REVIEW OF SEVERE WEATHER METEOROLOGY

at

GENERAL ELECTRIC COMPANY
VALLECITOS, CALIFORNIA

by

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Professor of Meteorology
The University of Chicago

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1. INTRODUCTION

The General Electric Company, Vallecitos, California, is located in the Vallecitos Valley at 37°37'N and 121° 50'W (Refer to Figure 1).

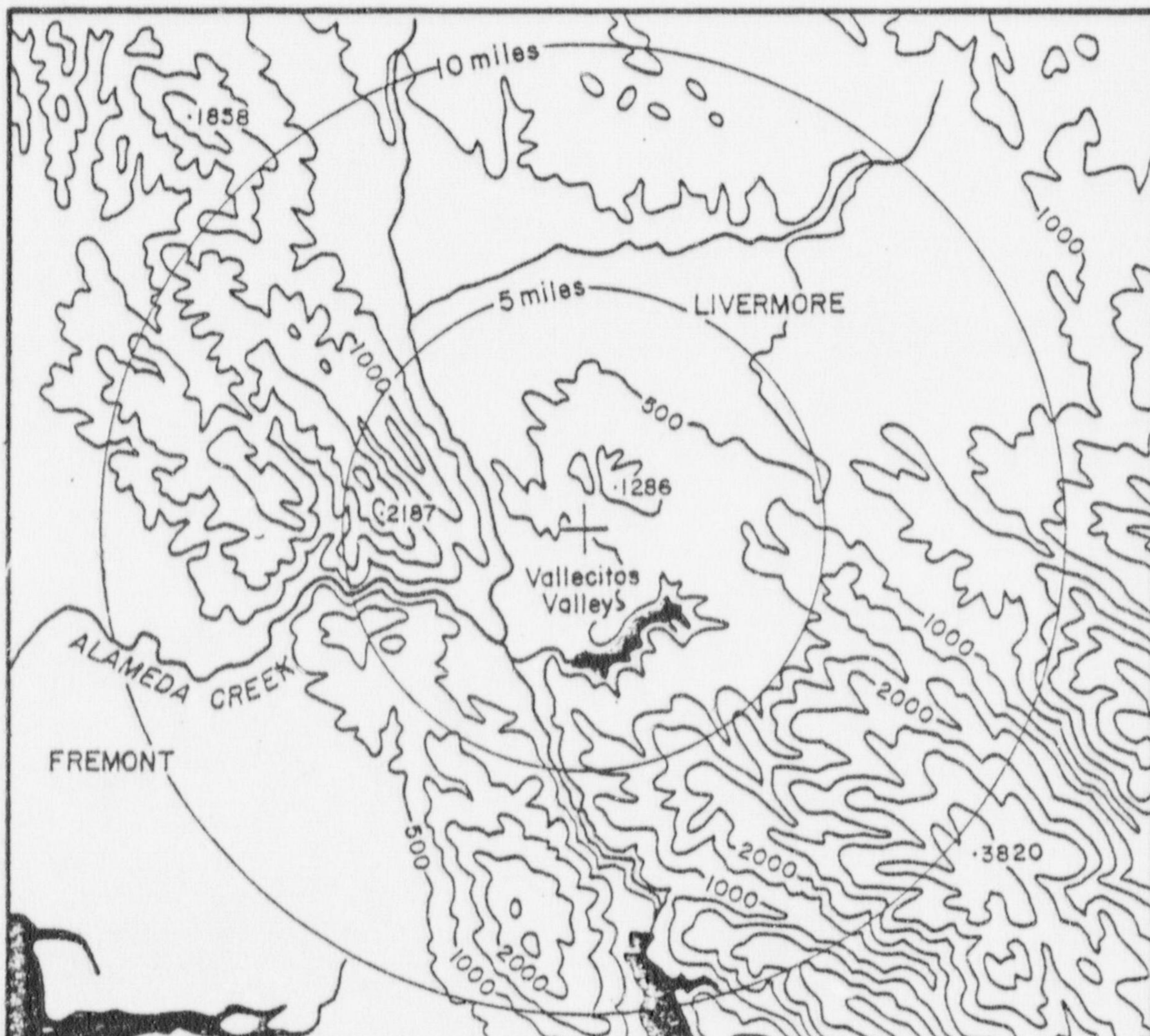

Figure 1. General Electric Company and vicinity. The Company is located in the Vallecitos Valley, 510 ft MSL. Height contours were drawn at 500 ft intervals.

According to Pautz (1969),[1] the SELS Log reported no occurrence of 50 kt or greater wind storms and 3 tornado cases within the one-degree box of latitudes and longitudes which includes the Company site. It is the purpose of this review to determine the intensity of severe weather events which could affect this location.

Both straight-line winds and tornadoes are regarded as prime phenomena, because no hurricane has ever been reported in this part of the country.

This site is located in Region II of WASH-1300. The calculated tornado windspeed by five-degree squares for 10^{-7} per year probability is 280 mph.[2]

2. STRAIGHT-LINE W[illegible]

Straight-line w[illegible] occur more frequently than tornadoes, but their interpretation and evaluation are difficult. "Climatological Data" include four stations from which the fastest-mile windspeeds are available. These stations are Oakland, San Francisco, S. F. Airport, and Stockton (see Figure 1A).

Most of the winds during the fastest-mile periods are from southerly directions. SSE to SW winds were the strongest in the Bay areas. These winds occur predominantly during the cold season, October through February.

Shown in Table 1 are the maximum fastest-mile winds by year during the 26-year period, 1950-75. The San Francisco urban winds are missing in the years 1963 and 1973-75 while the Stockton data became available at the beginning of 1964.

The mean windspeed at the S. F. Airport is predominantly higher than the three other values. The airport winds are probably higher due to the open exposure of the anemometer. The S. F. Airport winds are, therefore, normalized to those of San Francisco City simply by multiplying the ratio of mean winds from the City and the Airport. Normalized speeds are tabulated in ( ).

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[1] Pautz, Maurice E. (1969): Severe Local Storm Occurrences, 1955-1967. ESSA Tech. Memo WBTM FCST 12.

