THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Civil Engineering Meteorological Laboratories

Final Report

METEOROLOGICAL ANALYSIS

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PREFACE

This final report summarizes several projects sponsored by Power Reactor Development Company of Detroit, Michigan. All the projects are interrelated, concerning themselves with the meteorological aspects of the Enrico Fermi Atomic Power Plant. The first project was a climatological project begun in August, 1956. Five project reports were written covering the installation of the measuring equipment and seasonal and yearly summaries of the observations taken until 30 November 1959.

The second project was a diffusion study which was made to determine diffusion characteristics at the plant site and in the surrounding environs. The diffusion studies were carried out under varying meteorological conditions including inversion conditions. Two progress reports describing the equipment and technique used in the study and qualitatively describing the days on which data were collected were written. A technical report described the diffusion in a quantitative manner.

Several other smaller projects are also summarized in the report. They are the computations made for the design and location of the waste-gas stack and graphs of maximum and minimum temperatures for use as design criteria.

The authors wish to acknowledge again the help of the many individuals and agencies in making these several projects successful. In particular, thanks is given to Mr. Jal N. Kerawalla and Miss Ana Lucia Torres P. for aid in making some of the calculations, and to Mrs. Anne C. Rivette for typing the original manuscript.

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ABSTRACT

Wind, lapse-rate, and precipitation observations for the three-year period 1 December 1956 to 30 November 1959 are reviewed and summarized, emphasizing those factors which are of major importance to plant operation and diffusion characteristics. Extremes of temperature are included in this summary report. Diffusion characteristics based upon the observations from the diffusion project are discussed and summarized as well as the meteorological criteria used in the stack design. General conclusions summarizing the site meteorology are also presented.

I. WIND SUMMARY

1. INTRODUCTION

The data referred to in this section are those from the three-year period 1 December 1956 to 30 November 1959. Some of these data are being reproduced in this report to aid in summarizing the material. Detailed data by seasons and by years are found in earlier progress reports.[1-5] The following table may be used as a basis for such references.

TABLE I

SUMMARY OF DATA CONTAINED IN PROGRESS REPORTS

Report Number	Data
2515-1-P	Details of instrumentation and observations prior to 12/1/56
2515-2-P	Observations from 12/1/56 to 5/31/57
2515-3-P	Observations from 12/1/56 to 11/30/57 plus 1957 summary and lake breeze discussion
2515-4-P	Observations from 12/1/57 to 11/30/58 plus 1958 summary
2515-5-P	Observations from 12/1/58 to 11/30/59 plus 1959 and 3-year summary

2. WIND DIRECTION

Table II is the three-year summary of the wind-direction distribution grouped according to wind-speed categories. There are several features to be emphasized. The first is with reference to the prevailing wind direction and major population centers. Figure 1, a map of the area surrounding the plant site, will aid in the discussion. The prevailing wind directions are from SSW through WNW. Such winds occur about 45% of the time. Figure 1 shows that these wind directions are toward the lake and the Ontario shores area, a relatively distant and sparsely populated area. Except for SSW winds which after crossing several miles of marshy shore area would reach communities down river from Detroit, no significant population center is in the path of these winds.

TABLE II

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 December 1956 - 30 November 1959
(3-Year Summary)

Wind Direction	Speed, mph						Total Observations		Mean Speed	
	0-3	4-12	13-24	25-31	32 and Over	Total 4 and Over	%	No.	mph	% of Overall Mean
N	0.2	2.9	0.8	0.1		3.8	4.0	1015	10.1	81
NNE	0.2	2.4	1.4	0.1		3.9	4.1	1023	12.6	102
NE	0.2	1.6	3.7	0.2	0.0	5.5	5.7	1423	15.3	123
ENE	0.2	2.0	2.7	0.2	0.0	4.9	5.1	1271	14.2	115
E	0.2	1.9	1.9	0.2	0.1	4.1	4.3	1077	14.3	115
ESE	0.1	2.4	1.7	0.1	0.0	4.2	4.3	1070	12.4	100
SE	0.1	2.4	1.5	0.1		4.0	4.1	1033	12.0	97
SSE	0.1	3.4	1.3	0.0		4.7	4.8	1204	10.8	87
S	0.1	3.6	1.3	0.0		4.9	5.0	1264	10.7	86
SSW	0.2	4.6	3.2	0.1	0.0	7.9	8.1	2043	12.3	99
SW	0.2	4.9	4.5	0.1	0.0	9.5	9.7	2429	13.0	105
WSW	0.2	5.6	5.1	0.4	0.1	11.2	11.4	2851	13.4	108
W	0.2	4.7	3.5	0.2	0.0	8.4	8.6	2175	12.7	102
WNW	0.2	4.5	3.2	0.1	0.0	7.8	8.0	2013	12.3	99
NW	0.2	3.9	2.5	0.1		6.5	6.7	1690	11.9	96
NNW	0.2	4.0	1.6	0.1		5.7	5.9	1471	10.9	88
Calm	0.3						0.3	83	0.0	0
Totals	3.1	54.8	39.9	2.1	0.2	97.0	100.1	25135		
Average									12.4	100

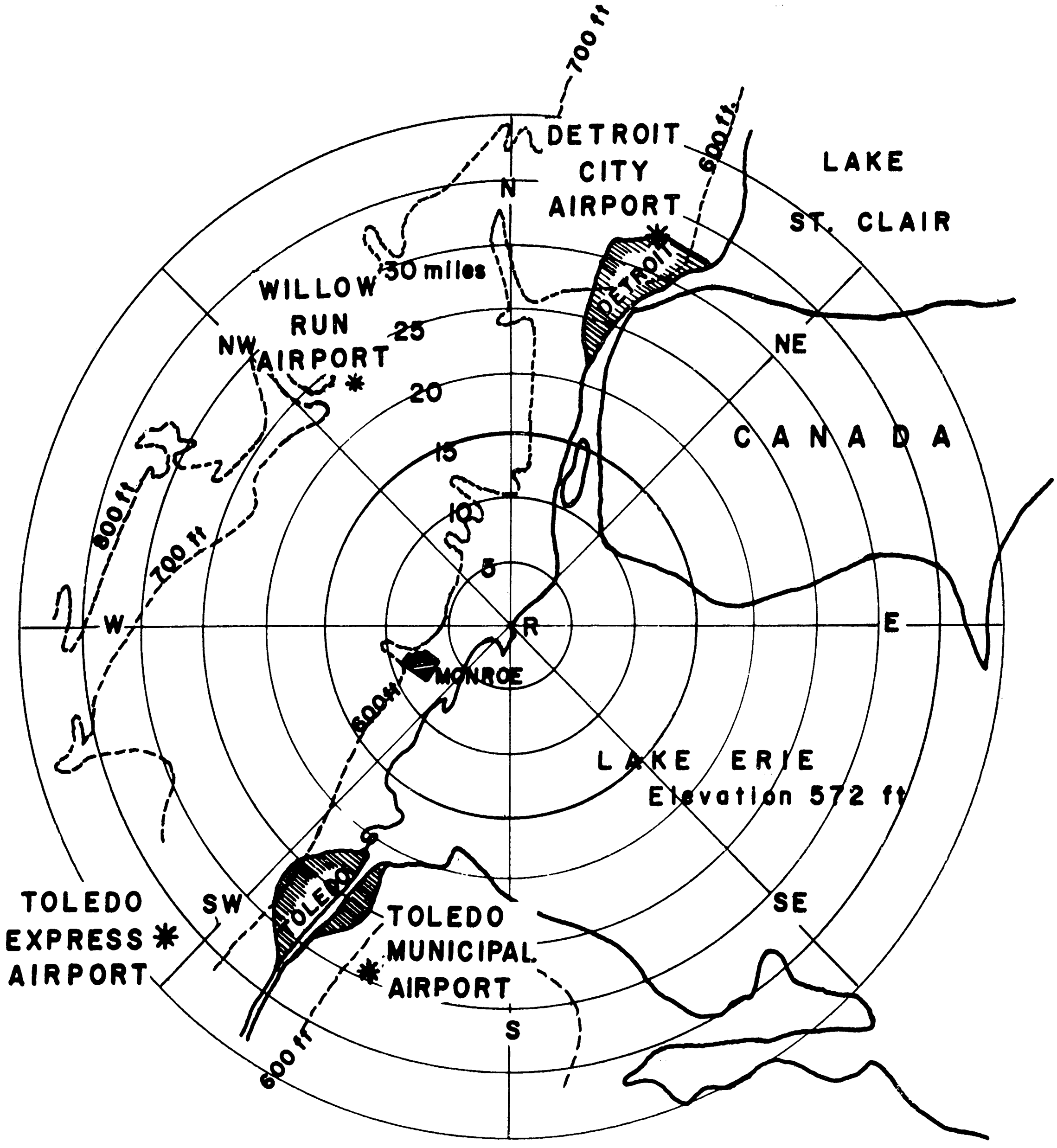


Fig. 1. A topographic map of Enrico Fermi site and surroundings.

Figure 2 shows that, in general, the wind-direction distribution at the plant site is representative for the general area surrounding western Lake Erie, but with a higher occurrence of easterly winds than stations further inland such as Toledo and Detroit.

It should also be noted from Table II that, when the wind speed is above 31 mph, winds blow only from the NE through E to ESE and from SSW through W to WNW. This bimodal distribution is a specific effect of the deep storms that traverse the mid-latitude regions, and is not a singularity associated with the plant site.

