My modified version of Ed's writeup 5/25/99

# Appendix nn

## Assessment of Tornados 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, cooling pumps, heat exchangers and water makeup sources, and may also affect recovery actions. A set of site specific evaluations for tornados and high winds was documented in NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States," Lawrence Livermore National Laboratory, December 1987. It is noted that this study was performed to assess core damage frequencies at operating plants. In NUREG/CR-2944, "Tornado Damage Risk Assessment," Brookhaven National Laboratory, September 1982, a methodology and assessment of tornado risk was developed.

The National Climatic Data Center (NCDC) in Asheville, N.C., keeps weather records for the U.S. for the period 1950 to 1995 (Ref: http://www.ncdc.noaa.gov/). 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, as shown in Figures 1 and 2.

Figure 1

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

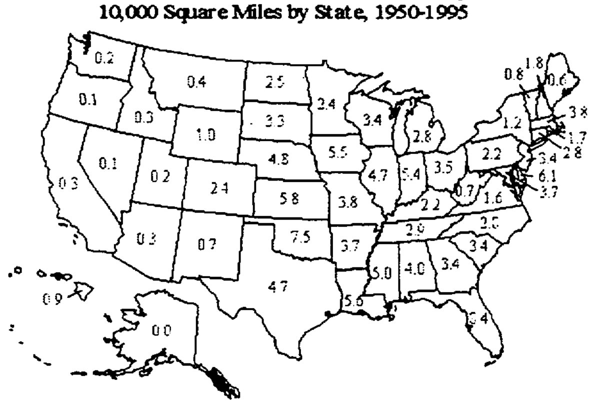
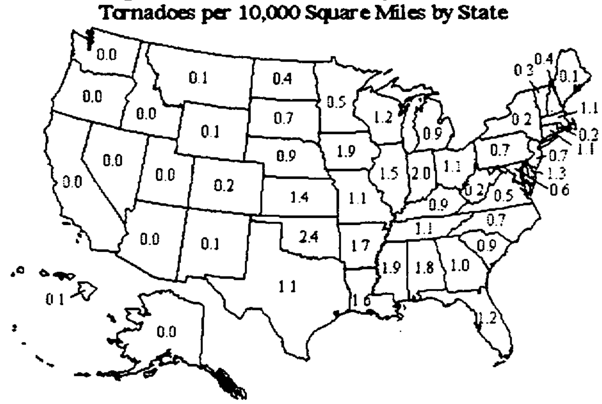


Figure 2

Average Annual Number of Strong-Violent (F2-F5) Tornadoes per 10,000 Square Miles by State



A comparison of the site specific evaluations (from NUREG/CR-5042) and general regional values from the NCDC database is presented in Table 1. The NCDC data was reviewed and a range of frequencies per square mile per year was developed 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.



