NTTF 2.1 Seismic Review of SFP Structures at Low GMRS Sites

1. BACKGROUND ON SFP STRUCTURES

Spent Fuel Pool structures are typically constructed as part of the reactor building or as part of a separate structure to support the fuel handling operations at the reactor. The spent fuel pool structures at nuclear power plants currently operating in the U.S. are configured differently depending on the reactor design vintages, site-specific design requirements and also to the design preferences of the engineering and construction companies involved in the design of the facility. To support the NTTF 2.1 seismic assessment of the spent fuel pools, industry surveys were conducted to identify the structural characteristics of the SFP and their supporting structures for the fleet of US operating nuclear plants. The key elements resulting from that survey are summarized in the sections below as they relate to the seismic capacity verifications of the SFP structures.

The fundamental structural configurations of the spent fuel pools themselves have similar characteristics due to functional design requirements (including radioactive shielding considerations) and due to structural design loading requirements (seismic, dead weight, etc.). The spent fuel pools are constructed of reinforced concrete shear walls with stainless steel liners attached to the floors and walls. The spent fuel pools are rectilinear with adjoining compartments next to the fuel storage pool for various operations, such a station for loading and unloading fuel, and a canal for transferring the fuel assemblies into and out of the reactor. The industry SFP survey results demonstrated that the SPF walls span from 30 ft to 120 ft with an average span of 52 feet. The wall thickness ranged from 42 inches to 78 inches with an average of 64 inches. The steel rebar reinforcement ratio ranged from 0.1% to 0.9% with an average ratio of 0.3%. The concrete strength ranged from 3 ksi to 5 ksi with an average strength of 3.6 ksi and the steel reinforcing strength ranged from 24 ksi to 60 ksi with an average steel reinforcing strength of 52 ksi. The liner thickness ranged from 1/8 inch to 3/8 inch with an average thickness of 1/4 inch.

The characteristics of the structures supporting/housing the spent fuel pools were also part of the industry survey of the SFPs. The spent fuel pools are part of the three different nuclear structures depending on the site design:

- Auxiliary Building – 33% of the plants
- Fuel Building – 38% of the plants
- Reactor/Containment Buildings – 29% of the plants

The Boiling Water Reactors (BWR) and the Pressurized Water Reactors (PWR) typically have different designs of the structures housing the SFPs. The spent fuel storage pools at BWR sites are typically located within the BWR reactor building at an elevation above grade, which allows alignment of the top of the pool with the operating deck used for re-fueling the reactor. Figure 1 depicts a typical BWR plant configuration including the location of the spent fuel pool. The BWR structures housing the SFPs are typically designed with reinforced concrete shear walls

providing the primary structural load path. In a few cases, the primary load path also contains reinforced concrete moment frame elements or structural steel frame members. In one case, the structural load path included post-tensioned concrete walls associated with the containment structure.

