

Tornado Impact Evaluation for the Molten Salt Research Reactor in Abilene, Texas



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1. Introduction

A Molten Salt Research Reactor is proposed for construction in Abilene, Texas, on the campus of Abilene Christian University. Since this site is at the edge of “tornado alley,” calculating the probabilities of tornadoes striking the building in which the reactor will be housed was given particular attention.

2. Methods

Probabilities for tornadoes of different Enhanced Fujita Scale ratings were calculated. We looked only at tornadoes rated EF 2 or stronger, however, since only they were deemed able to cause significant damage. We used a value of 360 tornado days per century and calculated probabilities based on Abilene’s 1° x 1° latitudinal and longitudinal box, as defined by Pacific Northwest National Laboratory (PNNL) for the U.S. Nuclear Regulatory Commission. [1] The probabilistic area was calculated by multiplying the probabilistic lengths and widths for each tornado classification. All calculations are available in Appendix A. Since there is a Weibull distribution for both the lengths and widths, we looked at the 90th, 75th, and 25th percentile values. [2] The likelihood values are unitless probability ratios for a specific EF category divided by the total number of tornadoes, called segments. More common tornado categories have a higher likelihood value. The likelihood values for each tornado category are based on historical data in the central United States from 1950 to 2003. Likelihood values are detailed in the Data Collection section below. This data is from NUREG/CR-4461, Rev 2, created by PNNL. [1] The probability of impact (per century) was found by multiplying the likelihood of that tornado by the expected number of tornadoes per century (360) by the ratio of the area of the reactor to the area of the Abilene box.

$P = \text{likelihood of EF type} * \text{tornadoes per century in Abilene box}$

$$* \frac{\text{Probabilistic area of tornado}}{\text{Area of Abilene box}} * \frac{\text{Area of reactor site}}{\text{Area of Abilene box}} \quad (1)$$

Distances, measured using Google Maps, are detailed below in Data Collection.

The area of the Abilene box is 10400 km².

The area of the reactor site is 0.0607 km² (15 acres).

3. Data Collection

The 10th, 25th, 75th, and 90th percentile values for the probabilistic lengths and widths were measured from two images of box and whisker plots created by Harold Brooks. [2] An on-screen ruler and the plot legend were used to extract the actual values from the plot images. The 50th percentile values for the probabilistic lengths and widths were taken from Table 1 and Table 2 of the Brooks document. [2]

The area of the reactor site (15 acres) was converted to square kilometers for these calculations.

The 1° latitude by 1° longitude box that Abilene is in was recorded by marking the 4 corners of the box on Google Maps and measuring the distance between the corners, taking the average value of the two distances for each set of corners. The average length and width of the box were multiplied together for the area of the box.

Tornado likelihood data comes from Table 2-10 of NUREG/CR-4461, Rev 2 from PNNL. [1] The number of segments for each tornado category was divided by the total number of segments to calculate the likelihood of each tornado category. A tornado segment includes a portion or all of a

tornado. Since about 90% of all tornadoes comprise one segment, we treated each segment as one tornado.

4. Results

Probabilities of EF 2 through EF 5 tornadoes striking the reactor site are shown separately in the following four tables.

Table 1. EF 2 Tornado Strike

Result: Likelihood of 0.2114

Percentile	Probabilistic Area (km ²)	Probability of Tornado Impact per century
90	1.9	8.2E-08
75	1.6	6.9-08
50	1.35	5.72E-08
25	1.2	4.9E-08

Table 2. EF 3 Tornado Strike

Result: Likelihood of 0.07087

Percentile	Probabilistic Area (km ²)	Probability of Tornado Impact per century
90	9.2	1.3E-07
75	7.5	1.1E-07
50	5.93	8.45E-08
25	4.8	6.8E-08

Table 3. EF 4 Tornado Strike

Result: Likelihood of 0.0252

Percentile	Probabilistic Area (km ²)	Probability of Tornado Impact per century
90	33	1.6E-07
75	26	1.3E-07
50	20.1	1.02E-07
25	15	7.6E-08

Table 4. EF 5 Tornado Strike

Result: Likelihood of 0.00344

(For EF 5 tornadoes, only 50th percentile data was available.) [2]

Percentile	Probabilistic Area (km ²)	Probability of Tornado Impact per century
50	30.3	2.10E-08

REFERENCES

[1] Ramsdell, Jr, J. V., Rinshel, J. P., “Tornado Climatology of the Contiguous United States,” NUREG/CR-4461, Rev. 2, Pacific Northwest National Laboratory, Feb. 2007.
<https://www.nrc.gov/docs/ML0708/ML070810400.pdf>

[2] H. E. Brooks, “On the Relationship of Tornado Path Length and Width to Intensity,” *Weather and Forecasting*, vol. 19, no. 2, pp. 310–319, Apr. 2004, doi: 10.1175/1520-0434(2004)019<0310:OTROTP>2.0.CO;2.

