TORNADO AND STRAIGHT WIND HAZARD PROBABILITY

for

YANKEE ROWE NUCLEAR POWER REACTOR SITE, MASSACHUSETTS

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
Lubbock, Texas

FOREWORD

Hazard probability assessment for tornadoes and other extreme winds at the Yankee Rowe nuclear power generation 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 Yankee Rowe nuclear power generation site (see Fig. 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).

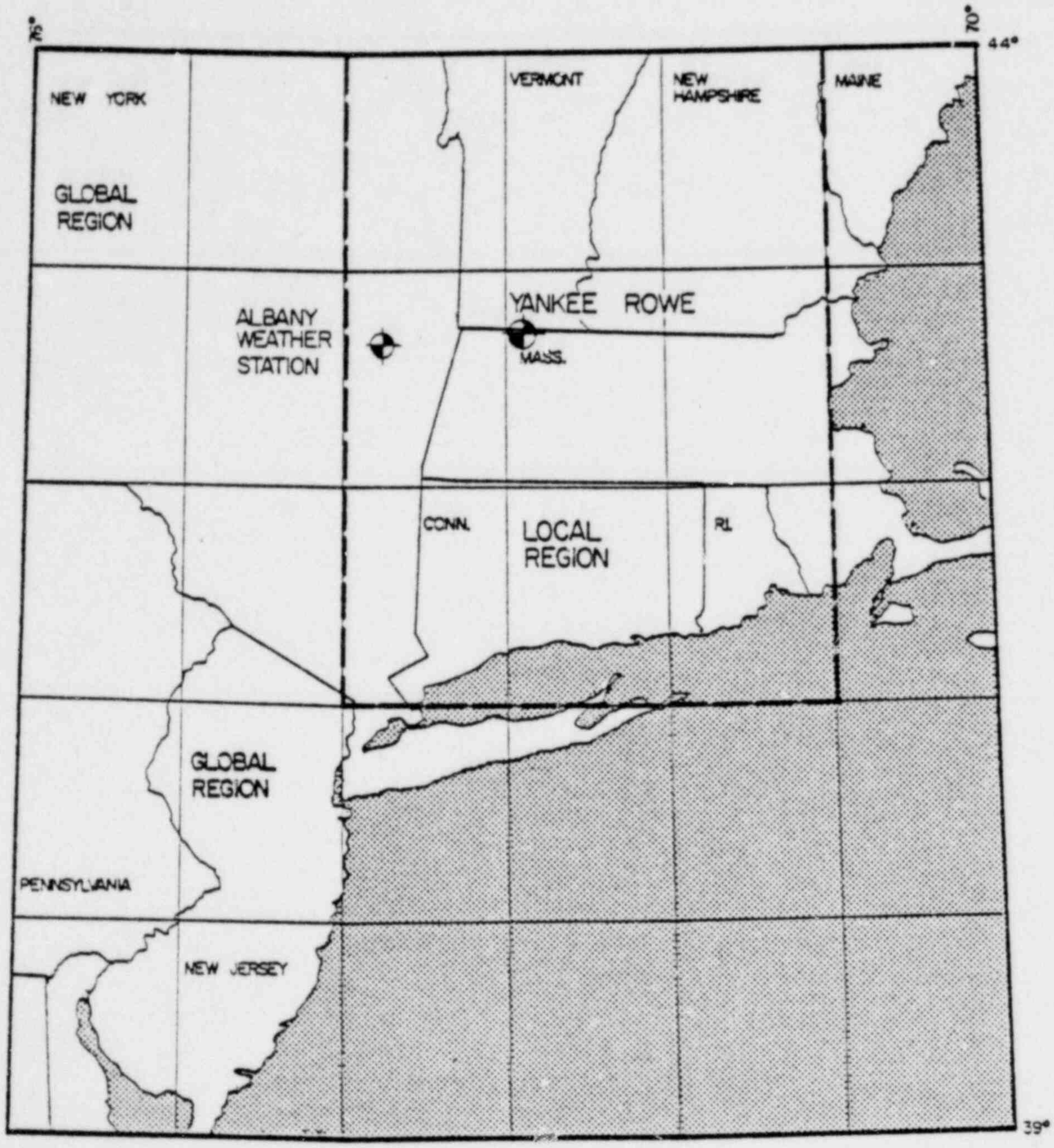

FIGURE 1. LOCAL AND GLOBAL REGIONS FOR YANKEE ROWE

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. 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

Yankee Rowe Nuclear Power Generating Station

2. Coordinates

Latitude 42^{o} 43' 41" N

Longitude 72^{o} 55' 29" 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 log-log plot, yields the following functional relationship:

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

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	0.0[illegible]	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. Occurrence-Intensity Relationship

Local Region

Latitude 41° to 44°

Longitude 71° to 74°

Area = 31,718 - 2773

= 28,945 sq mi

An area of 2773 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.

