TORNADO AND STRAIGHT WIND HAZARD PROBABILITY

for

DRESDEN NUCLEAR POWER REACTOR SITE, ILLINOIS

by

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Prepared for

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

May, 1980

Institute for Disaster Research
Texas Tech University
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FOREWORD

Hazard probability assessment for tornadoes and other extreme winds at the Dresden nuclear power reactor site are presented herein at the request of Robert F. 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 Dresden nuclear power reactor site (See Figure 1). 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).

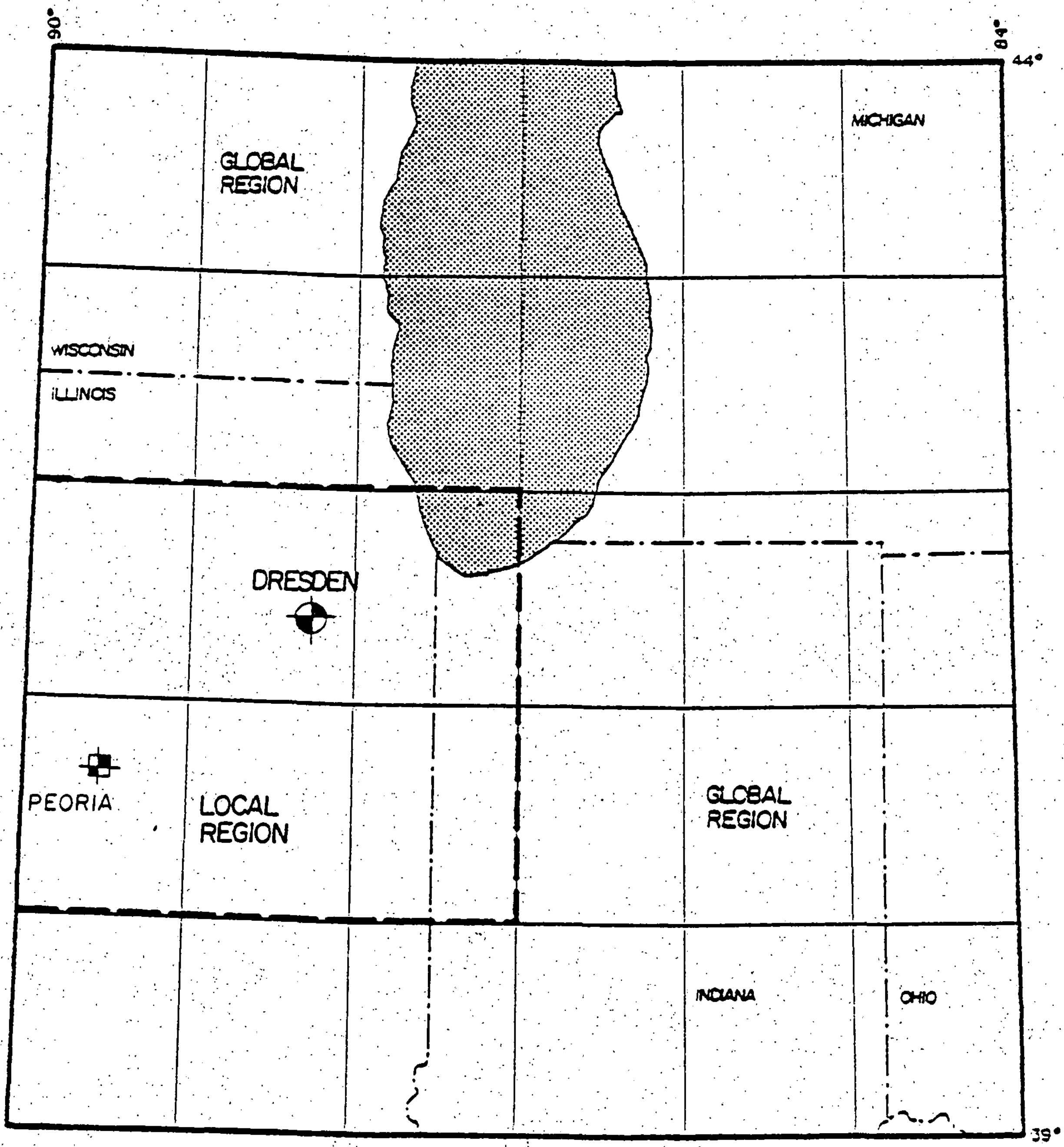

FIGURE 1. LOCAL AND GLOBAL REGIONS FOR DRESDEN

II. TORNADO HAZARD PROBABILITY ASSESSMENT

A. METHODOLOGY

The tornado hazard model developed by the Institute 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. <u>Site</u>