[2] WASH-1300 by Markee, E. H., Jr., J. G. Beckerley, and K. E. Sanders (1974): Technical Basis for Interim Regional Tornado Criteria. U. S. Atomic Energy Commission, Office of Regulation.

Table 1. The maximum fastest-mile windspeed in mph by year during the 26-year period, 1950-75. From Climatological Data, 1950-1975. Speeds in ( ) are normalized to those of San Francisco City. For locations, see next page.

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Oakland	43	48	46	49	38	46	32	46	43	40
San Francisco	43	42	46	41	35	42	35	34	40	40
S. F. Airport	51	48	50	55	48	53	40	47	48	48
(normalized)	(41)	(39)	(40)	(44)	(39)	(43)	(32)	(38)	(39)	(39)
Stockton	--	--	--	--	--	--	--	--	--	--

Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Oakland	41	40	35	40	46	38	35	35	35	32
San Francisco	36	31	38	--	36	47	36	40	35	34
S. F. Airport	52	39	50	60	59	51	48	49	45	47
(normalized)	(42)	(31)	(40)	(48)	(48)	(41)	(39)	(39)	(36)	(38)
Stockton	--	--	--	--	40	44	39	46	33	32

Year	1970	1971	1972	1973	1974	1975	Mean Windspeed
Oakland	35	31	30	31	33	32	38.5 mph
San Francisco	34	33	34	--	--	--	37.8 mph
S. F. Airport	41	40	32	39	39	41	46.9 mph
(normalized)	(32)	(32)	(26)	(31)	(31)	(33)	(37.8 mph)
Stockton	39	36	31	35	32	35	36.8 mph

The seasonal variation of the occurrence of maximum windspeeds is presented in Table 2. It is evident that the occurrences are centered in the cold months when California, in general, experiences precipitation in advance of cyclones from the Pacific.

Table 2. Frequency of the maximum fastest-mile windspeed (mph) by month, 1950-75.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oakland	3	2	3							4	3	11
San Francisco	5	1		3	1	2	1			2	1	6
S. F. Airport	7	3		3	1	1	1		1	3	1	5
Stockton	3	2	2	1						2		2
Total	18	8	5	7	2	3	2	0	1	11	5	24

Figure 1A. Location of four climatological stations in relation to the General Electric site at Vallecitos, California. Topographic features within 10-mile circle is shown in Fig. 1.

Windspeeds of peak gusts are higher than those of fastest mile, because the duration of peak gust is considerably shorter than the period of the fastest-mile wind. In this paper the former is regarded as being 25% larger than the latter. Namely,

Peak Gust $\cong$ 1.25 Fastest-mile Speed.

The probabilities of the occurrence of the maximum windspeed should be defined differently from those of tornadoes. For tornadoes, the National Weather Service lists all storms, even if they occur on the same day or even a few minutes later. The maximum fastest-mile speed is listed in "Climatological Data"(1) by month and by year. There is no mention as to how often the maximum speed occurred within one month or one year. Furthermore, the period of the straight-line winds, especially the ones caused by continental cyclones, is long, lasting hours or days. There will be numerous maxima during such a long period.

We should, therefore, define the following terms:

Fastest-mile day..... the day on which the speed occurred.

Fastest-mile month .. the month in which the speed occurred.

Fastest-mile year.... the year in which the speed occurred.

These are similar to the term

Tornado day......... the day in which one or more tornadoes occurred.

In these cases the number of occurrences within the stated period is not important.

The probabilities of the fastest-mile year can be computed by

$$P_s = \frac{\text{Number of years in whi specific speed or larger speed occurred}}{\text{Total number of years used in statistics}}$$

where P_s denotes the occurrence probability per year.

The probabilities in Table 3 were computed by combining the observation years at the four stations together: 26 years at Oakland and S. F. Airport; 22 years at San Franciso; and 12 years at Stockton. The observation years total 86.

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(1) "Climatological Data". Publication of NOAA, published monthly with an Annual Summary. May be obtained from Environmental Data Service, National Climatic Center, Federal Building, Asheville, North Carolina 28801.

Table 3. Frequencies of maximum fastest-mile of the year 1950-75. Data includes Oakland, San Francisco, City, S.F. Airport normalized to City, and Stockton. Equivalent peak gust is estimated to be 25% larger than fastest-mile speed.

Fastest-mile of the year	Corresponding peak gust	Years of occurrence	Cumulative years	Probability per year
49 mph	61 mph	1	1	0.01
48	60	3	4	0.05
47	59	1	5	0.06
46	58	6	11	0.13
45	56	0	11	0.13
44	55	2	13	0.15
43	54	4	17	0.20
42	53	3	20	0.23
41	51	4	24	0.28
40	50	9	33	0.38
39	49	8	41	0.48
38	48	5	46	0.53
37	46	0	46	0.53
36	45	4	50	0.58
35	44	11	61	0.70
34	43	4	65	0.76
33	42	4	69	0.80
32	40	8	77	0.90
31	39	7	84	0.98
30	38	1	85	0.99
29	36	0	85	0.99
28	35	0	85	0.99
27	34	0	85	0.99
26	33	1	86	1.00
25	31	0	86	1.00

3. TORNADO FREQUENCIES

During the 26 years, 1950-75, a total of 29 tornadoes occurred within 144 miles of General Electric Company. The frequencies were 1.1 tornadoes per year (Refer to NSSFC Tornado Tape).

A breakdown of the frequencies for every 23-mile-range interval is shown in Table 4. By disregarding the area of the Pacific Ocean, included within range circles centered at General Electric, an attempt was made to express tornado frequencies as a function of the range. As shown in Figure 2, the best-fit parabolic curve is

$$N = 0.0018 R^2,$$

where N is the number of tornadoes within the range, R, in miles.

