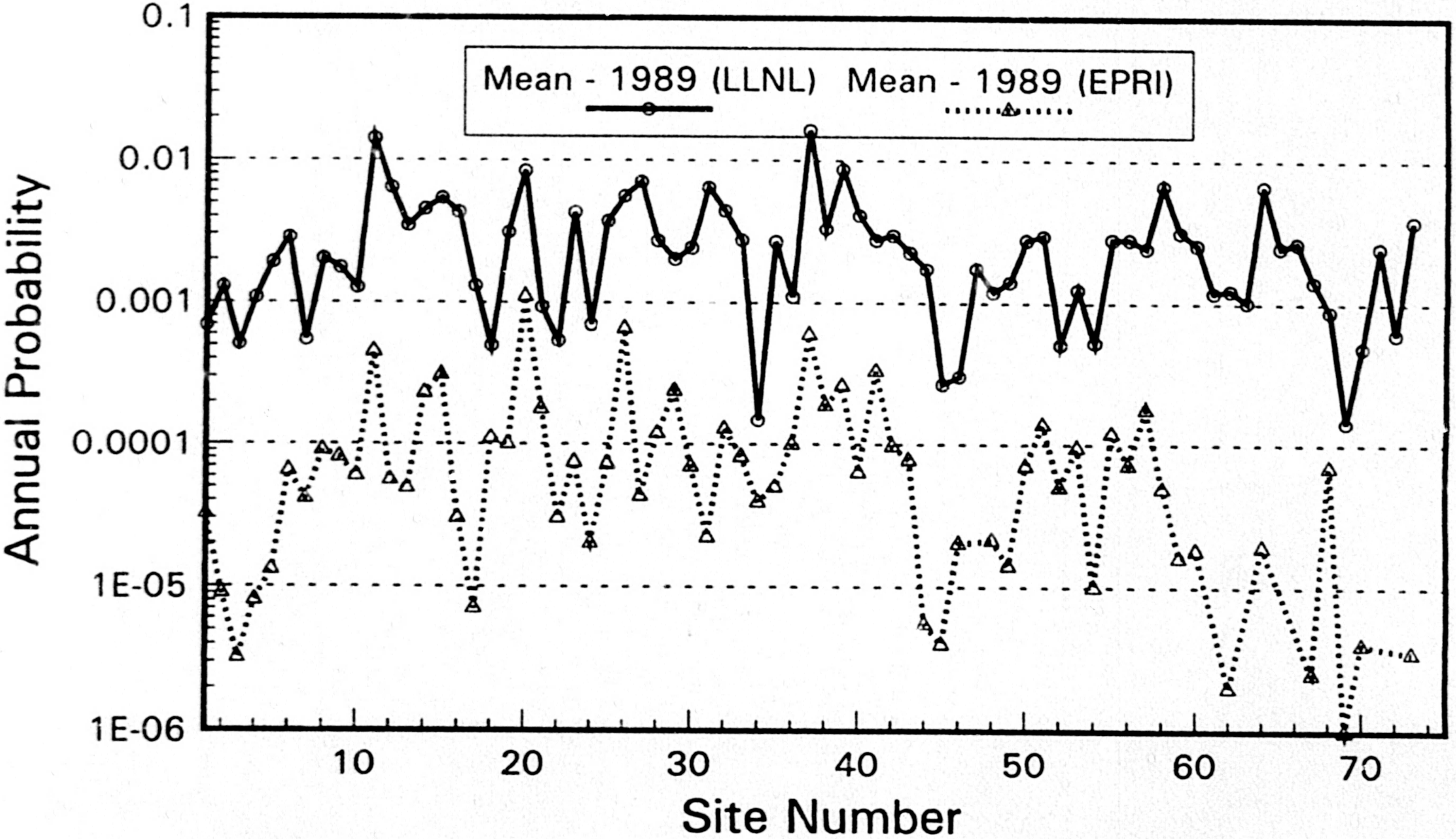

Figure 2

Probability of Exceeding the 5 & 10 hz Spectral

Ordinates at EUS NPPs. Comparisons Based on LLNL and EPRI Results. NUREG-1488 Spectra.