Dresden Nuclear Power Generating Station

2. <u>Coordinates</u>

Latitude 41° 23' 23" N

Longitude 88° 16' 17" W

3. <u>Area-Intensity Relationship</u>

Global Region

Latitude 39° to 44° N

Longitude 84° to 90° 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	91	28	6	0	0	0	0.316E-02
1	32	51	17	0	0	0	0.100E-01
2	16	61	19	4	0	0	0.316E-01
3	12	33	31	6	0	0	0.100E-00
4	6	28	17	5	0	0	0.316E-00
5	0	11	15	2	1	0	0.100E 01
6	0	2	7	8	6	1	0.316E 01
7	0	0	0	4	4	0	0.100E 02
8	0	0	0	1	1	0	0.316E 02
9	0	0	0	0	2	0	0.100E 03
10	0	0	0	0	0	0	0.316E 03
Totals	157	214	112	30	14	1	

*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	0.0268	0.1495	0.4141	3.3729	20.826	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:

$$\text{Log (Area)} = 3.744 \text{ Log } V - 8.173 \qquad (1)$$

The coefficient of determination is

$$r^2 = 0.974$$

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	.0236	.1546	.6367	1.9486	4.9535	11.0788
Lower Limit a_i, sq mi	.0119	.0783	.3221	.9846	2.4990	5.5789
Upper limit a_i, sq mi	.047	.305	1.258	3.856	9.819	22.001
Median F-scale Windspeed, mph	56	92.5	135	182	233.5	289.5

4. Occurrence-Intensity Relationship

Local Region

Latitude 40^o to 42^o

Longitude 87^o to 90^o

Area = 21,645 - 650

= 20,995 sq mi

An area of 650 sq mi is deducted from the local region because of Lake Michigan. There are, of course, no tornadoes recorded over water. See Figure 1 for definition of local region and its relationship to the site.

