UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 3, 1999

MEMORANDUM TO: Stuart A. Richards, Director
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

FROM: \ William C. Huffman, Project Manager
Decommissioning Section
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

SUBJECT: SCREENING CRITERIA FOR ASSESSING POTENTIAL SEISMIC
VULNERABILITIES OF SPENT FUEL POOLS AT DECOMMISSIONING
PLANTS

The staff is in the process of preparing a final draft of its technical study on spent fuel pool
accident risks at decommissioning plants. This final draft will be issued for public comment in
early January 2000. Included in this report will be a discussion on risks from a large seismic
event that exceeds the structural capacity of the spent fuel pool to the extent that a catastrophic
failure occurs. Such a failure would result in rapid draining of the spent fuel pool with no
capability of retaining water even if reflooded. The staff has previously acknowledged that
spent fuel pools are inherently robust and can withstand loads substantially beyond those for
which they were designed. Consequently, they have a significant seismic capacity. To take
credit for the seismic design margins existent in spent fuel pools, the staff sought an
appropriate method to identify potential structural vulnerabilities without having to perform a
detailed fragility review. At a public workshop conducted on July 15-16, 1999, development of
a simple spent fuel pool seismic screening checklist was proposed as way of assessing the
seismic vulnerabilities of spent fuel pools without performing quantifying analyses. In a letter to
the staff dated August 18, 1999, the Nuclear Energy Institute (NEI) proposed a "seismic
checklist" for screening potential spent fuel pool structural vulnerabilities on a plant-specific
basis. Based on the staff's recent input to the final draft report, the use of a checklist is
considered to be an excellent approach to plant-specific seismic assessments; however, some
deficiencies have been identified in the checklist proposed by NEI. The nature of the
deficiencies with the current version of the checklist was generally discussed in a public
meeting with NEI and other stakeholders on November 19, 1999. NEI indicated that it needed
additional details on the staff's findings relative to the checklist in order to propose effective
improvements.

The Attachment to this memorandum contains additional details on the deficiencies the staff
has found with use of the current seismic checklist. Copies of this memorandum with the
attached information will be provided to NEI and all other interested stakeholders in an effort to

94 210

DF03

further the dialogue relating to the seismic checklist and support the development of additional modifications that will resolve the deficiencies currently identified.

For comments to be considered for the draft report that will be issued in January 2000 for public comment, written comments must be received by the staff no later than December 13, 1999. Comments received after December 13, 1999, will be addressed in the final report that will be issued in early April 2000. The NRC staff contact for public comments is Mr. William Huffman. Mr. Huffman can be reached at (301) 415-1141.

Attachment: As stated

cc w/att: See next page

DISTRIBUTION:
Central File
PUBLIC
PDIV-D r/f
JZwolinski/SBlack
SRichards
GHolahan
GHubbard
OGC
ACRS
RDudley
RBarrett
DJackson
TEaton

EXCEL 107

To receive a copy of this document, indicate "C" in the box									
OFFICE	PDIV-3/PM	C	PDIV-3/LA	C		C	SPLB:BC	C	PDIV-3/SC	C
NAME	WHuffman		CJamerson		GBagchi		JHannon		MMasnik	
DATE	12 2 /99		12 2 /99		12 3 /99		12 3 /99		12 3 /99	

DOCUMENT NAME: G:\PDIV-3\Regulatory Improvement\Seismic Cklst.wpd
OFFICIAL RECORD COPY

further the dialogue relating to the seismic checklist and support the development of additional modifications that will resolve the deficiencies currently identified.

For comments to be considered for the draft report that will be issued in January 2000 for public comment, written comments must be received by the staff no later than December 13, 1999. Comments received after December 13, 1999, will be addressed in the final report that will be issued in early April 2000. The NRC staff contact for public comments is Mr. William Huffman. Mr. Huffman can be reached at (301) 415-1141.

