TORNADO AND STRAIGHT WIND HAZARD PROBABILITY

for

MILLSTONE NUCLEAR POWER REACTOR SITE, CONNECTICUT

by

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Prepared for

U.S. Nuclear Regulatory Commission
Site Safety Research Branch
Division of Reactor Safety Research

May, 1980

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Texas Tech University
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FOREWORD

Hazard probability assessment for tornadoes and other extreme winds at the Millstone nuclear power reactor site are presented herein at the request of Robert T. Abbey, Jr., Site Safety Research Branch, Division of Reactor Safety Research, U.S. Nuclear Regulatory Commission. The work is supported under NRC Contract NRC-04-76-345. Principal Investigator and Project Manager for the Institute for Disaster Research is James R. McDonald, P.E.

I. INTRODUCTION

The objective of this report is to assess tornado and straight wind probability hazards at the Millstone nuclear power reactor site. The hazard probability analyses are developed using storm records from the geographical region surrounding the site. Ninety-five percent confidence limits on the probabilities are presented to give an indication of the accuracy of the expected hazard probabilities.

The final hazard probability model is presented graphically in Figure 6. Windspeeds corresponding to selected probability values are summarized in Table 8. The basic data used in the calculations are presented in this report. Derivation of the tornado hazard assessment methodology, the rationale and assumptions are given in McDonald (1980). Use of the Type I extreme value distribution function for straight wind hazard assessment is well documented in Simiu and Scanlan (1978).

POOR ORIGINAL

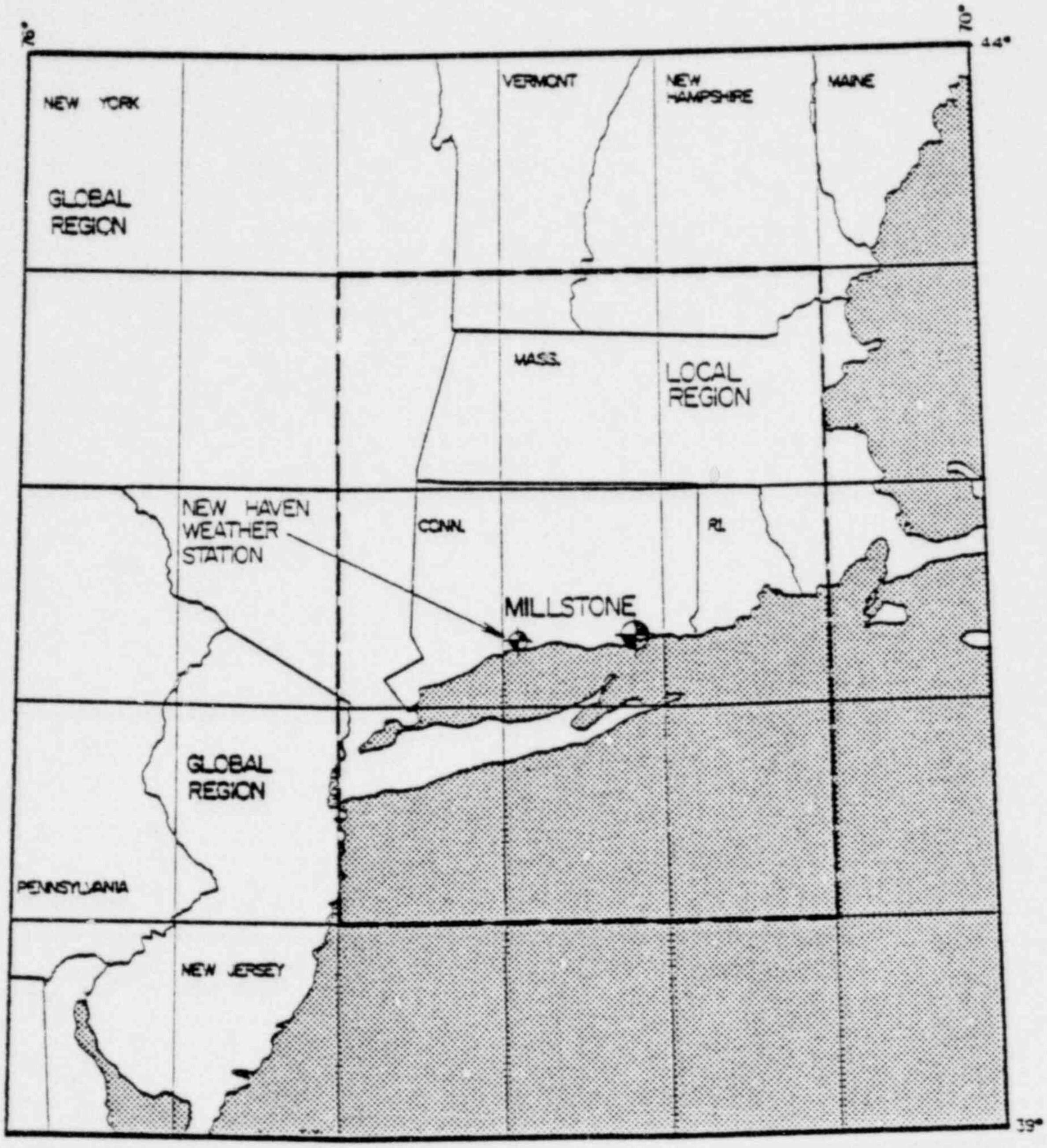

FIGURE 1. LOCAL AND GLOBAL REGIONS FOR MILLSTONE

II. TORNADO HAZARD PROBABILITY ASSESSMENT

A. METHODOLOGY

The tornado hazard model developed by the Institue for Disaster Research (IDR) accounts for gradations of damage across the tornado path width and along its length (McDonald, 1980). There are four basic steps involved in the methodology:

(1) Determination of an area-intensity relationship in a global region surrounding the site of interest.