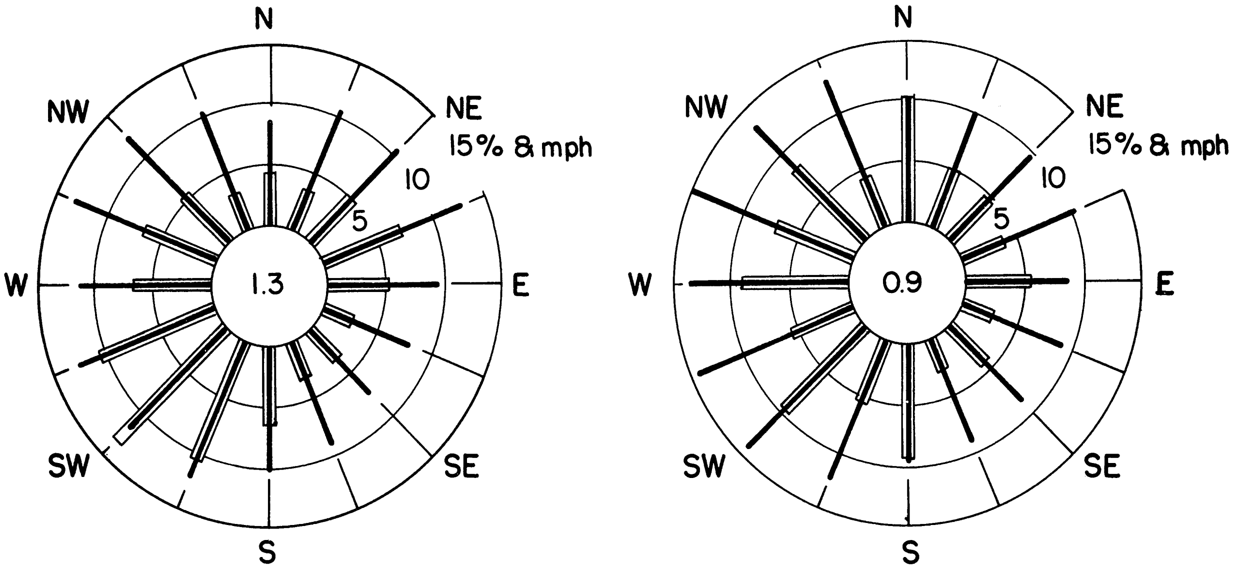
3. WIND SPEED

The most important fact about the wind speed observed at the plant site is that it averaged 12.4 mph over the three-year period. This is 1-2 mph greater than at Detroit City Airport or Toledo Express Airport during the same period. A small part of the excess wind speed at the plant site may be due to the higher location of the wind-measuring equipment at the plant, but most of it must be attributed to the relatively frictionless flow from off Lake Erie. Figure 2 shows that winds with an easterly component average 3-5 mph higher than corresponding winds at Toledo Express or Detroit City Airports. This fact is brought out more clearly in Fig. 3.

Table II shows that the average wind speed varies from 10.1 to 15.3 mph, which is quite a narrow range over all 16 directions. Other factors being equal, the concentration of any air pollutant at a point downstream varies inversely as the wind speed. Thus a high average wind speed regardless of direction improves diffusion.

Both Table II and Fig. 3 show that the incidence of calm conditions at the plant site is low, 0.3%. The incidence of calm conditions at Detroit City is three times greater, while at Toledo Express it is five times greater. The nearness of the plant site to Lake Erie allows a lake breeze to develop during periods that would normally be calm. Thus the lake-side location has a decided advantage over some inland sites.

In addition to the indications of the observational data, which are favorable, as an additional precaution it is planned to release waste gases from a stack which is 200 ft high. This means that the average wind speed at the top of the stack will probably be near 13.5 mph if a 1/7th power law is assumed. Any additional wind speed may be regarded as beneficial.

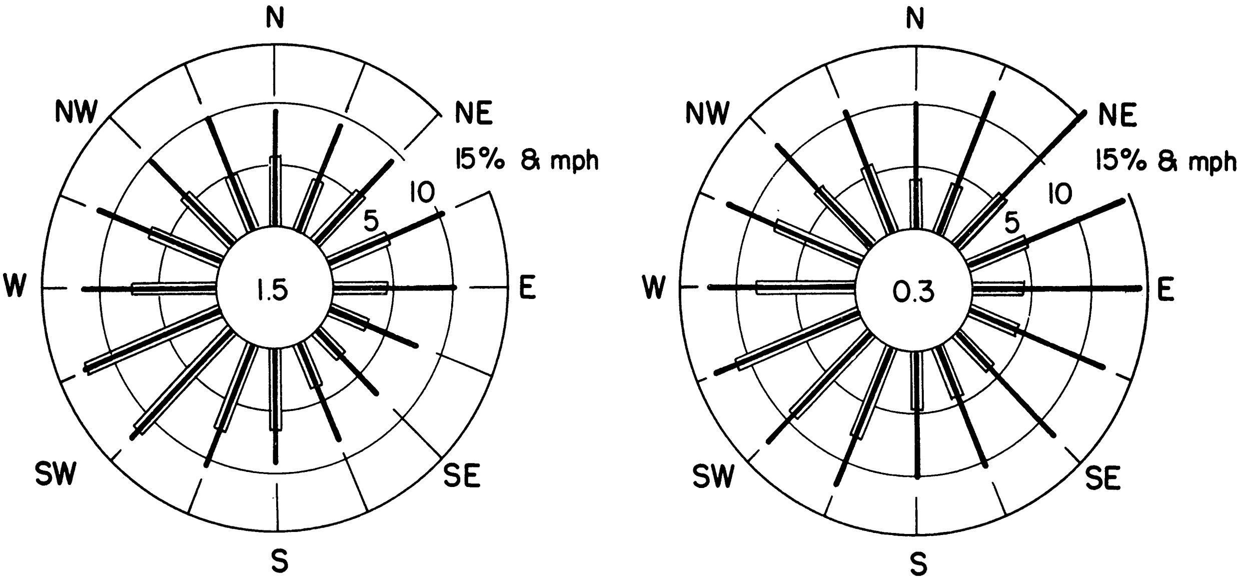


TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 47 ft.
Five year Summary 1950-1954

DETROIT CITY AIRPORT
DETROIT, MICHIGAN

Wind Instrument at Height of 81 ft.
Three year Summary 1956-1959



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 72 ft.
Three year Summary 1956-1959

ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Aerovane at Height of 102 ft.
Three year Summary 1956-1959

Fig. 2. Percentage frequency of occurrence of winds from 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) at Toledo Municipal Airport, Five-Year Summary, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi Site, Three-Year Summary, 1956-1959.

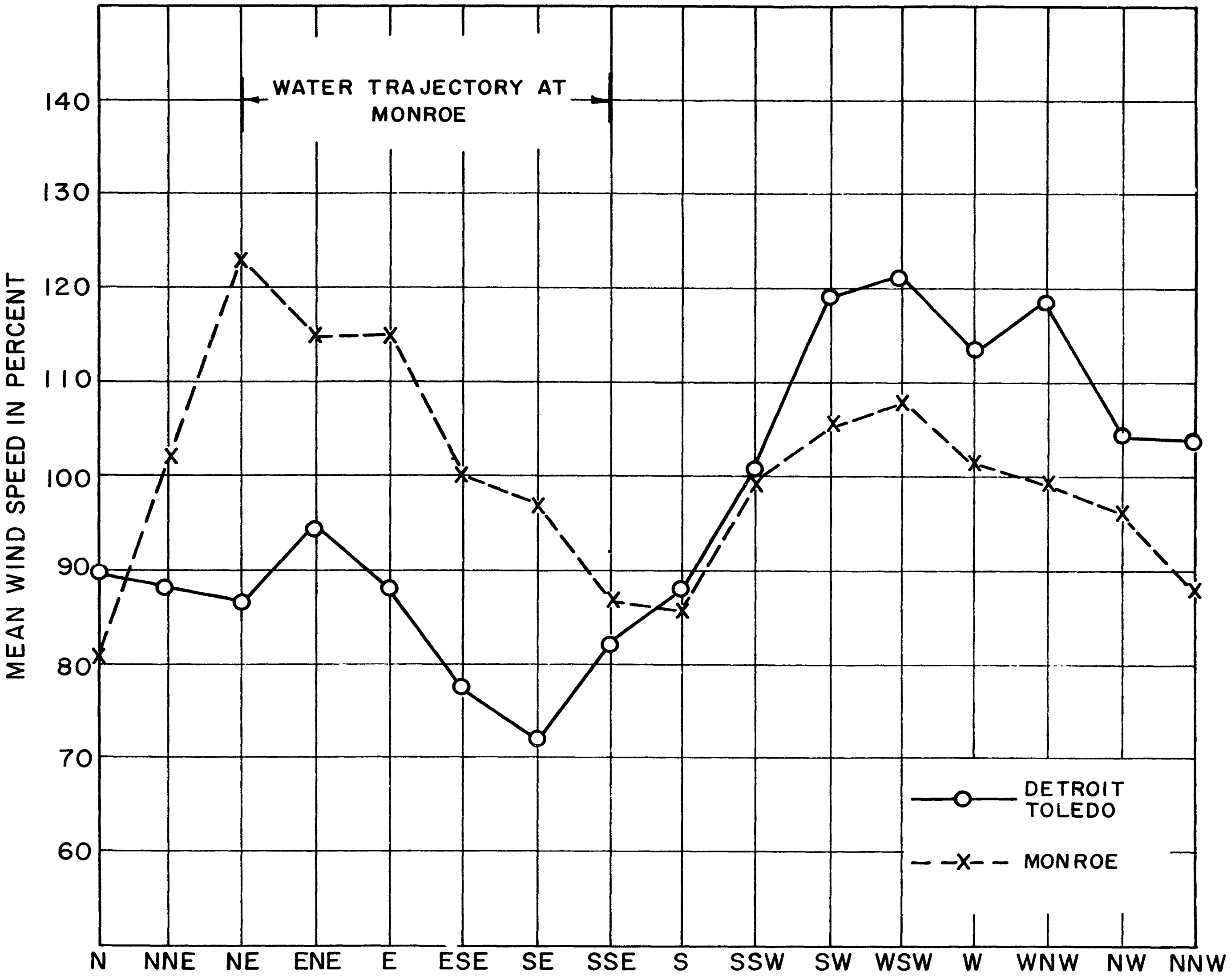


Fig. 3. Mean wind speed at the Enrico Fermi Site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the over-all mean three-year wind speed, 1956-1959.

II. TEMPERATURE-LAPSE-RATE SUMMARY

1. INTRODUCTION

Data are again reproduced from earlier reports for the summary. Table I will aid in finding the references in earlier reports for specific details.

Because the inversion condition is regarded as the poorest one for diffusion, more analysis has been made of this condition than of any of the other lapse-rate categories. Several factors need highlighting. The first is that the lapse-rate measurements at the plant site are made only in the vertical height interval from 25 ft to 100 ft. This is a very thin layer and does not represent the lapse rate existing at the tope of the stack which is 200 ft high. It does permit a good analysis of the thin layer near the ground in which the reactor shell itself is located.

The meteorological tower where the lapse-rate measurements are made is within 100 ft of the lake shore. Again, then, the observations at this point are not necessarily indicative of even the entire plant site. Wiresonde measurements made during the summer of 1960 indicate that the lake-breeze inversion is not only quite shallow but of limited horizontal extent. Therefore, the measurements made at the meteorological tower are characteristic of a thin and narrow layer of air near the lake shore. Diffusion conditions further inland and aloft may be different.

The fact that conditions at the tower may not be representative of those at the stack mouth which is higher or of those on portions of the site farther from the lake does not invalidate the data for purposes of analysis. Diffusion can, in general, be expected to be poorer at the tower due to its low height and its proximity to the lake. Accordingly, tower conditions are conservative and from the lapse rates and wind observations at the tower, it is possible to make conservative engineering estimates of the lapse rate and diffusion at various distances from the plant under a variety of atmospheric and lake conditions.