APPENDIX A: TORNADO IMPACT PROBABILITIES FOR THE MOLTEN SALT RESEARCH REACTOR IN ABILENE, TEXAS

		Tornado days per year (Abilene area)		Area_site /Area_Abilene				
		3.6		5.82E-06				
		per century		Area_site (km ²)				
		360		0.0607	15 acres			
		Tornado segments in central US (1950-2003)		Area_Abilene box (km ²)				
		36911		10428.336	(3 significant figures)			
EF 5								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	200	2000	400	0.0384	2.23E-07	2.77E-07	3.62E+06
127	75	-	-	-	-	-	-	-
Likelihood per tornado	50	54.6	555.5	30.3	0.00291	1.69E-08	2.10E-08	4.77E+07
0.00344	25	-	-	-	-	-	-	-
EF 4								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	53	609	33	0.0031	1.8E-08	1.6E-07	6.1E+06
930	75	49	529	26	0.0025	1.4E-08	1.3E-07	7.7E+06
Likelihood per tornado	50	43.6	460.7	20.1	0.00193	1.12E-08	1.02E-07	9.83E+06
0.0252	25	38	395	15	0.0014	8.4E-09	7.6E-08	1.3E+07
EF 3								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	27	345	9.2	0.00088	5.1E-09	1.3E-07	7.7E+06
2616	75	25	304	7.5	0.00072	4.2E-09	1.1E-07	9.3E+06
Likelihood per tornado	50	22.5	263.6	5.93	0.000569	3.31E-09	8.45E-08	1.18E+07
0.07087	25	21	227	4.8	0.00046	2.7E-09	6.8E-08	1.5E+07

Figure A.1. Impact Probabilities (EF 5 – EF 3)

EF 2								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	12	156	1.9	0.00018	1.1E-09	8.2E-08	1.2E+07
7804	75	12	141	1.6	0.00016	9.1E-10	6.9E-08	1.4E+07
Likelihood per tornado	50	10.7	125.9	1.35	0.000129	7.52E-10	5.72E-08	1.75E+07
0.2114	25	10	115	1.2	0.00011	6.5E-10	4.9E-08	2.0E+07
EF 1								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	5.6	74.4	0.42	4.0E-05	2.3E-10	2.9E-08	3.5E+07
12543	75	5.3	69.2	0.36	3.5E-05	2.0E-10	2.5E-08	4.0E+07
Likelihood per tornado	50	4.7	64	0.30	2.9E-05	1.7E-10	2.1E-08	4.9E+07
0.33982	25	4.4	58.1	0.25	2.4E-05	1.4E-10	1.7E-08	5.8E+07
EF 0								
<u>Segments (1950-03)</u>	Percentile	Probabilistic Length of Tornado Path (km)	Probabilistic Width of Tornado Path (m)	Probabilistic Area (km ²)	A_tornado/A_Abilene	P(Reactor Impact if in box)	P(Reactor Impact per century)	Years until impact
Tornadoes	90	2.0	35.9	0.070	6.7E-06	3.9E-11	4.9E-09	2.0E+08
12891	75	1.7	32.5	0.056	5.3E-06	3.1E-11	3.9E-09	2.6E+08
Likelihood per tornado	50	1.4	28.4	0.040	3.8E-06	2.2E-11	2.8E-09	3.6E+08
0.34925	25	1.4	23.9	0.033	3.2E-06	1.9E-11	2.3E-09	4.3E+08

Figure A.2. Impact Probabilities (EF 2 – EF 0)

All data sourced from H. E. Brooks, "On the Relationship of Tornado Path Length and Width to Intensity," Weather and Forecasting, vol. 19, no. 2, pp. 310-319, Apr. 2004, doi: 10.1175/1520-0434(2004)019<0310:OTROTP>2.0.CO;2.													
										25/75 percentile		10/90 percentile	
F scale	μ length (km)	μ width (m)	Average Area (km ²)		F4	Percentile	Length (km)	Width (m)	Area (km ²)	LENGTH			
0	1.4	28.4	0.03976			90	53.33208586	609.4017094	32.50066429	Bar0	1.39683	1.195012021	
1	4.7	64	0.3008			75	48.75013263	529.0598291	25.79173684	Bar1	1.71429	1.958670892	
2	10.7	125.9	1.34713			25	37.9894849	394.8717949	15.00097609	Bar2	4.38095	4.180223972	
3	22.5	263.6	5.931			10	33.54637874	337.6068376	11.32548684	Bar3	5.26984	5.63811818	
4	43.6	460.7	20.08652			50				Bar4	10.1587	9.52583607	
5	54.6	555.5	30.3303		F3					Bar5	11.5556	12.37220095	
						90	26.53460184	345.2991453	9.162375335	Bar6	20.9113	19.38397786	
Significant Figures						75	24.79901349	304.2735043	7.545682738	Bar7	24.799	26.53460184	
Screen Ruler	3					25	20.9112956	227.3504274	4.754191992	Bar8	37.9895	33.54637874	
Width from Brooks	2					10	19.38397786	203.4188034	3.943065582	Bar9	48.7501	53.33208586	
Length from Brooks	3					50							