(2) Determination of an occurrence-intensity relationship in a local region surrounding the site.

(3) Calculation of the probabilities of a point within the local region experiencing windspeeds in some windspeed interval.

(4) Determination of the probability of windspeeds in the local region exceeding the interval values.

B. CALCULATIONS

1. Site

Millstone Nuclear Power Reactor Site

2. Coordinates

Latitude 41^{o} 18' 32" N

Longitude 72^{o} 10' 04" W

3. Area-Intensity Relationship

Global Region

Latitude 39^{o} to 44^{o} N

Longitude 70^{o} to 76^{o} W

Data

DAPPLE Tornado Data Tape UT1678 (Fujita, et al., 1979)

Period of Record

1971 - 1978

See Figure 1 for definition of the global region. The region is selected to be as large as possible and still give reasonably homogenous conditions for tornado formation. The relatively short period of record is used because the data are more complete and accurate than that collected prior to 1971, especially with regard to tornado damage path characteristics. The area-intensity matrix is shown in Table 1. It gives the number of tornadoes in each corresponding area-intensity classification. From this information, the mean damage path area per F-scale can be obtained.

TABLE 1

AREA-INTENSITY MATRIX

Number of Tornadoes*

Area Interval	F0	F1	F2	F3	F4	F5	Mean Area (sq mi)
0	4	13	1	0	0	0	0.316E-02
1	10	26	7	0	0	0	0.100E-01
2	4	25	5	2	0	0	0.316E-01
3	2	12	10	2	0	0	0.100E-00
4	0	5	7	1	0	0	0.316E-00
5	0	2	0	0	0	0	0.100E 01
6	0	0	0	0	1	0	0.316E 01
7	0	0	1	0	0	0	0.100E 02
8	0	0	0	0	0	0	0.316E 02
9	0	0	0	0	0	0	0.100E 03
10	0	0	0	0	0	0	0.316E 03
Totals	20	83	31	5	1	0	

*Those tornadoes outside the dashed lines are considered outliers and have been eliminated from the data set.

Mean Damage Path Area Per F-Scale

	F0	F1	F2	F3	F4	F5
Mean Area, sq mi	0.0220	0.0707	0.4337	0.1158	3.160	--
Median Windspeed, mph	56	92.5	135	182	233.5	289.5

Area-Intensity Function

Linear regression analysis of the above area-intensity data, based on a long-log plot, yields the following functional relationship:

$$\text{Log (Area)} = 2.95 \text{ Log } V - 6.889 \qquad (1)$$

The coefficient of determination is

$$r^2 = 0.897$$

Area-Intensity Relationship

The expected mean area is obtained from Equation (1) above. Upper and lower bound confidence limits are calculated at the 95 percent level. These values are shown in Table 2. Figure 2 shows a plot of the area-intensity relationship.

TABLE 2

AREA-INTENSITY RELATIONSHIP WITH 95 PERCENT CONFIDENCE LIMITS

	F0	F1	F2	F3	F4	F5
Expected Mean area, a_i, sq mi	0.0187	0.0824	0.2516	0.6079	1.2687	2.3933
Lower limit a_i, sq mi	0.0079	0.0349	0.1063	0.2542	0.5239	0.9744
Upper limit a_i, sq mi	0.045	0.194	0.596	1.454	3.072	5.878
Median F-scale Windspeed, mph	56	92.5	135	182	233.5	289.5

4. <u>Occurrence-Intensity Relationship</u>

Local Region

Latitude 40^o to 43^o

Longitude 71^o to 74^o

Area = 32,220 - 11,660
= 20,560 sq mi

An area of 11,660 sq mi is deducted from the local region because of the ocean. There are, of course, no tornadoes recorded over water. See Figure 1 for definition of local region and its relationship to the site.