The number of tornadoes, N, can be prorated by multiplying the ratio of land and water areas, thus

$$N_p = N \frac{\text{total area within R}}{\text{land area within R}} .$$

This prorated number represents the tornado frequency if the entire area within any range from General Electric had no water areas. Since the water area is up to 32% of the total circular area, prorated numbers within some ranges are significantly higher than actual numbers. For prorated numbers, we obtain the best-fit parabola expressed by

$$N_p = 0.0025 R^2$$

where N_p denotes the prorated tornado number or frequency.

Shown in Table 5 are the frequencies by month as listed in the 1950-75 NSSFC tape. Apparently the tornado season begins in January and ends in May. There is a small peak in October, however.

Table 4. Frequencies of tornadoes within 144 miles from General Electric Company as a function of the distance from the Company. Based on NSSFC tape, 1950-75.

Distance							
n.miles	0-20	20-40	40-60	60-80	80-100	100-120	120-125
s.miles	1-23	23-46	46-69	69-92	92-115	115-138	138-144
Frequency	1	7	3	5	5	7	1

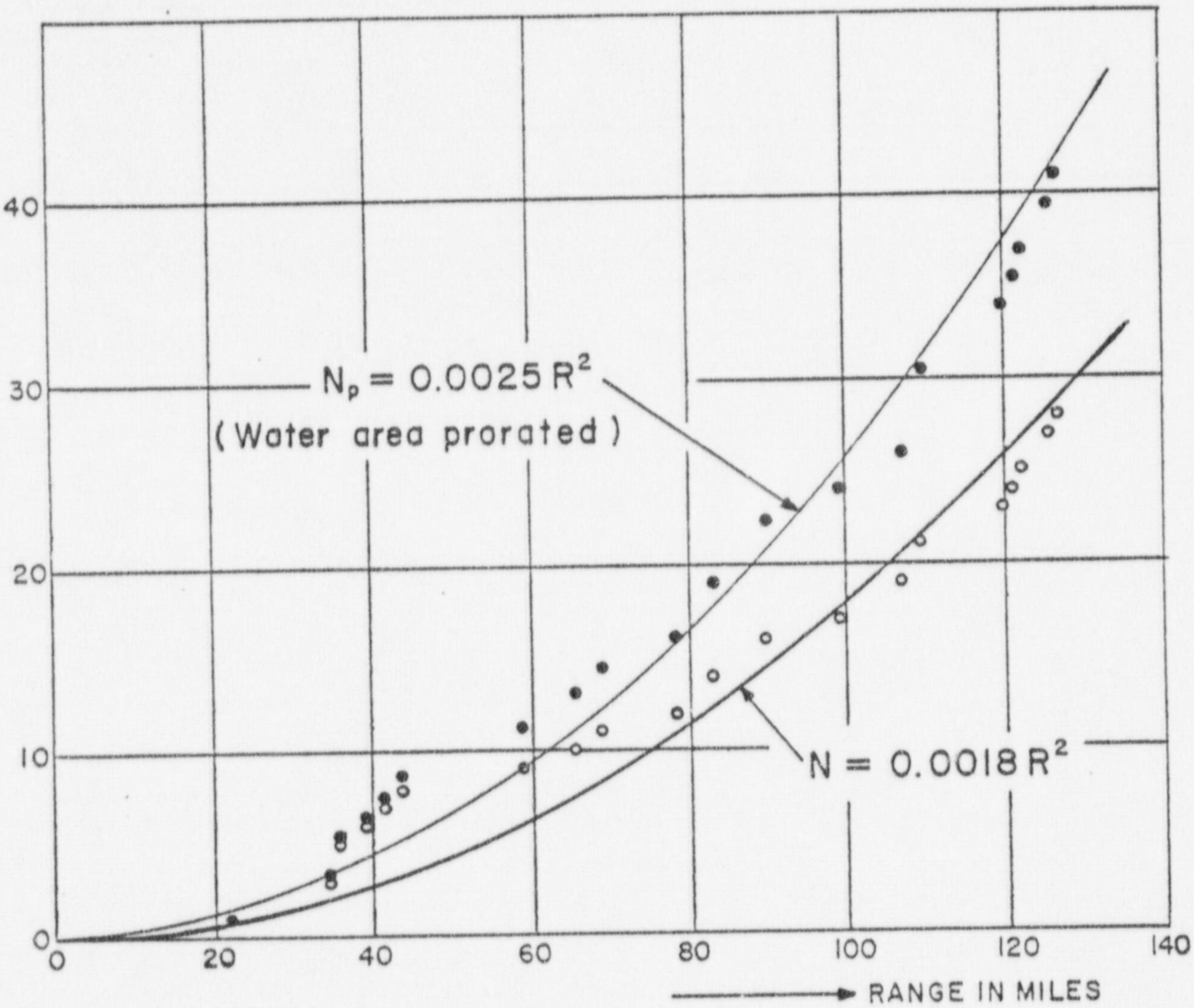

Figure 2. Cumulative number of tornadoes as a function of the distance from General Electric Company. Based on the 29 tornadoes in NSSFC tape, 1950-75. Open circles represent actual number and painted circles are prorated numbers.

Table 5. Frequencies of tornadoes within 144 miles from General Electric Company by month. Based on NSSFC tape, 1950-75.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Frequencies	3	3	3	12	1	2	0	0	0	4	1	0

The tornado frequencies by year, according to the NSSFC tape, had peak years: six in 1958 followed by four in 1967. In some years no tornadoes occurred within 144 miles from the Company. These years were 1950, 1952, 1954, 1956, 1960, 1961, 1963, 1966, 1968, 1970, 1973, and 1974 (see Table 6).

Table 6. Frequencies of tornadoes within 144 miles from General Electric Company by year. Based on NSSFC tape, 1950-75.

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Frequencies	0	1	0	1	0	1	0	1	6	1

Years	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Frequencies	0	0	1	0	2	1	0	4	0	1

Years	1970	1971	1972	1973	1974	1975
Frequencies	0	3	3	0	0	3

4. DESCRIPTION OF TORNADOES

Three data sources--Report of the Chief of the Weather Bureau, Monthly Weather Review, and Climatological Data--were used in assessing tornadoes which were reported since 1916.

