version 7/26/02 to M Rubin + G. Hubbard

Appendix 2b Structural Integrity of Spent Fuel Pools Subject to Seismic Loads

1. Introduction

The staff's concern regarding seismic issues at spent fuel pools involves very large earthquakes that can structurally fail the pool. Under this scenario, the pool will suffer a significant breach, it will drain rapidly, and it will be incapable of being refilled. This would lead to rapid cladding heat up followed by a zirconium cladding fire. The staff evaluated how large an earthquake would be required to cause such damage and what would be the return frequency of such large earthquakes. Attachment 1 to this appendix provides the checklist proposed by NEI and enhanced by the staff to assure adequate seismic capacity at SFPs for decommissioning sites that wish to be granted exemptions to EP. Attachment 2 to this appendix provides the analysis of earthquake return periods from Dr. Robert Kennedy for nuclear power plant sites based on a 1.2 g spectral acceleration high confidence, with low probability of failure (HCLPF) value for spent fuel pools.

Spent fuel pool structures at nuclear power plants are seismically robust. They are constructed with thick reinforced concrete walls and slabs lined with stainless steel liners 1/8 to 1/4 inch thick[1]. Pool walls vary from 4.5 to 5 feet in thickness, and the pool floor slabs are around 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 supported on the ground or partially embedded in the ground. The location and supporting arrangement of the pool structures determine their capacity to withstand seismic ground motion 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 able to withstand loads substantially beyond those for which they were designed.

The Commission asked the staff to determine if there were a risk-informed basis for providing exemptions for decommissioning plants and to provide a technical basis for potential rule making. After this, the staff began to investigate the capacity of spent fuel pools to withstand large earthquakes beyond the site's normal design bases. While performing the evaluation, it became apparent that the staff does not have detailed information on how all the spent fuel pools were designed and constructed. Detailed fragility analyses of spent fuel pools were only available for a few plants. The staff originally performed a simplified bounding seismic risk analysis in its June 1999 draft assessment of decommissioning plant risks to help determine if there might be a seismic concern. The analysis indicated that seismic events could not be dismissed on the basis of a simplified bounding approach. In addition after further evaluation and discussions with stakeholders, it was determined that it would not be cost effective to perform a detailed plant-specific seismic evaluation for each spent fuel pool. Working with its stakeholders, the staff developed other tools that help assure the pools are sufficiently robust.

2. Return Period of SFP-Failing Earthquakes

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[1]Except for Dresden Unit 1 and Indian Point Unit 1, whose spent fuel pools do not have any liner plates. They were permanently shutdown more than 20 years ago, and no safety significant degradation of the concrete pool structure has been reported.

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Based on existing spent fuel pool fragility analyses and engineering judgement, the staff determined that a high confidence, low probability of failure (HCLPF)[2] value of 1.2 g peak spectral acceleration (or in terms of peak ground acceleration, which is not as good an estimator, 0.5 g PGA)[3] probably existed for most SFPs. Given this assumption, with the assistance of Dr. Robert P. Kennedy (See Appendix 2b, Attachment 2), it was determined that the annual frequency of seismically induced failure of spent fuel pool structures varies from less than $1.0X10^{-6}$ to $13.6X10^{-6}$ per year.

The staff used a measure of $3x10^{-6}$ per year for the adequacy of seismic return period in its earlier versions of the report. However, comments from the Advisory Committee on Reactor Safeguards and other stake holders indicated that the proposed measure and the approach the staff was using were too conservative. Also, the proposed approach contained different assessments for the Eastern and the Western United States and was complicated by the fact that seismic fragility information for ground motion levels beyond 0.5 g is not readily available from a peer reviewed data base.

The staff reexamined the results of Table 3, Appendix 2b, Attachment 2, which estimates the return frequencies of large earthquakes that could fail spent fuel pools. It was decided that the HCLPF value of 1.2 g peak spectral acceleration was a good measure of seismic adequacy for decommissioning plant SFPs that need only be tied to the return period of the earthquake and not to the safe shutdown earthquake magnitude for the site. The staff's review indicates that only three operating eastern plant sites have frequencies greater than $4.5X10^{-6}$ per year of having an earthquake with a peak spectral acceleration greater than 1.2 g. The staff finds $4.5X10^{-6}$ per year to be an acceptable criterion for seismic return period for earthquakes that could fail the spent fuel pools since it is a factor of 2 less than the $1x10^{-5}$ per year PPG and the estimated frequency of zirconium cladding fires from other initiators is an order of magnitude lower. Such a margin is warranted due to the uncertainties of the seismic hazard and spent fuel pool fragilities at each site.

