Appendix 8

Structural Integrity of Spent Fuel Pool Structures
Subject to Tornadoes and High Winds

Tornado or high winds damage, resulting from missile generation, can affect the structural integrity of the spent fuel pool or affect the availability of nearby support systems, such as power supplies, heat exchangers and water makeup sources, and may also affect recovery actions. We documented a set of site specific evaluations for tornadoes and high winds in NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States," Lawrence Livermore National Laboratory (LLNL), December 1987. It is noted that this study was performed to assess core damage frequencies at operating plants.

The National Climatic Data Center (NCDC) in Asheville, N.C., keeps weather records for the U.S. and the world. Data for the period 1950 to 1995 is presented in Figures 1 and 2. (Ref: http://www.ncdc.noaa.gov/ol/climate/severeweather/tornadoes.html). These data are reported as the annual average number of (all) tornadoes per 10,000 square mile per state, and the annual average number of strong-violent (F2 to F5) tornadoes per square mile per state.

Figure 1

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① CMU = Concrete masory unit

② single wythe → an A&E term – akin to 4" brick – typical building

③ → wythe ≡ layer "generally"

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Annual Average Number of Tornadoes per 10,000 Square Miles by State, 1950-1995

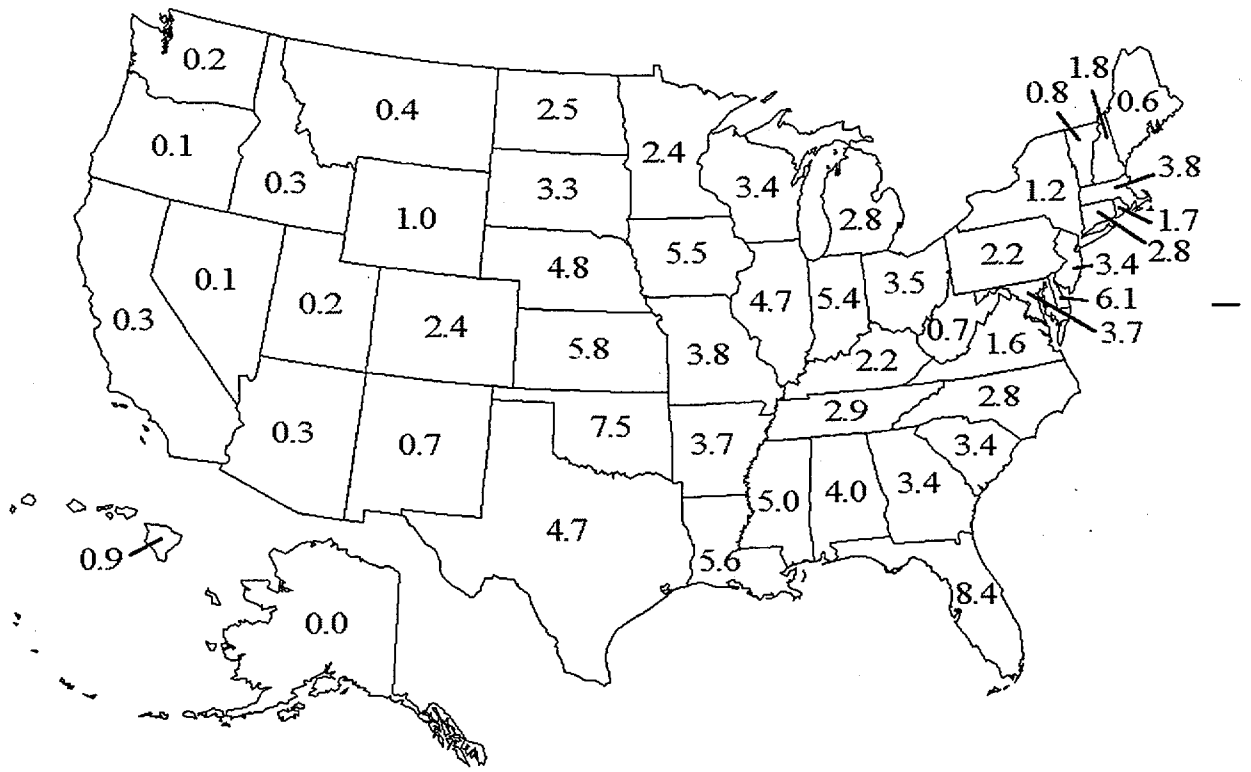
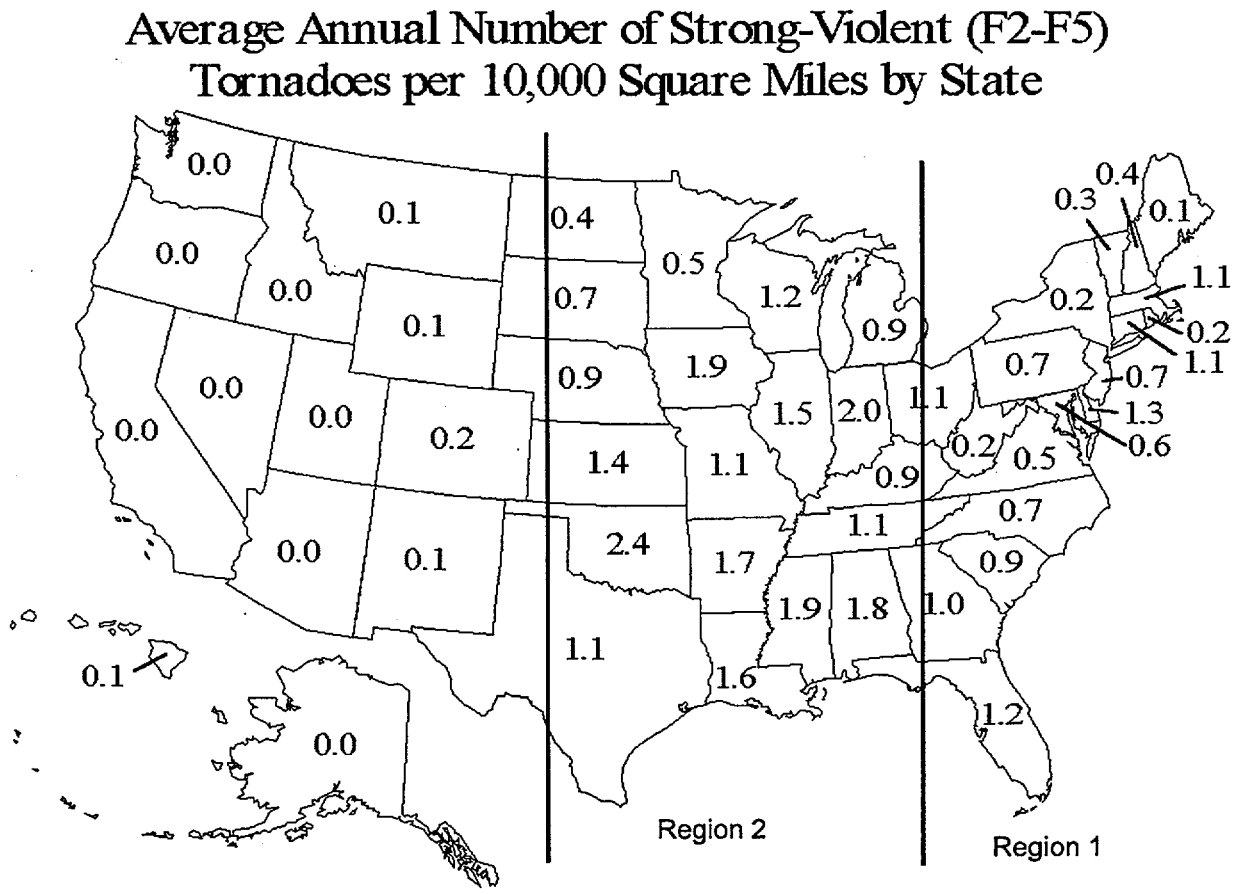


Figure 2



In Table 1 we present a comparison of the site specific evaluations and general regional values. We reviewed the NCDC data and developed a range of frequencies per square mile per year based on the site location and neighboring state (regional) data. In general, the comparison of the NUREG/CR-5042 tornado frequencies for all tornadoes to the NCDC tornado frequencies for all reported tornadoes shows good agreement between the two sets of data.