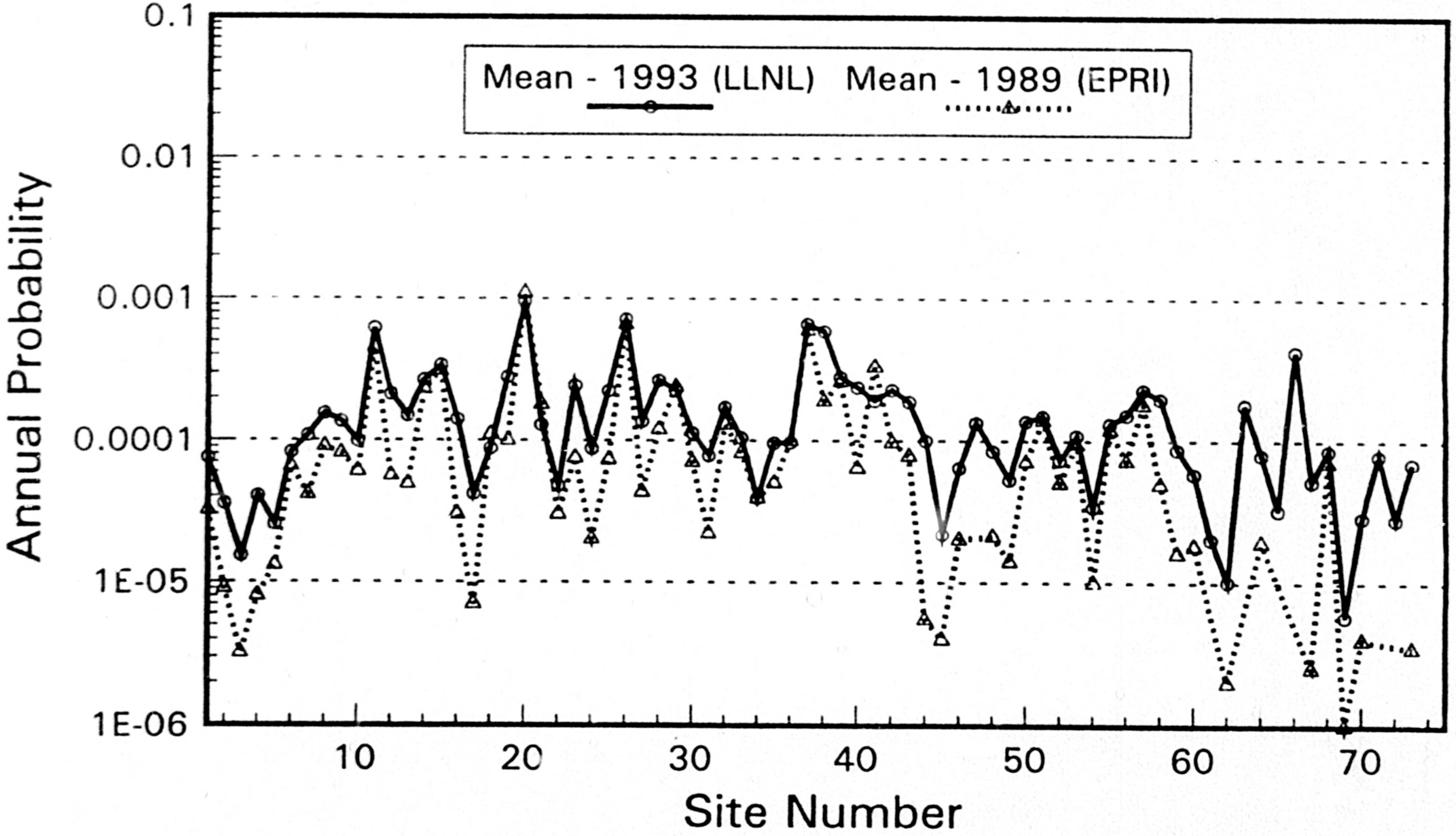

Figure 3

Progression of the LLNL Seismic Hazard Estimates

at 9 Eastern U.S. Sites

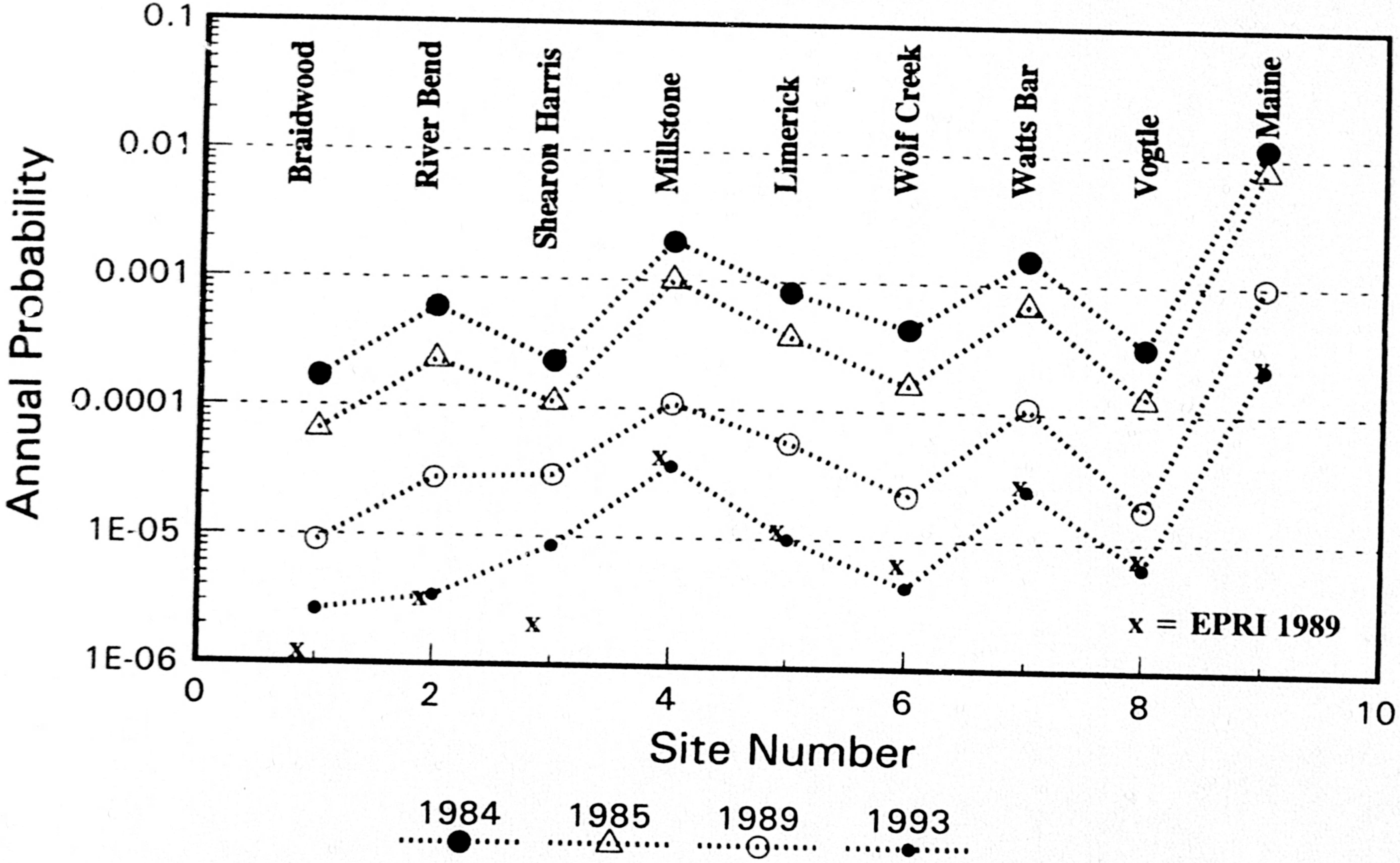

Figure 4

Probability of Exceeding the 5 & 10 hz Spectral

Ordinates at EUS NPPs. Comparisons Based on LLNL 1984 & 1993 Results. NUREG-1488 Spectra.