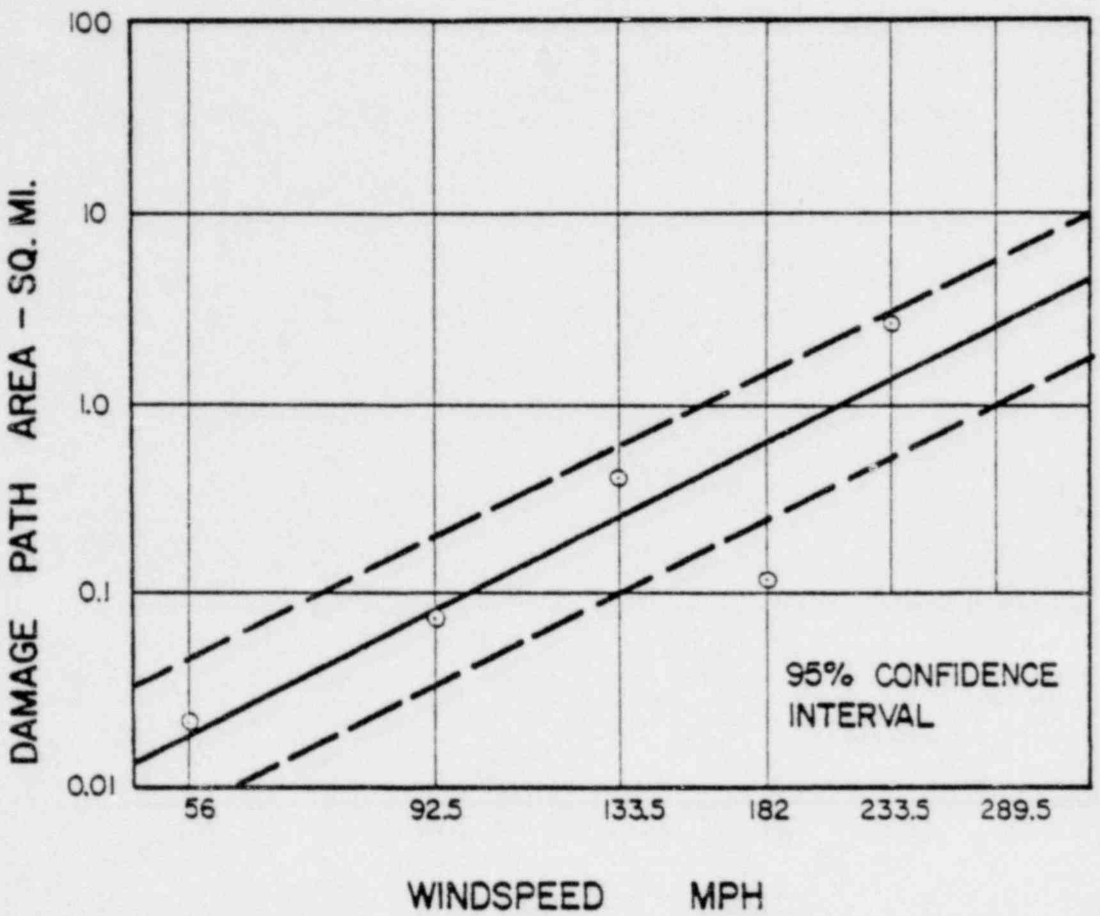

FIGURE 2. AREA-INTENSITY RELATIONSHIP FOR YANKEE ROWE

Data

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

Period of Record

1950 to 1973

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 100 persons per sq mi) 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	40	120	53	9	1	1
Cumulative Number	224	184	64	11	2	1
Lower Bound 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. 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. The effect does not eliminate the possibility of an F5 tornado. 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:

$$y = (284.32)10^{-0.00259x} \qquad (x < 85 \text{ mph})$$
$$y = (3968.99)10^{-0.0160x} \qquad (x \geq 85 \text{ mph}) \qquad (2)$$