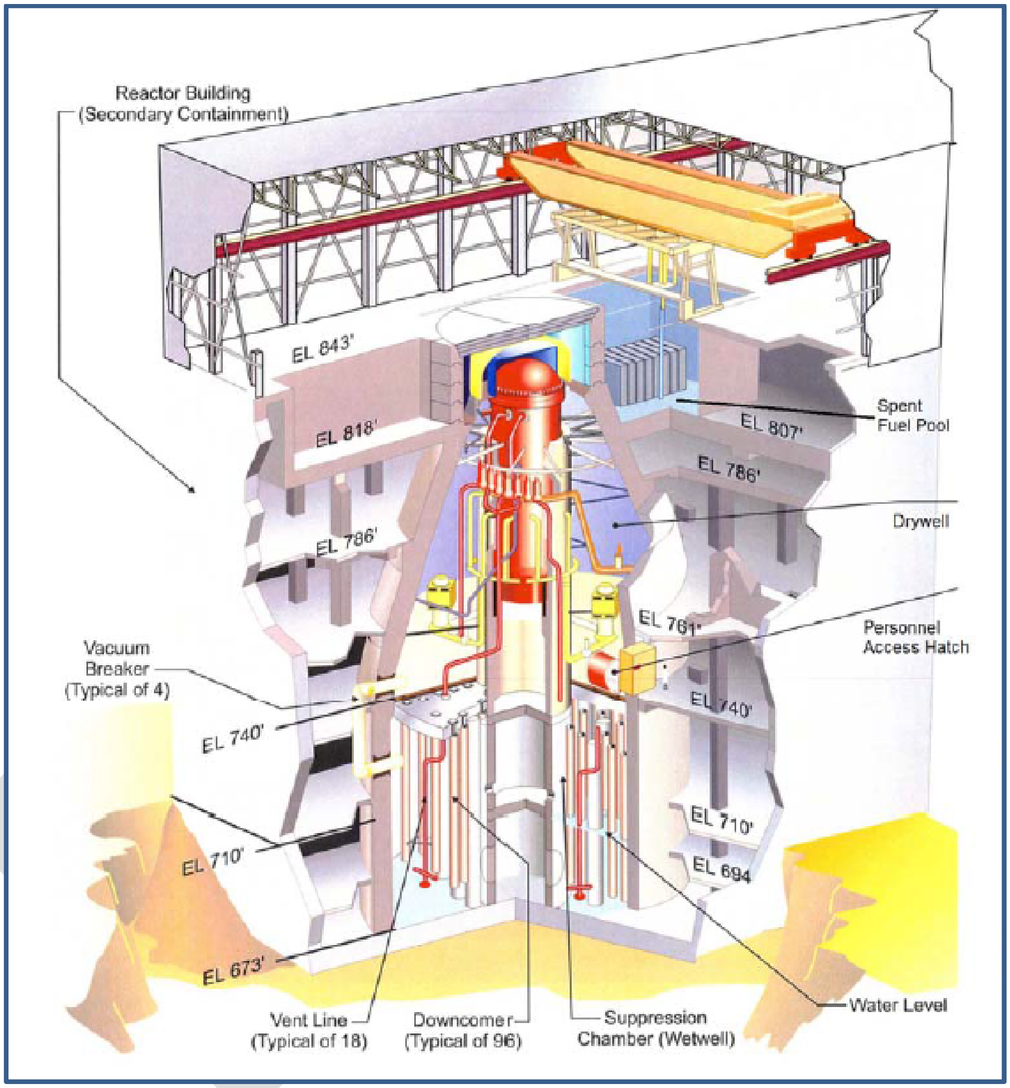

Figure 1: Schematic for Typical BWR Configuration with Spent Fuel Storage Pool

At PWR sites, the floor (bottom) of the pool is generally on or even partially below grade with the pool floor constructed as part of a thick foundation. Figure 2 depicts a typical PWR plant configuration including the location of the spent fuel pool. The structures housing the spent fuel pool typically have load paths with reinforced concrete shear walls with the pool bottom typically supported directly on the building foundation. As with the BWR structures, there are a

few PWRs where the spent fuel pool structural load paths include reinforced concrete frame members and/or structural steel frame members.

