## Outline- White Paper on Seismic Risk of Spent Fuel Pool in Decommissioning

Current Approach:

A potential scenario that has been proposed for the release of radioactive material from a decommissioned plant is the catastrophic failure of the spent fuel pool due to earthquake vibratory motion and the rapid loss of cooling water resulting in the heating up of the spent fuel causing a fire. Because of the need for radiation shielding the spent fuel pool structures at nuclear power reactor facilities are constructed with thick reinforced concrete walls and floor slabs. This construction provides the pool structures considerable strength reserve for resisting seismic loads much beyond its design basis seismic loading (safe shutdown earthquake vibratory motion). The safe shutdown earthquakes for U. S. operating nuclear power plants are based on evaluations to obtain the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material using deterministic methods. A comparison of the safe shutdown earthquake (SSE) ground motions of eastern U. S. nuclear power plants to the seismic hazard estimates of two currently available studies, one by the Lawrence Livermore National Laboratory (LLNL) and the other by the Electric Power Research Institute (EPRI) indicate that in general the SSE have frequencies of exceedance on the order of 1XE-3 to 1XE-4 per year.

The study of the failure probability of spent fuel pools was conducted for the NRC by Dr. Robert Kennedy utilizing the seismic hazard estimates of LLNL and the EPRI studies. The result of the Kennedy study shows that the seismic probability of failure of spent fuel pools generally fall below 1.3XE-6 using the LLNL hazard estimates, except for about 9 sites where the probability of failure is somewhat higher. This was a generic study using a capacity assumption of 1.2 g spectral acceleration. The capacity at individual spent fuel pools could be higher in many cases; except for the cases of elevated pool structures where the failure can be caused by an out of plane shear force.

In order to determine a criteria for generically eliminating the concern for seismic failure, the NRC staff proposed an approach based on a physical verification of the pool structure followed by a confirmation of structural capacity at the levels of 2XSSE and 3XSSE for the west and east coast sites respectively. Considering the conservatism used in determining the SSE for the plants and the regulatory requirement that it represent the maximum earthquake potential for the site, the possibility of having ground motions 2XSSE (west coast sites) and 3XSSE (east coast sites) at operating plants under the current tectonic regime is extremely unlikely. This was a bounding approach and the staff was very confident that the plants screened out by this approach would have a very low failure probability and in a risk informed sense, the seismic failure likelihood for these plants can be ignored as being too small. Although, from a risk point of view the seismic failure probability was assumed to be 1.3E-6; keeping in mind that there is a factor of conservatism in the capacity of pool structures, the failure probability could be lower. Probabilistic ground motion estimates at annual frequencies of exceedance of 1XE-5 or less for the eastern U. S. nuclear power plants are very uncertain due to the flat slope of the seismic hazard curves at these frequencies and the lack of tectonic strain, in these areas, large enough to generate the events capable of producing ground motions at these levels (1.2 g spectral acceleration).

From the seismic hazard stand point, both the LLNL and the EPRI estimates are equally credible estimates and the divergence in individual site results stem, in part, from the large

4/21

uncertainty in the ground motion modeling. The modeling uncertainty in seismic hazard estimates is large and dominate uncertainties in the seismic risk estimates. These large uncertainties make it difficult to compare point estimates of seismic risk with the point estimates of risks from other initiators. In any comparison it is important to consider the full distribution, sources of uncertainties, and the nature of uncertainties, and the differences in the ways the expert judgements were elicited in the two studies.

Key Assumptions:

1. Site specific SSE values vary in frequency in the range of 1XE-3 to 3XE-4 per year in the eastern US. Therefore, a seismic demand set at 3XSSE will ensure that the initiating frequency of the highest ground motion is about 1XE-5, although at some sites the resulting frequency can be much lower.
2. LLNL and EPRI hazard estimates are equally valid. LLNL results being generally higher represent upper bound of estimates .
3. High confidence low probability of failure (HCLPF) capacity of spent fuel pool is 1.2 g spectral acceleration (~ 0.5g peak ground acceleration). Uncertainty estimates on the fragility of pool structures generically apply to all plants. The range of this uncertainty comes from reinforcement details, design strength of concrete and whether or not the pools are above ground or supported on the ground.
4. A physical verification of the structural integrity of spent fuel pools, confirmation of structural strength based verification of construction drawings, affirmation of no ongoing age related degradation and verification that there are no sources of seismic interaction between pool structures and the superstructure are to be conducted through the use of a seismic check list.

Sources of Conservatism:

1. For some eastern US sites, the SSE frequency is very low or does not correlate to the seismic hazard estimate. Therefore, the use of 3XSSE as a generic threshold represents a conservative bound which when satisfied by the pool structure capacity assures very low seismic vulnerability.
2. Although the 1993 LLNL hazard estimates correlated well with the EPRI results at the SSE levels and both methods are consistent in the relative sense (i.e., the ranking of sites from high to low hazard is almost identical), the LLNL hazard estimates for earthquakes several times larger than the SSE levels are significantly higher than EPRI estimates.
3. The structural capacity of spent fuel pools is set at a relatively low value that can be readily verified through a peer reviewed data base.