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, $\hat{n}$	40.00	122.22	50.00	9.84	1.67	0.265
Lower limit $\hat{n}$	28.77	107.62	37.79	3.83	--	--
Upper limit $\hat{n}$	51.24	136.83	62.22	15.85	4.20	1.27
Expected number of tornadoes per year λ_i	1.38	4.21	1.72	0.34	0.06	0.009
Lower limit λ_i	0.99	3.71	1.30	0.13	--	--
Upper limit λ_i	1.77	4.72	2.15	0.55	0.14	0.044

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.

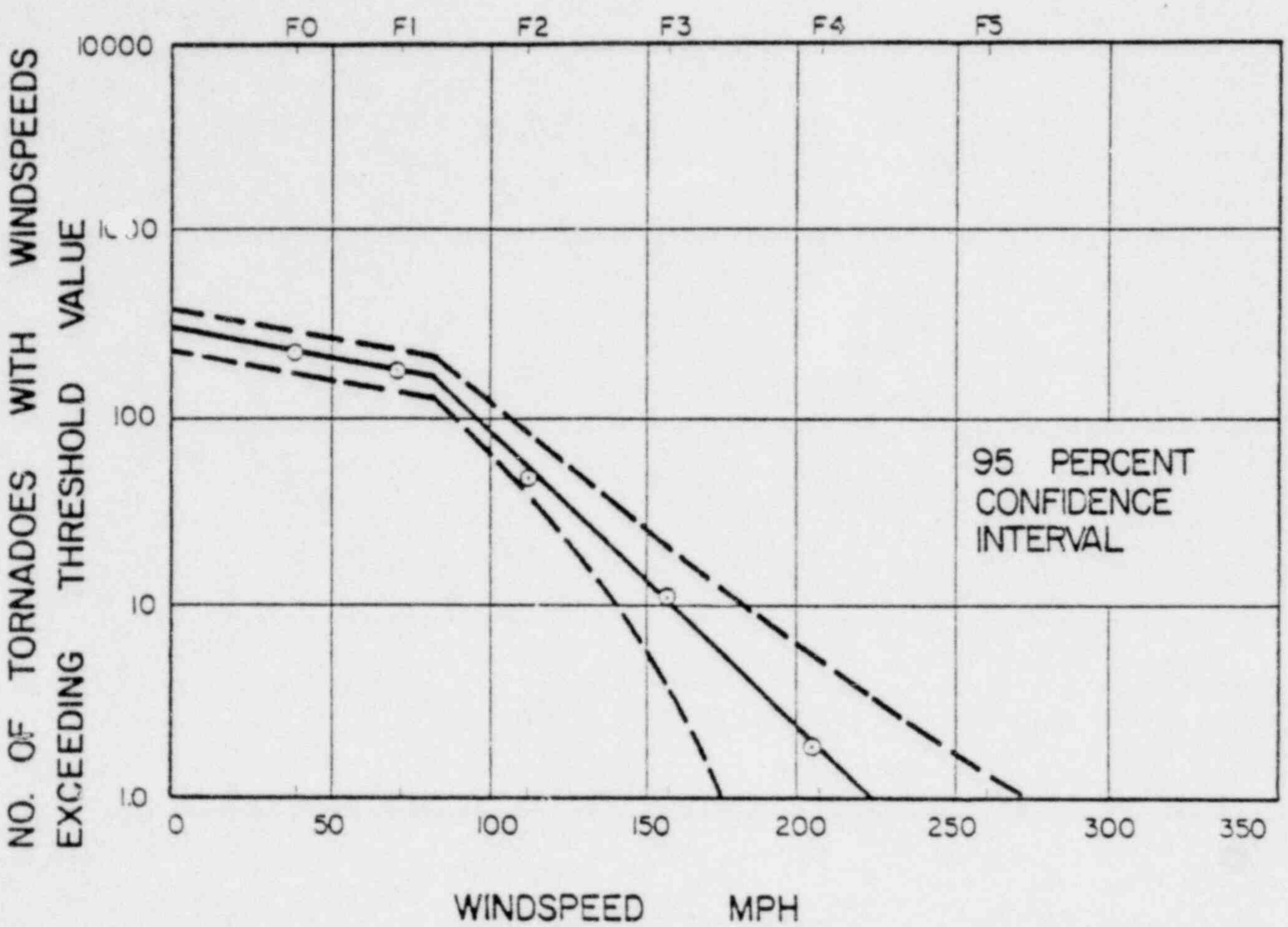

FIGURE 3. OCCURRENCE-INTENSITY RELATIONSHIP FOR YANKEE ROWE

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}	40	--	87
100,000	1.0×10^{-5}	122	77	174
1,000,000	1.0×10^{-6}	188	142	244
10,000,000	1.0×10^{-7}	248	190	291

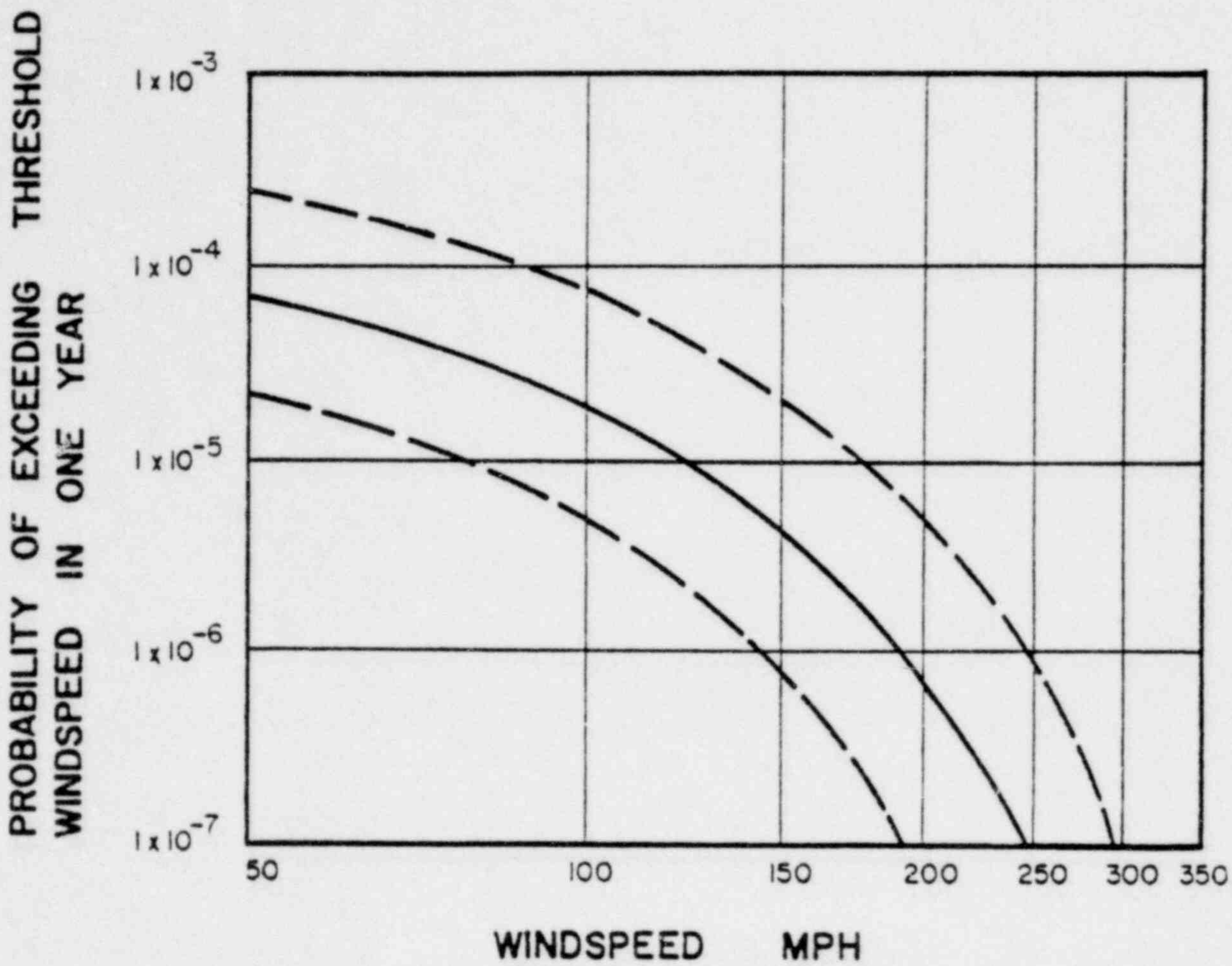

FIGURE 4. TORNADO HAZARD PROBABILITY WITH 95 PERCENT CONFIDENCE LIMITS

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).