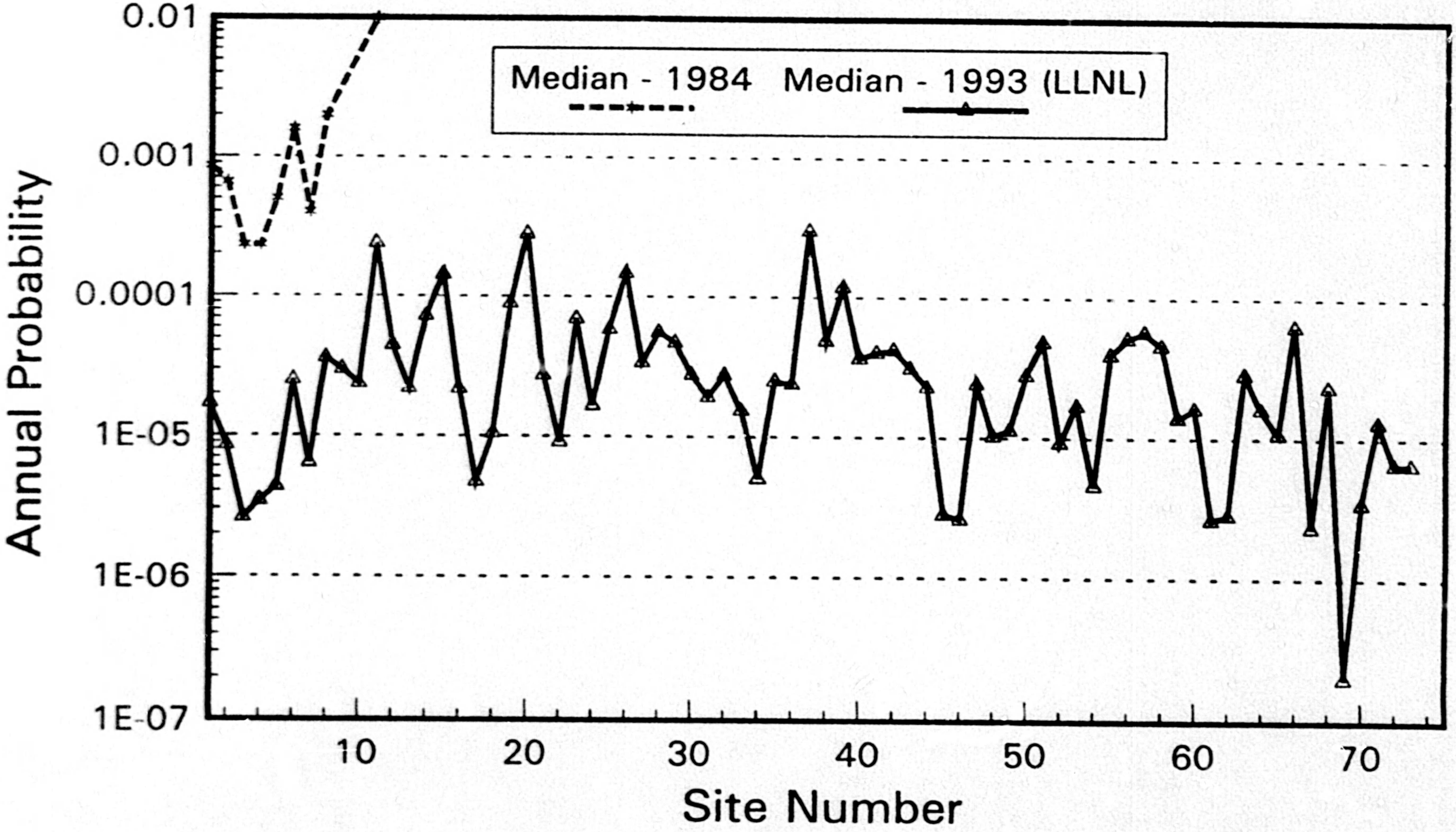

Figure 5

Probability of Exceeding the 5 & 10 hz Spectral

Ordinates at EUS NPPs. Comparisons Based on LLNL and EPRI Results. NUREG-1488 Spectra.