2. DISTRIBUTION OF LAPSE RATES

The distribution of lapse rates with wind direction is shown in Table III. An important fact to note is that for the three-year period there is a frequency of strong lapse rate 45.4% of the time, of weak lapse 26.7% of the time, and of inversion conditions 27.9%. The association of the noninversion and inversion condition with wind direction and wind speed can be seen in Fig. 4 and in Table IV. The general shape of the distributions in Fig. 4 follows the basic wind pattern given in Fig. 2. There is no particular preference for one wind direction when an inversion occurs or when a noninversion condition occurs.

THE ASSOCIATION OF TEMPERATURE-LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1959
(3-Year Summary)

Wind Direction	Hourly Lapse Rates			Compass Totals	Percent Frequency of Lapse Rate					
					Observations Within Categories			Total Observations		
	S	W	I		S	W	I	S	W	I
N	462	167	201	830	5.1	3.1	3.6	2.3	0.8	1.0
NNE	444	144	206	794	4.9	2.7	3.7	2.2	0.7	1.0
NE	885	135	162	1182	9.7	2.5	2.9	4.4	0.7	0.8
ENE	754	120	115	989	8.2	2.2	2.0	3.7	0.6	0.6
E	529	148	128	805	5.8	2.7	2.3	2.6	0.7	0.6
ESE	418	233	192	843	4.6	4.3	3.4	2.1	1.1	0.9
SE	302	209	300	811	3.3	3.9	5.3	1.5	1.0	1.5
SSE	280	213	433	926	3.1	4.0	7.7	1.4	1.1	2.1
S	259	289	471	1019	2.8	5.4	8.4	1.3	1.4	2.3
SSW	494	519	664	1677	5.4	9.6	11.8	2.5	2.6	3.3
SW	487	685	761	1933	5.3	12.7	13.5	2.4	3.4	3.8
WSW	893	881	557	2331	9.8	16.3	9.9	4.4	4.4	2.8
W	703	575	465	1743	7.7	10.7	8.3	3.5	2.9	2.3
WNW	791	408	403	1602	8.7	7.6	7.2	3.9	2.0	2.0
NW	730	367	317	1414	8.0	6.8	5.6	3.6	1.8	1.6
NNW	700	282	222	1204	7.7	5.2	3.9	3.5	1.4	1.1
Calm	16	20	32	68	0.2	0.4	0.6	0.1	0.1	0.2
Totals	9147	5395	5629	20171	100.3	100.1	100.1	45.4	26.7	27.9

Code:

S = Strong lapse = a lapse rate in excess of the dry adiabatic lapse rate.

W = Weak lapse = a positive lapse rate that is less than the dry adiabatic lapse rate.

I = Inversion = temperature increase with height.

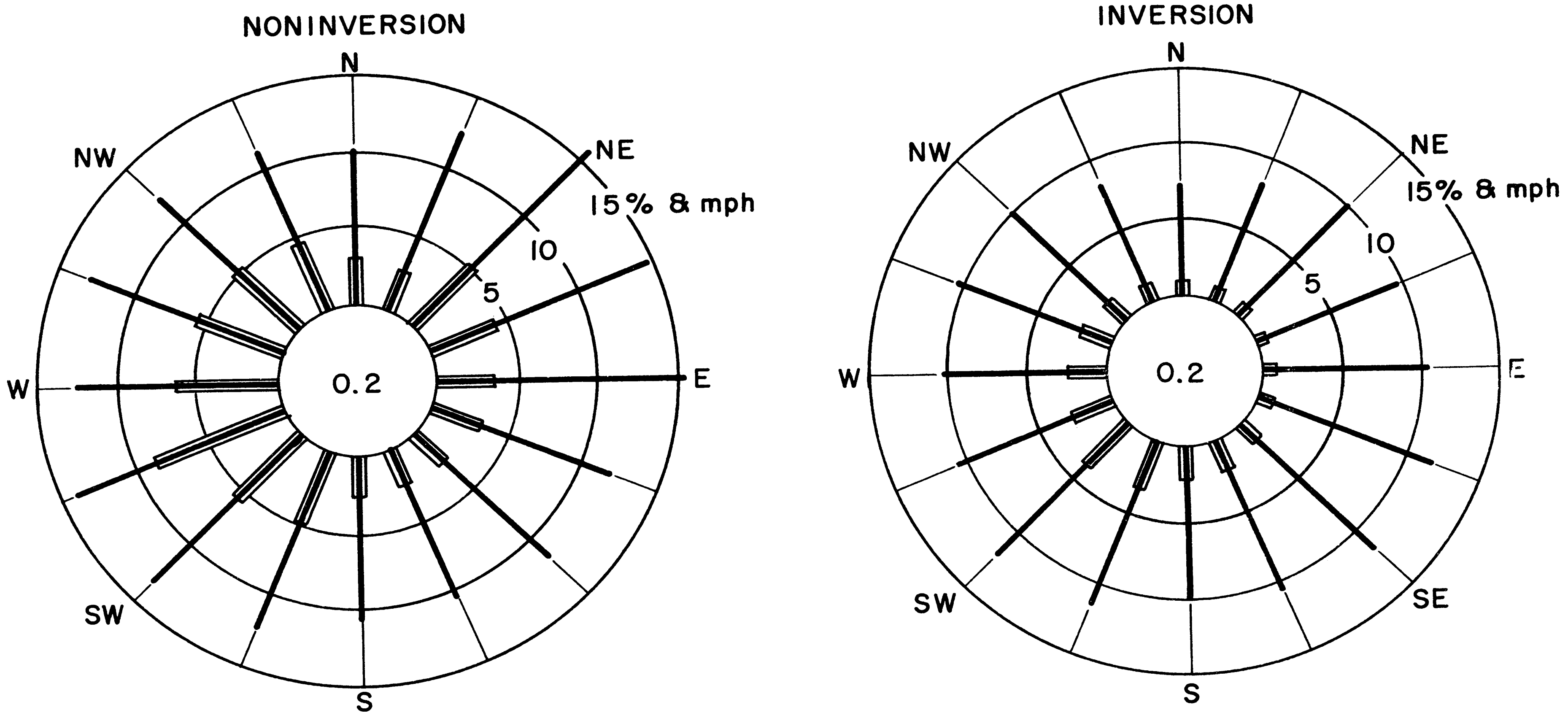


Fig. 4. Percentage frequency of inversions and noninversions associated with winds for 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) at the Enrico Fermi Site: Three-Year Summary, 1956-1959.

TABLE IV

WIND DIRECTION AND MEAN WIND SPEED ASSOCIATED WITH INVERSIONS AND NONINVERSIONS AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1959
(3-Year Summary)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	1.0	7.1	3.1	10.1
NNE	1.0	8.1	2.9	12.4
NE	0.8	9.8	5.1	15.9
ENE	0.6	9.6	4.3	14.8
E	0.6	10.2	3.3	15.3
ESE	0.9	11.8	3.2	11.8
SE	1.5	11.8	2.5	11.7
SSE	2.1	10.6	2.5	10.6
S	2.3	10.0	2.7	10.7
SSW	3.3	11.5	5.1	12.4
SW	3.8	12.0	5.8	13.2
WSW	2.8	10.6	8.8	14.0
W	2.3	10.1	6.4	12.6
WNW	2.0	10.3	5.9	13.0
NW	1.6	10.0	5.4	12.1
NNW	1.1	8.2	4.9	11.4
Calm	0.2	0.0	0.2	0.0
Totals	27.9		72.1	
Average		10.4		12.8

It has been mentioned earlier in Section I-3 that the average wind speed over the three-year period 1956-1959 was 12.4 mph. Table IV shows that the average speed with an inversion condition is 10.4 mph while with a noninversion it is 12.8 mph. Under the poorer diffusion condition, this wind speed is still considered moderately high. As pointed out earlier, the high wind speed is a factor that lowers the concentration at any point downstream. Figure 4 shows even more clearly that, when an inversion does occur, the wind speed regardless of direction is on the average near 10 mph, the wind speeds from the NNW through the NNE being lowest.

3. DIURNAL VARIATION OF INVERSIONS

Table V shows a breakdown of inversions by wind directions for daytime and nighttime. As would be expected, the nighttime winds are slightly lower in speed than are the daytime ones. This table also shows that there is almost an equal occurrence of inversions by day and by night. Table VI gives a breakdown of inversions by hours of the day. Figure 5 is a plot of the same data plus a plot of similar data from the WJBK-TV tower located in northwestern suburban Detroit. Over the three-year period, the average number of hours of inversions at the plant site and WJBK-TV tower are nearly the same. The plot of the WJBK-TV tower data shows a typical diurnal pattern of inversions found at a continental station: a maximum frequency of inversions in the early morning hours followed by a minimum in the midafternoon and then a slow rise after sunset to the early morning maximum. This pattern is created by the well-known and often discussed nocturnal or radiational inversion, which is destroyed by solar radiation during the daylight hours.

The plant site and WJBK-TV tower data in Fig. 5 show two distinct differences. The diurnal variation in frequency is much less at the plant site than at the WJBK-TV site and the minimum occurs in the late morning hours at the site rather than in the afternoon as in suburban Detroit. These differences can definitely be attributed to the proximity of the plant site to Lake Erie.

The water has a modifying effect on the local climate. One result is that the advection of air from over water which is relatively warmer than the land does not allow the formation of as many nocturnal inversions at the plant site as a typical continental station would normally have. Thus the maximum inversion frequency at the plant site is less than at the WJBK-TV tower. Counterbalancing this effect is the lake-breeze-induced inversion which occurs during the daylight hours. When the lake is cooler than the land and if the pressure gradient is weak enough, cool air from off the lake is advected over the land, causing an inversion to form over a narrow area paralleling the lake shore. So as the nocturnal inversion effects are being destroyed by solar radiation, the same solar radiation is causing a lake breeze inversion to form. The diurnal minimum frequency of inversions occurs when the nocturnal inversion has largely disappeared and before the lake breeze inversion has become pronounced.

