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To: George Hubbard
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Subject: I will bring you up a copy of the markup too so you can see where the fixes are

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MAIN BODY SEISMIC WRITEUP

3.4.1 Seismic Events

When performing the evaluation of the effect of seismic events on spent fuel pools, it became apparent that the staff does not have detailed information on how all the spent fuel pools were designed and constructed. The staff originally performed a simplified bounding seismic risk analysis in its June 1999 draft risk assessment 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. After further evaluation and discussions with stakeholders, it was determined that it would not be cost effective to perform a 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.

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 thick¹. 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. Consequently, they have significant seismic capacity.

During stakeholder interactions with the staff, the staff proposed the use of a seismic checklist, and 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). The staff has concluded that plants that satisfy the revised seismic checklist can demonstrate with reasonable assurance a high-confidence low-probability of failure (HCLPF)² at a ground motion that has a very small likelihood of exceedence.

U.S. nuclear power plants, including their spent fuel pools, were designed such that they can be safely shutdown and maintained in a safe shutdown condition if subjected to ground motion from an earthquake of a specified amplitude. This design basis ground motion is referred to as

¹Except 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.

²The 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.

the safe shutdown earthquake (SSE). The SSE was determined on a plant-specific basis consistent with the seismicity of the plant's location. In general, plants located in the eastern and central parts of the U.S. had lower amplitude SSE ground motions established for their designs than the plants located in the western parts of the U.S., which had significantly higher SSEs established for them because of the higher seismicity for locations west of the Rocky Mountains. As part of this study, the staff with assistance from Dr. Robert P. Kennedy (See Appendix 2b), reviewed the potential for spent fuel pool failures to occur in various regions in the U.S. due to seismic events with ground motion amplitudes exceeding established SSE values.

Using a HCLPF value of 0.5 g PGA, Dr. Kennedy's study indicates (See Table 3, Appendix 2b) that the annual frequency of seismically induced failure of spent fuel pool structures varies from less than 1.0×10^{-6} to 13.6×10^{-6} per year. The staff assumes that the seismic induced failure of the spent fuel pool structure directly leads to the uncovering of the fuel and radioactive release. In the draft recommendation, the staff proposed to use 3×10^{-6} as the annual frequency of seismic failure and equivalently the frequency of radioactive release. However, comments from the Advisory Committee on Reactor Safeguards and other stake holders indicated that the proposed approach was 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. Our review indicates that only three operating eastern plant sites have frequencies greater than 4.5×10^{-6} per year, a factor of 2 less than the 1×10^{-5} per year PPG. Therefore, the staff recommends that only those plants which significantly exceed 4.5×10^{-6} per year value should be required to conduct plant-specific analysis beyond the confirmation of the checklist. This process results in identification of four sites in the Eastern US, 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.

The seismic checklist (Appendix 2b) 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).

APPENDIX 2b

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

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 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 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. For western plants, the mean frequency for PGA equal to

¹A 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.

2 X SSE is equivalently small.

These low probabilistic frequency-of-occurrence estimates are supported by deterministic considerations. 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. 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 it is reasonable to conclude that the frequency of ground motion exceeding 3 X SSE for CEUS plants and 2 X SSE for western plants is less than $2E-5$ per year.

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 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 5a.

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 5b 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 5c). In a letter from Mr. Alan Nelson, dated December 13, 1999 (Appendix 5d), 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 5f), that the industry seismic screening criteria are adequate for the vast majority of CEUS sites.

3. Seismic Risk - Catastrophic Failure

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 $2E-5$. For western plants, the mean frequency of ground motion exceeding 2 X SSE is comparably small. 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 pool failure frequency for a site with HCLPF of 1.2² peak spectral acceleration if sited at each of the 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 $1E-6$ ³. Dr. Kennedy's report notes that 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.

For those CEUS plants where the ground motion of 3 X SSE is less than or equal to the NEI screening criterion of 0.5g PGA, the staff concludes that the risk is acceptably low. A similar conclusion can be drawn for western plants where the ground motion at 2 X SSE is within the screening criterion. For CEUS plants where 3 X SSE exceeds the screening criterion, a detailed assessment will be required to demonstrate that the pool HCLPF equals 3 X SSE. A similar conclusion can be drawn for western plants where the ground motion at 2 X SSE exceeds the screening criterion.

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

In his letter of December 28, 1999, Dr. Kennedy concurred that this performance goal assures

²Damage to critical SSCs does not correlate very well to 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 plants SSCs. The spectral acceleration of 1.2g corresponds to the screening level recommended in the reference document cited in the NEI checklist, and this spectral ordinate is approximately equivalent to a ground motion with 0.5g PGA.

³These estimates are based on the Lawrence Livermore National Laboratory 1993 (LLNL 93) seismic hazard curves. Recently, the Senior Seismic Hazard Analysis Committee (SSHAC) published NUREG-CR-6372, "Recommendation for Probabilistic Seismic Hazard Analysis: Guidance On Uncertainty and Use of Experts." The report gives guidance on future application of seismic hazards. However, site specific hazard estimates have not been performed for all sites with the new method.

an adequately low seismic risk for the spent fuel pool.

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. We 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 1×10^{-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 1×10^{-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 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 1×10^{-8} per year. The risk from support system failure due to seismic events is bounded by other more likely initiators.

5. Conclusion

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). Thus, sites in the central and eastern part of the U.S. that have three times SSE values less than or equal to 0.5 g PGA and pass the seismic check list would have an acceptably low level of seismic risk. Similarly, West Coast sites that have two times SSE values less than 0.5 g. and pass the seismic check list would have acceptably low values of seismic risk. From a practical point of view, a limited number of sites in the central and eastern part of the U.S. have three times SSE values greater than 0.5g; the two times SSE values exceed 0.5g for two West Coast plants. In order to demonstrate acceptably low seismic risk, those central and eastern sites for which the three times SSE values exceed 0.5g and the two West Coast sites would have to perform additional plant specific analyses to demonstrate HCLPF for their spent fuel pools at three times SSE and two times SSE values of ground acceleration, respectively. For these sites the frequency of failure is bounded by 3×10^{-6} per year, and other considerations indicate the frequency may be significantly lower. Plants which cannot demonstrate HCLPF values equivalent to 3 X SSE or 2 X SSE as appropriate may perform a risk assessment to demonstrate acceptably low frequency of SFP failure.