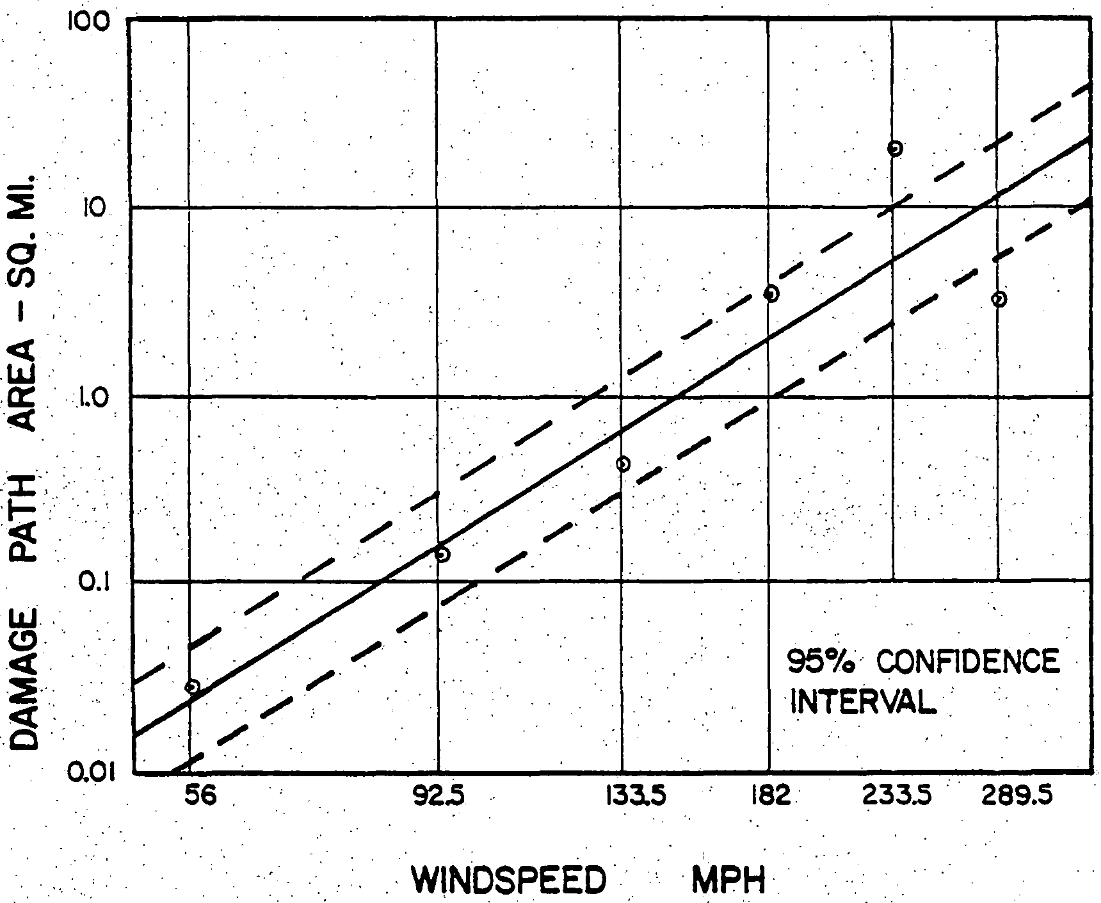

FIGURE 2. AREA-INTENSITY RELATIONSHIP FOR DRESDEN

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 high (greater than 800 persons per square mile) 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 five 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	86	122	79	24	7	0
Cumulative Number	318	232	110	31	7	0
LowerBound F-Scale Windspeed, mph	40	73	113	158	207	261

Occurrence-Intensity Function

The function used is obtained by performing a linear regression analysis using the F0 and F1 tornadoes and another linear regression analysis using the F2 to F5 tornadoes.

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

$$y = (466.02)10^{-0.00415x} \quad (x < 96 \text{ mph})$$
$$y = (3077.02)10^{-0.01273x} \quad (x \geq 96 \text{ mph}) \qquad (2)$$

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, $\hat{n}$	86.00	119.99	82.07	22.82	5.66	1.46
Lower limit $\hat{n}$	70.48	103.05	66.78	13.80	1.04	--
Upper limit $\hat{n}$	101.53	136.93	97.36	31.84	10.28	3.83
Expected number of tornadoes per year λ_i	2.97	4.14	2.83	0.79	0.20	0.05
Lower limit λ_i	2.43	3.55	2.30	0.48	0.04	--
Upper limit λ_i	3.50	4.72	3.36	1.10	0.35	0.13

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.

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.