Tornado frequencies by decade show a gradual increase until the end of the 1940s. Thereafter, the frequencies by decade are more or less constant; about one tornado per year within a 140-mile range from General Electric Company (see Table 7).

For some reason, no tornado was reported in the 1940s within 140 miles from the Company, although 2 occurred elsewhere in California. Apparently, tornado activities were very low in California in that decade.

Of 34 tornadoes during the 61-year period, 1916-76, 17 were rated as F0, 10 as F1, and 7 as F2.

Two tornadoes, possibly three, originated as waterspouts off the Pacific Coast. Two tornadoes, identified as Pacific Tornado and Merced 46 NE Tornado, occurred on the western slope of the Sierra Nevada at 4,000 to 5,000 ft MSL.

Most tornadoes occurred in San Joaquin Valley near Highway 99 which goes through high population areas between Sacramento and Fresno. It is likely that some rural tornadoes in the Valley are not reported to the National Weather Service.

Within the narrow coastal basin between parallel mountain ranges there were reports of occasional tornadoes, especially in the cold season between November and February. Due to the high population density most Bay-area tornadoes were likely to have been reported (see Figure 3).

Shown in Table 8 is a list of 34 tornadoes, numbered according to the range from General Electric Company. An account of each tornado is also presented.

Table 7. Frequencies of tornadoes within 140 m[illegible]s from General Electric Company by decade.

Decades	1916-19	1920s	1930s	1940s	1950s	19[illegible]	1970-76	Total
F 0	0	0	3	0	3	6	5	17
F 1	0	2	0	0	3	2	3	10
F 2	0	0	1	0	4	1	1	7
Total	0	2	4	0	10	9	9	34

Table 8. List of tornadoes between 1916 and 1976 which were reported within 140 miles from General Electric Company.

Number	Range	Year - Mo - Day	F	Length	Name of tornado
1	20 mi	1951 - 01 - 11	2	3.0 mi	SUNNYVALE
2	21	1951 - 01 - 11	1	3.0	SAN JOSE
3	26	1969 - 10 - 16	0	0.1	MODESTO 20W
4	30	1958 - 04 - 01	1	0.3	S.F. AIRPORT
5	35	1971 - 04 - 24	0	0.3	STOCKTON
6	39	1970 - 04 - 27	1	1.5	STOCKTON
7	40	1967 - 05 - 31	2	0.3	STOCKTON
8	42	1953 - 04 - 27	1	1.0	MODESTO
9	43	1965 - 04 - 01	0	0.3	CORRALITOS
10	47	1926 - 04 - 05	1	4.0	ESCALON
11	47	1933 - 03 - 16	0	0.1	LODI
12	56	1958 - 04 - 01	2	2.0	TURLOCK
13	60	1933 - 03 - 16	2	0.3	DELHI
14	60	1936 - 12 - 26	0	0.2	SONOMA COUNTY
15	66	1921 - 10 - 26	1	0.2	SACRAMENTO
16	67	1975 - 04 - 05	1	0.3	LOS BANOS
17	69	1967 - 04 - 22	0	0.1	MERCED 20SW
18	74	1933 - 03 - 16	0	0.2	CARMICHAEL
19	78	1958 - 01 - 10	2	15.0	SEBASTOPOL
20	82	1972 - 10 - 15	0	0.1	SACRAMENTO 11NE
21	84	1964 - 11 - 10	1	1.0	WINDSOR
22	90	1967 - 04 - 22	0	0.1	FRESNO 40W
23	99	1959 - 02 - 17	0	0.5	FT. ROSS
24	107	1957 - 04 - 21	1	0.2	MADERA 5SW
25	107	1958 - 03 - 12	2	0.5	MADERA
26	109	1972 - 10 - 01	0	0.1	PACIFIC
27	111	1972 - 10 - 15	0	0.1	MERCED 46NE
28	118	1975 - 04 - 05	0	0.3	FRESNO
29	119	1970 - 06 - 28	1	3.0	GRIDLEY
30	122	1958 - 02 - 03	1	1.0	GUALALA
31	126	1962 - 03 - 22	0	0.2	FRESNO
32	127	1957 - 05 - 19	0	1.0	FRESNO
33	127	1964 - 01 - 21	0	1.0	FRESNO
34	136	1975 - 03 - 13	2	0.3	FOWLER