Attachment: As stated

cc w/att: See next page

Mr. Ralph Beedle
Senior Vice President
  and Chief Nuclear Officer
Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, DC 20006-3708

Mr. Alex Marion, Director
Programs
Nuclear Energy Institute
1776 I Street, Suite 400
Washington, DC 20006-3708

Mr. David Modeen, Director
Engineering
Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, DC 20006-3708

Mr. Anthony Pietrangelo, Director
Licensing
Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, DC 20006-3708

Mr. Jim Davis, Director
Operations
Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, DC 20006-3708

Ms. Lynnette Hendricks, Director
Plant Support
Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, DC 20006-3708

Mr. H. A. Sepp, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

Mr. Charles B. Brinkman, Director
Washington Operations
ABB-Combustion Engineering, Inc.
12300 Twinbrook Parkway, Suite 330
Rockville, MD 20852

Mr. Michael Meisner
Maine Yankee Atomic Power Co.
321 Old Ferry Road
Wiscassett, ME 04578-4922

Mr. Paul Blanch
Energy Consultant
135 Hyde Road
West Hartford, CT 06117

New England Coalition on Nuclear
  Pollution
P. O. Box 545
Brattleboro, VT 05302

Mr. Ray Shadis
Friends of the Coast
P. O. Box 98
Edgecomb, ME 04556

Mr. David Lochbaum
Union of Concerned Scientists
1616 P St. NW, Suite 310
Washington, DC 20036

Mr. Paul Gunter
Nuclear Information Resource Service
1424 16th St. NW, Suite 404
Washington, DC 20036

Mr. Peter James Atherton
P.O. Box 2337
Washington, DC 20013

Mr. H. G. Brack
Center for Biological Monitoring
P.O. Box 144
Hull's Cove, ME 04644

Ms. Deborah B. Katz
Citizen's Awareness Network
P. O. Box 3023
Charlemont, MA 01339-3023

Mr. Robert Holden
National Congress of American Indians
Suite 200
1301 Connecticut Ave, NW
Washington DC, 20036

Structural Failure Modes

Amongst the various ways a pool structure can fail, the only failure modes that are of concern are those that involve pool floor slab failure, failure of side walls at the bottom of the pool or at the bottom corners. It is important to ensure that the structural integrity assessment is based on realistic failure modes for catastrophic loss of structural integrity. This should take into account physical interactions with adjacent structures and equipment.

For PWR spent fuel pools, the pool floor slab is not likely to fail except through the effect of local concrete spalling due to foundation uplift and impact with the subgrade or adjacent structures. Failure of walls in partially embedded pools is not likely. Bending moment capacity of the pool walls is very much dependent on reinforcing patterns and the walls are generally reinforced in an orthotropic pattern, such that the resistance in the horizontal and vertical directions are unequal. The resistance is also unequal between one wall and another wall. This requires a case by case assessment of the bending capacity of walls.

For BWR spent fuel pools, the floor slab, walls and supporting columns and shear walls need scrutiny to determine the critical failure mode. As in the case of PWR spent fuel pools, the effect of adjacent structures and equipment on structural failure needs to be evaluated.

The stainless steel liner plate is used to assure leak-tightness; cracks in the welded seams are not likely to lead to catastrophic loss of water inventory unless there is a simultaneous massive failure of the concrete structure.

The emphasis here is that spent fuel pool structures not only vary in layout and elevation between PWRs and BWRs, they can also vary within each group. The process of realistic assessment of structural capacity of pool structures begins with a methodical consideration of likely failure modes associated with a catastrophic loss of integrity.

The efforts involved in the assessment of seismic capacity of pool structures typically consist of the following:

- Inspect the pool structure and its vicinity and note:

    - physical condition such as cracking and spalling of concrete, signs of leakage or leaching and separation of pool walls from the grade surface, potential for piping connections, either buried underground or above ground, to fail due to a large seismic excitation or interaction with adjacent equipment, and cause drainage of the pool below the safety level of the pool water,

    - arrangement and layout of supporting columns and shear walls, assessment of other loads from tributary load areas carried by the supporting structure of the pool, as-built dimensions and mapping of any existing structural cracks,

    - adjacent structures that can impact the pool structure both above and below the grade surface, supporting arrangement for superstructure and crane and potential for failure of the superstructure and the crane, potential impact from heavy objects that can drop in the pool structure and the corresponding drop heights.