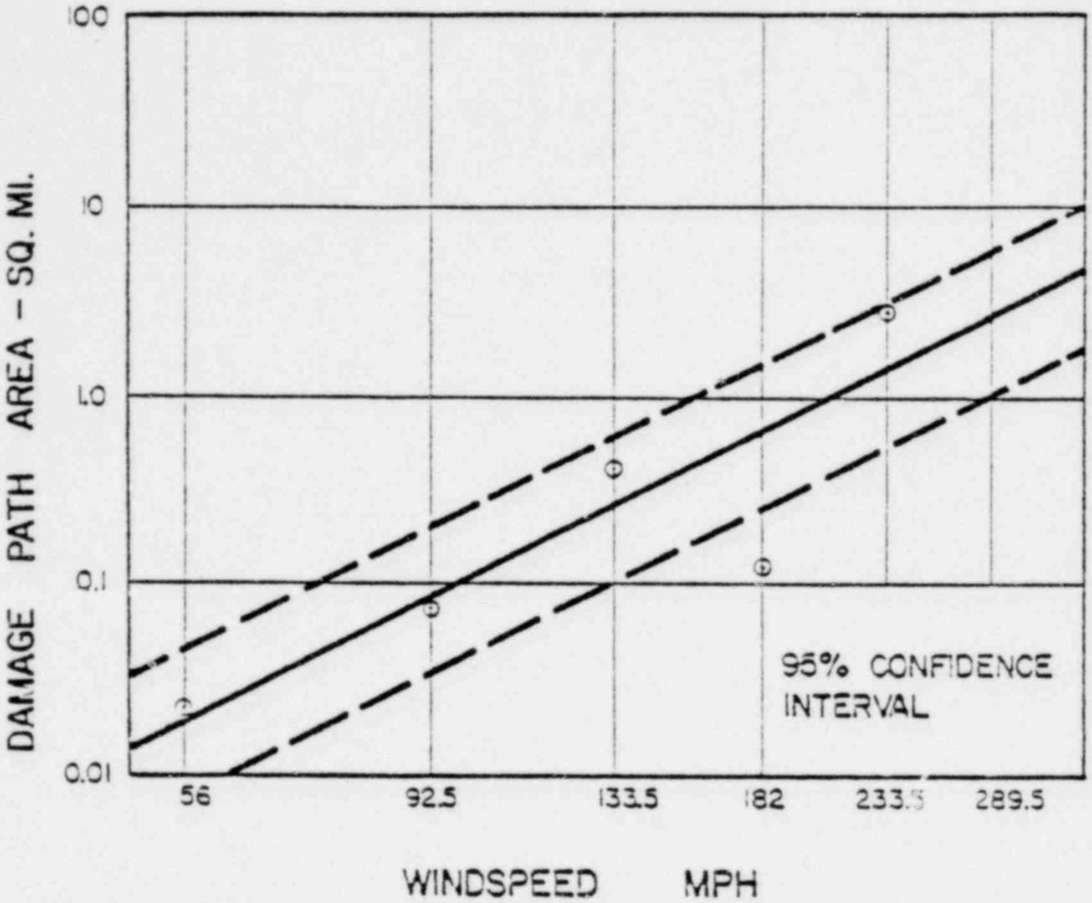

FIGURE 2. AREA-INTENSITY RELATIONSHIP FOR MILLSTONE

Data

DAPPLE Tornado Data Tape UT1678 (Fujita, et al., 1979)

Period of Record

1950 to 1978

The records used do not necessarily include every tornado that has occurred in the local region. For one reason or another, some tornadoes go unreported. Because the population density of the local region is fairly high (greater than 200 persons per sq mi, USNRC, 1979) and because the terrain is such that identifiable paths can be seen should a tornado touch down (damage to structures, trees, fences, or power lines), the number of unreported tornadoes in the region is likely to be less than ten percent. The number of reported tornadoes in the local region is shown in Table 3.

TABLE 3

NUMBER OF TORNADOES IN THE LOCAL REGION

	F0	F1	F2	F3	F4	F5
Number of Tornadoes	38	98	49	9	1	1
Cumulative Number	196	158	60	11	2	1
Lower Bound F-Scale Windspeed, mph	40	73	113	158	207	261

Occurren[illegible]tensity Function

The funct[illegible]ed is obtained by performing a linear regression analysis using [illegible]F0 and F1 tornadoes and another linear regression analysis using t[illegible] F2 to F5 tornadoes. The one F5 tornado in the records is the Worcester tornado of 1953. It creates problems with the occurrence-intensity relationship because it overloads the function towards the more intense tornado side. Because an F5 tornado is a rare event, and because the period of record is only 29 years, the one event will tend to overemphasize the more intense tornadoes. For this reason, a rationale judgment is made to treat the F5 tornado as if it is F4 in defining the occurrence intensity function. Over a longer period of record, a larger number of less intense tornadoes will occur so that if the regression analysis were performed at some time in the future, the net result would be essentially the same as the one performed today using the F5 tornado as an F4.

Linear regression analysis of the data in Table 3 on a semi-log plot gives the following functional relationships:

$$y = (254.51)10^{-0.00284x} \qquad (x < 88 \text{ mph})$$
$$y = (3487.55)10^{-0.0157x} \qquad (x \geq 88 \text{ mph}) \qquad (2)$$

where y is the cumulative number of tornadoes with windspeeds greater than or equal to x.

Occurrence-Intensity Relationship

The expected number of tornadoes in the 29 year period is obtained from the occurrence-intensity function (Equation 2). Upper and lower bound confidence limits are also obtained at the 95 percent level. These values are then divided by the period of record (29 years) to obtain the number of tornadoes per year for each F-scale classification λ_i which is the needed occurrence-intensity relationship required for the hazard probability assessment. Table 4 lists the values used in the probability calculation. Figure 3 shows a plot of the occurrence-intensity relationship.

TABLE 4

OCCURRENCE-INTENSITY RELATIONSHIP
WITH 95 PERCENT CONFIDENCE LIMITS

	F0	F1	F2	F3	F4	F5
Expected number of tornadoes in interval, $\hat{n}$	38.00	99.41	47.08	9.55	1.68	0.278
Lower limit $\hat{n}$	27.15	85.69	35.36	3.65	--	--
Upper limit $\hat{n}$	48.85	113.12	58.81	15.45	4.21	1.31
Expected number of tornadoes per year λ_i	1.31	3.43	1.62	0.33	0.06	0.010
Lower limit λ_i	.93	2.95	1.22	0.13	--	--
Upper limit λ_i	1.68	3.90	2.03	0.53	0.15	.045

5. Tornado Hazard Probability

The tornado hazard probability calculations are performed by computer, although they can easily be done by hand. The expected hazard probabilities are obtained by using the expected area-intensity relationship (a_i) and the expected occurrence-intensity relationship (λ_i). Upper and lower limits of hazard probability are obtained by using the upper and lower limit λ_i's and a_i's respectively. The computer printouts for these calculations are contained in Appendix A.