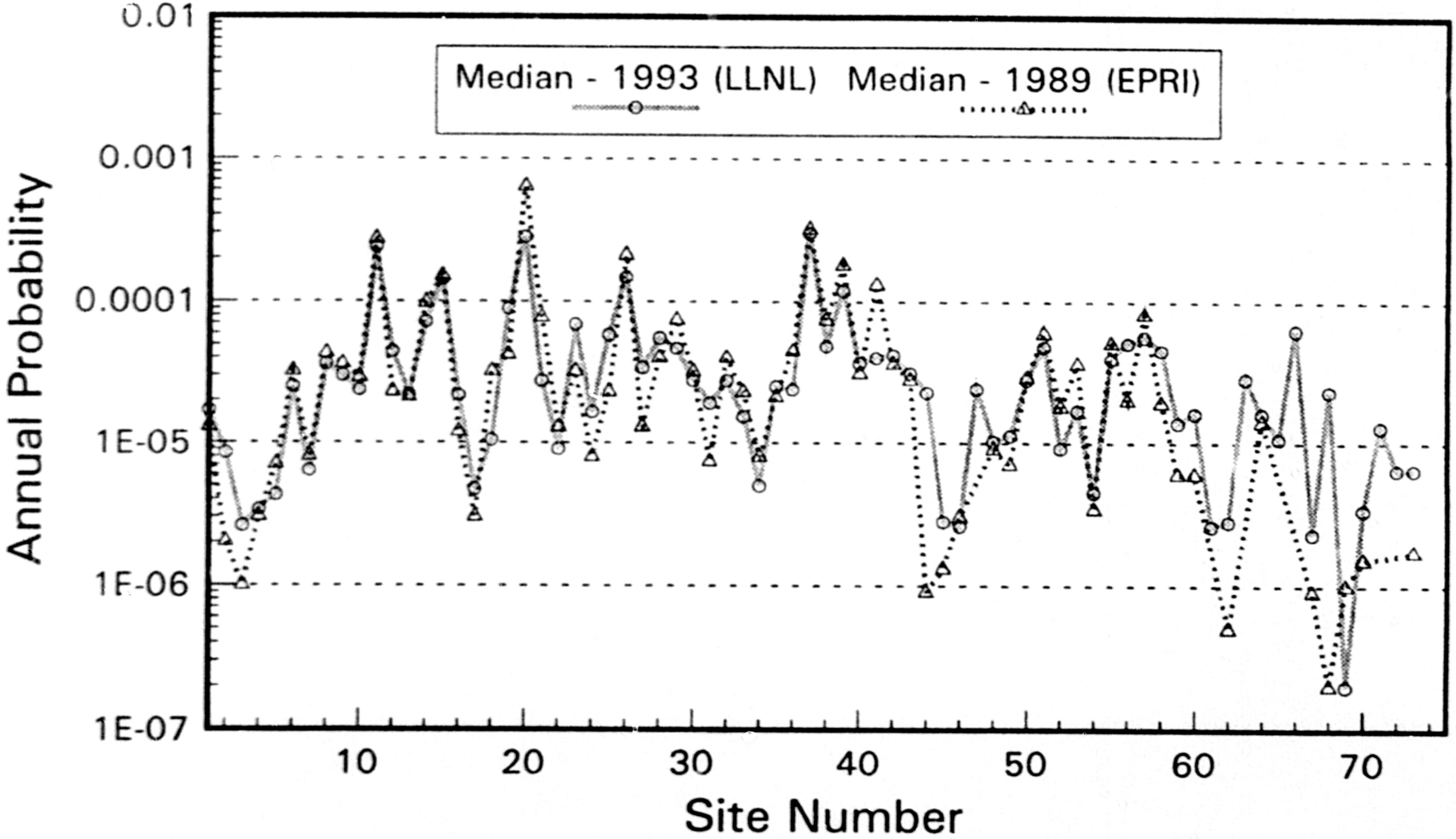

Figure 6

Probability of Exceeding the 5 & 10 hz Spectral

Ordinates at EUS NPPs. Comparisons Based on LLNL Results. NUREG-1488 Spectra.