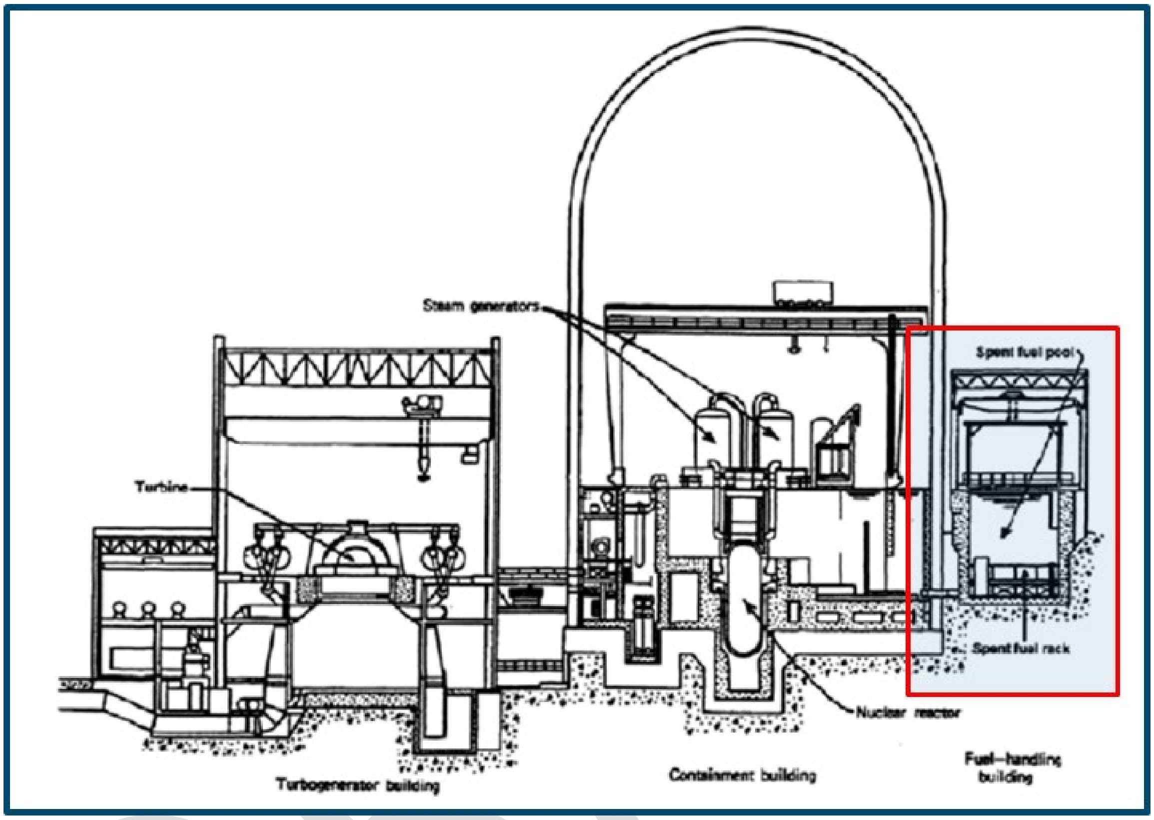

Figure 2: Schematic for Typical PWR Configuration with Spent Fuel Storage Pool

2. TREATMENT OF SPENT FUEL POOL STRUCTURES WITHIN NTTF 2.1 SEISMIC

The 50.54(f) letter requested that, in conjunction with the response to NTTF Recommendation 2.1, a seismic evaluation be made of the SFP. More specifically, plants were asked to consider "…all seismically induced failures that can lead to draining of the SFP." Such an evaluation would be needed for any plants that are not screened from further assessment based on the screening process documented in the SPID [7].

Previous evaluations in NUREG-1353 [1], NUREG-1738 [2] and NUREG/CR-5176 [3] characterized the generally robust nature of the design of SFPs currently in use. NUREG-1738 further identified a checklist that could be used to demonstrate that a SFP would achieve a very high HCLPF. Evaluations reported in NUREG/CR-5176 [3] for two older plants concluded that "…seismic risk contribution from spent fuel pool structural failures is negligibly small." Tearing of the stainless-steel liner due to overall structural failure of the fuel pool structure would be precluded by the successful completion of the EPRI NP-6041 structural evaluations. Tearing of the stainless-steel liner due to sliding or other movement of the fuel assemblies in the pool is

considered to be very unlikely [1]. The SPID defines that either the checklist in NUREG-1738 can be used to demonstrate that the structure is sufficiently robust or another approach can be used if sufficiently justified. The purpose of this section is to present the seismic adequacy justification for SFP structures at nuclear power plant sites with a relatively low GMRS being robust.

As noted in the SPID, the screening criteria for civil structures in EPRI NP-6041 [4] provide principles that would be helpful in evaluating the seismic capacity of SFP structures. The approach used for the screening of the lower GMRS sites is the EPRI NP-6041 assessment criteria presented in Table 2-3. As noted in the background section of this paper, the spent fuel pool structures have structural load paths consisting of one or more of the following structural configurations:

- Reinforced concrete shear walls
- Reinforced concrete moment frames
- Structural steel frames
- Post-tensioned containments

As such, the spent fuel pools and their supporting structures all fall within four rows of the NP-6041 Table 2.3 addressing these four structural configurations. Figure 3 shows the Table 2-3 structural screening criteria.