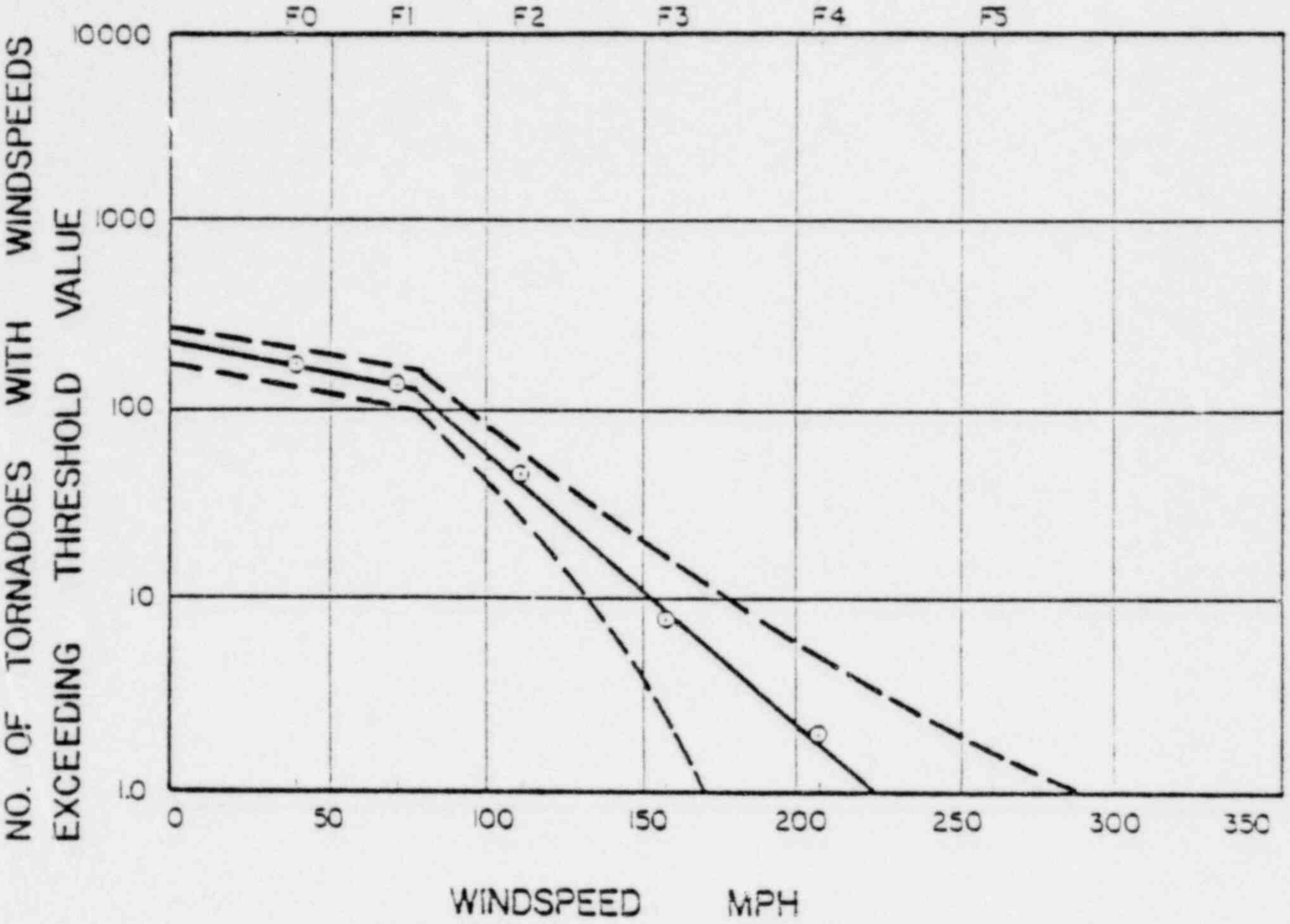

FIGURE 3. OCCURRENCE-INTENSITY RELATIONSHIP FOR MILLSTONE

Table 5 summarizes the tornado hazard probabilities, and includes the 95 percent confidence limits. The tornado hazard probability model is plotted in Figure 4. Final hazard probability results are summarized in Section IV of this report.

TABLE 5

TORNADO HAZARD PROBABILITIES
WITH 95 PERCENT CONFIDENCE LIMITS

Mean Recurrence Interval	Hazard Probability Per Year	Tornado Windspeeds, mph		
		Expected Value	Lower Limit	Upper Limit
10,000	1.0×10^{-4}	39	10	81
100,000	1.0×10^{-5}	120	74	170
1,000,000	1.0×10^{-6}	184	140	239
10,000,000	1.0×10^{-7}	245	203	314