TABLE V

THE ASSOCIATION OF INVERSION PERIODS AND WIND DIRECTION AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1959
(3-Year Summary)

Wind Direction	Daytime				Nighttime			
	No.	Occurrences, %		Mean Wind Speed	No.	Occurrences, %		Mean Wind Speed
		Total	Overall			Total	Overall	
N	58	2.3	1.0	7.2	143	4.6	2.5	7.1
NNE	63	2.5	1.1	8.1	143	4.6	2.5	8.2
NE	68	2.7	1.2	11.9	94	3.0	1.7	8.3
ENE	55	2.2	1.0	10.2	59	1.9	1.0	9.3
E	66	2.6	1.2	9.7	63	2.0	1.1	10.6
ESE	128	5.0	2.3	11.3	64	2.1	1.1	12.9
SE	228	9.0	4.1	11.3	77	2.5	1.4	12.2
SSE	324	12.8	5.6	10.6	104	3.4	1.8	10.9
S	232	9.1	4.1	10.0	239	7.7	4.2	10.0
SSW	290	11.4	5.2	11.5	374	12.1	6.6	11.6
SW	347	13.7	6.2	13.1	414	13.4	7.4	11.0
WSW	214	8.4	3.8	11.8	342	11.1	6.1	9.8
W	168	6.6	3.0	11.8	297	9.6	5.3	9.2
WNW	138	5.4	2.5	12.0	265	8.6	4.7	9.4
NW	93	3.7	1.7	12.2	224	7.3	4.0	8.9
NNW	54	2.1	1.0	9.1	168	5.4	3.0	7.9
Calm	14	0.6	0.2	0.0	18	0.6	0.3	0.0
Totals	2540	100.1	45.2		3088	99.9	54.7	
Average				11.2				9.8

TABLE VI

HOURLY PERCENTAGE FREQUENCY OF INVERSIONS AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1959

Hour Ending	Annual			3-Year Summary
	1957	1958	1959	
0100	22.4	36.8	39.1	32.8
0200	23.4	37.1	42.9	34.5
0300	22.4	36.5	43.0	34.0
0400	22.4	35.0	43.4	33.6
0500	22.9	35.1	40.5	32.8
0600	23.5	35.3	41.1	33.3
0700	21.7	33.9	39.0	31.5
0800	17.2	29.9	27.8	25.0
0900	17.6	23.5	17.0	19.4
1000	12.2	22.1	15.7	16.7
1100	12.6	21.1	18.6	17.4
1200	17.1	18.5	16.5	17.4
1300	16.8	19.0	20.5	18.8
1400	20.2	23.9	24.8	23.0
1500	22.0	31.3	27.1	26.8
1600	22.7	33.2	35.0	30.3
1700	19.0	36.5	36.0	30.5
1800	17.2	34.4	38.3	30.0
1900	15.5	37.3	36.3	29.7
2000	18.0	36.7	35.2	30.0
2100	18.8	35.7	41.0	31.8
2200	19.4	35.9	42.6	32.6
2300	20.4	33.4	39.7	31.2
2400	19.0	34.0	38.7	30.6
Average	19.4	31.5	33.3	28.1

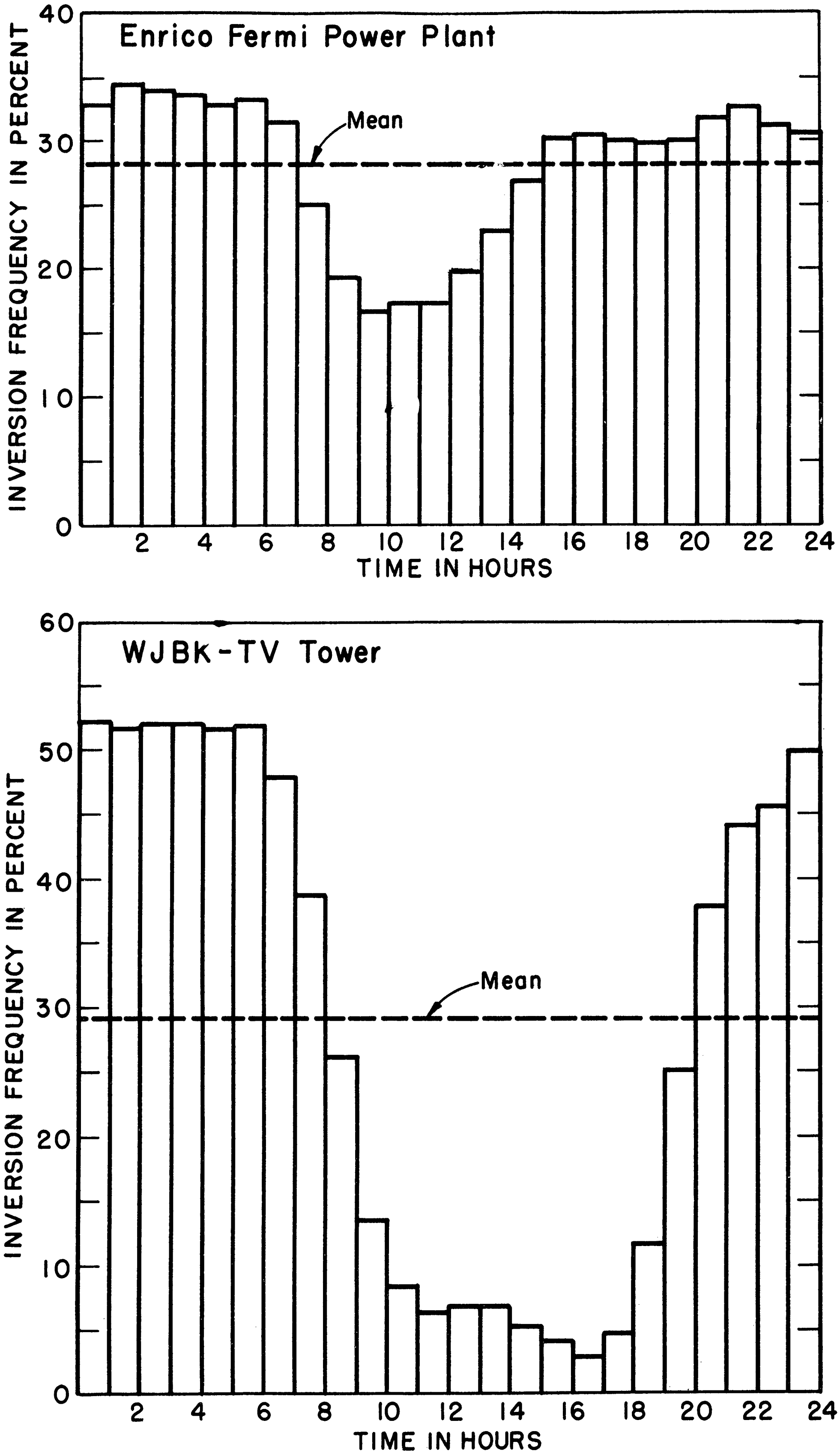


Fig. 5. Diurnal variation of inversions at the Enrico Fermi Site and at WJBK-TV tower: Three-Year Summary, 1956-1959.

On the average, this minimum frequency occurs between 0900 and 1000. Since there are two separate inversion types at the plant site, the minimum frequency there is greater than at the WJBK-TV tower.

4. PERSISTENCE OF INVERSIONS

As noted in the previous section, the lake effect has a tendency both to create and also to destroy inversions. Another effect is that of sometimes maintaining inversion conditions once they have formed. Some evidence of this may be found in past reports by comparing the continuous inversions listed at the plant site with those listed at the WJBK-TV tower (see Appendices B of Refs. 4 and 5). In general, the periods of inversion at the plant site lasting 24 hr or longer coincide with either an inversion or a weak lapse rate condition at the WJBK-TV tower. The nearness to the lake and the lack of a heat source from a large population area are the primary factors which account for the differences in the persistence of inversions at the plant site and at the WJBK-TV tower. When warm air is advected into the general area over ground that is relatively cold, there are occasional long periods of continuous inversions observed at both the plant site and WJBK-TV tower (see Munn[6] for a discussion of such an inversion).

Table VII contains a compilation of the frequency of continuous inversions from 1 December 1956 to 30 November 1959. Figure 6 is a plot of the same data. Such data may be looked at in two ways. The first way is to suppose an inversion exists, and then to ask what the probability is of having a 20-hr inversion. By looking at the relative frequency it is seen that a 20-hr inversion occurs 0.9% of the time. The next question is what the probability is of such an occurrence relative to the whole spectrum of meteorological occurrences. This is answered simply by multiplying the relative frequency of occurrence by the frequency of occurrence of inversions, 27.9%, so the result is the joint probability of having an inversion which lasts for 20 hr. This value is 0.25%. Such a circumstance then would be likely to occur one time in four hundred.

Although the observations show that there have been some long periods of continuous inversions, the observational data from the diffusion studies and wiresonde flights during the summer of 1960 strongly indicate that many of the situations observed as inversions at the plant site are actually quite shallow and narrow in their extent. In such cases diffusion is probably significantly better a short distance inland than at the site itself.

One last point must be made clear concerning the persistence of inversion conditions. Long periods of inversion, that is those over 72 hr in duration, are caused by the large-scale circulation features. These are the inversion conditions that may blanket an entire area such as the whole Ohio River valley or all of the eastern United States. Recorded catastrophic fumigations such as those at Donora, the Meuse Valley, London, etc., are some of the extreme cases. Stagnation of the pressure systems causes these conditions. As of this

TABLE VII

NUMBER OF OCCURRENCES AND PERCENTAGE FREQUENCY OF OCCURRENCE OF CONTINUOUS INVERSIONS AT ENRICO FERMI PLANT SITE

1 December 1956 - 30 November 1959
(3-Year Summary)

Length of Inversion, hr	No. of Occurrences	No. of Hours	Frequency of Occurrence with Respect to	
			Inversions, %	All Lapse Rates, %
1-5	--	1370	24.3	6.78
6	56	336	16.3	4.55
7	38	266	11.0	3.07
8	37	296	10.8	3.04
9	33	297	9.6	2.68
10	25	250	7.3	2.04
11	10	110	2.9	0.81
12	26	312	7.6	2.06
13	14	182	4.1	1.14
14	24	336	7.0	1.95
15	8	120	2.3	0.64
16	11	176	3.2	0.89
17	10	170	2.9	0.81
18	12	216	3.5	0.98
19	7	133	2.0	0.56
20	3	60	0.9	0.25
21	3	63	0.9	0.25
22	1	22	0.3	0.08
23	4	92	1.2	0.33
25	2	50	0.6	0.17
26	2	52	0.6	0.17
27	1	27	0.3	0.08
28	2	56	0.6	0.17
29	2	58	0.6	0.17
33	1	33	0.3	0.08
34	1	34	0.3	0.08
35	1	35	0.3	0.08
37	1	37	0.3	0.08
39	1	39	0.3	0.08
40	1	40	0.3	0.08
42	1	42	0.3	0.08
43	1	43	0.3	0.08
47	1	47	0.3	0.08
50	1	50	0.3	0.08
56	1	56	0.3	0.08
58	1	58	0.3	0.08
65	1	65	0.3	0.08
Totals	344	5629	100.4	27.91