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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 | $1.00x10^{-4}$ | $1.00x10^{-4}$ | $2.50x10^{-5}$ | $<1.0x10^{-7}$ | $1.2\text{-}2.2x10^{-4}$ | $0.2\text{-}0.7x10^{-4}$ |
| Indian Pt. 3 | $1.00x10^{-4}$ | $1.00x10^{-4}$ | $1.80x10^{-5}$ | $<1.0x10^{-7}$ | $1.2\text{-}2.2x10^{-4}$ | $0.2\text{-}0.7x10^{-4}$ |
| Limerick 1-2 | $1.13x10^{-4}$ | $2.30x10^{-4}$ ( <F1 ) | $9.00x10^{-9}$ | $<1.0x10^{-8}$ | $2.2\text{-}3.4x10^{-4}$ | $0.7\text{-}1.3x10^{-4}$ |
| Millstone 3 | $1.87x10^{-4}$ | $1.87x10^{-4}$ | Low | $<1.0x10^{-7}$ | $2.8\text{-}3.4x10^{-4}$ | $0.2\text{-}1.1x10^{-4}$ |
| Oconee 3 | $2.50x10^{-4}$ | $3.50x10^{-3}$ 1 mi rad. | Low | $<1.0x10^{-9}$ | $2.8\text{-}3.4x10^{-4}$ | $0.7\text{-}0.9x10^{-4}$ |
| Seabrook 1-2 | $1.26x10^{-3}$ | $7.75x10^{-5}$ | $<3.89x10^{-8}$ | $2.06x10^{-9}$ LOSP & RWST | $1.8\text{-}3.8x10^{-4}$ | $0.4\text{-}1.1x10^{-4}$ |
| Zion ½ | $1.00x10^{-3}$ | $1.00x10^{-3}$ | N.A. | $<1.0x10^{-8}$ | $3.4\text{-}5.4x10^{-4}$ | $1.2\text{-}2.0x10^{-4}$ |
| GSI A-45 PRAs | Regional Local | | w/o recovery of offsite power | | | |
| ANO 1 | $5.18x10^{-4}$ $4.37x10^{-4}$ | $1.53x10^{-3}$ | $5.69x10^{-6}$ | $2.53x10^{-4}$ | $3.7\text{-}7.5x10^{-4}$ | $1.7\text{-}2.4x10^{-4}$ |
| Point Beach 1-2 | $6.98x10^{-4}$ $4.11x10^{-4}$ | $5.38x10^{-4}$ | $1.00x10^{-5}$ | $5.00x10^{-5}$ | $3.4\text{-}4.7x10^{-4}$ | $1.2\text{-}1.5x10^{-4}$ |
| Quad Cities 1-2 | $5.18x10^{-4}$ $5.44x10^{-4}$ | $1.04x10^{-3}$ | $<<1.0x10^{-8}$ | $5.08x10^{-7}$ | $3.4\text{-}5.4x10^{-4}$ | $1.2\text{-}2.0x10^{-4}$ |
| St. Lucie 1 | $6.98x10^{-4}$ $1.20x10^{-3}$ | $1.70x10^{-4}$ | $<<1.0x10^{-8}$ | $1.61x10^{-8}$ | $8.4x10^{-4}$ | $1.2x10^{-4}$ |
| Turkey Pt. 3 | $3.37x10^{-4}$ $5.83x10^{-3}$ | $1.70x10^{-4}$ | $3.30x10^{-5}$ | $2.54x10^{-6}$ | $8.4x10^{-4}$ | $1.2x10^{-4}$ |

The Storm Prediction Center (SPC) raw data, for the period 1950 to 1995, has been used 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). It is estimated 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 site where tornadoes are not considered a viable threat, to account for objects or debris a 2x4 inch timber plank weighing 15 lbs is considered as a missile for straight winds and hurricanes. With a recommended impact speed of 50 mph at a maximum height of 30 ft above ground, this missile would break annealed glass, perforate sheet metal siding and wood siding up to to 3/4-in thick. For weak tornadoes, the timber missile horizontal speed is 100 mph effective to a height of 100 ft above ground and a vertical speed of 70 mph. A second missile is considered: a 3 in diameter steel pipe weighing 75 lbs with an impact velocity of 50 mph, effective to a height of 75 ft above ground and a vertical velocity of 35 mph. For the straight wind missile, an 8 in CMU wall, single wythe (single layer) brick wall with stud wall, or a 4 inch concrete (reinforced) is considered adequate to prevent penetration. For the tornado missile, an 8 to 12 in CMU (concrete masonry unit) wall, single wythe brick wall with stud wall and metal ties, or a 4 to 8 inch concrete (reinforced) slab is considered 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 the same 2x4 inch timber is considered but for heights above ground to 50 ft. The tornado missiles are (1) the 15 lbs, 2x4 inch timber with a horizontal speed of 150 mph effective up to 200 ft 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 sped of 50 mph effective up to 100 ft above ground; and (3) a 3,000 lbs automobile with ground speed up to 25 mph. For the straight wind missile, an 8 in CMU wall, single wythe brick wall with stud wall, or a 4 inch concrete (reinforced) is considered adequate to prevent penetration. For the tornado missile, an 8 in CMU reinforced wall, or a 4 to 10 inch concrete (reinforced) slab is considered 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 generally less intense and lower in magnitude than those associated with tornadoes. Generally, high winds from wind storms and hurricanes are considered 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 tornado strike probabilities for each F-Scale interval was determined from the SPC raw data on a state basis. For each F-Scale, the probability was obtained from the following equation, for the point strike probability:

$$P_{fs} = \left( \frac{\Sigma_N < a >_T}{A_{ob}} \right) \times \frac{1}{Y_{int}} \quad \text{Equation 1}$$

where:

$P_{fs}$ = strike probability for F-Scale (fs)
$<a>_T$ = tornado area, $mi^2$
$A_{ob}$ = area of observation, $mi^2$ (state land area)
$Y_{int}$ = interval over which observations were made, years
$\Sigma_N$ = sum of reported tornados in the area of observation

The tornado area, $<a>_T$, was evaluated at the mid-point of the path-length and path-width intervals shown in Table 2.