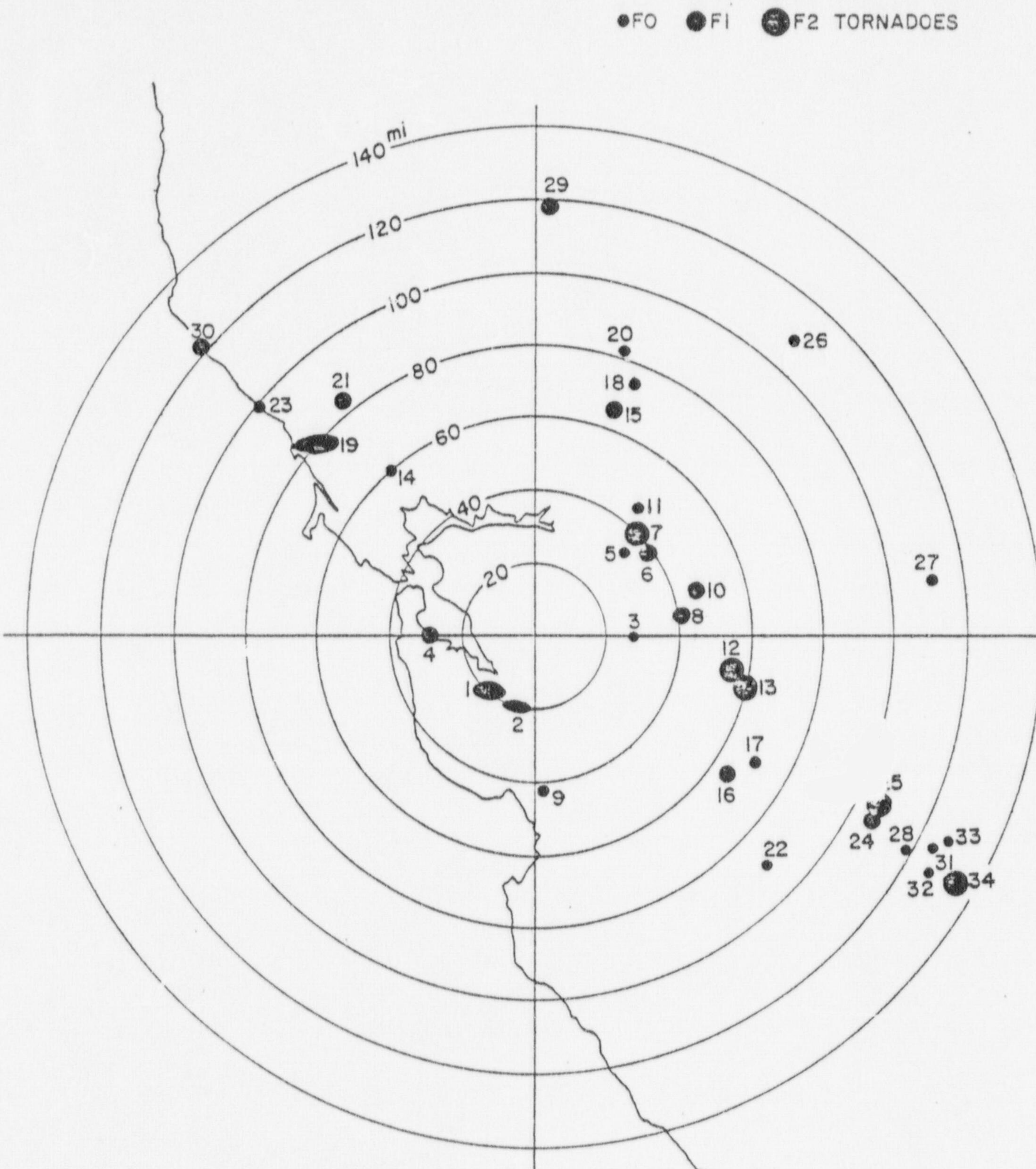

Figure 3. Locations of tornadoes during the 61-year period, 1916-1976, within 140-mile range from General Electric Company. Concentric circles denote ranges 20, 40, 60, 80, 100, 120, and 140 miles.

NO. 1 SUNNYVALE TORNADO (Jan. 11, 1951) FPP = 2,1,4

After damaging Los Altos residential area tornado left skipping path eastward to El Camino Real. Then it went through Sunnyvale business district. Southern Pacific Railroad depot, Westinghouse and Woolridge plants were hard hit. This tornado was associated with a cold front with 78 (fastest mile 47 mph) gust at San Francisco Airport, 23 miles NW of the tornado.

NO. 2 SAN JOSE TORNADO (Jan. 11, 1951) FPP = 1,1,2

A tornado moved eastward passing near City Hall (old location). Roofs ripped off; trees forced down; structures damaged.

NO. 3 MODESTO 20W TORNADO (Oct. 16, 1969) FPP = 0,0,0

Pilot reported a spout in sight approximately 20 miles west of Modesto picking up dirt from ground. No report of wind received from observers on the ground.

NO. 4 S.F. AIRPORT TORNADO (Apr. 1, 1958) FPP = 1,0,2

Damage confined to narrow path across air base. Extreme wind lasted for a few seconds. Some structural damage to hangar and two other buildings. Several parked automobiles damaged by flying debris.

NO. 5 STOCKTON TORNADO (Apr. 24, 1971) FPP = 0,0,0

Very small tornado west and northwest of Stockton caused minor damage to crops.

NO. 6 STOCKTON TORNADO (Apr. 27, 1970) FPP = 1,1,1

During a thunderstorm a funnel cloud touched down at three points, moving ESE. Trees were blown over, some of them damaging automobiles.

NO. 7 STOCKTON TORNADO (May 31, 1967) FPP = 2,0,2

A boathouse was lifted into the air and dropped on several boats; the roof was thrown across the channel, damaging other boats.

NO. 8 MODESTO TORNADO (Apr. 27, 1953) FPP = 1,1,1

A twister demolished a 32 stanchion dairy barn, damaged other structures, and uprooted trees. Twister was erratic, passing over some districts without damage. Power lines broke in 3 places.

NO. 9 CARRALITOS TORNADO (Apr. 1, 1965) FPP = 0,0,2

Newspaper reports minor damage to buildings and trees.

NO. 10 ESCALON TORNADO (Apr, 5, 1926) FPP = 1,2,3

A tornado moved north causing much damage to buildings and fruit trees. The path was several miles long and 1/4 mile wide.

NO. 11 LODI TORNADO (Mar. 16, 1933) FPP = 0,0,0

Garage shifted on foundation, instrument shelter overturned.

NO. 12 TURLOCK TORNADO (Apr. 1, 1958) FPP = 2,1,1

A tornado moved NE across a poultry farm. Demolished fences; lifted 2 buildings. Deposited concrete piers and trusses on top of other buildings.

NO. 13 DELHI TORNADO (Mar. 16, 1933) FPP = 2,0,0

House and garage demolished, fruit trees uprooted. Damage to $2,000.

NO. 14 SONOMA COUNTY TORNADO (Dec. 26, 1936) FPP = 0,0,0

Rural property damaged.

NO. 15 SACRAMENTO TORNADO (Oct. 26, 1921) FPP = 1,0,1

A tornado moved NE causing $17,000 property damage to roofs and buildings under construction. Several persons were slightly injured.

NO. 16 LOS BANOS TORNADO (Apr. 5, 1975) FPP = 1,0,1

Storm damaged several homes and sheds, uprooted trees and scattered debris over a large area.

NO. 17 MERCED 20SW TORNADO (Apr. 22, 1967) FPP = 0,0,0
Pilot reported sighting tornado.

NO. 18 CARMICHAEL TORNADO (Mar. 16, 1933) FPP = 0,0,0
Tornado-like winds uprooted rose bushes, torn blackberry vines, property damaged.