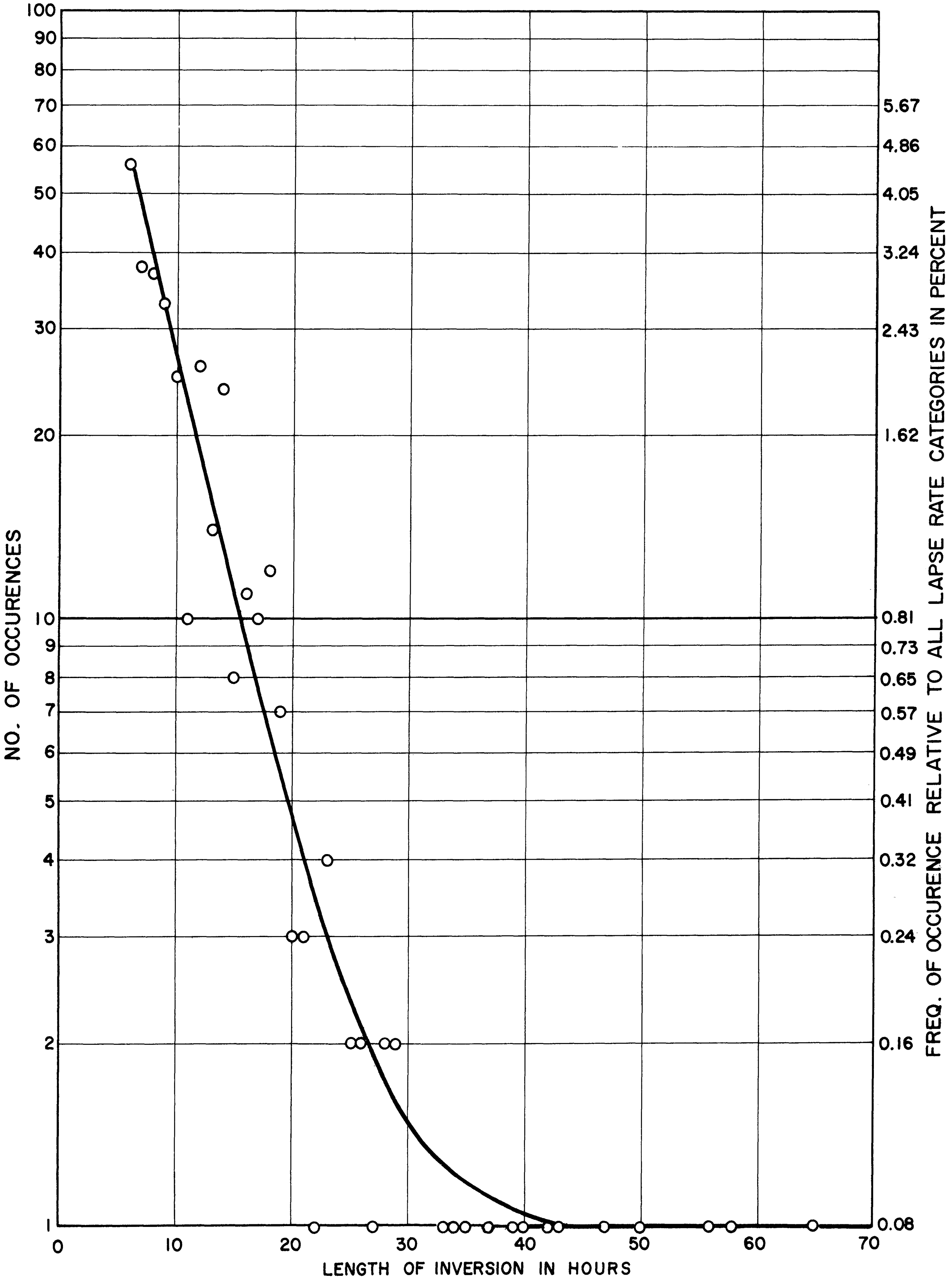


Fig. 6. Percentage frequency of continuous inversions at Enrico Fermi Plant Site: Three-Year Summary, 1956-1959.

date, no observations of such a condition have been made at the Enrico Fermi Plant site. There is ample reason to believe that under such severe stagnation conditions, diffusion at and near the plant site is likely to be substantially better than in some other areas. Table VIII gives the number of stagnation occurrences that may be expected by months which last 4 days or longer in the Detroit area. These data are based upon 20 years of observation.[7]

TABLE VIII

PERIODS OF STAGNATION BY MONTHS IN THE DETROIT AREA[7]

Month	No. of Occurrences in 20 yr
January	0
February	0
March	0
April	3
May	0
June	3
July	0
August	4
September	3
October	4
November	0
December	0

As indicated, the stagnant conditions just described are rare but, when they occur, they may apply over a widespread area. It is relevant for the nuclear industry generally, as well as for other industries, to consider precautions during these stagnant periods, such as imposing extra restrictions on the discharge of airborne pollutants. The U. S. Weather Bureau has recently initiated a warning service to alert interested parties about forthcoming periods of stagnant conditions.

III. PRECIPITATION SUMMARY

1. INTRODUCTION

The importance of precipitation as a scavenging or cleansing agent on the atmosphere has been referred to in several previous reports. To emphasize this statement, Fig. 7 is being included in this report.[8] Figure 7 shows the effect of the particle size of the particulate being scavenged, rainfall rate, and duration of rainfall on the scavenging effect of the precipitation. For a typical mid-latitude storm system, the warm frontal rain might occur with a rainfall rate of 10 mm/hr. Such a storm may give rain for a period of at least 2 hr. If these values are entered into Fig. 7 using a 4μ particle diameter, it is seen that the cleansing action is almost complete. Another viewpoint may be taken, as follows. If, during such a rainy period, the wind speed averaged 10 mph, then according to Fig. 7, at least 50% of the particles 4μ and larger in diameter would be scavenged within 1/4 of an hour or within an area 2-1/2 miles downwind from the point of injection into the atmosphere. If a release occurred in an area such as that which surrounds the plant site, that is, an area of sparse population, a large percentage of the particulate matter would be washed out of the atmosphere before such a particulate cloud would arrive over a large population center. But natural horizontal diffusion is active even under strong inversion conditions if a trajectory of some miles is considered; and if there were no washout immediately, this diffusion would lower the total contaminant over a unit area, so much so that, should washout take place over a population center, the amount of contaminant at and just above the ground would be substantially less than that at a location near the plant.

As is implied in the above paragraph, washout is an atmospheric process that can be considered as either favorable or unfavorable, depending upon where the washout takes place. Washout over the area surrounding the plant site may be viewed as good relative to a situation where polluted convective clouds of low concentration give showers over the Detroit area. Observations during the summer of 1960 indicate that, with a lake breeze and a light southwesterly gradient, a very typical summertime situation, convective clouds form parallel to the lake shore about 3-4 miles inland in an area of low level convergence. This would be a preferred area for rain showers and is over a relatively unpopulated area.

The maximum amounts of washout are likely to occur with warm frontal rain, which in turn occurs mainly with winds from E to S. Population is sparse in those directions, and even these maximum amounts will be relatively small a few miles from the plant because of the pronounced horizontal diffusion which occurs under all meteorological conditions, even strong inversions.

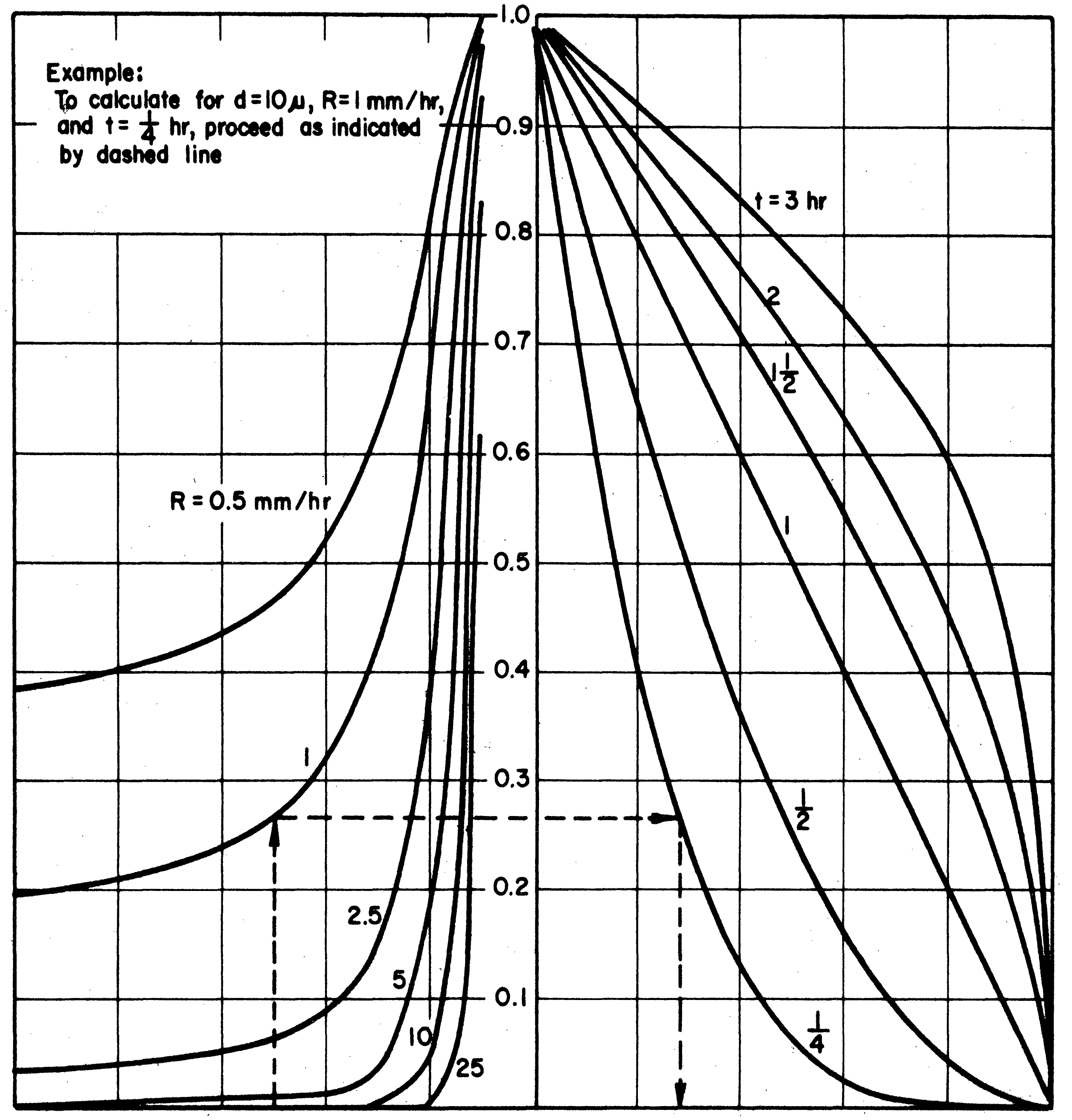


Fig. 7. Percentage of particles, of a given diameter, scavenged from cloud by raindrops as function of rainfall rate, R, and time duration of the rate, t.

2. DISTRIBUTION AND FREQUENCY OF PRECIPITATION

Table IX and Fig. 8 show the results of three years of precipitation data from the plant site. From Table IX it is seen that the wind speed is 2 mph higher when it rains than the average wind over the entire period. From the diffusion standpoint this is favorable because it causes greater dilution. Secondly, precipitation occurs 12.7% of the time during the entire three-year period. These three years are generally normal, in a climatological sense, so precipitation is not a major factor in the climatology of the plant site area.