Table 2-3

SUMMARY OF CIVIL STRUCTURES SCREENING CRITERIA FOR SEISMIC MARGIN EVALUATION
(Page 1 of 2)

Type of Structure	5 Percent-Damped Peak Spectral Acceleration <0.8g	0.8 - 1.2g	>1.2g
Concrete containment (post-tensioned and reinforced)	no	(a)*	(b)
Freestanding steel containment	(c)(d)	(c)(d)	yes
Containment internal structures	(e)	(f)	yes
Shear walls, footings and containment shield walls	(e)	(f)	yes
Diaphragms	(e)	(g)	yes
Category I concrete frame structures	(e)	(f)	yes
Category I steel frame structures	(e)	(h)	yes
Masonry walls	yes	yes	yes
Control room ceilings	(i)	(i)	yes

Figure 3: Table 2-3 Section from EPRI NP-6041

The first column in Table 2-3 presents the requirements for the assessment of different types of structures to a peak spectral (5% damped) ground peak spectral acceleration of 0.8 g's. The SFP structures for all NPPs fall within the first, fourth, sixth and seventh rows of Table 2-3. Row #1 addresses concrete containments designed using post-tensioning and reinforcement. These post-tensioned containment structures have been shown to be rugged up to the 0.8 g peak spectral acceleration level and can be screened from further consideration based solely on demonstration of meeting the "0.8 g spectral acceleration" first column. For the first column of Table 2-3 of EPRI NP-6041, the footnote requirements for the other three structural configurations (shear wall structures, concrete frame structures and steel frame structures) being reviewed for this SFP study are defined within the single footnote "e". Footnote e is defined below.

e. *Evaluation not required for Category I structures if design was for a SSE of 0.1 g or greater.*

All spent fuel pool structures are, by necessity, Category 1 structures since they contain spent fuel and they all are designed to an SSE. All US nuclear plants have design basis SSEs (or the equivalent DBEs) at or exceeding the 0.1 g threshold. Thus, all operating US nuclear plant SFP structures meet the EPRI NP-6041 criteria that demonstrates that they have a high confidence of

exceeding the 0.8 g spectral acceleration capacity in the free field. The criteria associated with EPRI NP-6041 stipulates that the 0.8 g screening level would apply to sites where the peak spectral acceleration of their review level earthquake (RLE) is less than or equal to this 0.8 g spectral acceleration. For purposes of the spent fuel pool structure review, the GMRS is used as the RLE.

3. PLANTS WITH GMRS LESS THAN 0.8 G SPECTRAL ACCELERATION

All US operating nuclear plants have now submitted GMRS values to the NRC. Based on the review of the industry GMRS submittals and the NRC responses, 21 plants screen out of having to conduct a review of the spent fuel pools. Of the remaining 42 plants, 31 plants have GMRS peak spectral acceleration (5% damping) values are below the 0.8 g threshold value (Figure 4). Thus, based on the NP-6041 Table 2-3 criteria, these 31 plants can demonstrate seismic adequacy of the SFP structure to the GMRS level. As such they can demonstrate that they have adequate seismic capacity to withstand the new seismic hazard at their sites based on verifying that:

a) the GMRS is less than or equal to the 0.8 g spectral acceleration capacity level from column 1 of Table 2-3 of EPRI NP-6041,

b) the structure housing the SFP was designed to an SSE of at least 0.1 g, and

c) the structure load path to the spent fuel pool consists of some combination of reinforced concrete shear wall elements, reinforced concrete frame elements, post-tensioned concrete elements and/or structural steel frame elements