It is important to note that the most easily quantifiable source of conservatism - the plant capacities - will require detailed plant-specific analysis. As noted earlier, the benefits are non-uniform. It is very likely that most PWRs will show much larger safety margin with relatively little less effort. Benefits to BWRs will greatly depend on the specific configurations.

Reduction of uncertainties in the hazard estimates (see additional discussions below), and hence conservatism in the mean estimates, is a significant plant-specific undertaking requiring incorporation of the recent ground motion models.

Sources of Uncertainty

1. The primary source of uncertainty is in the ground motion estimates at very low frequencies in the 1XE-5 to 1XE-6 range. These uncertainties come from seismogenic source characterizations and the assumptions of ground motion attenuation. The NEI study shows that a change in sigma, the attenuation uncertainty, from 0.4 to 0.5 changes the probability of exceeding 1000 cm/sec $^2$, an acceleration value in the range of interest for structural failures, by a factor of about 100.
2. New ground motion modeling would likely reduce uncertainty and reduce level of motion at large return periods.
3. Plant specific fragility uncertainties could be smaller in some cases.

Assessment of Uncertainty

1. The joint NRC and DOE developed methodology for performing seismic hazard studies recently completed can be used to better estimate the seismic hazard. It is expected that in a large majority of cases, the frequency of large ground motions would be reduced. It is the staff judgement that there is a factor of 2 to 3 in the seismic hazard itself.
2. In the spent fuel pool fragility evaluation, the deep box shape of the pool needs to be taken into account. The available fragility evaluation has not considered the ultimate failure mode. Near the lower part of the pool membrane stretching would be the primary mode of load transfer and in the upper part of the pool the load would be carried by out of plane shear. Since the out of plane shear in the upper part would be quite a bit less, there will be some margin that is currently not recognized. In the absence of a detailed three dimensional finite element analysis of the pool structures, it is the staff judgement that the additional margin is on the order of a factor of 2.
3. The overall factor of conservatism is judged to be about a factor of 5.

Proposed approach

Considering the ACRS comment, detailed NEI comments and reviewing the factors of conservatism as discussed above, the staff finds that in Table 3 of Dr. Kennedy's report the probability of failure of 4.5XE-6 provides a convenient line of demarcation between sites with low probability of failure and the four sites (three operating sites) with relatively higher probability of failure. This also means that the seismic check list can be used with a 0.5 g capacity screening. In the NEI letter of November 2, 1999 there is a figure which shows a 1XE-6 per year failure probability line that covers all but five sites. These two approaches produce essentially the same ranking of plant failure probability. Although the figures of merit in the two cases are different, when used in relative sense they yield the same result. Given the factors of conservatism, one can argue that the seismic screening of plants and a physical verification of structural adequacy of the pools at 1.2 g spectral acceleration provides assurance of a low probability of failure due to earthquakes on the order of 1XE-6 per year.

The end result of the proposed approach is that three eastern plants may have to do additional calculations to estimate capacities beyond the walkdown and checklist. Note that, no matter what approach is adopted, the confirmation and verification of no vulnerabilities through walkdown and checklist will be necessary. This approach is the most efficient approach if the seismic risk, which is on the order of 10E-6, is treated as other low risk initiators.

Demonstration of seismic risk much below this value will require significant effort and may not be achievable in all cases.

Decision-Making Framework for Seismic Risk:

The staff intends to display separate results for both LLNL and EPRI as indicators of range of results and also to display mean and median (may require additional calculations) results to high light uncertainties, sources of uncertainties, and to provide a perspective on seismic risk when compared to other initiators.

Conclusions and Recommendations:

Using either the LLNL or the EPRI/NEI results, the plant risk ranking remains essentially the same and the proposed approach ensures, through the seismic check list and walkdown, an adequate seismic capacity and low risk. Only three Eastern US plants may require additional analysis.
Refinements will not lead to a different conclusion as the results will be very plant specific and factors greater than 5 (for example) will be difficult to obtain because of probabilistic hazard driven uncertainties.

Considering the above factors (i.e., knowing the bounding range, sources of uncertainties, and nature of uncertainties), the most useful index for risk-informed decision is the capacity measure, that is, if a plant demonstrates or confirms that the plant's spent fuel pool's HCLPF is greater than 1.2g spectral acceleration (~0.5g peak ground acceleration), the seismic risk is acceptably low and should be treated in the same fashion as other low-risk initiators. The seismic risk should not be a determinant of requirements for EP, insurance, etc.