A. CALCULATIONS

Annual extreme fastest-mile windspeed data are not available at the power plant site. The closest weather station with the needed data is Albany, New Yori, which is located 42 miles east 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 Simiu, Changery and Filliben (1979) and cover the forty-year period 1938 to 1977. Statistical tests indicate that the Type I extreme value distribution does not fit the Albany data as well as some other locations within the United States (the tail length parameter γ is 6 rather than infinity as required for 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 point.

The set of annual extreme fastest mile windspeeds for Albany, New York are given in Table 6, along with the date and direction. The windspeeds have been adjusted to a standard anemometer height of 10 m.

TABLE 6

ANNUAL EXTREME FASTEST-MILE WINDSPEEDS
AT ALBANY, NEW YORK

Year	Windspeed mph	Direction	Date
1938	45	W	09/21
1939	48	NW	01/25
1940	41	NW	04/05
1941	53	W	03/19
1942	44	W	03/19
1943	46	W	04/05
1944	52	W	12/28
1945	46	SW	04/05
1946	48	W	01/19
1947	44	W	01/21
1948	42	W	02/14
1949	41	W	01/19
1950	68	E	11/25
1951	50	NW	01/21
1952	55	W	01/18
1953	68	NW	02/15
1954	47	W	04/08
1955	43	W	03/27
1956	41	NW	02/25
1957	47	W	01/23
1958	41	W	02/25
1959	55	W	01/23
1960	44	W	02/20
1961	46	S	09/02
1962	40	NW	04/25
1963	49	W	04/04
1964	46	W	01/10
1965	44	NW	10/31
1966	48	NW	06/06
1967	49	NW	02/16
1968	47	W	02/17
1969	46	W	01/08
1970	46	W	04/03
1971	62	NW	06/08
1972	46	NW	02/20
1973	38	NW	01/29
1974	51	NW	03/10
1975	49	NW	01/30
1976	53	NW	12/13
1977	46	NW	04/08

The expected windspeeds for various mean recurrence intervals along with 95 percent confidence limits are given in Table 7. The straight wind hazard probability model is plotted in Figure 5.

TABLE 7

STRAIGHT WIND HAZARD PROBABILITIES
WITH 95 PERCENT CONFIDENCE LIMITS

Mean Recurrence Level	Hazard Probability	Expected Fastest-Mile Windspeed, mph	Upper Limit mph	Lower Limit mph
10	1.0×10^{-1}	57	61	53
20	5.0×10^{-2}	61	66	55
50	2.0×10^{-2}	66	73	59
100	1.0×10^{-2}	70	78	61
200	5.0×10^{-3}	73	83	64
500	2.0×10^{-3}	78	89	67
1,000	1.0×10^{-3}	82	94	70
10,000	1.0×10^{-4}	94	110	79
100,000	1.0×10^{-5}	107	127	87
1,000.000	1.0×10^{-6}	119	143	96