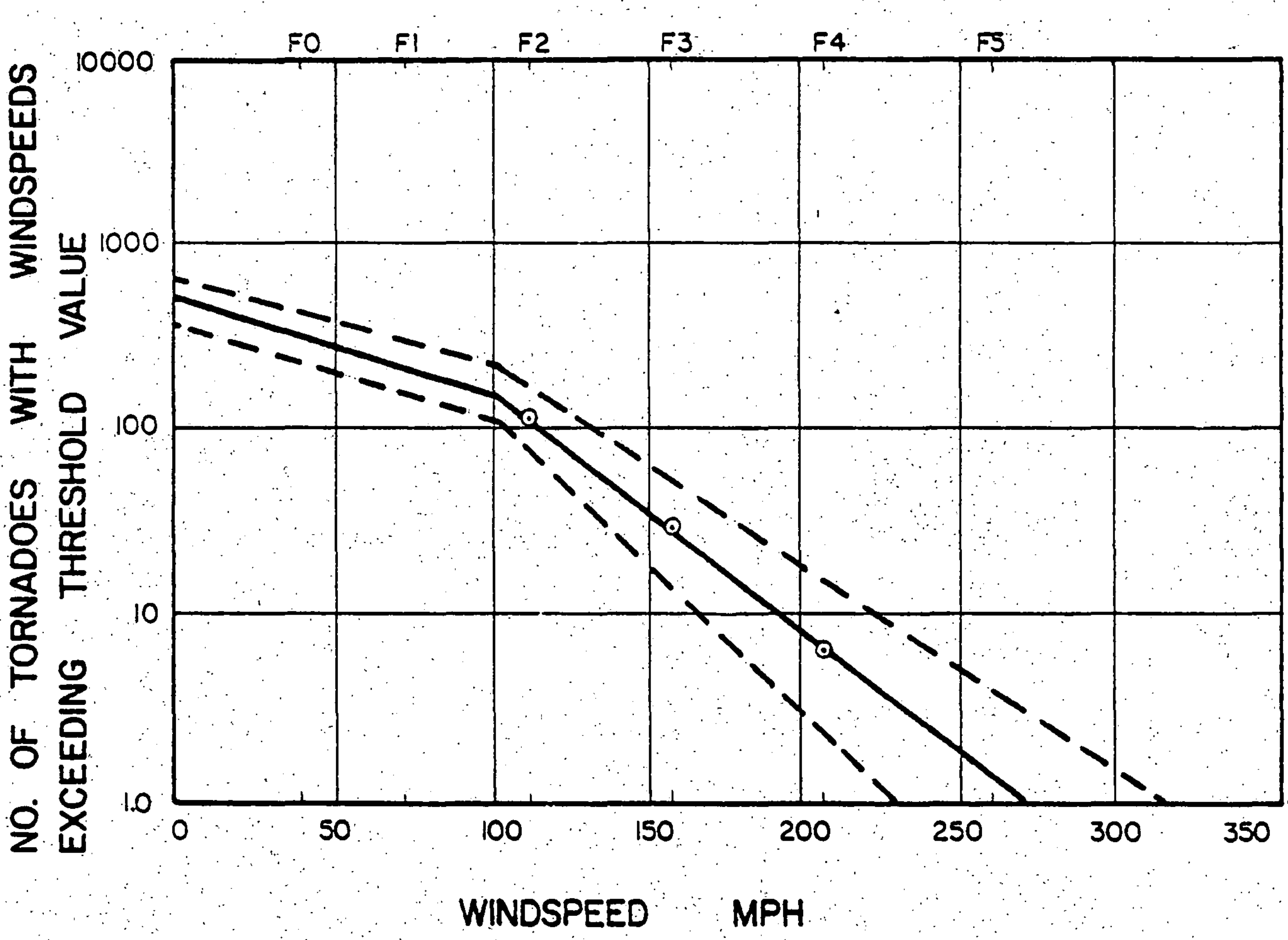

FIGURE 3. OCCURRENCE-INTENSITY RELATIONSHIP WITH 95 PERCENT CONFIDENCE LIMITS

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}	102	56	162
100,000	1.0×10^{-5}	195	138	242
1,000,000	1.0×10^{-6}	261	200	321
10,000,000	1.0×10^{-7}	337	259	417