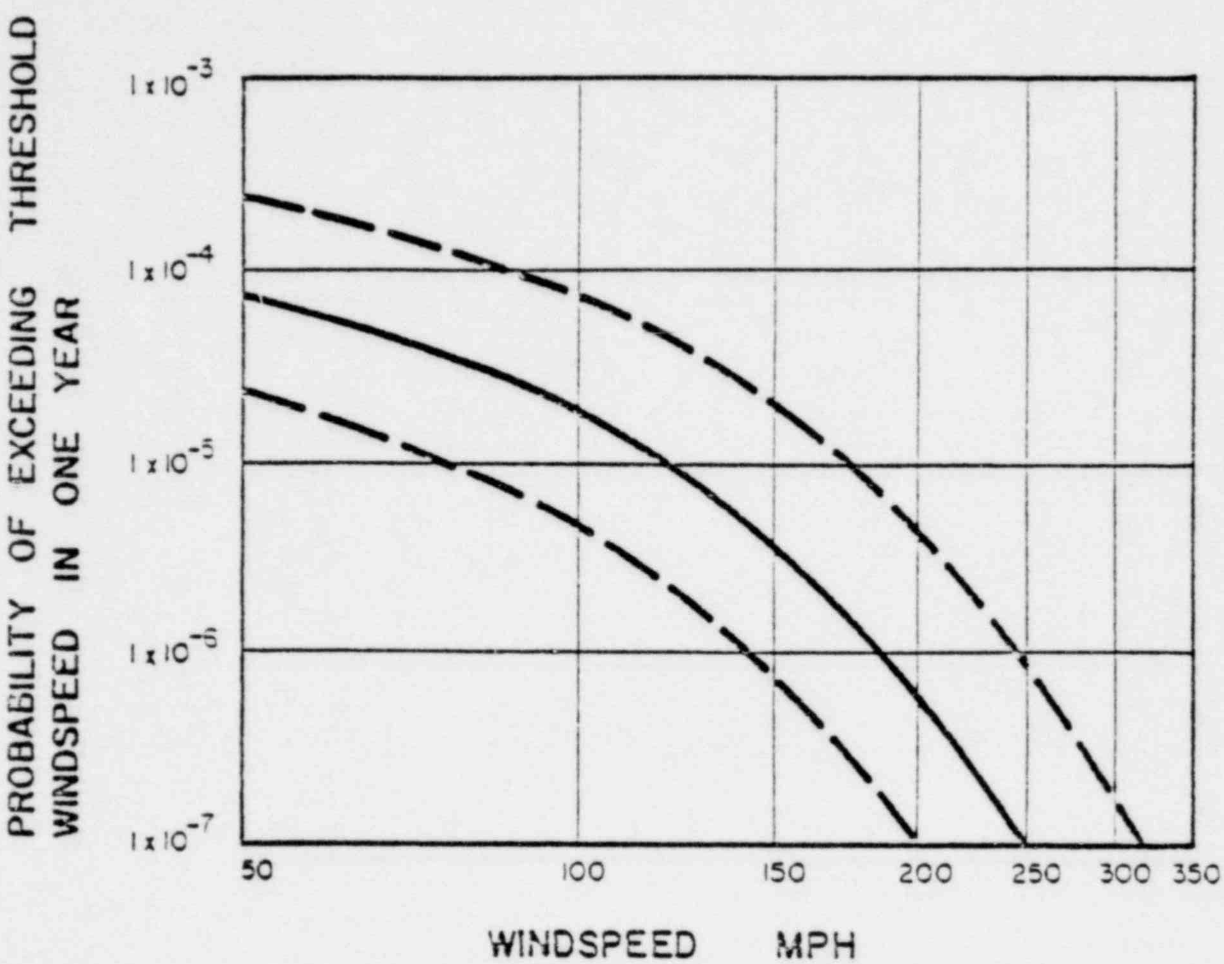

FIGURE 4. TORNADO HAZARD PROBABILITY MODEL WITH 95 PERCENT CONFIDENCE LIMITS

III. STRAIGHT WIND HAZARD ASSESSMENT

A. METHODOLOGY

A set of annual extreme fastest mile windspeeds are used to fit a cumulative probability distribution function in order to obtain the straight wind hazard probabilities. The Type I extreme value function generally fits the data well. In view of the studies by Simiu and Filliben (1975), the Type I distribution function is used in lieu of the Type II that was used previously (ANSI, 1972). A detailed description of the methodology is given in Simiu and Scanlan (1978).

B. CALCULATIONS

Annual extreme fastest-mile windspeed data are not available at the power plant site. The closest weather station with the needed data is New Haven, Connecticut, which is located twenty-five miles southwest of the site (See Figure 1). Terrain and meteorological conditions are such that the data should be representative of wind conditions at the site.

The data are taken from weather records from the Environmental Data Service, National Climatic Center, Asheville, North Carolina, and covers the eighty-year period 1888 to 1968. The set of annual extreme fastest mile windspeeds for New Haven, Connecticut is given in Table 6. The windspeeds have been adjusted to a standard anemometer height of 10 m.

A type I extreme value distribution function is fit to the data. The expected windspeeds for various mean recurrence intervals along with 95 percent confidence limits are given in Table 7.

TABLE 6

ANNUAL EXTREME FASTEST-MILE WINDSPEEDS
AT NEW HAVEN, CONNECTICUT

Year	Windspeed mph	Year	Windspeed mph
1888	46	1928	35
1889	33	1929	38
1890	41	1930	29
1891	32	1931	27
1892	?	1932	32
1893	38	1933	32
1894	31	1934	33
1895	40	1935	35
1896	41	1936	34
1897	38	1937	33
1898	36	1938	37
1899	33	1939	39
1900	36	1940	39
1901	38	1941	30
1902	41	1942	30
1903	51	1943	26
1904	43	1944	38
1905	38	1945	37
1906	32	1946	39
1907	38	1947	41
1908	43	1948	26
1909	39	1949	33
1910	40	1950	55
1911	38	1951	41
1912	38	1952	37
1913	38	1953	35
1914	42	1954	45
1915	43	1955	42
1916	32	1956	33
1917	33	1957	38
1918	35	1958	34
1919	38	1959	48
1920	32	1960	41
1921	30	1961	44
1922	33	1962	44
1923	30	1963	50
1924	38	1964	43
1925	38	1965	42
1926	37	1966	48
1927	40	1967	44
		1968	54

Mean Windspeed: 37.8 mph

Standard Deviation: 5.96 mph

TABLE 7

STRAIGHT WIND HAZARD PROBABILITIES
WITH 95 PERCENT CONFIDENCE LIMITS

Mean Recurrence Interval	Hazard Probability	Expected Fastest-Mile Windspeed, mph	Upper Limit mph	Lower Limit mph
10	1.0×10^{-1}	46	48	43
20	5.0×10^{-2}	49	52	45
50	2.0×10^{-2}	53	58	49
100	1.0×10^{-2}	56	62	51
200	5.0×10^{-3}	60	66	54
500	2.0×10^{-3}	64	71	57
1,000	1.0×10^{-3}	67	75	60
10,000	1.0×10^{-4}	78	88	68
100,000	1.0×10^{-5}	89	101	76
1,000,000	1.0×10^{-6}	99	114	84

The straight wind hazard probabilities along with the 95 percent confidence limits are presented in Figure 5.