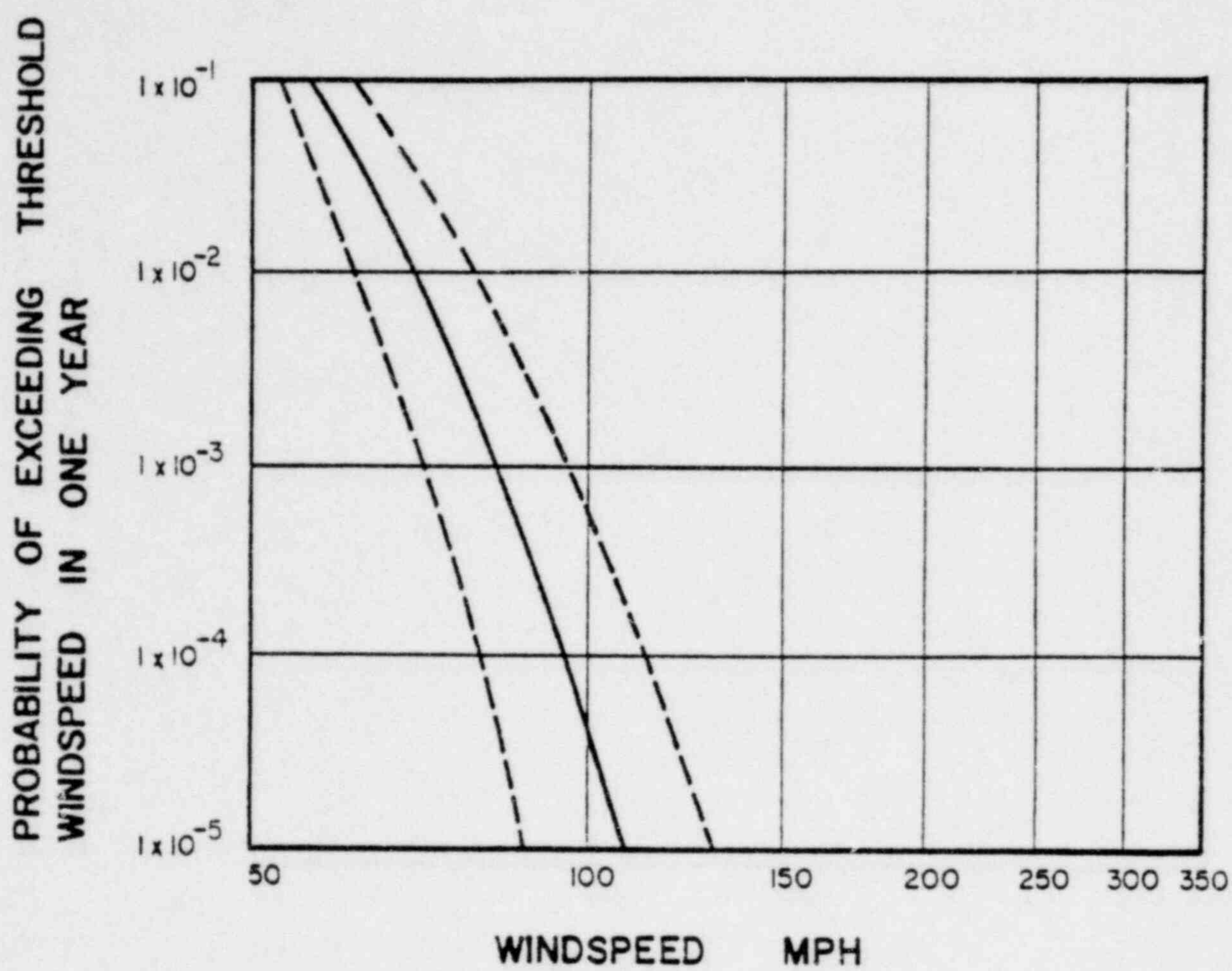

FIGURE 5. STRAIGHT WIND HAZARD PROBABILITIES WITH 95 PERCENT CONFIDENCE LIMITS

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 Albany, New York is used for the straight wind probability hazard assessment at the Yankee Rowe plant site. Thus, in effect, Albany and the plant 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.