The data presented in Figure 2 indicates that there are two regions that should be considered for tornadoes in the F2 to F5 range, where the high wind speeds are likely to generate significant missiles: Region (1) states east of (an including) Ohio to Georgia and region (2) states west (North Dakota to Texas). We consider the F2 to F5 tornado frequencies to be 1.0×10^{-4} per mi^2-year for Region (1) and 2.0×10^{-4} per mi^2-year for Region (2).

Table 1 - Tornado and high wind data summary

	NUREG/CR-5042 Data				NCDC data	
Site	Tornado frequency (per mi^2-year)	Tornado strike frequency (per year)	High wind damage frequency (per year)	Tornado damage frequency (per year)	Frequency 1950-1995 average for F0-F5 (per mi^2-year)	Frequency 1950-1995 average for F2-F5 (per mi^2-year)
Indian Pt. 2	1.00×10^{-4}	1.00×10^{-4}	2.50×10^{-5}	$<1.0 \times 10^{-7}$	$1.2\text{-}2.2 \times 10^{-4}$	$0.2\text{-}0.7 \times 10^{-4}$
Indian Pt. 3	1.00×10^{-4}	1.00×10^{-4}	1.80×10^{-5}	$<1.0 \times 10^{-7}$	$1.2\text{-}2.2 \times 10^{-4}$	$0.2\text{-}0.7 \times 10^{-4}$
Limerick 1-2	1.13×10^{-4}	2.30×10^{-4} (<F1)	9.00×10^{-9}	$<1.0 \times 10^{-8}$	$2.2\text{-}3.4 \times 10^{-4}$	$0.7\text{-}1.3 \times 10^{-4}$
Millstone 3	1.87×10^{-4}	1.87×10^{-4}	Low	$<1.0 \times 10^{-7}$	$2.8\text{-}3.4 \times 10^{-4}$	$0.2\text{-}1.1 \times 10^{-4}$
Oconee 3	2.50×10^{-4}	3.50×10^{-3} 1 mi rad.	Low	$<1.0 \times 10^{-9}$	$2.8\text{-}3.4 \times 10^{-4}$	$0.7\text{-}0.9 \times 10^{-4}$
Seabrook 1-2	1.26×10^{-3}	7.75×10^{-5}	$<3.89 \times 10^{-8}$	2.06×10^{-9} LOSP & RWST	$1.8\text{-}3.8 \times 10^{-4}$	$0.4\text{-}1.1 \times 10^{-4}$
Zion ½	1.00×10^{-3}	1.00×10^{-3}	N.A.	$<1.0 \times 10^{-8}$	$3.4\text{-}5.4 \times 10^{-4}$	$1.2\text{-}2.0 \times 10^{-4}$
GSI A-45 PRAs	Regional Local		w/o recovery of offsite power			
ANO 1	5.18×10^{-4} 4.37×10^{-4}	1.53×10^{-3}	5.69×10^{-6}	2.53×10^{-4}	$3.7\text{-}7.5 \times 10^{-4}$	$1.7\text{-}2.4 \times 10^{-4}$
Point Beach 1-2	6.98×10^{-4} 4.11×10^{-4}	5.38×10^{-4}	1.00×10^{-5}	5.00×10^{-5}	$3.4\text{-}4.7 \times 10^{-4}$	$1.2\text{-}1.5 \times 10^{-4}$
Quad Cities 1-2	5.18×10^{-4} 5.44×10^{-4}	1.04×10^{-3}	$<<1.0 \times 10^{-8}$	5.08×10^{-7}	$3.4\text{-}5.4 \times 10^{-4}$	$1.2\text{-}2.0 \times 10^{-4}$
St. Lucie 1	6.98×10^{-4} 1.20×10^{-3}	1.70×10^{-4}	$<<1.0 \times 10^{-8}$	1.61×10^{-8}	8.4×10^{-4}	1.2×10^{-4}
Turkey Pt. 3	3.37×10^{-4} 5.83×10^{-3}	1.70×10^{-4}	3.30×10^{-5}	2.54×10^{-6}	8.4×10^{-4}	1.2×10^{-4}