<div align="right">ATTACHMENT</div>

- Seismic capacity assessments of the pool structure typically consist of the following:

    - review existing layout drawings and structural dimensions and reconcile the differences, if any, between the as-built and as designed information and consider the effects of structural degradation as appropriate,

    - from design calculations determine the margin to failure and assess the extrapolated multiple of SSE level that the pool structure could survive, determine whether or not design dynamic response analysis including soil-structure interaction effects are still applicable at the capacity level seismic event; if not, conduct a new analysis using properties of soil at higher strain levels and reduced stiffness of cracked reinforced concrete,

    - determine the loads from pool structure foundation uplift and from impact of pool structure with adjacent structures during the capacity level seismic event, determine loads from the impact of a spent fuel rack on the pool floor and the side walls and determine the loads from dropping of heavy objects from the collapse of a superstructure or the overhead crane,

    - determine a list of plausible failure modes; failure of side walls due to the worst loading from the capacity level earthquake in combination with fluid hydrostatic and sloshing head and dynamic earth pressure as appropriate, failure of the pool floor slab in flexure and bending due to loads from the masses of water and the spent fuel and racks, local failure by punching shear due to impact between structures and the spent fuel racks or dropping of heavy objects,

    - the assessments to determine the lowest structural capacity can be based on ultimate strength of reinforced concrete structures due to flexure, shear and punching shear. When conducting a yield line analysis, differences in flexural yield capacities for the negative and positive bending moments in two orthogonal directions influence the crack patterns, and several sets of yield lines may have to be investigated to obtain the lowest capacity. For heterogeneous materials, the traditional yield line analysis provides upper bound solutions; consequently, considerable skill is needed to determine the structural capacity based on the yield lines that approximate the lower bound capacity.

Although the inspection of the pool structure is an essential part of establishing that the structure is in sound condition, some of the other attributes of a detailed capacity evaluation, as discussed above, may only be undertaken for plants that do not pass simple examination using a seismic checklist. Such an effort may be necessary for plants in high seismic hazard areas.

Other Considerations

NRC sponsored studies have treated the assessment of seismic capacity of spent fuel pools relying on the seismic margins method to determine the high confidence of low probability (less than 5% failure) of failure (HCLPF). The HCLPF value for a structural failure may well be unrealistic and unnecessarily conservative in terms of an instantaneous loss of water inventory.

This point needs to be emphasized because the shear and moment capacity of the walls and slabs are determined by using upper limits of allowable stresses. In the study which resulted in NUREG/CR 4982, the seismic capacities were based on the Oyster Creek reactor building and a shear wall from the Zion auxiliary building. For elevated pool structures, the Oyster Creek estimate may be an acceptable approximation, but the Zion shear wall may be too highly simplified to substitute for the catastrophic failure of the spent fuel pool structure. However, it is important to emphasize that out of plane loading on the pool walls from the hydrostatic head of the pool water can lead to flexure and shear-induced failures. Relatively low margin on allowable out-of-plane shear strength combined with the uncertainty of the extent to which reinforcement details ensure ductile behaviors make it imperative to ensure that seismic capacities of the pool walls and slab elements are adequate. The stainless steel pool liner was not designed to resist any structural load; nevertheless, it can provide substantial water-retaining capacity near the bottom half of the pool where structural deformations are likely to be low from seismic loading (this is due to the aspect ratio of the pool walls which are thick and form a deep box shape) except in a highly unlikely failure mode, such as puncturing the pool slab or the wall near the bottom of the pool.

For PWR pools that are fully or partially embedded, an earthquake motion that could cause a catastrophic failure is very high and is not a credible event. However, interaction with adjacent structures and equipment may have to be evaluated to determine the structural capacity on a case-by-case basis.