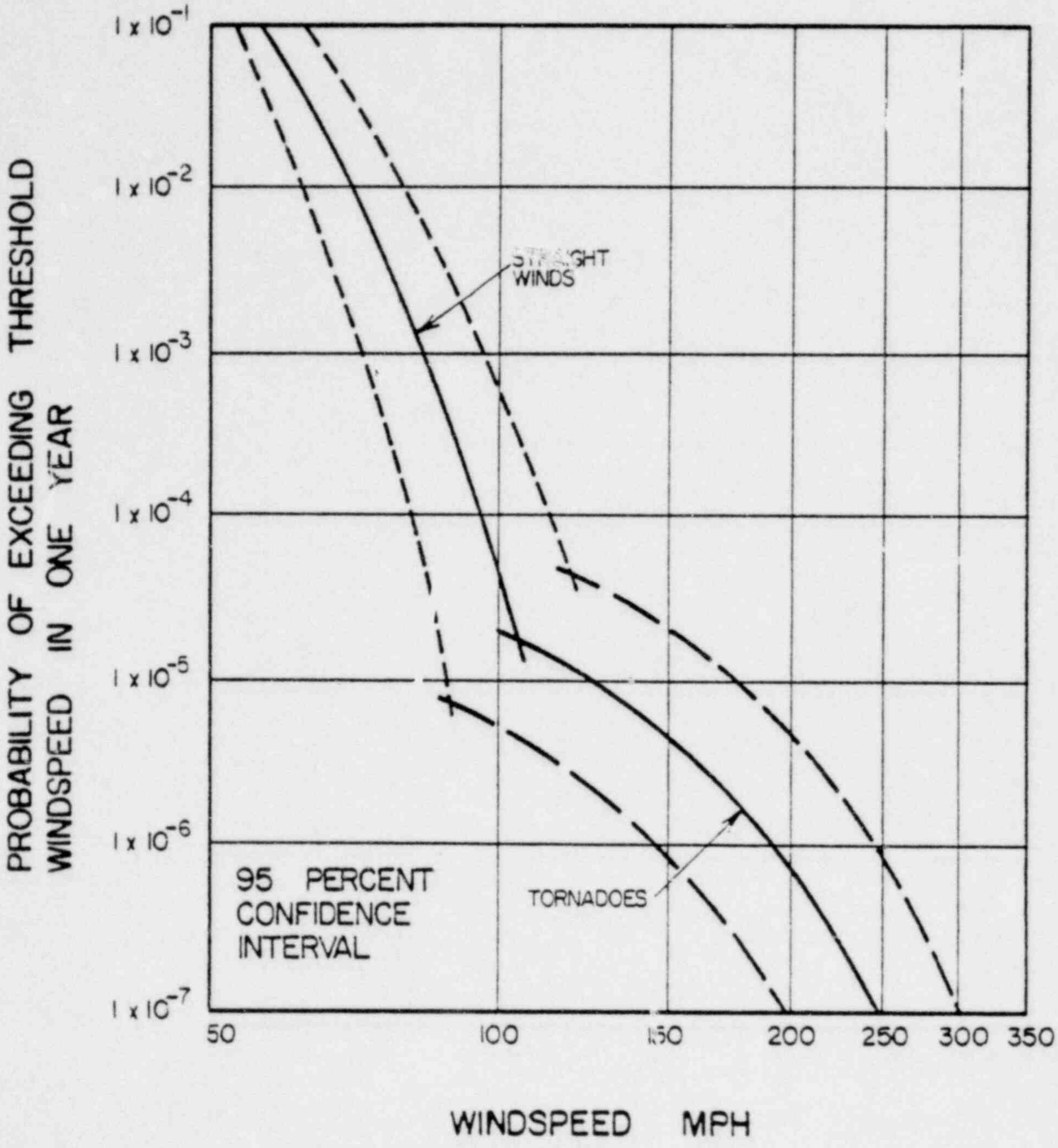

FIGURE 6. TORNADO AND STRAIGHT WIND HAZARD PROBABILITY MODEL FOR YANKEE ROWE

TABLE 8

SUMMARY OF WINDSPEED HAZARD
PROBABILITIES FOR YANKEE ROWE

Mean Recurrence Interval	Hazard Probability	Expected Windspeed mph	Type of Storm
10	1.0×10^{-1}	57	Straight Wind
100	1.0×10^{-2}	70	Straight Wind
1,000	1.0×10^{-3}	82	Straight Wind
10,000	1.0×10^{-4}	94	Straight Wind
100,000	1.0×10^{-5}	122	Tornado
1,000,000	1.0×10^{-6}	168	Tornado
10,000,000	1.0×10^{-7}	248	Tornado

REFERENCES

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

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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.