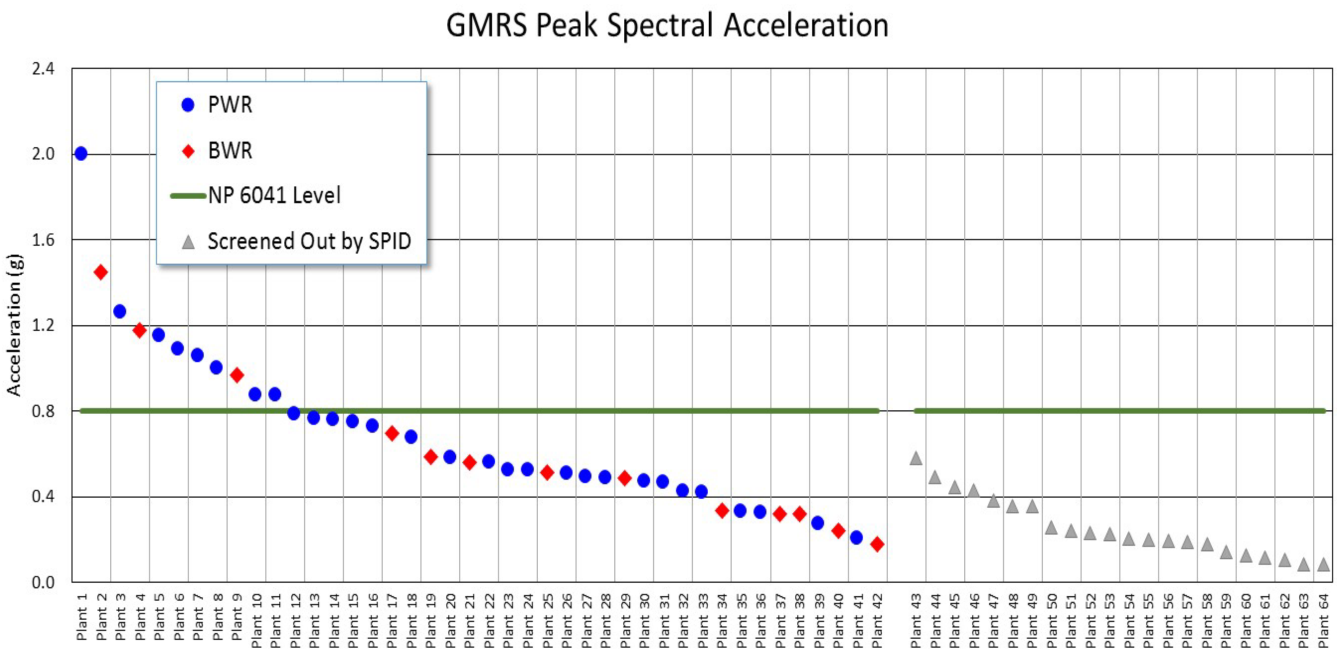

Figure 4: GMRS Peak Spectral Acceleration Comparisons to 0.8 g Ground Spectral Acceleration Threshold for US Plants

4. NON-STRUCTURAL CONSIDERATIONS FOR SFP AT SITES WITH RELATIVELY LOW GMRS

The SPID Section 7 identifies several non-structural considerations that could affect the ability of spent fuel pools to maintain SFP inventory 72 hours. These are:

- • penetrations that could lead to uncovering the fuel,
- • SFP cooling function failures that could lead to siphoning inventory from the pool,
- • sloshing losses, and
- • evaporative losses.

Each of those inventory loss paths are discussed below.

Piping Penetrations

TBD

Siphoning

TBD

Sloshing

TBD

Evaporative Losses

TBD

5. REFERENCES

1. NRC NUREG-1353, Regulatory Analysis for the Resolution of Generic Issue 82, "Beyond Design Basis Accidents in Spent Fuel Pools," April 1989
2. NRC NUREG-1738, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants. February 2001.
3. NRC NUREG/CR-5176, Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants. January 1989.
4. EPRI NP-6041-SL, "A Methodology for Assessment of Nuclear Plant Seismic Margin, Revision 1", Electric Power Research Institute, August 1991.
5. EPRI 1019200, Seismic Fragility Applications Guide Update, December 2009.
6. EPRI NP-7498, Industry Approach to Seismic Severe Accident Implementation Policy, November 1991.
7. Electric Power Research Institute, "Screening Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic", Report No. 1025287, February 2013.