3. Seismic Checklist

The staff determined that absent specific information about SFP seismic capacities, that some plant-specific evaluation of spent fuel pool capacity was warranted. During stakeholder interactions with the staff, the staff proposed the use of a seismic checklist that built on the work done for .... and could provide assurance of the capacity of spent fuel pools. In a letter dated August 18, 1999, NEI proposed a checklist that could be used to show robustness for a seismic ground motion with a peak ground acceleration (PGA) of approximately 0.5g. This checklist was reviewed and enhanced by the staff (See Appendix 2b, Attachment 1). Dr. Kennedy reviewed the enhanced checklist and concluded that the screening criteria are

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

[3]Damage to critical structures, systems, and components (SSCs) does not correlate very well to peak ground acceleration (PGA) of the ground motion. However, damage correlates much better with the spectral acceleration of the ground motion over the natural frequency range of interest, which is generally between 10 and 25 Hertz for nuclear power plant SSCs. The spectral acceleration of 1.2 g corresponds to the screening level recommended in the reference document cited in the NEI checklist, and this special ordinate is approximately equivalent to a ground motion of 0.5 g PGA.

adequate for the vast majority of central and eastern U.S. sites. The seismic checklist was developed to provide a simplified method for demonstrating a HCLPF at an acceptably low value of seismic risk. The checklist includes elements to assure there are no weaknesses in the design or construction nor any service induced degradation of the pools that would make them vulnerable to failure under earthquake ground motions that exceed their design basis ground motion. Spent fuel pools that satisfy the seismic checklist, as written, would have a high confidence in a low probability of failure for seismic ground motions up to 0.5 g peak ground acceleration (1.2g peak spectral acceleration).

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). The staff evaluated what would happen to spent fuel pool support systems (i.e., the pool cooling and inventory make-up systems) in the event of an earthquake three times the SSE. The staff modeled some recovery as possible (although there would be considerable damage to the area's infrastructure at such earthquake accelerations). The estimate in the preliminary report for the contribution from this scenario was $1x10^{-6}$ per year. In this report, this estimate has been refined based on looking at a broader range of seismic accelerations and further evaluation of the conditional probability of recovery under such circumstances. The staff estimates 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. The staff quantified a human error probability of $1x10^{-4}$ that represents the failure of the fuel handlers to obtain off-site resources. The event was quantified using the SPAR HRA technique. The ~~probability~~ performance 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 recommends that those plants that exceed $4.5X10^{-6}$ per year frequency for exceeding 1.2 g peak spectral acceleration in their spent fuel pool should be required to conduct plant-specific analysis beyond the confirmation of the checklist if they desire to obtain exemptions from EP, indemnification or security at decommissioning sites. This process results in identification of four sites in the eastern U.S., only three of which are operating reactor sites - Pilgrim, H. B. Robinson, and Vogtle sites, with Maine Yankee the decommissioning site. In the western U.S., the Diablo Canyon and San Onofre sites are also beyond the scope of a simple screening evaluation. Based on the NRC sponsored study, "Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear power Plants," NUREG/CR 5176, January 1989, the seismic HCLPF capacity of the H. B. Robinson spent fuel pool has been estimated to be 0.65 g. For the Vogtle, Pilgrim, Diablo Canyon, and San Onofre sites, it may be necessary for the utilities to conduct a detailed site-specific seismic risk evaluation if they desire an exemption from EP when the site is in decommissioning.

To summarize the staff recommendation for seismic vulnerability of spent fuel pools, (1) all sites must conduct an assessment of the spent fuel pool structures using the revised seismic check list in order to identify any structural degradation, potential for seismic interaction from superstructures and over head cranes, and to verify that they have a seismic HCLPF value of 0.5 g or higher, (2) those sites that cannot demonstrate that a seismic HCLPF value exists, may either under take appropriate remedial action or conduct site-specific seismic risk assessment and (3) Pilgrim, H. B. Robinson, Vogtle, Diablo Canyon and San Onofre sites would have to use the seismic check list to identify any structural degradation or other anomalies and then conduct a site specific seismic risk assessment if they desire an exemption from EP when their sites are in decommissioning.