For BWR pools, the seismic capacity is likely to be somewhat less than that of a PWR pool and can vary significantly from one plant to another. This is because for most BWR pools that are at higher elevation there is amplification of seismic motion, and the pool floor may not be supported on the subgrade. Shear failure of the pool floor can occur at a relatively lower level of seismic input for BWR pools. More important, a combination of the hazard and the spent fuel pool structural capacity can bring down the likelihood of a catastrophic structural failure to a negligible risk. On the other hand, plant-specific hazard and seismic fragility of spent fuel pools can combine to produce a risk that needs to be examined on a case-by-case basis.

Using the data from NUREG-1488 (new Lawrence Livermore National Laboratory (LLNL) data) for currently operating plants in the eastern and central United States, the mean probability of exceedance (POE) of the peak ground acceleration values for the SSE were examined. The plant grouping approach, Reduced Scope, Focused Scope, Full Scope, etc., used in NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities" Final Report was also reviewed. The objective of plant grouping for IPEEE was to put plants into groups with similar seismic vulnerability; consequently, it was useful to look at these plant groups. However, the evaluation in this draft study is driven by the 1993 LLNL seismic hazard results, and it was determined that, except for a small number of plants, the POEs for SSE are lower than $1X10^{-4}$ per reactor year and for three times the SSE, the POEs are below $1X10^{-5}$. For these plants, the likelihood of a catastrophic pool structure failure at a HCLPF value of three times the SSE should be less than $5X10^{-7}$. This makes the simplifying assumption that the conditional probability of failure (POF) or reaching the end state of a structure is $5X10^{-2}$. In this approach there is confidence that the seismic hazard is low (at three times the SSE) and there is also a plant specific structural assessment of the HCLPF value which is more than or equal to three times the SSE. For spent fuel pools located at sites that meet the HCLPF value of three times the SSE, a catastrophic structural failure from an earthquake much larger than the design basis SSE is not

credible. However, this approach may not be feasible at sites where the likelihood of the spent fuel pool structure failure due to beyond design basis earthquake is higher. For such sites in the eastern United States, a more detailed examination of the probability of the earthquake, a realistic assessment of the ground motion caused by the event at the site and the structural capacity of the spent fuel pool structure may be necessary.

NEI Draft Seismic Checklist

The draft checklist provided in an NEI letter to the staff postmarked August 18, 1999, includes seven elements that identify areas of potential weaknesses. The use of such a checklist would ensure that potential vulnerabilities are either rectified or mitigation measures are put in place. The checklist is quite comprehensive. But it can be improved by taking into account out-of-plane shear capacity of shear walls such as those that form the pool when they are not backed up by backfill. Other considerations might include pre-existing degradation of concrete and the liner plate. With minor modifications the checklist can be finalized.

Kennedy Report

As a part of an independent technical review, Dr. Robert P. Kennedy was requested to conduct this review. This review activity was supported by the Office of Nuclear Regulatory Research, Division of Engineering Technology. Dr. Kennedy attended the public workshop on July 16, 1999. The report does endorse the feasibility of the use of the seismic screening concept and identifies eight sites by site numbers for which seismically induced probability of failure (POF) is greater than 3×10^{-6} using the LLNL 93 Hazard. It is important to recognize that sites where POF is greater than 3×10^{-6}, in addition to the use of the seismic checklist, an evaluation of the POF using plant-specific fragility information will be necessary. For all other sites, the use of the seismic checklist should be adequate. Appropriate excerpts of the Kennedy Report are contained in the Enclosure.

Recommendation

The following actions are recommended:

1. The seismic checklist should consider out of plane shear and flexure.

2. Identification of preexisting concrete and liner plate degradation be added to the checklist.

3. The checklist should be augmented to discuss potential mitigation measures for vulnerabilities that may be identified.

4. Higher seismic hazard sites in the Eastern U.S., should be further evaluated by the industry to determine (a) a list of such sites, (b) a credible ground motion description at which the seismic hazard frequency is low enough at these sites, and (c) plant specific seismic capacity evaluation using credible ground motion description at the site.