NO. 19 SEBASTOPOL TORNADO (Jan. 10, 1958) FPP = 2,3,2
A tornado moved from Bodega Bay on the Pacific Coast to between Sebastopol and Santa Rosa. Trees uprooted; houses and ranch buildings damaged; a few small outbuildings demolished completely. The path extended ENE across 200 to 500 ft hills.

NO. 20 SACRAMENTO 11NE TORNADO (Oct. 15, 1972) FPP = 0,0,0
Tornado reported 11 miles northeast of Sacramento.

NO. 21 WINDSOR TORNADO (Nov. 10, 1964) FPP = 1,1,1
Small tornado damaged buildings, trees, billboards, and utility lines.

NO. 22 FRESNO 40W TORNADO (Apr. 22, 1967) FPP = 0,0,0
Pilot reported sighting tornado moving toward south.

NO. 23 FORT ROSS TORNADO (Feb. 17, 1959) FPP = 0,0,1
Small tornado moved NE. Shingles ripped from 12 x 54 ft area of roof. Fences destroyed and branches twisted off. Heavy rain and lightning.

NO. 24 MADERA 5SW TORNADO (Apr. 21, 1967) FPP = 1,0,1
Funnel cloud observed from 5:00 to 5:30 PM. Cloud touched ground 5:30 to 5:40 damaging small buildings. Storm moved to northeast.

NO. 25 MADERA TORNADO (Mar. 12, 1958) FPP = 2,0,0
A tornado moved NE across a golf course. A white funnel about 1,000 ft long was preceded by hail and rain. Heavy shake roofing ripped off; supporting posts ripped off concrete footings. A heavy bench carried into air and demolished.

NO. 26 PACIFIC TORNADO (Oct. 1, 1972) FPP = 0,0,0
Tornado with hail accumulated to 3 inches on ground.

NO. 27 MERCED 46NE TORNADO (Oct. 15, 1972) FPP = 0,0,0
A tornado reported 46 miles northeast of Merced.

NO. 28 FRESNO TORNADO (Apr. 5, 1975) FPP = 0,0,3
Storm struck on western outskirts of Fresno in a thinly populated area. Minor damage to houses and sheds.

NO. 29 GRIDLEY TORNADO (Jun. 28, 1970) FPP = 1,1,3
Small tornado skipped along over a path of about 3 miles. Several hundred orchard trees were damaged or uprooted, and several barns suffered damage.

NO. 30 GUALALA TORNADO (Feb. 3, 1958) FPP = 1,1,1
A waterspout landed and moved northward across Del Mar Ranch. 3 large cypress trees were uprooted. A cone-shaped funnel 150 to 200 ft high was followed by thunderstorm with hail.

NO. 31 FRESNO TORNADO (Mar. 22, 1962) FPP = 0,0,0
A funnel cloud and damage on a farm reported. No eyewitnesses.

NO. 32 FRESNO TORNADO (May 19, 1957) FPP = 0,1,0
Tornado first observed as a vertical funnel moved ENE with roaring noise. It ripped shingles from homes and uprooted Almond tree.

NO. 33 FRESNO TORNADO (Jan. 21, 1964) FPP = 0,1,0
Tornado moved NE through north part of Fresno, damaging several homes and minor structure.

NO. 34 FOWLER TORNADO (Mar. 13, 1975) FPP = 2,0,0
A steel shed weighing over one ton lifted over 200 ft and dropped 100 yds away. Roofing and rafters torn. Pilot reported tornado but no ground sighting of funnel due to rain.

5. TORNADO PROBABILITIES

The NSSFC tape reveals that the mean damage area of the 22 tornadoes with known path characteristics is 0.01 sq. mile per tornado. The statistics are based on the 1950-75 tornadoes within a 144-mile radius of the General Electric Company.

Applying this mean tornado area to the total number of 29 tornadoes, we estimate the total damage area to be

$$0.01 \times 29 = 0.29 \text{ sq. mile in 26 years.}$$

The area within the 144-mile radius from the Company, excluding lake areas, is 44,300 sq. miles. The tornado probability from these data is

$$\frac{\text{tornado area}}{\text{land area} \times \text{years}} = \frac{0.29}{44,300 \times 26} = 2.52 \times 10^{-7} \text{ per year.}$$

Although the definition of the tornado area is rather vague, it probably represents the area affected by F0 to F1 or stronger winds.

The DAPPLE (Damage Area Per Path LEngth) METHOD developed by Abbey and Fujita (1975) is capable of computing tornado probabilities as a function of the F-scale damage categories, which can be converted into windspeeds (see Table 9).

Using the DAPPLE METHOD the area of specific windspeed can be computed by the product

$$\text{Windspeed area} = \text{Path length} \times \text{DAPPLE}$$

where path length denotes that of specific intensity tornado.

Table 9. Range of F-scale windspeeds and their weighted mean values. (Refer to Abbey, Robert (1977): Risk probabilities associated with tornado windspeeds. Proc. of Symp. on Tornadoes, Assessment of knowledge and implications for man.)

F scale	F 0	F 1	F 2	F 3	F 4	F 5	
Range of windspeed	40-72	73-112	113-157	158-206	207-260	261-318	mph
Weighted mean speed	59	92	131	177	227	276	mph

Since F-scale assessments assume an accuracy of one scale, tornadoes are classified into three categories (instead of six) for DAPPLE computation purposes. These categories are VIOLENT (F4 and F5), STRONG (F2 and F3), and WEAK (F0 and F1). DAPPLE values were then obtained based on 147 tornadoes of April 3-4, 1974 Superoutbreak (see Table 10).

No DAPPLE values have been computed for the California tornadoes, because practically no survey data for DAPPLE are available. The use of Table 1 will, therefore, overestimate the damage areas because Midwestern tornadoes are usually larger than California tornadoes.

Table 10. DAPPLE in miles as a function of tornado windspeed. Values were obtained from 147 tornadoes of April 3-4, 1974 Superoutbreak.