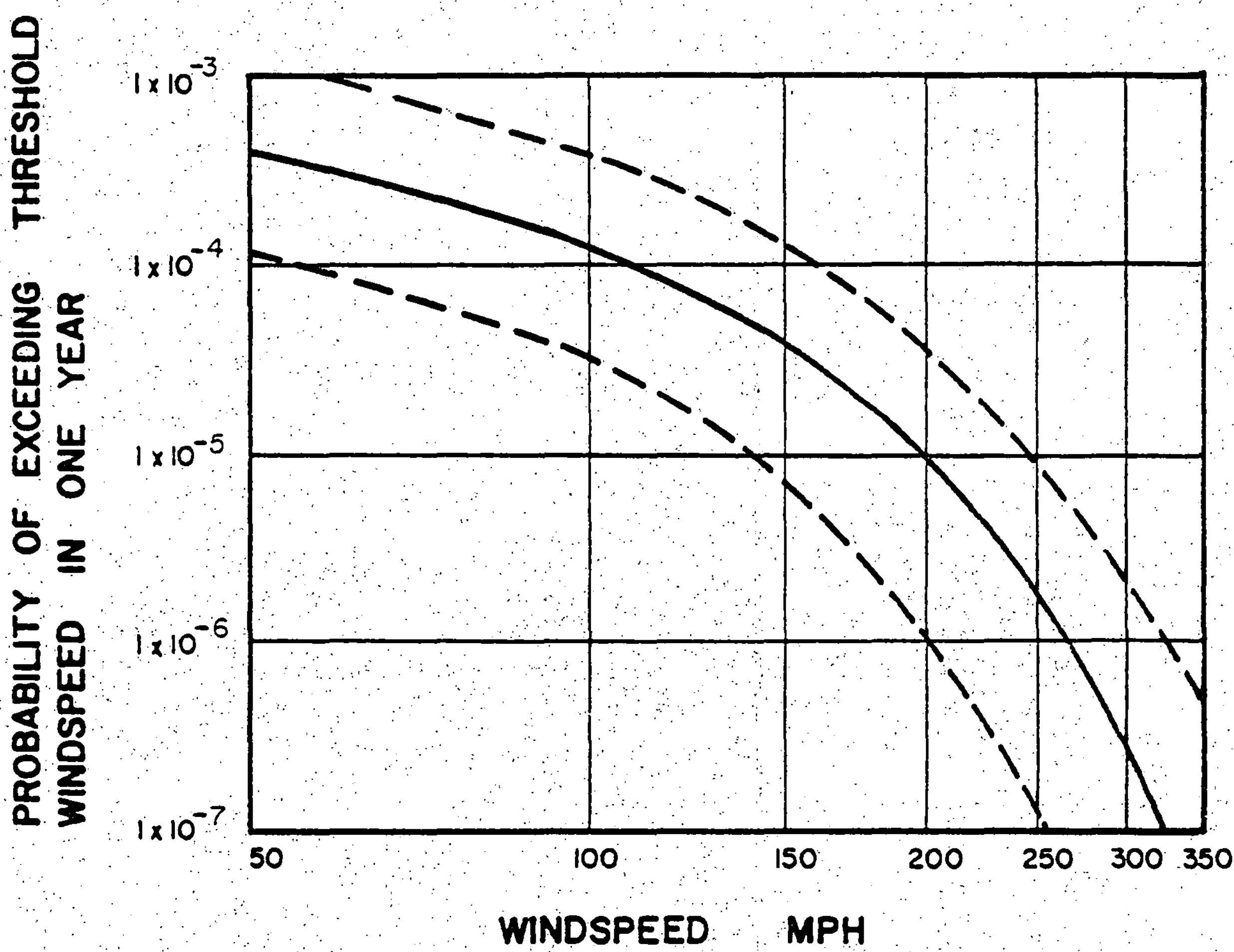

FIGURE 4. TORNADO HAZARD PROBABILITY MODEL WITH 95 PERCENT CONFIDENCE LIMITS

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 reactor site. Although the closest weather station with the needed data is Midway Airport (located approximately 40 mi northwest of the site), it is felt that the data at Peoria, Illinois (located 83 mi southwest of the site) is a better representative for wind conditions at the site.

The data are taken from Simiu, Changery and Filliben (1979) and covers the 35-year period 1943 to 1977. Statistical tests performed by Simiu (1979) indicate that the Type I extreme value distribution does not fit the Peoria data quite as well as some other locations within the United States (the tail length parameter γ is 350 rather than infinity as required for a true Type I distribution). However, because the Type II distribution predicts windspeed values at low probability levels that exceed the physical characteristics of the wind, the Type I distribution function is recommended for straight wind hazard probability assessment at this site. The Type I distribution as found in Simiu, Changery and Filliben (1979) for Peoria is used for the straight wind model at the Dresden reactor site.

The set of annual extreme fastest-mile windspeeds for Peoria, Illinois are given in Table 6, along with the date and direction. The windspeeds have been adjusted to a standard anemometer height of 10 m. The straight wind hazard probabilities for various mean recurrence intervals, along with 95 percent confidence limits, are shown in Table 7. The same data are plotted in Figure 5.

TABLE 6

ANNUAL EXTREME FASTEST-MILE WINDSPEEDS
AT ALBANY, NEW YORK

Year	Windspeed mph	Direction	Date
1943	63	NW	07/28
1944	52	E	04/11
1945	52	SW	11/08
1946	52	W	06/12
1947	69	SW	04/05
1948	54	SW	12/05
1949	49	W	01/27
1950	57	SW	05/05
1951	47	W	09/26
1952	47	SW	11/26
1953	70	NW	07/05
1954	51	SW	05/31
1955	47	NW	03/22
1956	61	W	08/13
1957	49	SW	03/14
1958	56	SW	10/09
1959	56	W	09/26
1960	51	NW	05/24
1961	47	SW	03/27
1962	44	W	04/30
1963	45	NW	07/19
1964	61	W	11/20
1965	56	W	09/14
1966	44	NW	03/31
1967	50	NW	02/23
1968	43	NW	12/04
1969	47	W	06/25
1970	48	NE	05/13
1971	50	SW	12/15
1972	41	W	01/24
1973	59	NW	06/16
1974	54	W	07/14
1975	55	W	07/23
1976	47	W	03/04
1977	48	SW	03/30

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}	62	67	57
20	5.0×10^{-2}	66	72	60
50	2.0×10^{-2}	71	79	63
100	1.0×10^{-2}	75	84	66
200	5.0×10^{-3}	79	90	69
500	2.0×10^{-3}	84	96	72
1,000	1.0×10^{-3}	88	102	75
10,000	1.0×10^{-4}	102	119	84
100,000	1.0×10^{-5}	115	137	93
1,000,000	1.0×10^{-6}	128	154	102

