1. Introduction

As a part of the Generic Issue 82, "Beyond Design Basis Accidents in Spent Fuel Pools," NRC has studied the hypothetical event of an instantaneous loss of spent fuel pool water. The recommendation from a study in support of this generic issue indicates that a key part of a plant specific evaluation for the effect of such an event, is the need to obtain a realistic seismic fragility of the spent fuel pool. The failure or the end state of concern in the context of this generic issue is a catastrophic failure of the spent fuel pool which leads to an almost instantaneous loss of all pool water and the pool having no capacity to retain any water even if it were to be reflooded.

Spent fuel pool structures at nuclear power plants are constructed with thick reinforced concrete walls and slabs lined with stainless steel liners 1/8 to 1/4 inch thick. Dresden Unit 1 and Indian Point Unit 1 are exceptions to this in that these two plants do not have any liner plates. They were decommissioned more than 20 years ago and no safety significant degradation of the concrete pool structure has been reported. The spent fuel pool walls vary from 4.5 to 5 feet in thickness and the pool floor slabs are approximately 4 feet thick. The overall pool dimensions are typically about 50 feet long by 40 feet wide and 55 to 60 feet high. In boiling water reactor (BWR) plants, the pool structures are located in the reactor building at an elevation several stories above the ground. In pressurized water reactor (PWR) plants, the spent fuel pool structures are located outside the containment structure and are supported on the ground or partially embedded in the ground. The location and supporting arrangement of the pool structures help determine their capacity to withstand loads beyond their design basis. The dimensions of the pool structure are generally derived from radiation shielding considerations rather than structural needs. Spent fuel structures at operating nuclear power plants are inherently rugged in terms of being able to withstand loads substantially beyond those for which they were designed. Consequently, they have significant seismic capacity.

2. Seismic Checklist

In the preliminary draft report published in June 1999, the staff assumed that the spent fuel pools were robust for seismic events less than about three times the safe shutdown earthquake (SSE). It was assumed that the high confidence, low probability of failure (HCLPF)[1] value for pool integrity is 3 times SSE. For most Central and Eastern U.S. (CEUS) sites, 3 X SSE is in the peak ground acceleration (PGA) range of 0.35 to 0.5 g (where g is the acceleration of gravity). Seismic hazard estimates developed by the Lawrence Livermore National Laboratory (NUREG-1488) show that, for most CEUS plants, the mean frequency for a PGA equal to 3 X SSE is less than 2E-5 per year. In the June 1999 report, the working group used the approximation that the frequency of a seismic event that will challenge the spent fuel pool integrity is 5% of 2E-5, or a value of 1E-6.

Several public meetings were held from April to July 1999 to discuss the staff's draft report. At the July public workshop, the NRC proposed, and the industry group agreed to develop a seismic checklist, which could be used to examine the seismic vulnerability of any given plant. In a letter dated August 18, 1999, the Nuclear Energy Institute (NEI) proposed a checklist which

---

[1]A HCLPF is the peak acceleration value at which there is 95% confidence that less than 5% of the time the structure, system or component will fail.

410

is based on assuring a robustness for a seismic ground motion with a PGA of approximately 0.5g. A copy of this submittal is included in Appendix 5.a.

The NRC contracted with Dr. Robert P. Kennedy to perform an independent review of the seismic portion of the June draft report, as well as the August 18, 1999, submittal from NEI. Dr. Kennedy's comments and recommendations were contained in an October 1999 report entitled "Comments Concerning Seismic Screening and Seismic Risk of Spent Fuel Pools for Decommissioning Plants," which is included as Appendix 5.b of this report. Dr. Kennedy raised three significant concerns about the completeness of the NEI checklist.

The results of Dr. Kennedy's review, as well as staff comments on the seismic checklist, were forwarded to NEI and other stakeholders in a December 3, 1999, memorandum from Mr. William Huffman (Appendix 5.c). In a letter from Mr. Alan Nelson, dated December 13, 1999 (Appendix 5.d), NEI submitted a revised checklist, which addressed the comments from Dr. Kennedy and the NRC staff. Dr. Kennedy reviewed the revised checklist, and concluded in a letter dated December 28, 1999 (Appendix 5.f), that the industry seismic screening criteria are adequate for the vast majority of CEUS sites.

The staff has considered the question of what criterion should be established for an acceptable HCLPF value; i.e., a HCLPF value which yields an acceptably low frequency of spent fuel pool failure. The design basis earthquake ground motion, or the SSE ground motion, for nuclear power plant sites were based on the assumption of the largest event geophysically ascribable to a tectonic province or a capable structure at the closest proximity of the province or fault to the site. In the case of the tectonic province in which the site is located, the event is assumed to occur at the site. For the eastern seaboard, the Charleston event is the largest magnitude earthquake and current research has established that such large events are confined to the Charleston region. The New Madrid zone is another zone in the central US where very large events have occurred. Recent research has identified the source structures of these large New Madrid earthquakes. Both of these earthquake sources are fully accounted for in the assessment of the SSE for currently licensed plants. The SSE ground motions for nuclear power plants are based on conservative estimates of the ground motion from the largest earthquake estimate to be generated under the current tectonic regime. If we these SSE ground motions are amplified by a factor of three, the estimated ground motion borders on the limit of credibility for the particular site.

The seismic hazards at the west coast sites are generally governed by known active fault sources, consequently, the hazard curves, which are plots of ground acceleration versus frequency of occurrence, have a much steeper slope near the higher ground motion end. In other words, as the amplitude of the seismic acceleration increases, the probability of its occurrence decreases rapidly. Therefore, for west coast sites a seismic ground motion event greater than 2 times the SSE could be considered to be too large to be credible. Spent fuel pool structures at these sites would then need to have capacity against catastrophic failure at 2 times the SSE.