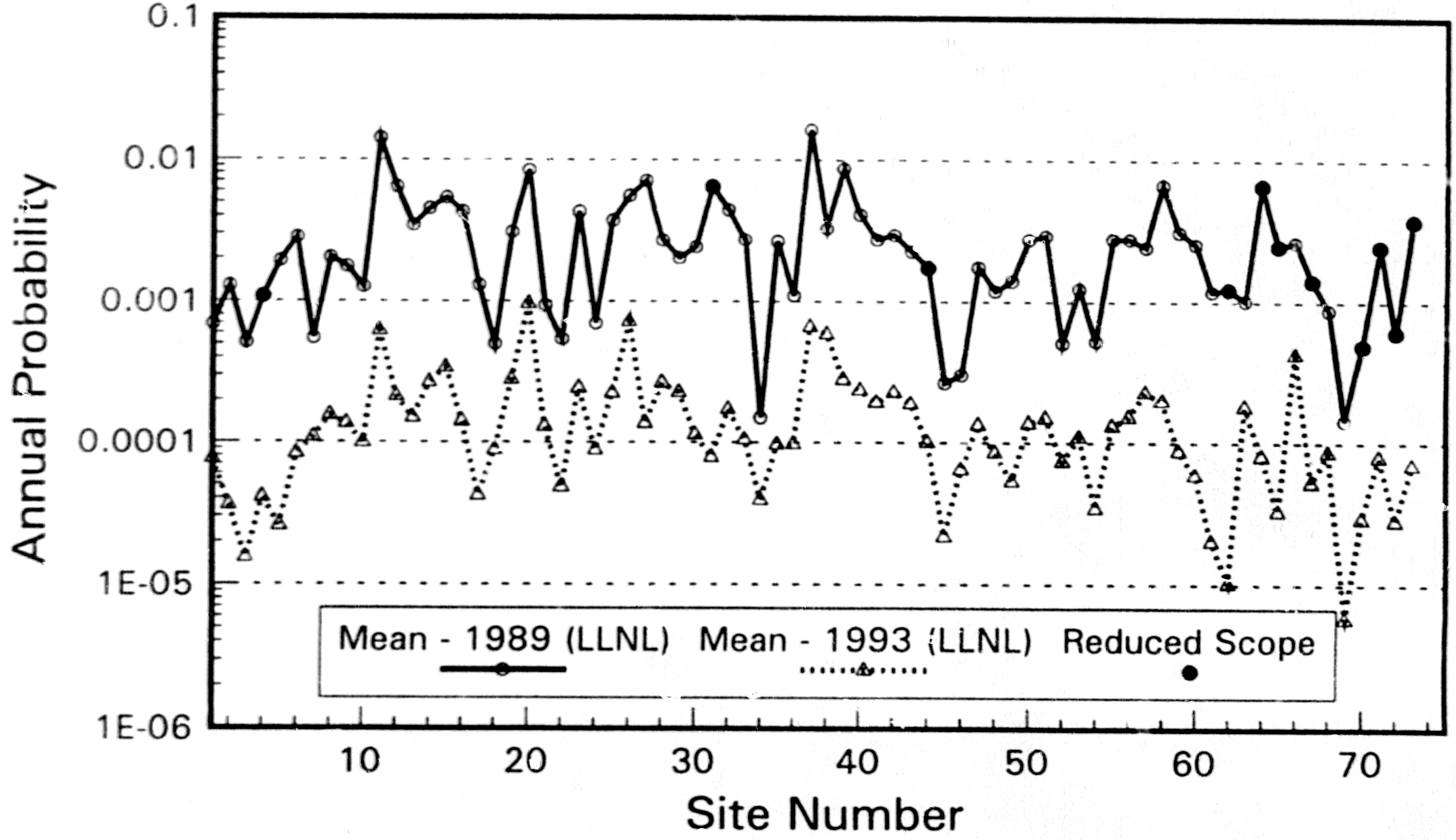

Figure 7

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Comparison of LLNL 1989 Probability of