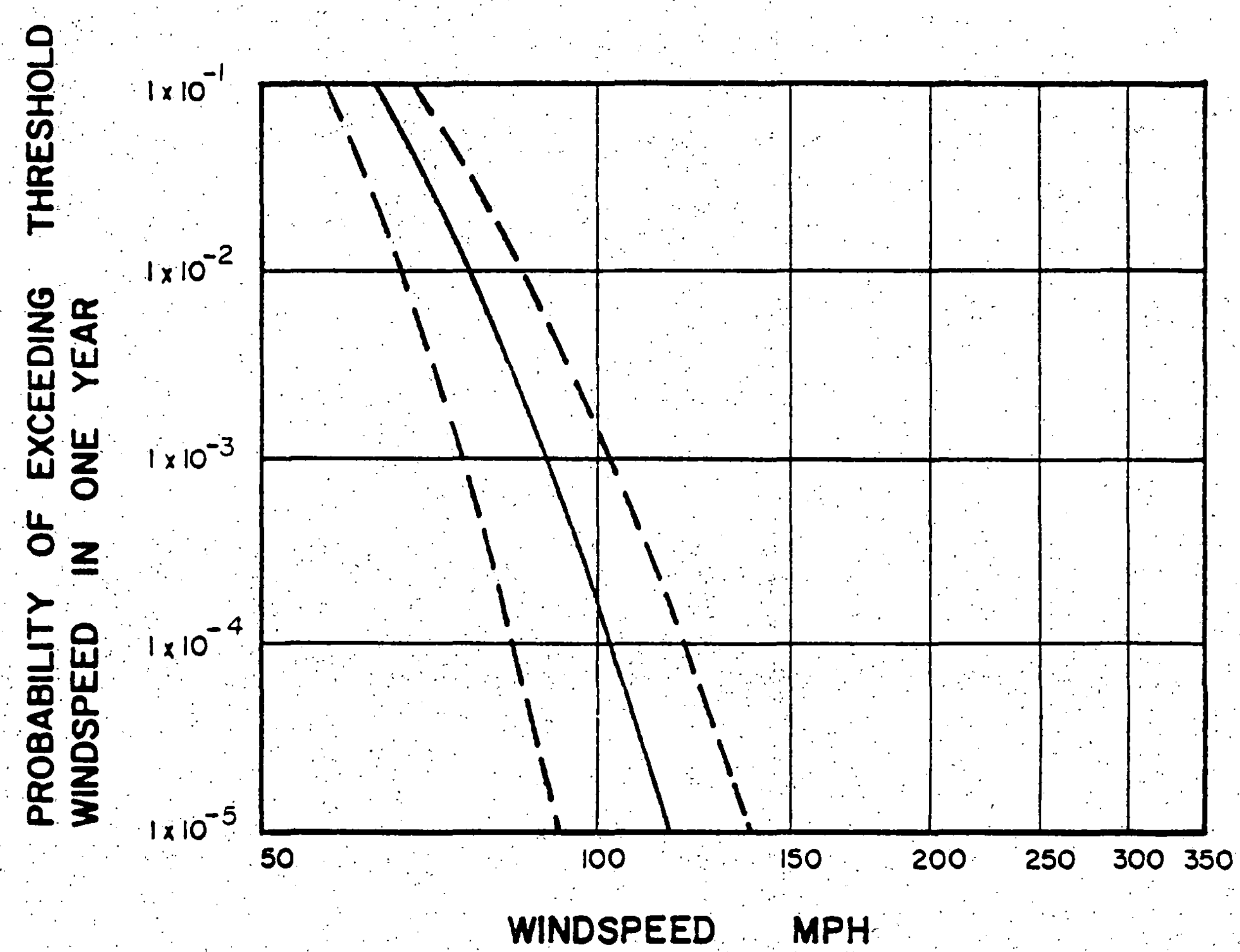

FIGURE 5. STRAIGHT WIND HAZARD PROBABILITIES WITH 95 PERCENT CONFIDENCE LIMITS

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 Peoria, Illinois is used for the straight wind probability hazard assessment at the Dresden reactor site. Thus, in effect, Peoria 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 102 mph, the straight wind model governs. For windspeeds greater than

102 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.