Figure 8 shows a bimodal distribution of the frequency of occurrence of the wind direction when rain occurs. The easterly mode is caused by prewarm frontal rains while the southwesterly mode is caused by precold frontal shower activity. Wind speeds are always greater than 11 mph when it rains, regardless of direction.

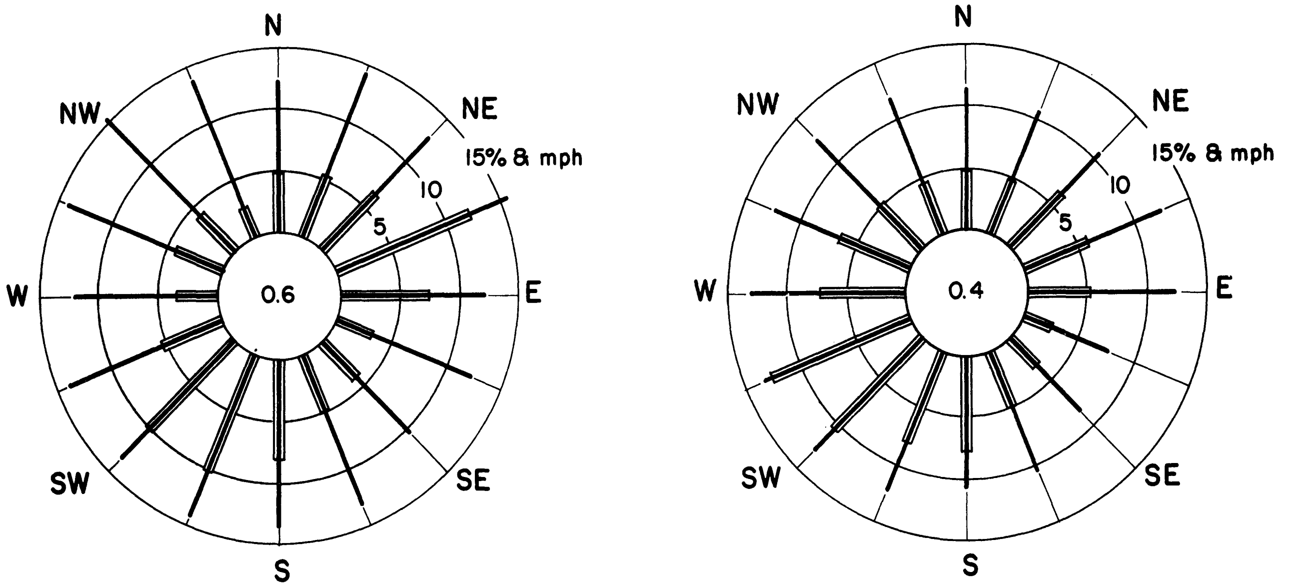
Table IX shows that precipitation with winds from the east to south, which might give warm frontal washout, occurs only a total of 2.7% of the total time. Calm air occurs only 0.2% of the time when it rains or 0.02% of the total time. Certainly this is an insignificant percentage. Thus the probability of widespread washout over the plant site is very small.

TABLE IX

THE ASSOCIATION OF PRECIPITATION WITH WINDS AT THE ENRICO FERMI SITE

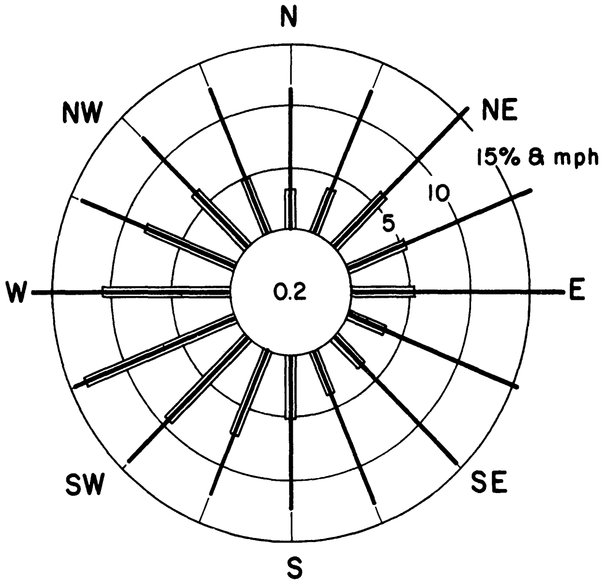
1 Decmeber 1959 - 30 November 1959
(3-Year Summary)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	10.1	11.2	105	3.4	0.4
NNE	12.6	12.5	128	4.1	0.5
NE	15.3	16.0	191	6.1	0.8
ENE	14.2	16.8	167	5.3	0.7
E	14.3	17.9	165	5.3	0.7
ESE	12.4	15.3	108	3.4	0.4
SE	12.0	14.4	101	3.2	0.4
SSE	10.8	3.3	123	3.9	0.5
S	10.7	12.5	166	5.3	0.7
SSW	12.3	12.6	229	7.3	0.9
SW	13.0	14.1	302	9.6	1.2
WSW	13.4	14.7	432	13.8	1.7
W	12.7	16.6	349	11.1	1.4
WNW	12.3	14.0	260	8.3	1.0
NW	11.9	12.5	200	6.4	0.8
NNW	10.9	12.9	161	5.1	0.6
Calm	0.0	0.0	7	0.2	0.0
Totals			3194	101.8	12.7
Average	12.4	14.4			



TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO
Annual (1 Dec.-30 Nov.) 1950-54

TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO
3yr. sum. (1 Dec.-30 Nov.) 1956-59



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN
3yr. sum. (1 Dec.-30 Nov.) 1956-59

C-25

Fig. 8. Percentage frequency of occurrence of winds from 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) with precipitation at Toledo Minicipal Airport, Five-Year Summary, 1950-1954, and Toledo Express Airport, and the Enrico Fermi Site, Three-Year Summary, 1956-1959.

IV. EXTREMES OF TEMPERATURE

During the course of this project, a deck of IBM data cards was obtained from the U. S. Weather Bureau state climatologist for the Monroe climatological station which is located at the Monroe water works. These cards contain data on maximum and minimum temperatures, occurrence of hail, rain, snow, thunderstorms, tornadoes, etc. Such information is quite valuable in determining the climatological background of the local area. In addition, it is a source for design criteria concerning the probability of occurrence of the observed meteorological variables. The card deck has been used to determine the probability of extreme values of maximum and minimum temperature at the Monroe station and hence for the area surrounding the station.

The extremes of minimum temperature are significant during the months which have the coldest weather, whereas during the summer months the minimum temperature is not as important except perhaps as a relief from a heat wave. Basing the work on such concepts, the months were divided into two categories, those in which a minimum temperature would be important for design or operational routines and those in which a maximum temperature would be important for similar reasons. The month of April was omitted because it is a transitional month when there are neither extremes of heat or cold. The April data added nothing to the computations, whereas September and October data did have significance.

The major value of these graphs is in design work where a certain temperature can or cannot be tolerated because it might cause equipment failure. The probability of a given temperature and its return period as determined from these computations must be weighed in relation to the cost of a failure and the time lost in repairing such a failure.

All the computations are based upon the methods of extreme value statistics, pioneered by Professor E. J. Gumble.[9] Details on the computations and analysis of the data may be found in either Gumble[9] or Court.[10]

1. MAXIMUM TEMPERATURES

The months of May, June, July, August, and September are contained in the group for which extremes of maximum temperature were computed. Figures 9 through 13 show the results of the computations. Figure 9 may be explained as follows. The heavy solid line is the line that expresses the expected extremes. The probability of not equaling or exceeding a maximum temperature of 95°F in the month of May is 91%. It is seen, also, that a maximum temperature of 95°F is apt to return once in approximately 11 years. The heavy solid line is drawn from computations, not drawn as a best fit of the plotted values, which are

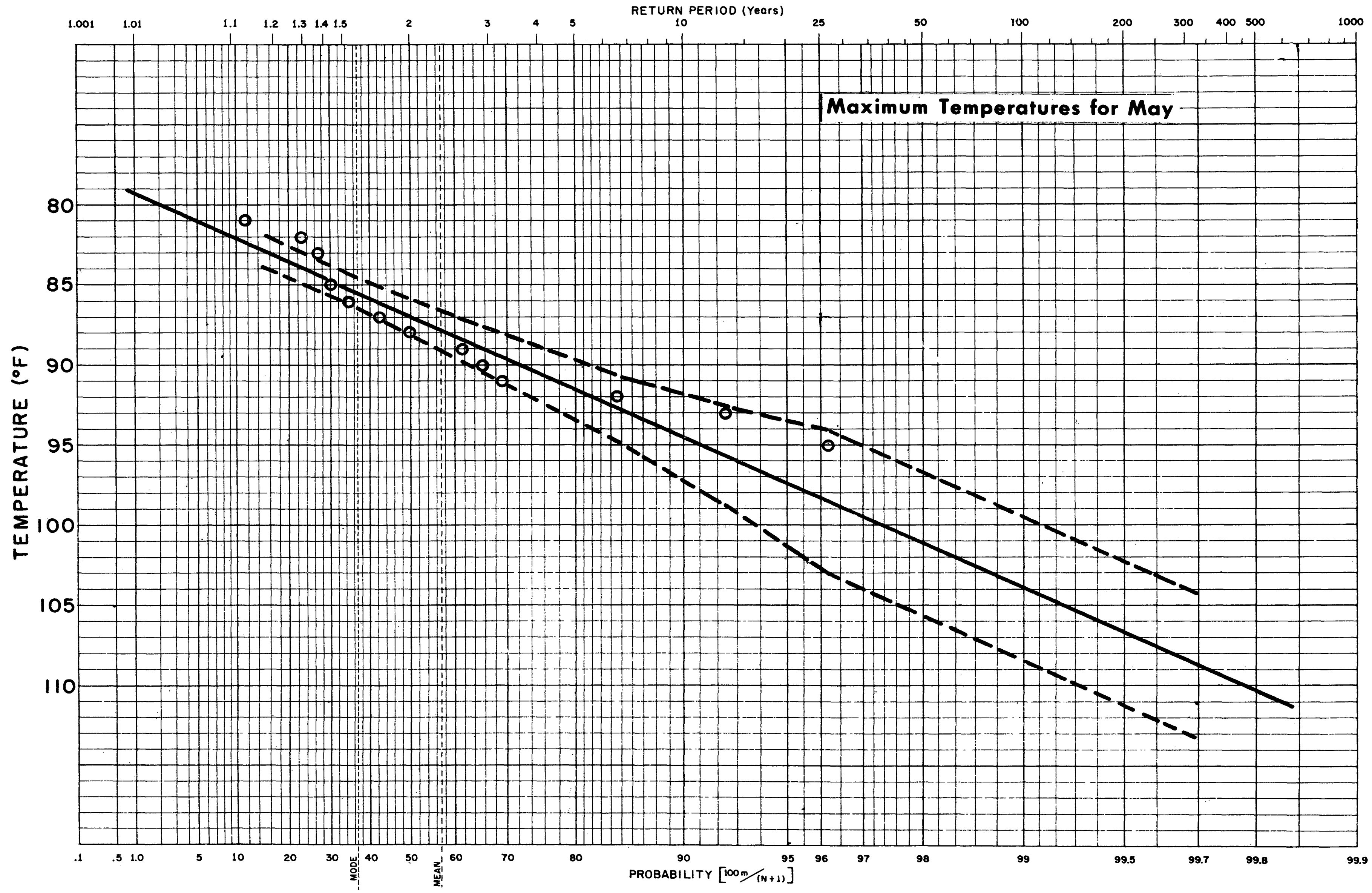


Fig. 9. Probability and return period of maximum temperatures during May.