The following data was taken from http://www.awc-kc.noaa.gov/spc/stats/Tornado_stats.html

Table 2 - Storm Prediction Center tornado statistics

STORM PREDICTION CENTER (NORMAN OK) ...THROUGH 1 PM CDT 04/16/99
STATISTICS FOR TORNADO TOTALS AND TORNADO RELATED DEATHS

	NUMBER OF TORNADOES							NUMBER OF TORNADO DEATHS					KILLER TORNADOES			
	1999		1998		1997	1996	3YR					3YR				
	PRELIM	FINAL	PRELIM	FINAL	FINAL	FINAL	AVG	99	98	97	96	AVG	99	98	97	
JAN	169	-	20	47	50	35	45	18	-	2	1	2	9	-	2	
FEB	18	-	56	72	23	14	38	-	41	1	1	14	-	4	1	
MAR	19	-	66	72	102	71	84	1	16	28	6	17	1	4	9	
APR	122	-	196	182	114	177	166	17	55	1	12	23	6	14	1	
MAY	-	-	309	313	225	235	262	-	10	29	1	13	-	5	3	
JUN	-	-	372	375	193	128	240	-	3	-	-	1	-	2	-	
JUL	-	-	59	82	188	202	157	-	-	4	1	2	-	-	4	
AUG	-	-	32	61	84	72	73	-	-	1	1	1	-	-	1	
SEP	-	-	61	105	32	101	81	-	2	1	-	1	-	2	1	
OCT	-	-	64	62	100	68	78	-	2	-	-	1	-	2	-	
NOV	-	-	18	18	25	55	33	-	-	-	2	1	-	-	-	
DEC	-	-	1	-	12	15	15	-	-	-	1	1	-	-	-	
SUM	328	-	1254	1389	1148	1173	1272	36	129	67	25	77	16	33	22	

Based on recent data collection, we estimate the reported number of tornadoes to be 1,250 per year (historical data from 1950 to 1995 would yield an average of 700 to 800 per year). The data indicates that the number of reported tornadoes is relatively constant (per year) and that there is an apparent correlation based on the time of the year, with tornadoes being more likely to occur during the period March through July.

We used the Storm Prediction Center (SPC) raw data to develop a data base for this assessment. There have been about 121 F5, and 924 F4, tornadoes recorded between 1950 and 1995 (an additional four in the 1996 to 1998 period). The data is provided in Table 4. We estimate that about 30 percent of all reported tornadoes are in the F2 to F3 range and about 2.5 percent are in the F4 to F5 range.

DOE-STD-1020-94, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities," January 1996, Department of Energy, provides some insights into wind generated missiles.

For sites where tornadoes are not considered a viable threat, to account for objects or debris we evaluate a 2x4 inch timber plank weighing 15 lbs as a missile for straight winds and hurricanes. With a recommended impact speed of 50 mph at a maximum height of 30 feet above ground, this missile would break annealed glass, perforate sheet metal siding and wood siding up to to 3/4-inch thick. For weak tornadoes, the timber missile horizontal speed is 100 mph effective to a height of 100 feet above ground and a vertical speed of 70 mph. We consider a second missile

for weak tornadoes: a 3 inch diameter steel pipe weighing 75 lbs with an impact velocity of 50 mph, effective to a height of 75 feet above ground and a vertical velocity of 35 mph. For the straight wind missile, we consider an 8 inch CMU wall, single wythe brick wall with stud wall, or a 4 inch concrete (reinforced) adequate to prevent penetration. For the tornado missile, we consider an 8 to 12 inch CMU wall, single wythe brick wall with stud wall and metal ties, or a 4 to 8 inch concrete (reinforced) slab adequate to prevent penetration (depending on the missile). (Refer to DOE-STD-1020-94 for additional details.)