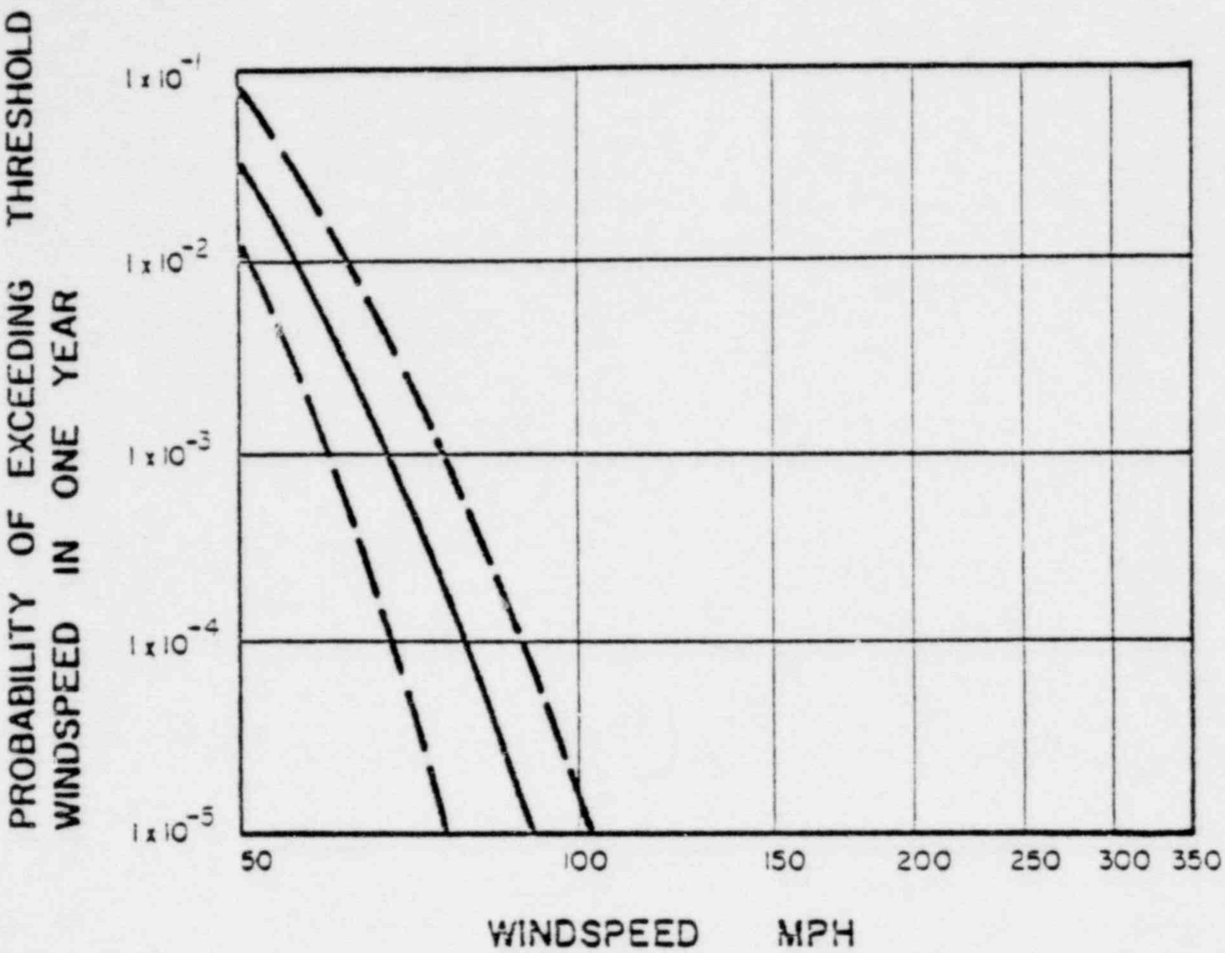

FIGURE 5. STRAIGHT WIND HAZARD PROBABILITIES WITH 95 PERCENT CONFIDENCE LIMITS

IV. WINDSPEED HAZARD PROBABILITY MODEL

Windspeed hazard probability, which includes both tornadoes and straight winds, is the probability of a point within some defined geographical region experiencing windspeeds greater than or equal to some threshold value in one year. Tornado hazard probabilities are the same at any point within the defined local region. The Type I extreme value distribution function obtained from data collected at New Haven, Connecticut is used for the straight wind probability hazard assessment at the Millstone reactor site. Thus, in effect, New Haven and the reactor site are contained in a common local region.

Tornado windspeeds are referenced to 30 ft above ground level (approximately 10 m) and are the maximum horizontal windspeeds. According to Fujita (1971), F-scale windspeeds are fastest-one-quarter mile winds. However, because of the translational speed of a tornado, winds acting on a structure may be of considerably shorter duration. Because tornado windspeeds are based on appearance of damage, they are considered to be effective velocities, which include effects of gust, structure size and structure frequency. For design purposes, the gust response factor for tornado winds may be taken as unity.

The straight winds are fastest-mile windspeeds which have a variable time duration, depending on the magnitude of the windspeeds. Values are normalized to a 10 m anemometer height. For design purposes, gust response factors greater than unity are appropriate (See ANSI A58.1, 1972).

The tornado and straight wind models are combined in Figure 6 to obtain the final windspeed model. For design or evaluation purposes, one needs to know the type of storm that controls the criteria. For windspeeds less than 105 mph, the straight wind model governs. For windspeeds greater than 105 mph, the tornado model governs. In the case of a tornado, the atmospheric pressure change and missiles must be taken into account in addition to the wind effects. Because of this, the union of the two events (tornado and straight winds) is not of particular interest. Table 8 summarizes the final windspeed hazard probabilities.