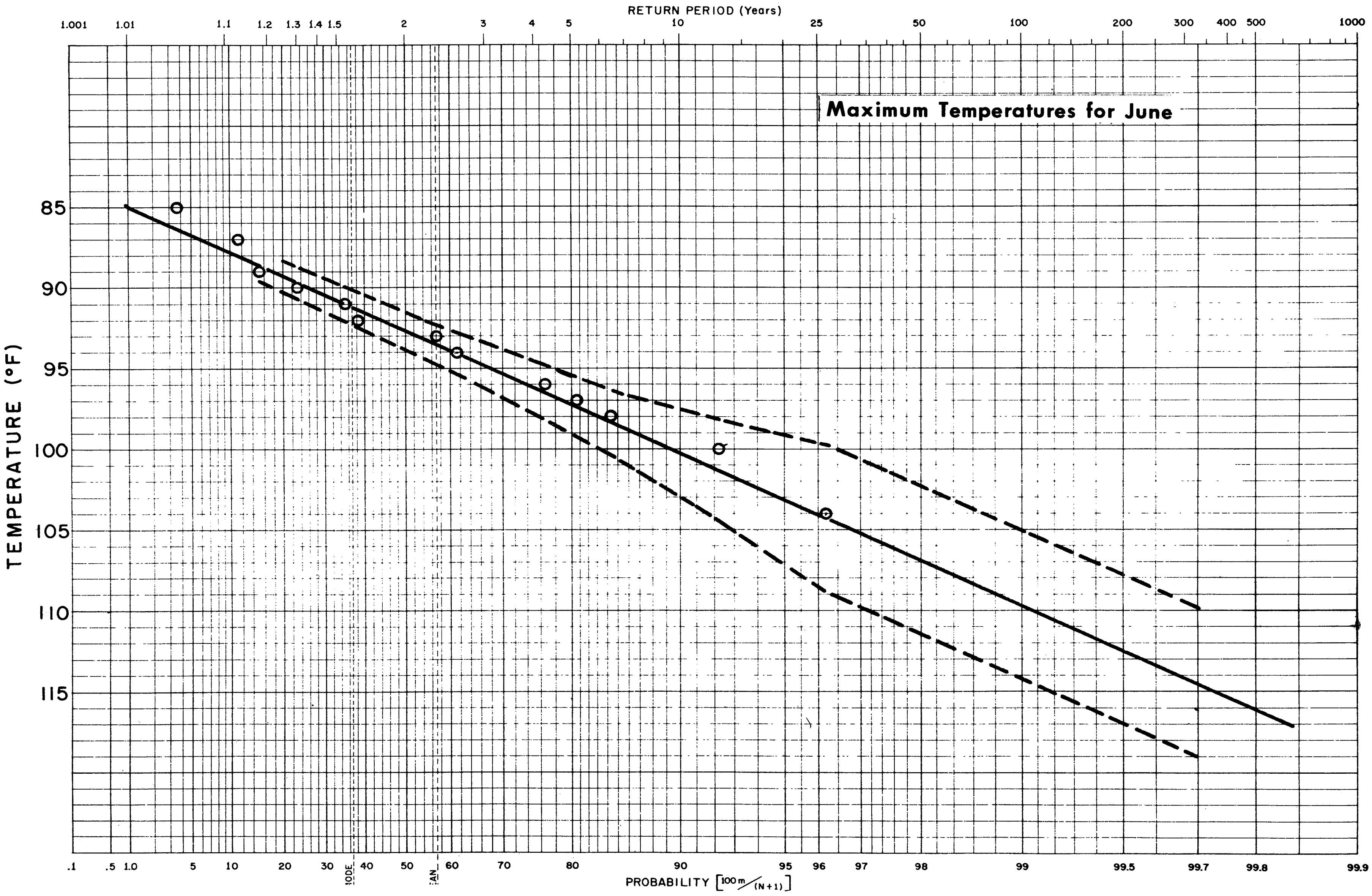


Fig. 10. Probability and return period of maximum temperatures during June.

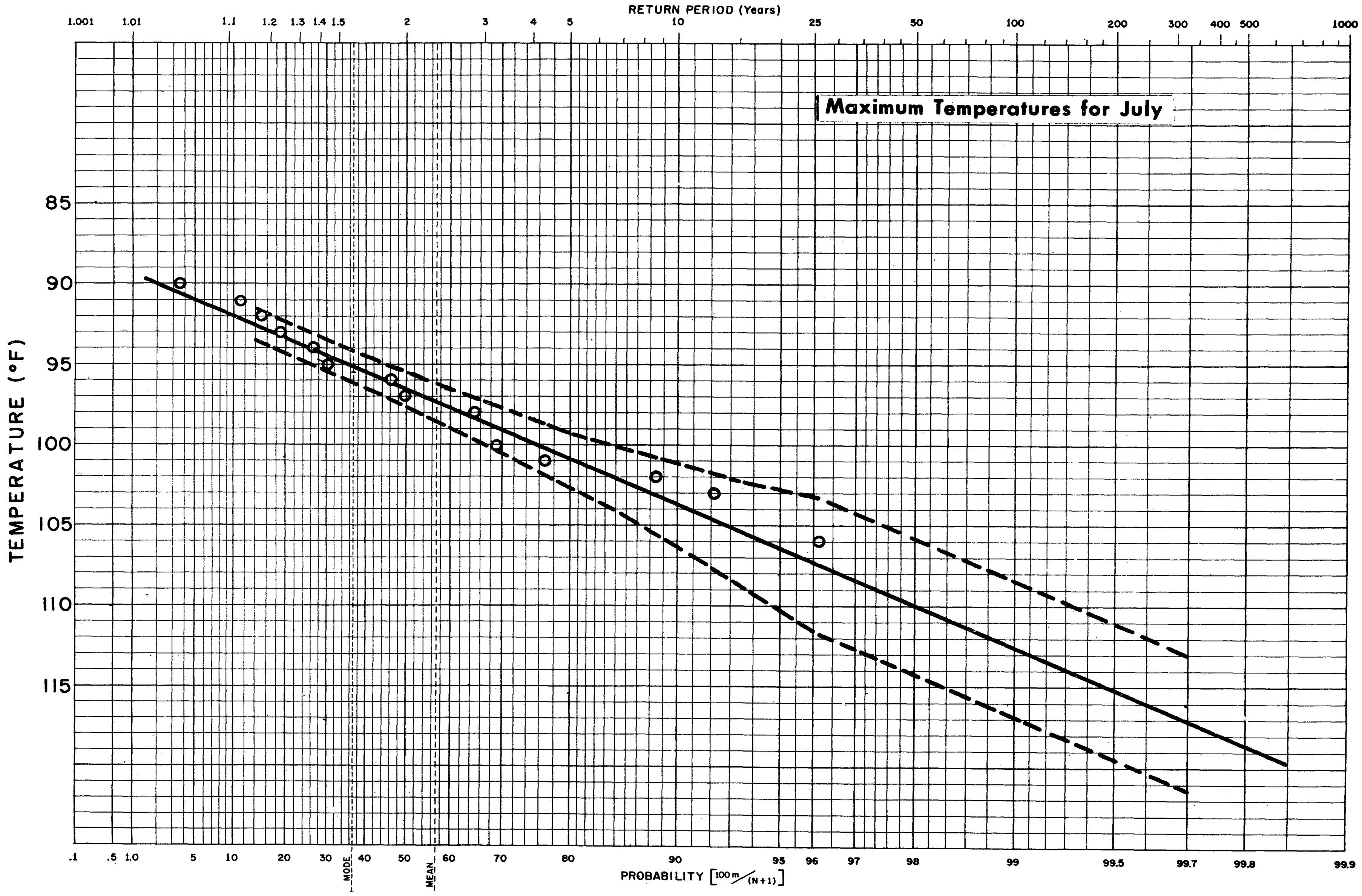


Fig. 11. Probability and return period of maximum temperatures during July.