For sites where tornadoes are considered a viable threat, to account for objects or debris, we consider the same 2x4 inch timber but for heights above ground to 50 feet. The tornado missiles are (1) the 15 lbs, 2x4 inch timber with a horizontal speed of 150 mph effective up to 200 feet above ground, and a vertical speed of 100 mph; (2) the 3 inch diameter, 75 lbs steel pipe with a horizontal speed of 75 mph and a vertical speed of 50 mph effective up to 100 feet above ground; and (3) a 3,000 lbs automobile with ground speed up to 25 mph. For the straight wind missile, we consider an 8 inch CMU wall, single wythe brick wall with stud wall, or a 4 inch concrete (reinforced) wall adequate to prevent penetration. For the tornado missile, we consider an 8 in CMU reinforced wall, or a 4 to 10 inch concrete (reinforced) slab adequate to prevent penetration (depending on the missile). (Refer to DOE-STD-1020-94 for additional details.)

The winds associated with hurricanes and other storms are less intense and lower in magnitude than those associated with tornadoes. Generally, we consider high winds from wind storms and hurricanes to be the controlling wind level at a higher frequency but at a lower magnitude.

Recommended values for risk-informed assessment of spent fuel pool

The SPC data has been evaluated by region as shown in Figure 1.

Region 1 The fraction of tornadoes in the F4-F5 range is 0.031, and the fraction in the F2-F5 range is 0.31 to 0.33.

Region 2 The fraction of tornadoes in the F4-F5 range is 0.021 to 0.045, and the fraction in the F2-F5 range is 0.28 to 0.37.

The bounding value for the F4-F5 range is taken as 0.045 and for the F2-F5 range, 0.40. See Table 4.

Significant pool damage

It is assumed that an F4 to F5 tornado would be required to consider an evaluation for possible significant damage to a PWR or BWR spent fuel pool.

Region 1 Given a frequency of 1×10^{-4} per mi^2-year, a target region of 1.0×10^{-2} mi^2 (about 300 x 300 feet) and an 0.03 probability of an F4 to F5 tornado, the recommended value is 3.0×10^{-8} per year.

Region 2 Given a frequency of $2x10^{-4}$ per mi^2-year, a target region of $1.0x10^{-2}$ mi^2 (about 300 x 300 feet) and an 0.045 probability of an F4 to F5 tornado, the recommended value is $9.0x10^{-8}$ per year.

The likelihood of significant spent fuel pool damage from tornadoes is less than $1.0x10^{-7}$ per year.

Support system availability

We assumed that an F2 to F5 tornado would be required to consider an evaluation of possible significantly damage a support system (power supply, heat exchanger or makeup water supply).

Region 1 Given a frequency of $1x10^{-4}$ per mi^2-year, a target region of $1.0x10^{-3}$ mi^2 (about 100 x 100 feet) and an 0.40 probability of an F2 to F5 tornado, we determined the value is $4.0x10^{-8}$ per year.

Region 2 Given a frequency of $2x10^{-4}$ per mi^2-year, a target region of $1.0x10^{-3}$ mi^2 (about 100 x 100 feet) and an 0.40 probability of an F2 to F5 tornado, we determined the value is $8.0x10^{-8}$ per year.

The likelihood of significant support system damage from tornadoes is less than $1.0x10^{-7}$ per year.