Figure A.3. Raw Length and Width Data (Brooks)

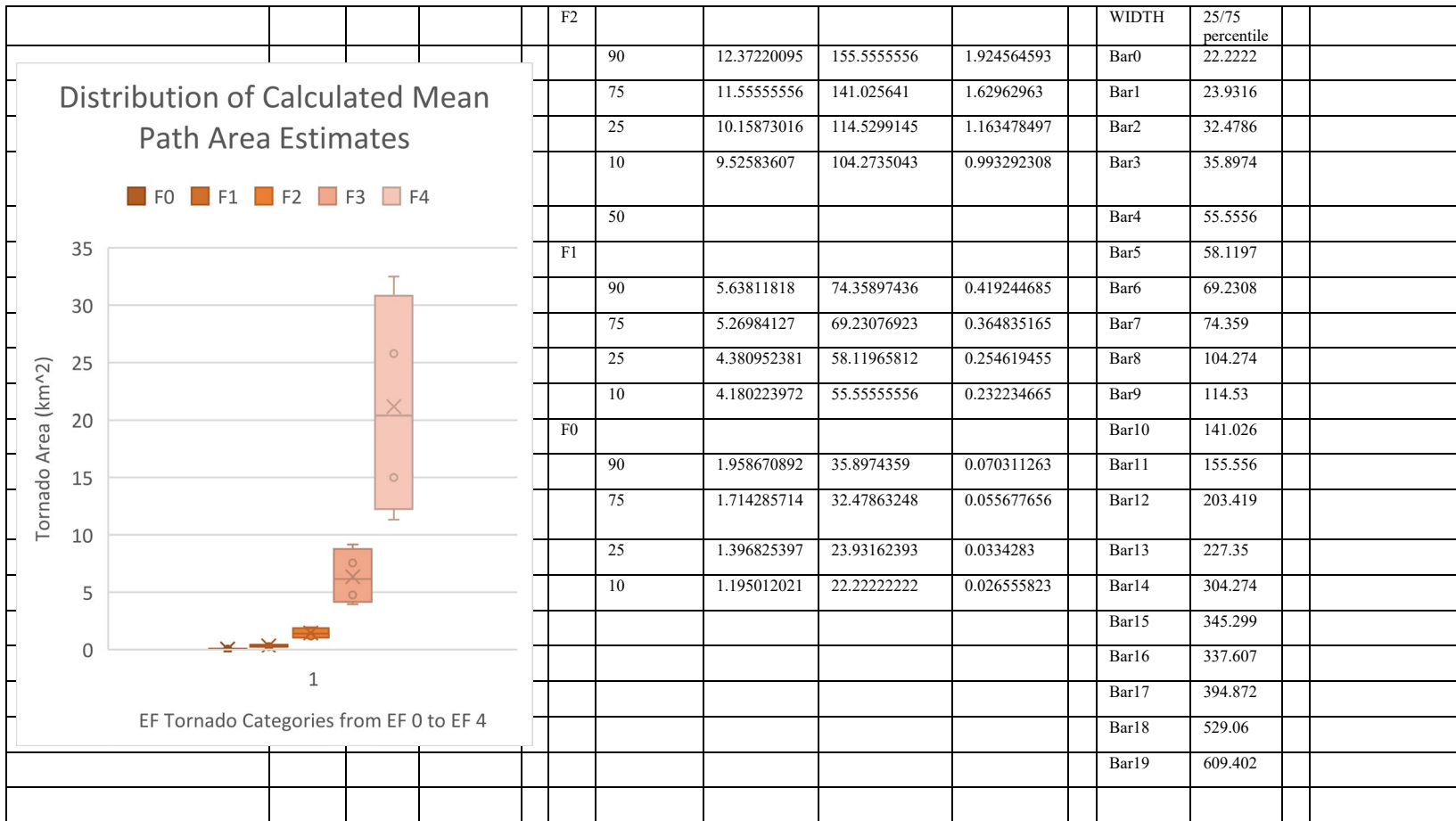


Figure A.4. Raw Length and Width Data cont. (Brooks)

All measurements sourced from Google Maps (May 2022)		
Abilene Box		
Right	111.2	km
Left	111.2	km
Top	93.26	km
Bottom	94.3	km
Avg Height	111.2	km
Avg Width	93.8	km
Area	10428	km ²

Figure A.5. Raw Measurements (Google Maps)