

## APPENDIX E

### Comparison of the Earthquake and Tsunami to Design Basis in Japan

NOTE: Unless otherwise indicated, all dates in this appendix are for 2011.

#### I. EARTHQUAKE

The following data regarding the Fukushima Daiichi, Fukushima Daini, Onagawa, and Tokai Daini nuclear power stations (NPSs) are repeated from a report by the Japanese government to the International Atomic Energy Agency (IAEA) [1].

**Table 1**  
**Observed Seismic Acceleration at Fukushima Daiichi NPS and Fukushima Daini NPS**

Observation Point (Lowest Basement of Reactor Buildings)		Observed Data <sup>a</sup>			Maximum Response Acceleration Against Design-Basis Ground Motion (gal)		
		Maximum Response Acceleration (gal)			Horizontal (N-S)	Horizontal (E-W)	Vertical
		Horizontal (N-S) <sup>b</sup>	Horizontal (E-W) <sup>c</sup>	Vertical			
Fukushima Daiichi	Unit 1	460 <sup>d</sup>	447 <sup>d</sup>	258 <sup>d</sup>	487	489	412
	Unit 2	348 <sup>d</sup>	550 <sup>d,e</sup>	302 <sup>d</sup>	441	438	420
	Unit 3	322 <sup>d</sup>	507 <sup>d,e</sup>	231 <sup>d</sup>	449	441	429
	Unit 4	281 <sup>d</sup>	319 <sup>d</sup>	200 <sup>d</sup>	447	445	422
	Unit 5	311 <sup>d</sup>	548 <sup>d,e</sup>	256 <sup>d</sup>	452	452	427
	Unit 6	298 <sup>d</sup>	444 <sup>d</sup>	244	445	448	415
Fukushima Daini	Unit 1	254	230 <sup>d</sup>	305	434	434	512
	Unit 2	243	196 <sup>d</sup>	232 <sup>d</sup>	428	429	504
	Unit 3	277 <sup>d</sup>	216 <sup>d</sup>	208 <sup>d</sup>	428	430	504
	Unit 4	210 <sup>d</sup>	205 <sup>d</sup>	288 <sup>d</sup>	415	415	504

<sup>a</sup> The data are interim and subject to change.

<sup>b</sup> North-South.

<sup>c</sup> East-West.

<sup>d</sup> The recording time was ~130 to 150 seconds.

<sup>e</sup> The observed acceleration exceeded the design basis.

**Table 2**  
**Observed Seismic Acceleration at Onagawa NPS**

Location of Seismometer		Record			Maximum Response Acceleration Against Design-Basis Ground Motion (gal)		
		Maximum Response Acceleration (gal)					
		Horizontal (N-S) <sup>a</sup>	Horizontal (E-W) <sup>b</sup>	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Unit 1	Roof	2000	1636	1389	2202	2200	1388
	Refueling floor (5th floor)	1303	998	1183	1281	1443	1061
	1st floor	573	574	510	660	717	527
	Basemat	540 <sup>c</sup>	587 <sup>c</sup>	439	532	529	451
Unit 2	Roof	1755	1617 <sup>c</sup>	1093	3023	2634	1091
	Refueling floor (3rd floor)	1270	830	743	1220	1110	968
	1st floor	605	569	330	724	658	768
	Basemat	607 <sup>c</sup>	461	389	594	572	490
Unit 3	Roof	1868	1578	1004	2258	2342	1064
	Refueling floor (3rd floor)	956	917	888	1201	1200	938
	1st floor	657	692	547	792	872	777
	Basemat	573 <sup>c</sup>	458	321	512	497	476

<sup>a</sup> North-South.

<sup>b</sup> East-West.

<sup>c</sup> The observed acceleration exceeded the design basis.

**Table 3**  
**Observed Seismic Acceleration at Tokai Daini NPS**

Location of Seismometer		Record			Maximum Response Acceleration Against Design-Basis Ground Motion (gal)		
		Maximum Response Acceleration (gal)					
		Horizontal (N-S) <sup>a</sup>	Horizontal (E-W) <sup>b</sup>	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Reactor building	6th floor	492	481	358	799	789	575
	4th floor	301	361	259	658	672	528
	2nd floor	225	306	212	544	546	478
	Basemat (2nd basement level)	214	225	189	393	400	456

<sup>a</sup> North-South.

<sup>b</sup> East-West.

At the Higashidori NPS, there was no damage reported from either the earthquake or the tsunami. The largest reported acceleration was 17 gal.

The values in red in Tables 1 and 2 indicate where the observed acceleration exceeded the design basis. As can be seen, in a few locations, the observed accelerations exceeded the design basis by up to 25%. Based on previous experience at the Kashiwazaki-Kariwa NPS, as well as many seismic fragility studies in support of probabilistic risk assessments, this amount of exceedance would not be sufficient to lose functionality of nuclear power plant (NPP) safety systems, and the NPP responses show that after the earthquake, for a period of ~1 hour before the tsunami struck, NPP safety systems were working. At the Tokai Daini NPS, measured accelerations did not exceed the design basis.

## II. TSUNAMI

The following data are taken from the report by the Japanese government to the IAEA [1].

**Table 4**  
**Observed Tsunami Levels at Eastern Japan NPSs**

Nuclear Power Station	Estimated Maximum Tsunami Level (m)	Grade Level (m)	Design-Basis Level in Establishment Permit (m)
Fukushima Daiichi Units 1 through 4	14 to 15	10	5.7
Fukushima Daiichi Units 5 and 6	14 to 15	13	5.7
Fukushima Daini	6.5 to 7	12	5.2
Onagawa	13	13.8	13.6
Tokai Daini	5.0 to 5.4	6.1 to 8.0	4.9

In the detailed report by the Japanese government to the IAEA [1], there are site maps that show more precisely where the flooding took place, and particular discussion is given to the effect of the tsunami on the seawater pumping systems that support heat removal to the ultimate heat sink, since the elevations quoted in Table 4 are for the main buildings. It is clear that in the case of the Fukushima Daiichi NPS, the maximum tsunami level far exceeded the design-basis level and also exceeded the NPP grade level; however, at Fukushima Daiichi Units 5 and 6, one air-cooled emergency diesel generator was spared, and it provided sufficient emergency power to maintain the core cooling safety function at Units 5 and 6.

Since the publication of the Japanese government report [1], there has been considerable discussion about why some historical data going back ~1000 years [2] were not used in the establishment of the design-basis tsunami level and why the Tokyo Electric Power Company was allowed to excavate the site for a more convenient elevation for port access for equipment and supplies [3]. In the United States, NPPs are designed against the most severe external natural phenomena that have happened or are estimated to have happened in the last 10,000 years. Therefore, this particular combination of earthquake and tsunami flooding that significantly exceeds NPP design basis should not happen in the United States.

## REFERENCES

[1] “Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety—The Accident at TEPCO's Fukushima Nuclear Power Stations,” Government of Japan (June 2011).

[2] L. MOHRBACH, T. LINNEMANN, G. SCHÄFER, and G. VALLANA, “Earthquake and Tsunami in Japan on March 11, 2011 and Consequences for Fukushima and Other Nuclear Power Plants Status: April 15, 2011,” VGB PowerTech (April 15, 2011).

[3] C. DAWSON and Y. HAYASHI, “Fateful Move Exposed Japan Plant,” *Wall Street Journal*, July 12, 2011.