Therefore, it appears reasonable to assume that a seismic ground motion greater than 3 times the SSE at a lower seismicity location (CEUS site) and 2 times the SSE at a higher seismicity location (west coast site) can be considered the maximum credible seismic ground motion for the site. Using these maximum credible seismic ground motions in conjunction with the seismic checklist simplifies the task of evaluating whether the seismic risk from the spent fuel pool is negligible. For those plants that can demonstrate that the maximum credible seismic ground

motion, per the guidelines given above, are appropriate for the site and that they satisfy the seismic checklist, it can be concluded with reasonable assurance that they could be eliminated from any further seismic evaluation. For sites that fail the seismic checklist screening of the pool structure and cannot demonstrate a HCLPF value appropriate for the site, the NRC has proposed and the industry has agreed, that it would be necessary to conduct a detailed assessment of the seismically induced probability of failure of spent fuel pool structures.

In his letter of December 28, 1999, Dr. Kennedy concurred that this performance goal assures an adequately low seismic risk for the spent fuel pool.

3. Seismic Risk - Catastrophic Failure

As noted above, the preliminary risk assessment report published in June 1999 used an approximate method for estimating the risk of spent pool failure. It was assumed that the HCLPF value for the pool integrity is 3 times SSE. For most CEUS sites, 3 X SSE has a ground motion with a PGA range of 0.35 to 0.5 g. Seismic hazard curves from the Lawrence Livermore National Laboratory (NUREG-1488) show that, for most CEUS sites, the mean frequency for PGA equal to 3 X SSE is less than 2E-5. In the June report, the working group used the approximation that the frequency of a seismic event that will challenge the spent fuel pool integrity is 5% of 2E-5, or a value of 1E-6.

Dr. Kennedy, in his October 1999 report, pointed out that this approximation is nonconservative for CEUS hazard curves with shallow slopes; i.e., where an increase of more than a factor of two in ground motion is required to achieve a 10-fold reduction in annual frequency of exceedance. Dr. Kennedy proposed a calculation method, which had previously been shown to give risk estimates that were 5 to 20% conservative when compared to more rigorous methods, such as convolution of the hazard and fragility estimates. Using this approximation, Dr. Kennedy estimated the spent fuel failure frequency for a pool with HCLPF of 1.2 peak spectral acceleration for all 69 CEUS sites. A total of 35 sites had frequencies exceeding 1E-6 per year, and eight had frequencies in excess of 3E-6 per year. The remaining sites had frequencies below 1E-6.

Dr. Kennedy's report offers two additional considerations. First, spent fuel pools that pass the appropriately defined screening criteria are likely to have capacities higher than the screening level capacity. Thus, the frequencies quoted above are upper bounds. Second, using the same approximations, Dr. Kennedy calculated frequencies approximately an order of magnitude lower, when using EPRI estimates of the seismic hazard rather than LLNL estimates.

The staff has no estimate of the seismic risk from western sites. However, based on considerations described above, the staff estimates that plants which can demonstrate a HCLPF greater than 2 X SSE will have an acceptably low estimate of risk.

4. Seismic Risk - Support System Failure

In its preliminary draft report published in June 1999, the staff assumed that a ground motion three times the SSE was the HCLPF of the spent fuel pool. This meant that 95% of the time the pool would remain intact (i.e., would not leak significantly). We evaluated what would happen to the support systems to the spent fuel pool (i.e., the pool cooling and inventory

makeup systems) in the event of an earthquake three times the SSE. We modeled some recovery as possible (although there would be considerable damage to the area's infrastructure at such earthquake accelerations). Our estimate in the preliminary report for the contribution from this scenario was $1x10^{-6}$ per year. In this report, we have refined this estimate based on looking at a broader range of seismic accelerations and further evaluation of the conditional probability of recovery under such circumstances. We estimate that for an average site in the northeast United States the return period of an earthquake that would damage a decommissioning plant's spent fuel pool cooling system equipment (assuming it had at least minimal anchoring) is about once in 4,000 years. We quantified a human error probability of $1x10^{-4}$ that represents the failure of the fuel handlers to obtain offsite resources. The event was quantified using the SPAR HRA technique. The probability shaping factors chosen were as follows: expansive time (> 50 times the required time), high stress, complex task because of the earthquake and its non-routine nature, quality procedures, poor ergonomics due to the earthquake, and finally a crew who had executed these tasks before, conversant with the procedures and one another. In combination we now estimate the risk from support failure due to seismic events to be on the order of $1x10^{-8}$ per year. The risk from support system failure due to seismic events is bounded by other more likely initiators.

5. Conclusion

The staff concludes that the frequency of spent fuel pool failure for a CEUS plant is acceptably low if the seismic capacity of its spent fuel pool structure is at least equal to 3 times the plant's SSE value, and the plant satisfies the seismic checklist proposed in NEI's December 13, 1999 letter (See Appendix 5). Although the risk has not been rigorously calculated for these sites, deterministic considerations lead the staff to conclude that peak ground accelerations in excess of 3 times SSE are not credible. For these sites the frequency of failure is bounded by $3x10^{-6}$ per year, and other considerations indicate the frequency may be significantly lower.

For those CEUS plants with spent fuel pool structures that do not pass the seismic checklist, a detailed evaluation of HCLPF would be necessary. Similarly, a detailed HCLPF would be necessary for all western plants since seismic capacity at the high levels of ground motion associated with the western plants are well above the generic HCLPF value of 1.2g peak spectral acceleration. For all CEUS plants which can demonstrate a HCLPF equal to 3 times their SSE, the risk is judged to be bounded by $3x10^{-6}$ per year. Similarly, for western sites which can demonstrate a HCLPF equal to 2 times their SSE, the risk is judged to be bounded by $3x10^{-6}$ per year.