Table 2 - Tornado characteristics

| F-Scale | Damage and wind speed | Path-length scale | Length (miles) | Path-width scale | Width (yards) |
|---|---|---|---|---|---|
| 0 | Light Damage (40-72 mph) | 0 | < 1.0 | 0 | < 18 yds. |
| 1 | Moderate Damage (73-112 mph) | 1 | 1.0 - 3.1 | 1 | 18 - 55 yds. |
| 2 | Significant Damage (113-157 mph) | 2 | 3.2 - 9.9 | 2 | 56 - 175 yds. |
| 3 | Severe Damage (158-206 mph) | 3 | 10.0 -31.9 | 3 | 176 - 527yds. |
| 4 | Devastating Damage (207-260 mph) | 4 | 32 - 99.9 | 4 | 528 - 1759 yds. |
| 5 | Incredible Damage (261-318 mph) | 5 | 100 > | 5 | 1760 yds > |

The tornado area, $<a>_T$, was then corrected using data from NUREG/CR-2944 (Table 6b, page 19 and Table 7b, page 21) to correct the area calculation for the variations in the tornado intensity along the path length and width.

The central U.S. region (12 states - Kansas, Oklahoma, Iowa, Missouri, Arkansas, Illinois, Indiana, Ohio, Kentucky, Tennessee, Mississippi and Alabama), was used to develop the tornado strike probabilities for each F-Scale interval. This region has the highest frequency of tornado occurrences and is about equal to the central region defined in NUREG/CR-2944 (region A in Figure 2, page 12.)

The SPC raw data for each state was used to determine the F-Scale, path-length and path-width characteristics of the reported tornadoes. Equation 1 was used for each state and the summation of the 12 states performed. The results are shown in Table 3.

Table 3 - Point strike probabilities

| F-scale | Tornado strike probability (per year) |
|---|---|
| 0 | $1.2x10^{-5}$ |
| 1 | $3.5x10^{-5}$ |
| 2 | $4.0x10^{-5}$ |
| 3 | $2.5x10^{-6}$ |
| 4 | $7.7x10^{-6}$ |
| 5 | $6.3x10^{-7}$ |

**Significant pool damage**

An F4 to F5 tornado would be needed to consider damage to the spent fuel pool from a tornado missile. The likelihood of a tornado of this magnitude even striking the plant is estimated to be $7.7x10^{-6}$ per year, or lower. In addition, the spent fuel pool is a multiple-foot thick reinforced concrete structure housed within another (normally) foot thick reinforced concrete structure (i.e., the building housing a spent fuel pool normally is designed to mitigate an F4 or F5 tornado.) Based on the DOE-STD-1020-94 information, it is very unlikely that a tornado missile would be able to penetrate the spent fuel pool. The staff concludes that tornado missile strikes from F4 and F5 tornadoes add negligibly to the risk from spent fuel pools at decommissioned plants.

**Support system availability**

An F2 or larger tornado would be needed to consider damage to a support system, such as power supplies, cooling pumps, heat exchangers and water makeup sources. The likelihood of this magnitude tornado striking the plant is estimated to be $4x10^{-5}$ per year, or lower.

**Recovery from loss of support systems**

If the spent fuel pool support system(s) are damaged by an F2 or larger tornado, then offsite recovery is considered to be available (e.g., fire trucks) to provide makeup to the spent fuel pool. The assumed conditional probability of unsuccessful offsite recovery is 0.02 for Cases 1 and 3, and 0.1 for Case 2. Combining the frequency of an F2 or larger tornado with failure of offsite recovery results in a frequency of fuel uncovery in the spent fuel pool in the range of $8x10^{-7}$ per year from damage to support systems caused by tornadoes for Cases 1 and 3 and in the range of $4x10^{-6}$ per year for Case 2.

The SPC data is summarized in Table 4.

Table 4 - 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 |

| | | Fujita damage scale | | | | | | Fraction in F-range | |
|---|---|---|---|---|---|---|---|---|---|
| State | Total | F0 | F1 | F2 | F3 | F4 | F5 | F4-F5 | F2-F5 |
| OR | 49 | 31 | 15 | 3 | 0 | 0 | 0 | 0.000 | 0.06 |
| PA | 506 | 93 | 220 | 143 | 26 | 22 | 2 | 0.047 | 0.38 |
| 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 |