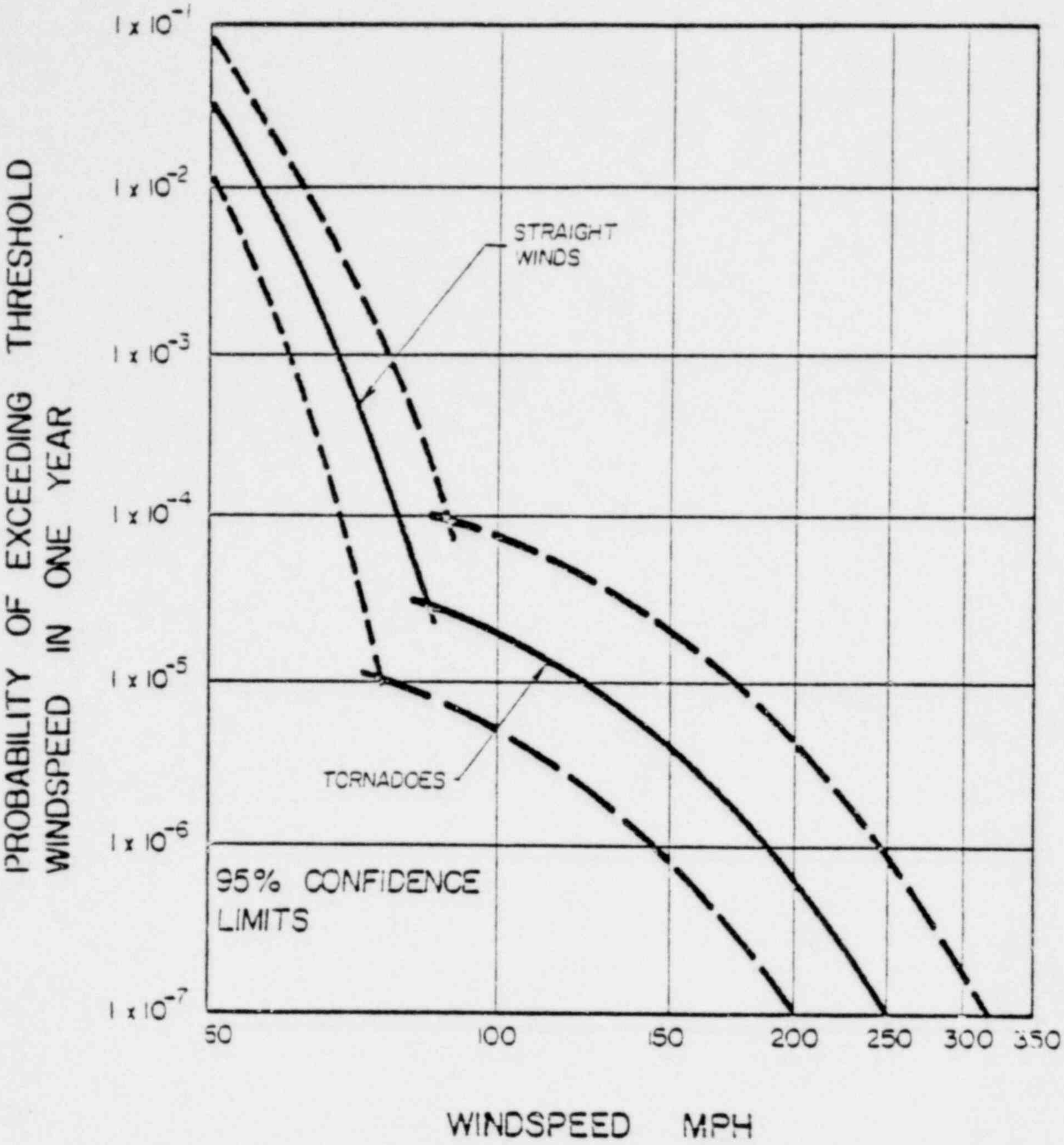

FIGURE 6. TORNADO AND STRAIGHT WIND HAZARD PROBABILITY MODEL FOR MILLSTONE POWER REACTOR SITE, CONNECTICUT

TABLE 8

SUMMARY OF WINDSPEED HAZARD PROBABILITIES FOR MILLSTONE

Mean Recurrence Interval	Hazard Probability	Expected Windspeed mph	Type of Storm
10	1.0×10^{-1}	46	Straight Wind
100	1.0×10^{-2}	56	Straight Wind
1,000	1.0×10^{-3}	67	Straight Wind
10,000	1.0×10^{-4}	78	Straight Wind
100,000	1.0×10^{-5}	120	Tornado
1,000,000	1.0×10^{-6}	184	Tornado
10,000,000	1.0×10^{-7}	245	Tornado

REFERENCES

1. ANSI, 1972: "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures," A58.1, American National Standards Institute, Inc., New York, New York.

2. Fujita, T. T., 1971: "Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity,: SMRP No. 91, The University of Chicago, Chicago, Illinois.

3. Fujita, T. T., Tecson, J. J., and Abbey, R. F., 1979: "Statistics of U. S. Tornadoes Based on the DAPPLE Tornado Tape," 11th Conference on Severe Local Storms, Kansas City, Missouri, October 2-5, 1979; published by American Meteorological Society, Boston, Massachusetts.

4. McDonald, J. R., 1980: "A Methodology for Tornado Hazard Assessment," Institute for Disaster Research, Texas Tech University, Lubbock, Texas.