Windspeeds	WEAK (F0&F1)	STRONG (F2&F3)
50 mph	0.074 mile	0.43 mile
100	0.0028	0.062
150	0.000052	0.0098
200	0.000000	0.0012
250	0.000000	0.000087

We have to realize, on the other hand, that California tornadoes have not been fully reported and assessed. The reasons being the weakness in tornado intensity, relatively low public awareness, etc. The use of Midwestern DAPPLE may as well offset the low reporting efficiency, resulting in a reasonable estimate of damage areas.

Path lengths of the two-category tornadoes, strong (F 2 & 3) and weak (F 0 & 1), were obtained from Table 8. The measurements were made for each of the annular rings, 20 miles apart. The cumulative path lengths were, then, obtained to determine the total path length within each radius from the Company site (see Table 11).

Table 11. The total path mileages of tornadoes within seven ranges from General Electric Company.

WEAK (F0 and F1) TORNADOES

Ranges	20	40	60	80	100	120	140 miles
1916-49	0.0	0.0	4.6	5.0	5.0	5.0	5.0 mi
1950-76	0.0	5.2	6.5	6.9	8.3	12.0	15.2
Total	0.0	5.2	11.1	11.9	13.3	17.0	20.2

STRONG (F2) TORNADOES

Ranges	20	40	60	80	100	120	140 miles
1916-49	0.0	0.0	0.3	0.3	0.3	0.3	0.3 mi
1950-76	3.0	3.3	5.3	20.3	20.3	20.8	21.1
Total	3.0	3.3	5.6	20.6	20.6	21.1	21.4

The DAPPLE values and path lengths can be used in computing the damage area for each windspeed. The damage area of a 100 mph windspeed, for instance, is computed as

$$A_{100} = \text{Path length of strong tornado} \times 0.062 + \text{Path length of weak tornado} \times 0.0028$$

where A_{100} is the area of 100 mph or stronger windspeed (see Table 12).

Table 12. Damage areas within seven ranges from General Electric Company. Areas were obtained by multiplying the path mileage in Table 11 by DAPPLE in Table 10. A 27 year period, 1950-76 was used because data in earlier years are, apparently, not representative.

Range (miles)	Land area (sq.mi.)	Windspeed (damage) area in sq. mi. 50 mph	100 mph	150 mph	200 mph
20	1,100	1.290	0.186	0.029	0.000
40	4,600	1.804	0.220	0.032	0.000
60	9,100	2.760	0.347	0.052	0.006
80	15,100	9.240	1.278	0.199	0.024
100	22,300	9.343	1.282	0.199	0.024
120	31,000	9.832	1.323	0.205	0.025
140	41,000	10.198	1.351	0.208	0.025

The tornado probabilities were computed based on the 27-year period, 1950-76. The formula used is

$$\frac{\text{Damage area of specific windspeed}}{\text{Land area} \times 27 \text{ years}}.$$

In computing probabilities windspeeds were varied: 50, 100, 150 and 200 mph. Meanwhile, the ranges of probability computations were varied between 20 and 140 miles at 20-mile intervals (see Table 13).

It is a difficult question to select a proper range of probability computations. Theoretically, the range must be small enough to preserve characteristics of the Company site. If we choose an excessive radius, the area could include Sierra Nevada which is entirely different from the Company site.

If we choose a 20- to 40-mile range, the number of tornadoes is so small that a statistical assessment will not be feasible.

In view of these difficulties, a 100-mile range was selected for assessment of the tornado risk applicable to the General Electric Company. Note that this area is considerably smaller than the 5-degree boxes used in WASH-1300.

Table 13. Probabilities of tornado windspeed within 7 ranges from General Electric Company. Based on 27-year data, 1950-76.

Range (miles)	Probabilities 50 mph	100 mph	150 mph	200 mph
20	4.34×10^{-5}	6.26×10^{-6}	9.76×10^{-7}	0.00
40	1.45×10^{-5}	1.77×10^{-6}	2.58×10^{-7}	0.00
60	1.12×10^{-5}	1.41×10^{-6}	2.11×10^{-7}	2.44×10^{-8}
80	2.26×10^{-5}	3.13×10^{-6}	4.88×10^{-7}	5.89×10^{-8}
100	1.55×10^{-5}	2.13×10^{-6}	3.31×10^{-7}	3.99×10^{-8}
120	1.17×10^{-5}	1.58×10^{-6}	2.45×10^{-7}	2.99×10^{-8}
140	9.21×10^{-6}	1.22×10^{-6}	1.88×10^{-7}	2.26×10^{-8}

6. SUMMARY AND CONCLUSIONS

Results of the foregoing computations of wir 'ↄpeed probabilities are summarized in Figure 4, which includes three curves:

A. Probability of fastest-mile year

B. Probability of peak gust assumed 1.25 times the fastest-mile speed

C. Tornado probability based on the 27-year data

The figure reveals that the speeds of straight-line winds are higher than tornado winds when the probability is greater than about 10^{-6} per year.

Table 14 gives the maximum windspeeds corresponding to the return periods of ɔne to 10 million years. It is obvious that tornadoes become important when the probability decreases below one in 1,000,000 years.

Table 14. Maximum windspeeds expected at the General Electric Company site as a function of the probability per year. (A)...fastest-mile speeds of straight-line winds. (B)...gust speed computed as 125% of A. (C)... tornado windspeeds based on 1950-74 data.

Probabilities	Return periods	Windspeeds in miles per hour (A)	(B)	(C)
10^{0} per year	1 year	38	47	-
10^{-1}	10	47	59	-
10^{-2}	100	53	66	-
10^{-3}	1,000	59	74	-
10^{-4}	10,000	66	83	-
10^{-5}	100,000	72	90	-
10^{-6}	1,000,000	-	-	122
10^{-7}	10,000,000	-	-	178

The three-category probabilities used in this site analysis are

High probability .... 10^{-3} per year

Low probability .... 10^{-6} per year

Remote probability...... 10^{-7} per year .

It should be noted that 10^{-7} per year is used in determining the design-basis tornadoes for nuclear power plants in WASH-1300.