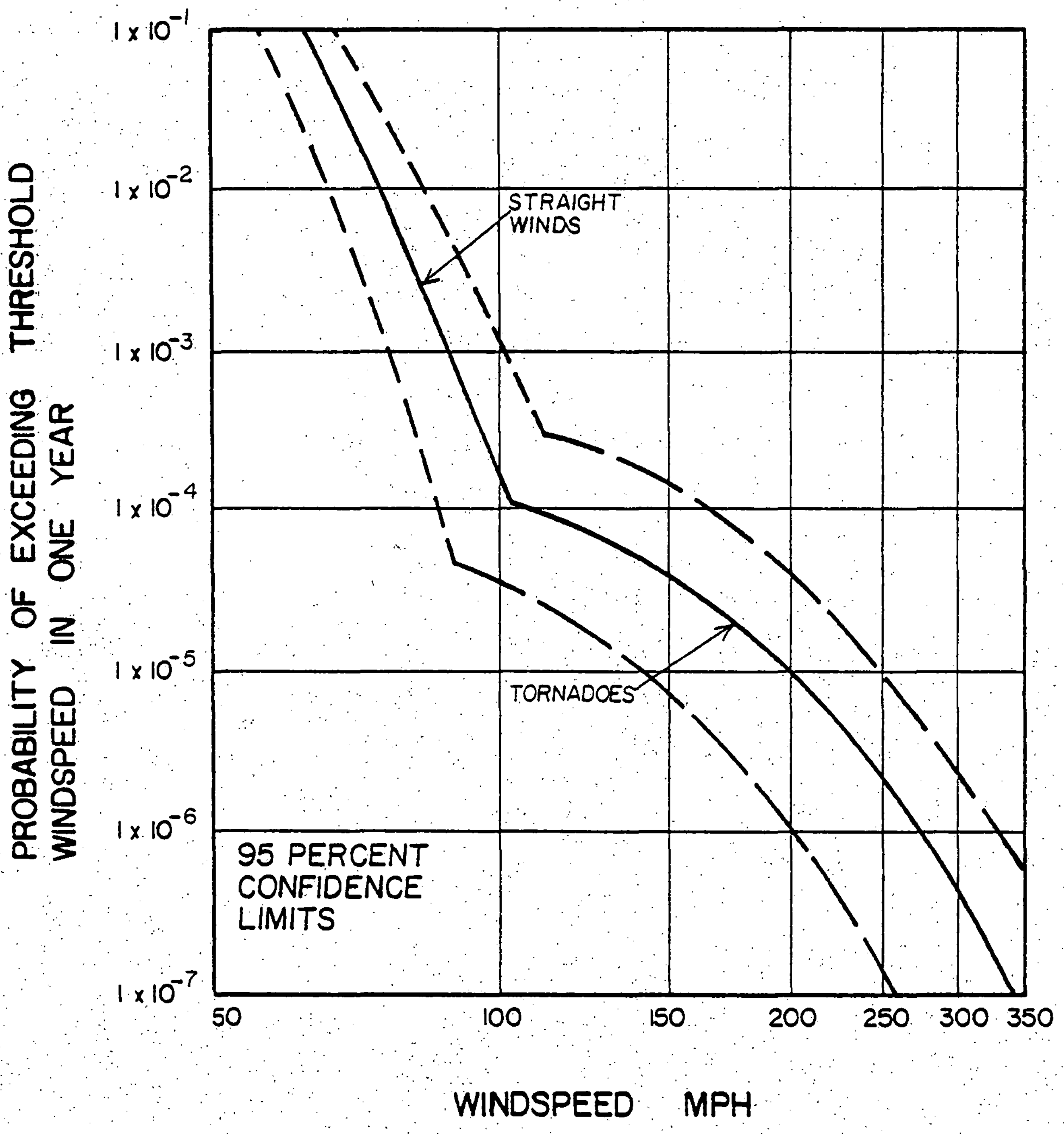

FIGURE 6. TORNADO AND STRAIGHT WIND HAZARD PROBABILITY MODEL FOR THE DRESDEN POWER REACTOR SITE, ILLINOIS

TABLE 8

SUMMARY OF WINDSPEED HAZARD PROBABILITIES FOR DRESDEN

Mean Recurrence Interval	Hazard Probability	Expected Windspeed mph	Type of Storm
10	1.0×10^{-1}	62	Straight Wind
100	1.0×10^{-2}	75	Straight Wind
1,000	1.0×10^{-3}	88	Straight Wind
10,000	1.0×10^{-4}	102	Straight Wind or Tornado
100,000	1.0×10^{-5}	195	Tornado
1,000,000	1.0×10^{-6}	261	Tornado
10,000,000	1.0×10^{-7}	337	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., Changery, M. J. and Filliben, J. J., 1979: "Extreme Wind-speeds at 129 Stations in the Contiguous United States," NBS Building Science Service 118, National Bureau of Standards, Washington, D.C.

6. Simiu, E. and Scanlan, R. H., 1978: Wind Effects on Structures, John Wiley and Sons, New York, New York.

7. Simiu, E. and Filliben, J. J., 1975: "Statistical Analysis of Extreme Winds," Technical Note No. 868, National Bureau of Standards, Washington, D. C.

8. U. S. Nuclear Regulatory Commission, 1979: Demographic Statistics Pertaining to Nuclear Power Reactor Sites, NUREG-0348, Office of Nuclear Reactor Regulation, Washington, D. C.