5. Simiu, E. and Scanlan, R. H., 1978: <u>Wind Effects on Structures</u>, John Wiley and Sons, New York, New York.

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APPENDIX A. COMPUTER PRINTOUTS

ASSESSMENT OF TORNADO RISK

PROGRAM BY JAMES R. MCDONALD,P.E. (4/3/79)

MILLSTONE REACTOR SITE EXPECTED PROBABILITY VALUES

K MATRIX

						A I	FAM I
1.075	0.000	0.000	0.000	0.000	0.000	0.019	1.310
1.420	0.455	0.000	0.000	0.000	0.000	0.002	3.428
1.067	0.512	0.291	0.000	0.000	0.000	0.252	1.624
0.927	0.482	0.280	0.174	0.000	0.000	0.208	0.359
0.962	0.421	0.261	0.128	0.087	0.000	1.269	0.058
0.965	0.387	0.228	0.160	0.077	0.043	2.193	0.010

XEAN(I,J) K(I,J)*A(I)*FAM(I)

0.046	0.000	0.000	0.000	0.000	0.000	
0.401	0.125	0.000	0.000	0.000	0.000	
0.435	0.267	0.119	0.000	0.000	0.000	
0.185	0.096	0.055	0.015	0.000	0.000	
0.071	0.031	0.019	0.009	0.002	0.000	
0.022	0.009	0.005	0.004	0.002	0.001	
------	------	------	------	------	------	
1.161	0.474	0.199	0.040	0.008	0.001	SUMMATION OF Z(I)
20560	20560	20560	20560	20560	20560	AREA OF LOCAL REGION SQ MI
5.65E 005	2.31E 005	9.70E 006	2.33E 006	3.97E 007	4.29E 008	PROB OF WINDSPEED IN INTERVAL I J
9.20E 005	3.55E 005	1.25E 005	2.77E 006	4.44E 007	4.29E 008	PROB OF EXCEED WINDSPEED IN INTERVAL I J
40	73	113	158	207	261	LOWER BOUND WINDSPEED IN INTERVAL I J

POOR ORIGINAL

ASSESSMENT OF TORNADO RISK

PROGRAM BY JAMES R. MCDONALD,P.E. (4/3/79)

MILLSTONE REACTOR SITE UPPER LIMIT 95% CONFIDENCE

K MATRIX

						A I	LAM I
1.875	0.000	0.000	0.000	0.000	0.000	0.045	1.684
1.420	0.455	0.000	0.000	0.000	0.000	0.194	3.901
1.067	0.512	0.298	0.000	0.000	0.000	0.596	2.028
0.927	0.482	0.280	0.174	0.000	0.000	1.454	0.533
0.962	0.421	0.261	0.128	0.087	0.000	3.072	0.145
0.965	0.387	0.228	0.166	0.077	0.042	5.878	0.045

ALAM(I,J)=K(I,J)*A(I)*LAM(I)

0.142	0.000	0.000	0.000	0.000	0.000	
1.075	0.344	0.000	0.000	0.000	0.000	
1.290	0.619	0.352	0.000	0.000	0.000	
0.718	0.374	0.217	0.135	0.000	0.000	
0.429	0.188	0.116	0.057	0.039	0.000	
0.255	0.102	0.060	0.042	0.020	0.011	
-----	-----	-----	-----	-----	-----	
3.909	1.627	0.745	0.334	0.059	0.011	SUMMATION ALAM(J)
20560	20560	20560	20560	20560	20560	AREA OF LOCAL REGION SQ MI
1.90E-004	7.91E-005	3.62E-005	1.14E-005	2.88E-006	5.40E-007	PROB OF WINDSPEED IN INTERVAL IJ
3.20E-004	1.30E-004	5.11E-005	1.48E-005	3.43E-006	5.40E-007	PROB OF EXCEED WINDSPEED IN INTERVAL IJ
40	73	113	158	207	261	LOWER BOUND WINDSPEED IN INTERVAL IJ

POOR ORIGINAL

ASSESSMENT OF TORNADO RISK

PROGRAM BY JAMES R. MCDONALD,P.E. (4/3/79)

MILLSTONE REACTOR SITE LOWER LIMIT 95% CONFIDENCE

K MATRIX

						A I	LAM I
1.875	0.000	0.000	0.000	0.000	0.000	0.008	0.936
1.420	0.455	0.000	0.000	0.000	0.000	0.035	2.955
1.067	0.513	0.291	0.000	0.000	0.000	0.105	1.219
0.927	0.482	0.280	0.174	0.000	0.000	0.254	0.126
0.962	0.421	0.261	0.128	0.087	0.000	0.524	0.035
0.965	0.387	0.228	0.160	0.077	0.043	0.974	0.004

WLAM(I,J)=K(I,J)*A(I)*LAM(I)

0.014	0.000	0.000	0.000	0.000	0.000	
0.146	0.047	0.000	0.000	0.000	0.000	
0.138	0.056	0.038	0.000	0.000	0.000	
0.030	0.015	0.009	0.006	0.000	0.000	
0.018	0.008	0.005	0.002	0.002	0.000	
0.004	0.002	0.001	0.001	0.000	0.000	
-----	-----	-----	-----	-----	-----	
0.350	0.138	0.052	0.009	0.002	0.000	SUMMATION WLAM(I)
20560	20560	20560	20560	20560	20560	AREA OF LOCAL REGION SQ MI
1.70E-005	6.71E-006	2.55E-006	4.15E-007	9.23E-008	7.92E-009	PROB OF WINDSPEED IN INTERVAL I-J
2.60E-005	9.77E-006	3.06E-006	5.15E-007	1.00E-007	7.92E-009	PROB OF EXCEED WINDSPEED IN INTERVAL I-J
40	73	113	158	207	261	LOWER BOUND WINDSPEED IN INTERVAL I-J