Exceeding a 0.3g NUREG/CR-0098 Spectrum vs the 1993 Probability of Exceeding the SSE

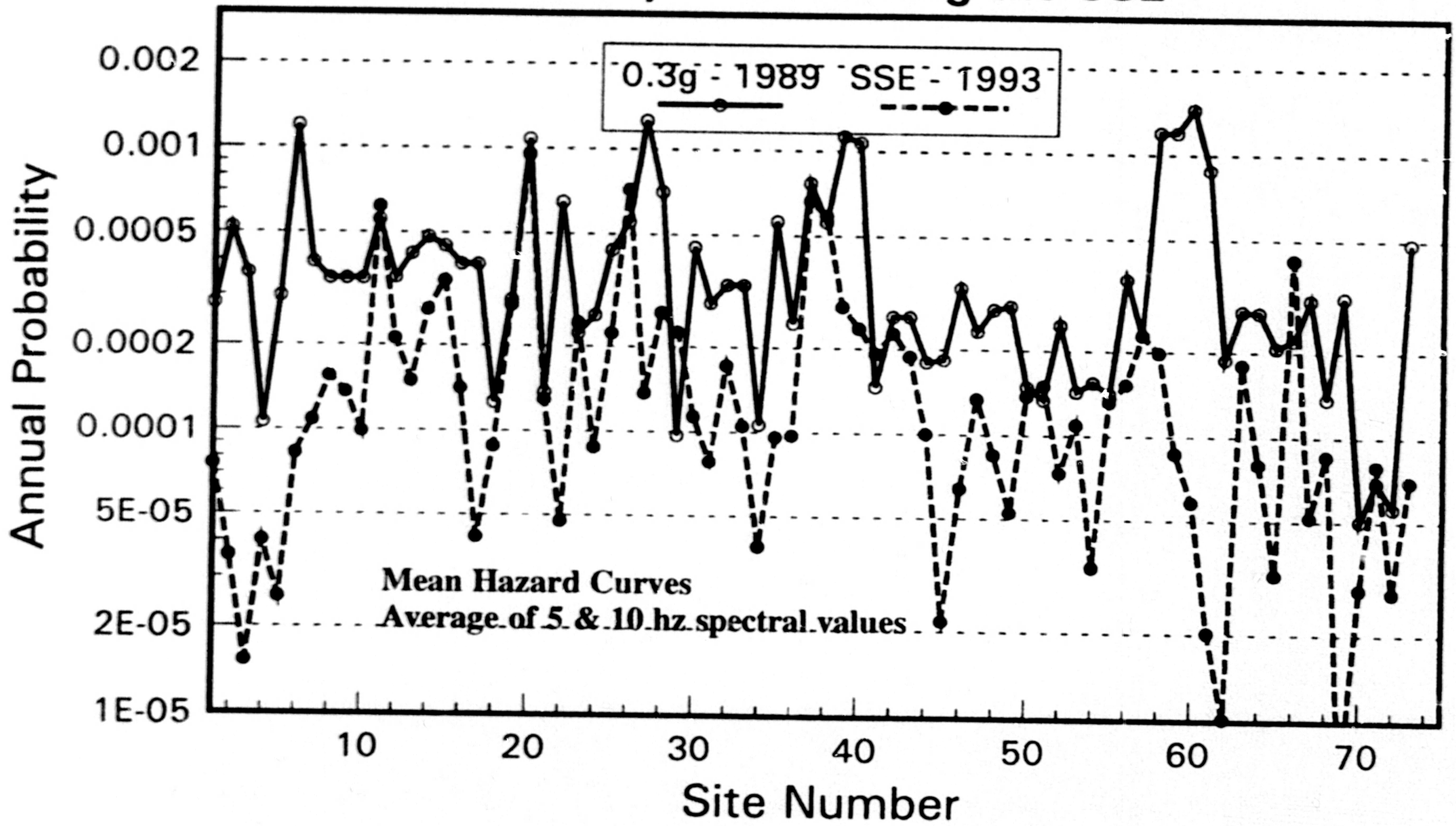

Figure 8