5. Proposed treatment of sites West of the Rocky Mountains

NOTE: Additional supplemental information from the Kennedy report is included in the following pages.

3. Development and Use of Seismic Screening Criteria

Screening criteria are very useful to reduce the number of structure, system, and component (SSC) failure modes for which either seismic fragilities or seismic margin HCLPF capacities need to be developed. Screening criteria are presented in Ref. 6 for SSCs for which failures might lead to core damage. These screening criteria were established by an NRC sponsored "Expert Panel" based upon their review of seismic fragilities and seismic margin HCLPF capacities computed for these SSCs at more than a dozen nuclear power plants, and their review of earthquake experience data. These screening criteria were further refined in Ref. 7.

The screening criteria of Refs. 6 and 7 are defined for two seismic margin HCLPF capacity levels which will be herein called Level 1 and Level 2. Refs. 6 defines these two HCLPF capacity levels in terms of the PGA of the ground motion. However, damage to critical SSCs does not correlate very well to PGA of the ground motion. Damage correlates much better with the spectral acceleration of the ground motion over the natural frequency range of interest which is generally between 2.5 and 10 Hz for nuclear power plant SSCs. For this reason, Ref. 7 defines these same two HCLPF capacity levels in terms of the peak 5% damped spectral acceleration (PSA) of the ground motion. The two HCLPF capacity screening levels defined in Refs 6 and 7 are:

	HCLPF Screening Levels	
	Level 1	Level 2
PGA (Ref. 6)	0.3g	0.5g
PSA (Ref. 7)	0.8g	1.2g

These two definitions (PGA and PSA) are consistent with each other based upon the data upon which these screening levels are based. However, in my judgment, it is far superior to use the Ref. 7 PSA definition for the two screening levels when convolving a fragility estimate with CEUS seismic hazard estimates. For these CEUS seismic hazard estimates from Ref. 8, the ratio PSA/PGA generally lies in the range of 1.8 to 2.4 which is lower than the PSA/PGA ratio of the data from which the screening tables were developed. A more realistic and generally lower estimate of the annual probability of failure will result when the seismic fragility is defined in terms of PSA and convolved with a PSA hazard estimate in which the PSA hazard estimate is defined in the 2.5 to 10 Hz range.

In the past, a practical difficulty existed with defining the seismic fragility in terms of PSA instead of PGA. The Ref. 8 PSA hazard estimates are only carried down to 10^{-4} annual frequency of exceedance whereas the PGA hazard estimates are extended down to about 10^{-6}. Since it is necessary for the hazard estimate to be extended to at least a factor of 10 below the annual failure frequency being predicted, it has not been practical to use the PSA seismic fragility definition with the Ref. 8 hazard estimates. However,

this difficulty has been overcome by Ref. 9 prepared by the Engineering Research Applications Branch of the Nuclear Regulatory Commission which extends the PSA seismic hazard estimates also down to 10^{-6}. Ref. 9 is attached herein as Appendix A.

In order to achieve a seismic induced annual failure probability P_F in the low 10^{-6} range for nearly all of the CEUS spent fuel pools with the Ref. 8 hazard estimates, it is necessary to apply the Level 2 screening criteria of Refs. 6 or 7, i.e., screen at a HCLPF seismic capacity of 1.2g PSA (equivalent to 0.5g PGA). The seismic screening criteria presented in Ref. 4 is properly based upon screening to Level 2. Furthermore, Ref. 4 appropriately summarizes the guidance presented in Ref. 7 for screening to Level 2. In general, I support the screening criteria defined in Ref. 4. However, I do have three concerns which are discussed in the following subsections.

3.1 Out-of-Plane Flexural and Shear Failure Modes for Spent Fuel Pool Concrete Walls and Floor

The screening criteria for concrete walls and floor diaphrams were developed to provide seismic margin HCLPF capacities based upon in-plane flexural and shear failures of these walls and diaphrams. For typical auxiliary buildings, reactor buildings, diesel generator buildings, etc., it is these in-plane failure modes which are of concern. For normal building situations, seismic loads are applied predominately in the plane of the wall or floor diaphram. Out-of-plane flexure and shear are not of significant concern. As one the primary authors of the screening criteria in both Refs. 6 and 7, I am certain that these screening criteria do not address out-of-plane flexure and shear failure modes.