Table 3 - SPC Tornado summary by state (1950 - 1995)

		Fujita damage scale						Fraction in F-range	
State	Total	F0	F1	F2	F3	F4	F5	F4-F5	F2-F5
AL	1031	165	364	323	129	36	14	0.049	0.49
AR	1007	198	298	331	149	31	0	0.031	0.51
AZ	160	90	57	11	2	0	0	0.000	0.08
CA	223	142	58	21	2	0	0	0.000	0.10
CO	1172	616	441	99	15	1	0	0.001	0.10
CT	65	9	29	20	5	2	0	0.031	0.42
DC	1	1	0	0	0	0	0	0.000	0.00
DE	55	20	23	11	1	0	0	0.000	0.22
FL	2148	1156	665	293	30	4	0	0.002	0.15
GA	1032	147	537	266	65	17	0	0.016	0.34
IA	1607	478	506	421	119	74	9	0.052	0.39
ID	124	63	53	8	0	0	0	0.000	0.06
IL	1342	431	440	316	113	39	3	0.031	0.35
IN	1038	246	336	263	108	77	8	0.082	0.44
KS	2363	1111	610	404	168	54	16	0.030	0.27
KY	483	79	168	133	65	35	3	0.079	0.49
LA	1254	225	620	268	123	16	2	0.014	0.33
MA	138	24	72	31	8	3	0	0.022	0.30
MD	172	49	92	26	5	0	0	0.000	0.18
ME	82	21	44	17	0	0	0	0.000	0.21
MI	807	195	308	210	57	30	7	0.046	0.38
MN	953	372	336	158	53	28	6	0.036	0.26
MO	1367	298	577	334	109	48	1	0.036	0.36
MS	1268	226	468	369	136	59	10	0.054	0.45
MT	253	174	42	33	4	0	0	0.000	0.15
NC	687	153	321	143	44	26	0	0.038	0.31
ND	830	490	211	91	28	7	3	0.012	0.16
NE	1818	827	585	255	105	42	4	0.025	0.22
NV	49	41	8	0	0	0	0	0.000	0.00
NH	75	24	34	15	2	0	0	0.000	0.23
NJ	127	42	58	23	4	0	0	0.000	0.21
NM	400	261	104	31	4	0	0	0.000	0.09
NY	268	101	106	35	21	5	0	0.019	0.23
OH	733	157	321	166	53	27	9	0.049	0.35
OK	2580	845	808	626	209	83	9	0.036	0.36
OR	49	31	15	3	0	0	0	0.000	0.06
PA	506	93	220	143	26	22	2	0.047	0.38

		Fujita damage scale						Fraction in F-range	
State	Total	F0	F1	F2	F3	F4	F5	F4-F5	F2-F5
RI	8	3	4	1	0	0	0	0.000	0.13
SC	516	136	234	100	31	15	0	0.029	0.28
SD	1172	651	259	197	57	7	1	0.007	0.22
TN	596	107	241	139	76	29	4	0.055	0.42
TX	5934	2632	1837	1067	317	76	5	0.014	0.25
UT	79	53	19	6	1	0	0	0.000	0.09
VA	318	84	132	68	28	6	0	0.019	0.32
VT	33	7	14	12	0	0	0	0.000	0.36
WA	56	24	17	12	3	0	0	0.000	0.27
WI	949	204	378	276	62	24	5	0.031	0.39
WV	87	27	36	16	8	0	0	0.000	0.28
WY	444	247	145	43	8	1	0	0.002	0.12
Total	38459	13776	13251	7834	2553	924	121	0.027	0.30

Table 4 - Summary evaluation of F4-F5 and F2-F5 tornadoes by region

		Fujita damage scale						Fraction in F-range	
Region	Total	F0	F1	F2	F3	F4	F5	F4-F5	F2-F5
NRC Reg I	2263	551	1017	500	125	59	11	0.031	0.31
NRC Reg II	8166	2280	3166	1850	612	227	31	0.032	0.33
Region 1	10429	2831	4183	2350	737	286	42	0.031	0.33
NRC Reg III	8063	2224	2881	1978	621	320	39	0.045	0.37
NRC Reg IV*	16958	6979	5228	3239	1156	316	40	0.021	0.28
Region 2	25021	9203	8109	5217	1777	636	79	0.029	0.31
Sum RI/IV	35450	12034	12292	7567	2514	922	121	0.029	0.31
Resid**	3009	1742	959	267	39	2	0	0.001	0.10

Notes:

* - Excludes AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA AND WY.

** - Number omitted in NRC Reg IV and Region 2 evaluation.