For secondary or short-life structures, one may wish to use maximum wind-speeds corresponding to the low- or even high-probability category.

The storm characteristics in Table 15 were computed for these three probabilities. If one wishes to protect a structure against the high probability (10^{-3}) storm, a 74-mph gust should be used as the design criteria.

Table 15. Characteristics of storms corresponding to three probability categories, remote (10^{-7}), low (10^{-6}), and high (10^{-3} per year). Air density at the Company site, 510-ft MSL, is assumed 1.2 kg/m^3 and radius of maximum wind, 100m for computational purposes.

Probabilities (per year)	Remote (10^{-7})	Low (10^{-6})	High (10^{-3})
Storm types	Tornado	Tornado	Straight wind
Maximum total speed (mph), V_{mt}	178	122	74 gust
Translational speed (mph), T	36	24	-
Tangential speed (mph)	142	98	-
Total press. drop (mb)	48.3	23.0	-
(psi)	0.70	0.33	-
Rate of pr. drop (mb/sec)	7.8	2.5	-
(psi/sec)	0.11	0.04	-

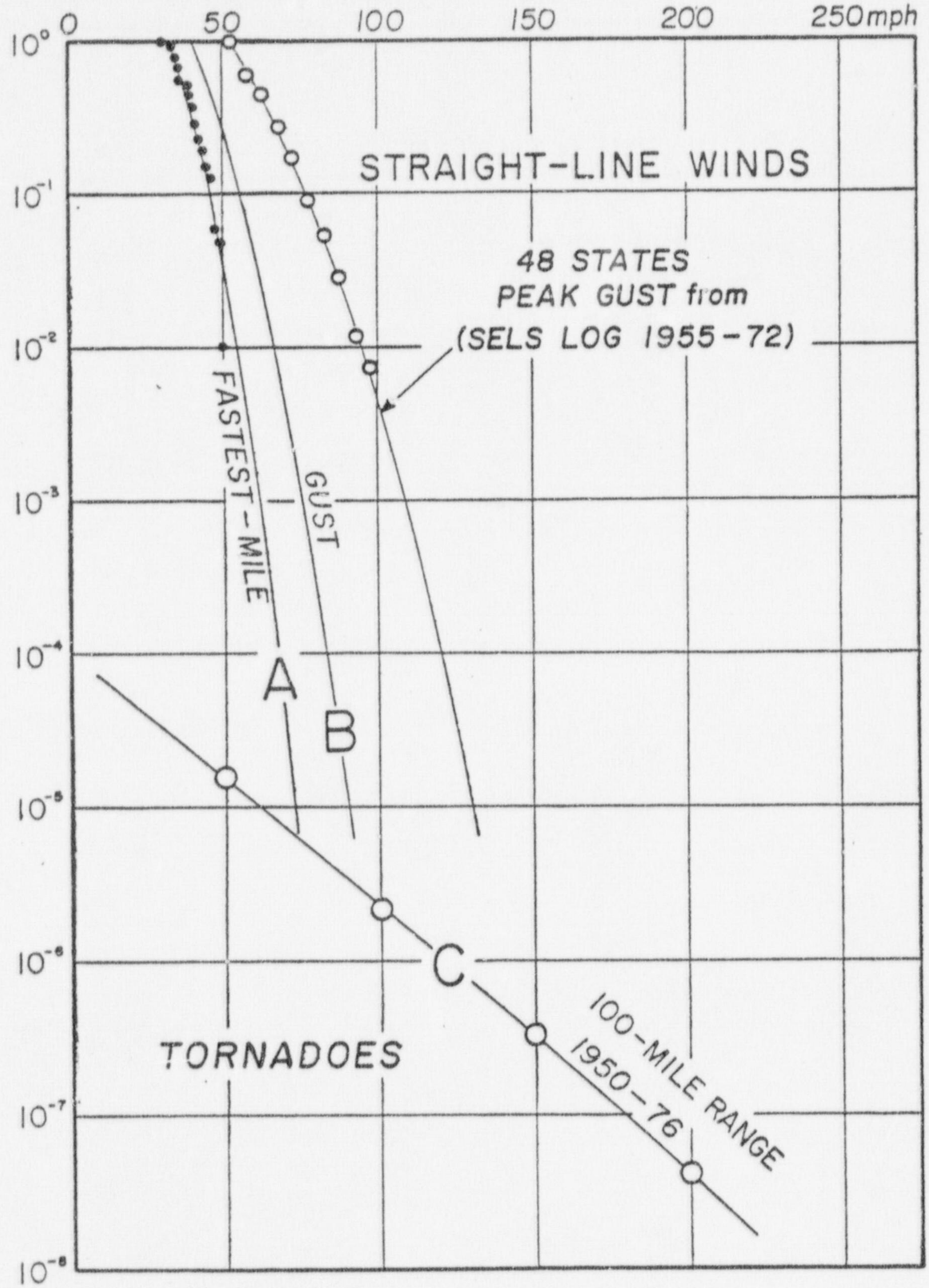

Figure 4. Probability of straight-line and tornado winds. The probability of straight-line gust is higher for windspeeds less than 100 mph. Above 100 mph, the probability of tornado wind exceeds that of straight-line winds.

The translational speed, T, was assumed as

$$T = 0.20\ V_{mt} \quad ,$$

where V_{mt} is the maximum total speed along the radius of maximum wind, r_m. Under the assumption of the combined Rankine vortex and cyclostrophic wind equation, the total pressure drop was computed from

$$P_0 = \rho V_m^2 \quad ,$$

where ρ at the 510-ft MSL Company site was assumed to be 1.2 kg/m³.

The rate of pressure drop was computed from

$$\frac{dP}{dr} = \frac{\rho V_m^2}{r_m} \quad \text{and} \quad dr = T dt$$

or

$$\frac{dP}{dt} = \frac{T}{r_m} \rho V_m^2$$

which is identical to Equation (3) of WASH-1300.

It is recommended that the team of structure analysts determine the proper probability category to be applied to each structure or portions of structure of the General Electric Company. Table 15 will, then, be used to determine the characteristics of the design-basis storm.

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