For an aboveground spent fuel pool in which the pool walls (and floor in some cases) are not supported by soil backfill, it is likely that either out-of-plane flexure or shear will be the expected seismic failure mode. These walls and floor slab must carry the seismic-induced hydrodynamic pressure from the water in the pool to their supports by out-of-plane flexure and shear. It is true that these walls and floor are robust (high strength), but they may not be as ductile for out-of-plane behavior as they are for in-plane behavior. For an out-of-plane shear failure to be ductile requires shear reinforcement in regions of high shear. Furthermore, if large plastic rotations are required to occur, the tensile and compression steel needs to be tied together by closely spaced stirrups. I question whether such shear reinforcement and stirrups exist at locations of high shear and flexure in the spent fuel pool walls and floor. As a result, I suspect that only limited credit for ductility can be taken.

Without taking credit for significant ductility, it is not clear to me that spent fuel pool walls and floors not supported by soil can be screened at a seismic HCLPF capacity level as high as 1.2g PSA (equivalent to 0.5g PGA). I am aware of only one seismic fragility analysis having been performed on such unsupported spent fuel pool walls. That analysis was the Vermont Yankee spent fuel pool analysis reported in Ref. 5 for which the reported seismic HCLPF capacity was 0.48g PGA. A single analysis case does not provide an adequate basis for establishing a screening level for all other cases, particularly when the computed result is right at the desired screening level. The

screening criteria in Refs 6 and 7 are based upon the review of many cases at more that a dozen plants.

In my judgement, it will be necessary to have either seismic fragility or seismic margin HCLPF computations performed on at least six different aboveground spent fuel pools with walls not supported by soil before out-of-plane flexure and shear HCLPF capacity screening levels can be established for such spent fuel pools.

Section 3.2 not included

3.3 Seismic Level 2 Screening Requirements

In order to screen at a seismic HCLPF capacity of 1.2g PSA (0.5g PGA), the Level 2 screening criteria for concrete walls and diaphrams requires that such walls and diaphrams essentially comply with the ductile detailing and rebar development length requirements of either ACI 318.71 or ACI 349.76 or later editions. It is not clear to me how many CEUS spent fuel pool walls and floors essentially comply with such requirements since earlier editions of these codes had less stringent requirements. Therefore, it is not clear to me how many spent fuel pool walls and floors can actually be screened at Seismic Level 2 even for in-plane flexure and shear failure mode.

4. Seismic Risk Associated With Screening Level 2
4.1 Simplified Approaches for Estimating Seismic Risk Given the HCLPF Capacity

As mentioned in Section 2, the seismic risk of failure of the spent fuel pool can be estimated by either rigorous convolution of the seismic fragility and the seismic hazard, or by a simplified approximate method. The simplified approximate method defined by Eqn. (3) was used in Ref. 1. However, as also mentioned in Section 2, this approximate method understates the seismic risk by a factor of 2 to 4 for typical CEUS hazard estimates.

Ref. 10 presents an equally simple approach for estimating the seismic risk of failure of any component given its HCLPF capacity C_{HCLPF} and a hazard estimate. This approach tends to introduce from 0% to 25% conservative bias to the computed seismic risk when compared with rigorous convolution. Given the HCLPF capacity C_{HCLPF} this approach consists of the following steps:

Step 1:   Estimate the 10% conditional probability of failure capacity $C_{10\%}$ from:

$$C_{10\%} = F_{\beta} C_{HCLPF}$$

$$F_{\beta} = e^{1.044\beta}$$
                                                                (6)

where β is the logarithmic standard deviation of the fragility estimate and 1.044 is the difference between the 10% non-exceedance probability (NEP) standard normal variable (-1.282) and the 1% NEP standardized normal variable (-2.326). F_{β} is tabulated below for various fragility logarithmic standard deviation β values.