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APPENDIX A. COMPUTER PRINTOUTS

[illegible]

[illegible]

[illegible]

						A I	LAM I
[illegible]	0.000	[illegible]	0.000	0.000	0.000	0.917	1.379
[illegible]	[illegible]	0.009	0.006	0.000	0.000	0.082	4.215
1.66[illegible]	0.512	0.251	0.000	0.009	0.009	0.252	1.724
0.927	0.482	0.280	0.174	0.000	0.000	0.608	0.339
[illegible]	0.4[illegible]1	0.[illegible]61	0.128	0.087	0.000	1.249	0.058
0.965	0.382	0.229	0.160	0.077	0.012	2.393	0.009

[illegible]

0.547	0.600	[illegible]	0.000	0.050	0.000	
0.471	0.157	[illegible]	0.030	0.006	0.030	
0.164	[illegible]	0.126	0.000	0.000	0.000	
[illegible]	0.059	0.058	0.036	0.000	0.009	
[illegible]	0.031	0.019	0.005	0.005	0.000	
[illegible]	[illegible]	0.005	[illegible]	0.002	0.001	
1.296	0.518	[illegible]	0.042	0.001	0.001	[illegible]
20550	20550	20550	20550	20550	20550	[illegible]
[illegible]	[illegible]	1.01E-005	2.3[illegible]-006	[illegible]	1.40E-008	[illegible]
1.51E-004	3.71E-005	[illegible]	2.[illegible]-006	[illegible]	1.40E-008	[illegible]
40	73	113	158	207	261	[illegible]

POOR ORIGINAL

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	0.065	[illegible]	0.000	0.000	0.000	A I	[illegible]
[illegible]	[illegible]	[illegible]	0.000	0.000	0.000	0.915	1.762
[illegible]	0.517	[illegible]	0.000	0.000	0.000	0.194	4.718
[illegible]	[illegible]	[illegible]	[illegible]	0.000	0.000	0.595	2.135
[illegible]	0.474	[illegible]	0.128	0.087	0.000	1.153	0.548
[illegible]	[illegible]	[illegible]	0.169	0.077	0.047	3.072	0.145
						5.878	0.044

[illegible]

[illegible]	0.000	0.000	0.000	0.000	0.000
[illegible]	0.417	[illegible]	0.000	0.000	0.000
1.351	[illegible]	[illegible]	0.000	0.000	0.000
[illegible]	0.303	[illegible]	0.130	0.000	0.000
[illegible]	0.188	0.115	[illegible]	0.639	[illegible]
[illegible]	0.109	[illegible]	0.031	0.030	0.011

[illegible]	1.741	[illegible]	0.237	0.052	0.011	SUMMATION OVER [illegible]
26550	26550	[illegible]	26550	26550	26550	AREA OF LOCAL REGION-SQ MI
[illegible]	9.42E-005	[illegible]	1.15E-005	7.85E-006	5.20E-007	PROB OF WINDSPEED IN INTERVAL EJ
[illegible]	1.53E-004	[illegible]	1.2[illegible]E-005	5.38E-006	5.20E-007	PROB OF EXCEED WINDSPEED IN INTERVAL EJ
[illegible]	[illegible]	113	158	202	254	LOWER BOUND WINDSPEED IN INTERVAL EJ

POOR ORIGINAL

[illegible] OF TORNADO RISK

[illegible]

[illegible]

[illegible]

						[illegible]	[illegible]
[illegible]	0.000	0.050	0.000	0.005	0.000	0.000	0.992
[illegible]	[illegible]	0.029	0.002	0.000	0.000	0.035	3.711
[illegible]	0.542	0.291	0.006	0.000	0.000	0.106	1.303
[illegible]	0.487	0.386	0.174	0.000	0.000	0.254	0.132
[illegible]	0.471	0.251	0.123	0.087	0.000	0.524	0.050
[illegible]	0.387	[illegible]	0.160	0.077	0.012	0.974	0.008

[illegible]

0.015	0.050	0.000	0.000	0.000	0.000	
0.111	0.057	0.000	0.000	0.000	0.000	
0.147	0.071	0.046	0.000	0.000	0.000	
0.031	0.015	0.009	0.006	0.000	0.000	
[illegible]	0.011	0.007	0.003	0.002	0.000	
[illegible]	[illegible]	[illegible]	0.051	0.001	0.000	
0.410	0.150	[illegible]	0.010	0.003	[illegible]	SUMMATION OF AREA
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	AREA OF LOCAL REGION SQ MI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PROB OF WINDSPEED IN INTERVAL FJ
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PROB OF EXCEED WINDSPEED IN INTERVAL FJ
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LOWER BOUND WINDSPEED IN INTERVAL FJ

POOR ORIGINAL