Comparison of Estimated Mean Core Damage

Frequencies - 1989 LLNL + 1989 EPRI vs. 1993 LLNL + 1989 EPRI

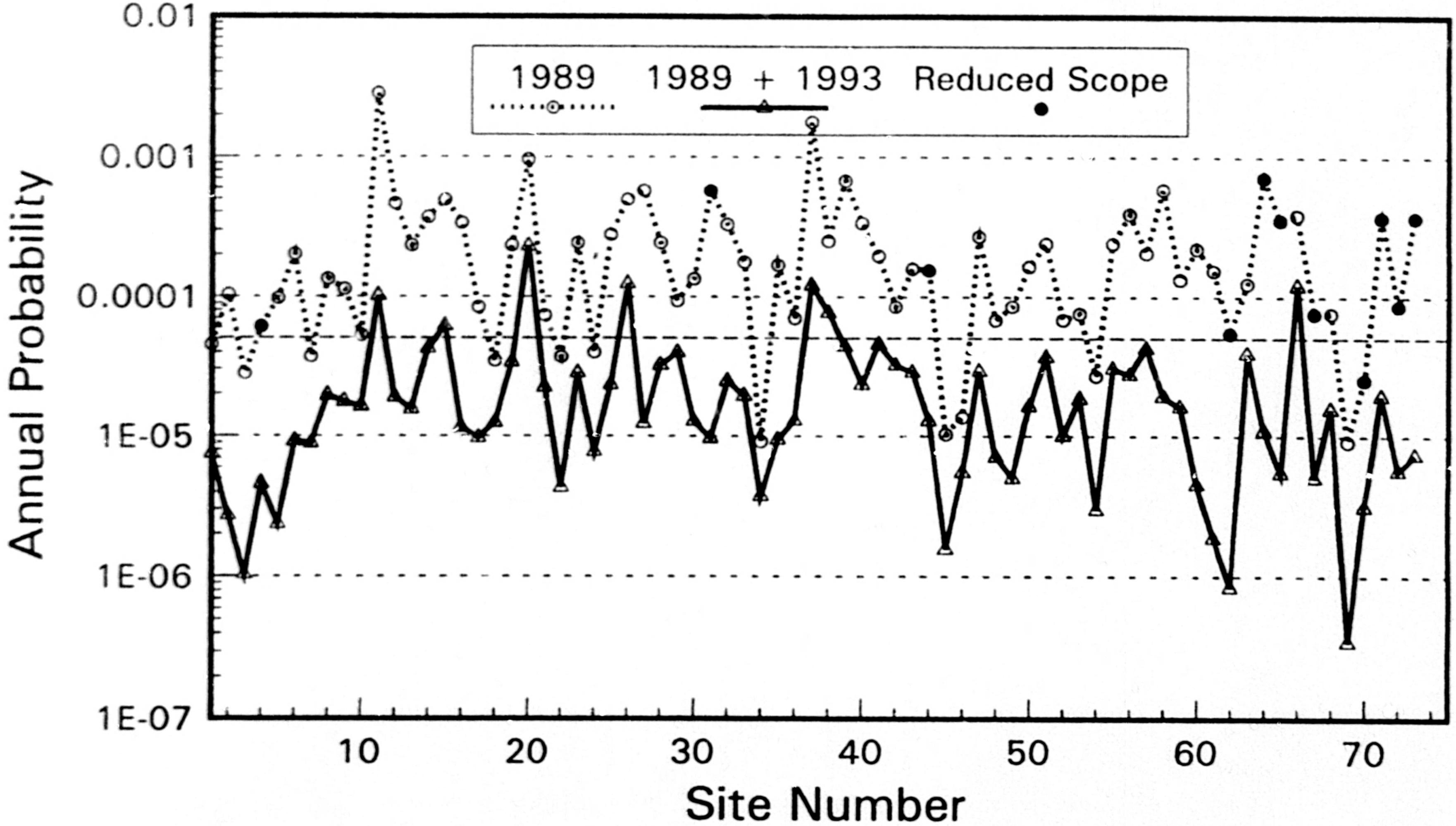

Figure 9

42