β	Median/CDFM Capacity $(C_{50\%}/C_{CDFM})$	$F_{\beta}=(C_{10\%}/C_{HCLPF})$
0.3	2.01	1.37
0.4	2.54	1.52
0.5	3.20	1.69
0.6	4.04	1.87

For structures such as the spent fuel pool, β typically ranges from 0.3 to 0.5. Ref. 10 shows that over this range of β, the computed seismic risk is not very sensitive to β. Therefore, I recommend using a midpoint value for β of 0.4.

Step 2:   Determine hazard exceedance frequency $H_{10\%}$, that corresponds to $C_{10\%}$ from the hazard curve.

Step 3:   Determine seismic risk P_F from:

$$P_F = 0.5\, H_{10\%}$$
                                                                (7)

Table 1 presents the Peak Spectral Acceleration PSA seismic hazard estimates from Ref. 8 and 9 (LLNL93 results) for the Vermont Yankee and Robinson sites. In order to accurately estimate the seismic risk for a seismic HCLPF capacity C_{HCLPF} of:

$$C_{HCLPF} = 1.2g\ PSA = 1176\ cm/sec^2\ PSA$$
                                                                (8)

associated with Screening Level 2 for the Vermont Yankee site by rigorous convolution, it is necessary to extrapolate the Ref. 9 hazard estimates down to the 2×10^{-8} exceedance frequency. Also, intermediate values in Table 1 have been obtained by interpolation.

Table 2 compares the seismic risk of spent fuel pool failure for these two sites as estimated by the following three methods:

1. Ref. 1 simplified approach, i.e., Eqn. (3).

2. Ref. 10 simplified approach, i.e., Steps 1 through 3 above.

3. Rigorous convolution of the hazard and fragility estimates.

For all three approaches the Screening Level 2 HCLPF capacity defined by Eqn. (8) was used. In addition, for both the Ref. 10 and rigorous convolution approaches, a fragility logarithmic standard deviation β of 0.4 was used.

From Table 2, it can be seen that the Ref. 1 method (Eqn. (3)) underestimates the seismic risk by factors of 2.3 and 3.5 for Vermont Yankee and Robinson, respectively. The simplified approach recommended in Ref. 10 and described herein overestimates the seismic risk by 20% and 5% respectively for these two cases. These results are consistent with the results I have obtained for many other cases.

4.2 Estimated Seismic Risk of Spent Fuel Pools Screened at Screening Level 2 Using Mean LL93 Hazard Estimates from Ref. 8 and 9

Using the Ref. 10 simplified approach described in the previous subsection, I have estimated the spent fuel pool seismic risk of failure corresponding to Screening Level 2 for all 69 CEUS sites with LLNL93 seismic hazard estimates defined in Refs. 8 and 9. These sites are defined in terms of an NRC site number code (OCSP_) used in Ref. 9. For each site, I assumed that the HCLPF capacity C_{HCLPF} was defined by Eqn. (8). A total of 35 of the 69 sites had estimated seismic risks of spent fuel pool failure associated with Screening Level 2 of greater than 1×10^{-6}. The estimated seismic risk of 26 of these sites exceeded 1.25×10^{-6}. These 26 sites with their estimated seismic risk corresponding to Screening Level 2 are listed in Table 3. As can be seen in Table 3, only 8 of the 69 sites had estimated seismic risks of spent fuel pool failure exceeding 3×10^{-6}. One of these sites is Shoreham at which no fuel exists.

It should be noted that the seismic risks of spent fuel pool failure tabulated in Table 3 are based on the assumption that the HCLPF capacity of the spent fuel pool exactly equals the Screening Level 2 HCLPF capacity of 1.2g PSA (equivalent to 0.5g PGA). In actuality, spent fuel pools which pass the appropriately defined screening criteria are likely to have capacities higher than the screening level capacity. Therefore these are upper bound seismic risk estimates for spent fuel pools that pass the to-be established screening criteria. Furthermore, the simplified approach used to estimate the seismic risks in Table 3 overestimates these risks by 0% to 25%.