APPENDIX A. COMPUTER PRINTOUTS

ASSESSMENT OF TORNADO RISK

PROGRAM BY JAMES R. MCDONALD, P.E. (4/3/77)

DRESDAN RISK MODEL EXPECTED VALUE

K MATRIX

						A-I	LAM-I
1.875	0.000	0.000	0.000	0.000	0.000	0.024	2.966
1.420	0.455	0.000	0.000	0.000	0.000	0.155	4.138
1.067	0.512	0.291	0.000	0.000	0.000	0.637	2.830
0.927	0.482	0.280	0.174	0.000	0.000	1.249	0.782
0.962	0.421	0.261	0.120	0.087	0.000	4.954	0.195
0.965	0.397	0.228	0.160	0.077	0.042	11.079	0.050

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

0.131	0.000	0.000	0.000	0.000	0.000	
0.709	0.291	0.000	0.000	0.000	0.000	
1.923	0.923	0.524	0.000	0.000	0.000	
1.422	0.739	0.429	0.267	0.000	0.000	
0.929	0.407	0.252	0.124	0.084	0.000	
0.539	0.216	0.127	0.089	0.043	0.023	
------	------	------	------	------	------	
5.852	2.576	1.333	0.480	0.127	0.023	SUMMATION ALAM(J)
21645	21645	21645	21645	21645	21645	AREA OF LOCAL REGION SQ MI
2.70E-004	1.19E-004	6.16E-005	2.22E-005	5.87E-006	1.08E-006	PROB OF WINDSPEED IN INTERVAL F.I
4.90E-004	2.20E-004	9.07E-005	2.91E-005	6.95E-006	1.08E-006	PROB OF EXCEED WINDSPEED IN INTERVAL F.I
40	73	113	158	207	261	LOWER BOUND WINDSPEED IN INTERVAL F.I

ASSESSMENT OF TORNADO RISK

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

DRESDAN RISK MODEL LOWER LIMIT

K MATRIX

							A-I	LAM-I
	1.875	0.000	0.000	0.000	0.000	0.000	0.012	2.430
	1.420	0.455	0.000	0.000	0.000	0.000	0.078	3.553
	1.067	0.512	0.291	0.000	0.000	0.000	0.322	2.303
	0.927	0.482	0.280	0.174	0.000	0.000	0.985	0.476
	0.962	0.421	0.261	0.128	0.087	0.000	2.499	0.036
	0.965	0.387	0.228	0.160	0.077	0.042	5.579	0.009

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

0.054	0.000	0.000	0.000	0.000	0.000	
0.395	0.127	0.000	0.000	0.000	0.000	
0.791	0.380	0.216	0.069	0.000	0.000	
0.424	0.226	0.131	0.082	0.000	0.000	
0.086	0.038	0.023	0.011	0.003	0.000	
0.048	0.019	0.011	0.008	0.004	0.002	
-------	-------	-------	-------	-------	-------	
1.809	0.789	0.382	0.101	0.012	0.002	SUMMATION ALAM(J)
21645	21645	21645	21645	21645	21645	AREA OF LOCAL REGION-SQ MI
8.36E-005	3.65E-005	1.76E-005	4.67E-006	5.30E-007	9.74E-008	PROB OF WINDSPEED IN INTERVAL FJ
1.43E-004	5.94E-005	2.29E-005	5.30E-006	6.35E-007	9.74E-008	PROB OF EXCEED WINDSPEED IN INTERVAL FJ
40	73	113	158	207	[illegible]	LOWER BOUND WINDSPEED IN INTERVAL FJ

ASSESSMENT OF TORNADO RISK

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

DRESMAN RISK MODEL UPPER LIMIT

K MATRIX

						A-I	LAN-I
1.875	0.000	0.000	0.000	0.000	0.000	0.047	3.501
1.420	0.455	0.000	0.000	0.000	0.000	0.305	4.722
1.067	0.512	0.291	0.000	0.000	0.000	1.258	3.357
0.927	0.482	0.280	0.174	0.000	0.000	3.856	1.098
0.963	0.421	0.261	0.128	0.087	0.000	9.819	0.354
0.965	0.387	0.228	0.160	0.077	0.042	22.001	0.132

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

0.309	0.000	0.000	0.000	0.000	0.000	
2.045	0.655	0.000	0.000	0.000	0.000	
4.507	2.162	1.227	0.000	0.000	0.000	
3.925	2.041	1.186	0.737	0.000	0.000	
3.347	1.465	0.908	0.445	0.303	0.000	
2.800	1.123	0.662	0.464	0.223	[illegible]	
-------	-------	-------	-------	-------	-------	
16.932	7.446	3.984	1.646	0.526	0.122	SUMMATION ALAM(J)
21645	21645	21645	21645	21645	21645	AREA OF LOCAL REGION-SQ MI
7.82E-004	3.44E-004	1.84E-004	7.61E-005	2.43E-005	5.63E-006	PROB OF WINDSPEED IN INTERVAL F.I
1.42E-003	6.39E-004	2.90E-004	1.06E-004	2.99E-005	5.63E-006	PROB OF EXCEED WINDSPEED IN INTERVAL F.I
40	73	113	158	207	261	LOWER BOUND WINDSPEED OF INTERVAL F.I