References

1. *Preliminary Draft Technical Study of Spent Fuel Pool Accidents for Decommissioning Plants*, Nuclear Regulatory Commission, June 16, 1999

2. *Draft EPRI Technical Report: Evaluation of Spent Fuel Pool Seismic Failure Frequency in Support of Risk Informed Decommissioning Energy Planning*, Duke Engineering and Services

3. *A Review of Draft NRC Staff Report: Draft Technical Study of Spent Fuel Pool Accidents for Decommissioning Plants*, NEI, August 27, 1999

4. *Seismic Screening Criteria for Assessing Potential Fuel Pool Vulnerabilities at Decommissioning Plants*, NEI, August 18, 1999

5. *Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants*, NUREG/CR-5176, Prepared for Nuclear Regulatory Commission, January 1989

6. *An Approach to the Quantification of Seismic Margins in Nuclear Power Plants*, NUREG/CR-4334, Prepared for Nuclear Regulatory Commission, August 1985

7. *A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)*, (EPRI NP-6041-SL), August 1991

8. *Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains*, NUREG-1488, Nuclear Regulatory Commission, October 1993

9. *Extension to Longer Return Periods of LLNL Spectral Acceleration Seismic Hazard Curves for 69 Sites*, provided by Engineering Research Applications Branch, Nuclear Regulatory Commission, September, 1999

10. Kennedy, R.P., *Overview of Methods for Seismic PRA and Margin Assessments Including Recent Innovations*, CSNI Seismic Risk Workshop, Tokyo, Japan, August 1999

11. Personal Communication from Tom O'Hara, Duke Engineering and Services to Robert Kennedy, October 19, 1999

Table 1
Seismic Hazard Estimates for Peak Spectral Acceleration for PSA
From Refs. 8 and 9 (LLNL 93 Results)

Exceedance Frequency H	Peak Spectral Acceleration PSA $(cm/sec.^2)$		
	Vermont Yankee	Robinson	
1×10^{-3}	93	232	
5×10^{-4}	151	369	
2×10^{-4}	246	676	
1×10^{-4}	354	991	
5×10^{-5}	501	1349	*
2×10^{-5}	759	2054	*
1×10^{-5}	1058	2801	
5×10^{-6}	1396	3915	*
2×10^{-6}	1884	6096	*
1×10^{-6}	2308	8522	
5×10^{-7}	2661	--	**
2×10^{-7}	3330	--	**
1×10^{-7}	3802	--	**
5×10^{-8}	4266	--	**
2×10^{-8}	5248	--	**

* By Interpolation

** By Extrapolation

Table 2
Comparison of Seismic Risk Estimated by Various Approaches

$$C_{HCLPF} = 1.2g \ PSA, \quad \beta = 0.4$$

Site	Computed Seismic Risk P_F (to be multiplied by 10^{-6})		
	Ref. 1 Method Eqn. (3)	Ref. 10 Method Steps 1 through 3	Rigorous Convolution
Vermont Yankee	0.38	1.07	0.89
Robinson	3.7	13.6	13.0

Table 3
Seismic Risk Associated With Screening Level 2

$C_{HCLPF} = 1.2g$ Peak Spectral Acceleration

Site Number	Annual Seismic-Induced Probability of Failure P_F (to be multiplied by 10^{-6})	
	LLNL93 Hazard	EPRI89 Hazard
36	13.6	0.14
18	8.3	1.9
25	6.6	0.57
8	5.5	0.21
43	4.5	0.12
59	4.4	*
21	4.2	*
62	4.1	*
27	2.9	0.38
49	2.8	0.27
40	2.5	0.10
16	2.5	0.14
38	2.3	0.21
63	2.2	0.06
54	2.2	0.26
19	1.8	0.17
32	1.8	0.17
28	1.7	0.04
4	1.6	*
50	1.5	0.20
44	1.5	*
20	1.5	0.55
31	1.4	0.06
39	1.4	0.14
14	1.3	0.60
13	1.3	0.33

* Not Available