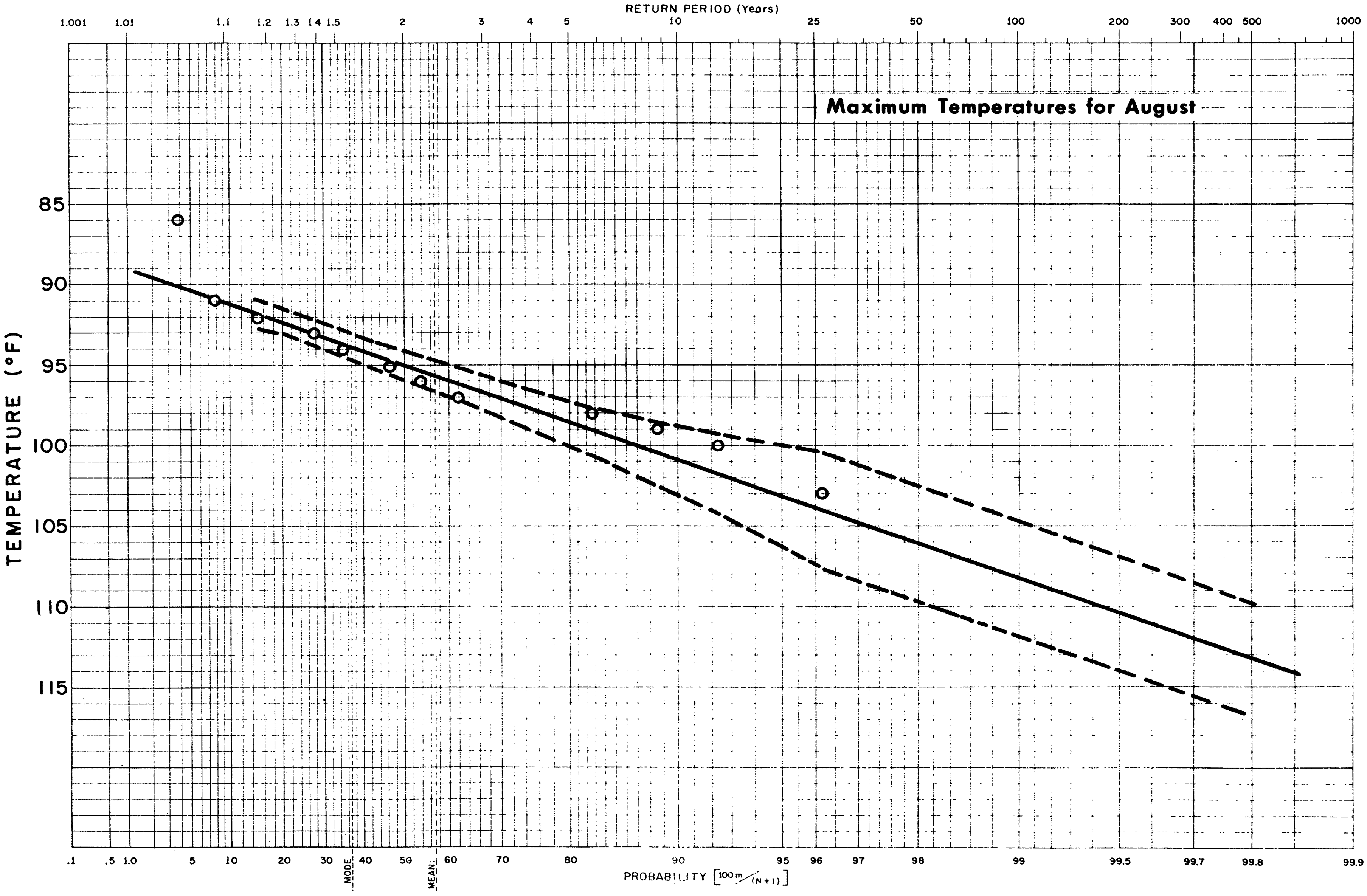


Fig. 12. Probability and return period of maximum temperatures during August.

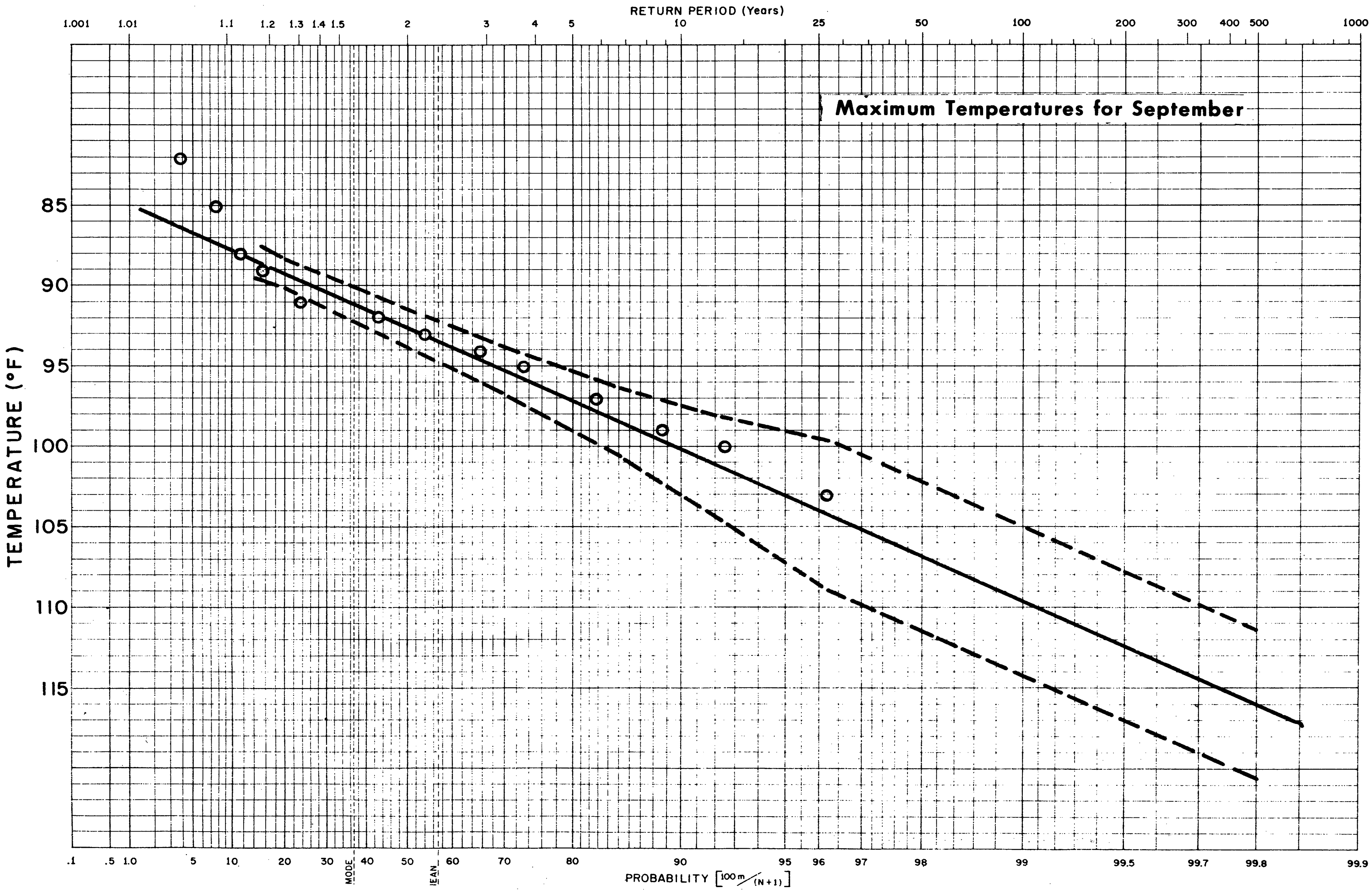


Fig. 13. Probability and return period of maximum temperatures during September.

the encircled points. The dashed lines around the solid line are the one-sigma confidence limits. That is to say, the probability is 0.68 that a maximum temperature of 95°F ± 3°F will have a return period of 11 years during the month of May. The confidence band flares out near the largest and next to largest extreme because there is less stability to these numbers than to other values which have occurred more often.

Figures 9 through 13 are based upon 25 years of record, a time period usually quite adequate for most climatological work.

2. MINIMUM TEMPERATURES

Figures 14 through 19 are plots of similar data for minimum temperatures during October, November, December, January, February, and March. Again the graphs are based on 25 years of observed data. The interpretation of the graphs is the same as with the maximum temperature. By looking at Fig. 19, it can be seen that a temperature of -5°F or lower might be expected to occur in March once in 33 years with a probability of 99%; in other words, the value of -5°F has a probability of 99% of not being equaled or exceeded in March once in 33 years.

In all the plots, Figs. 9 through 19, the observed extremes usually fall within the 68% probability confidence band, indicating that the extreme values are adequately represented by the theory of extreme values.

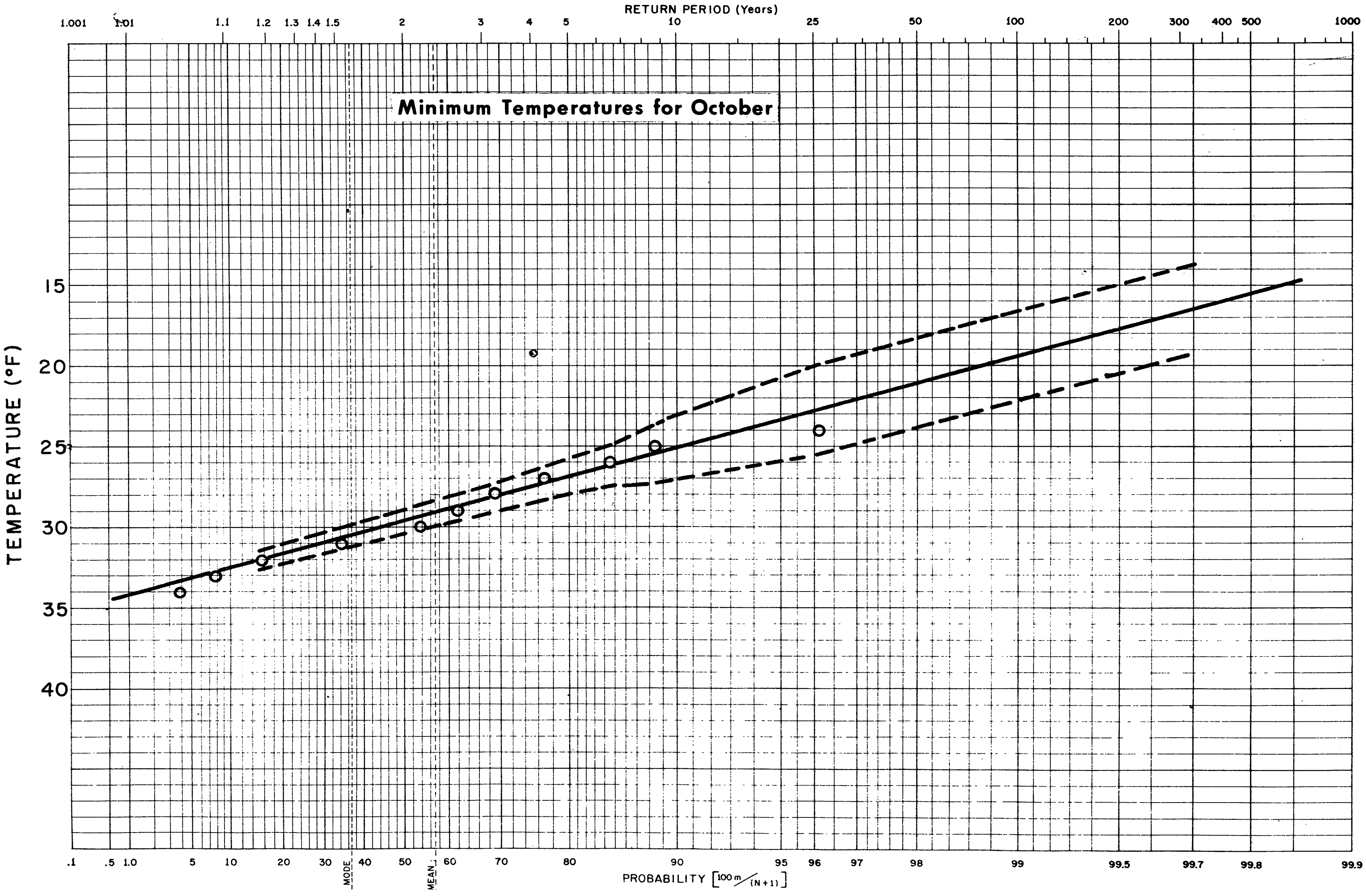


Fig. 14. Probability and return period of minimum temperatures during October.

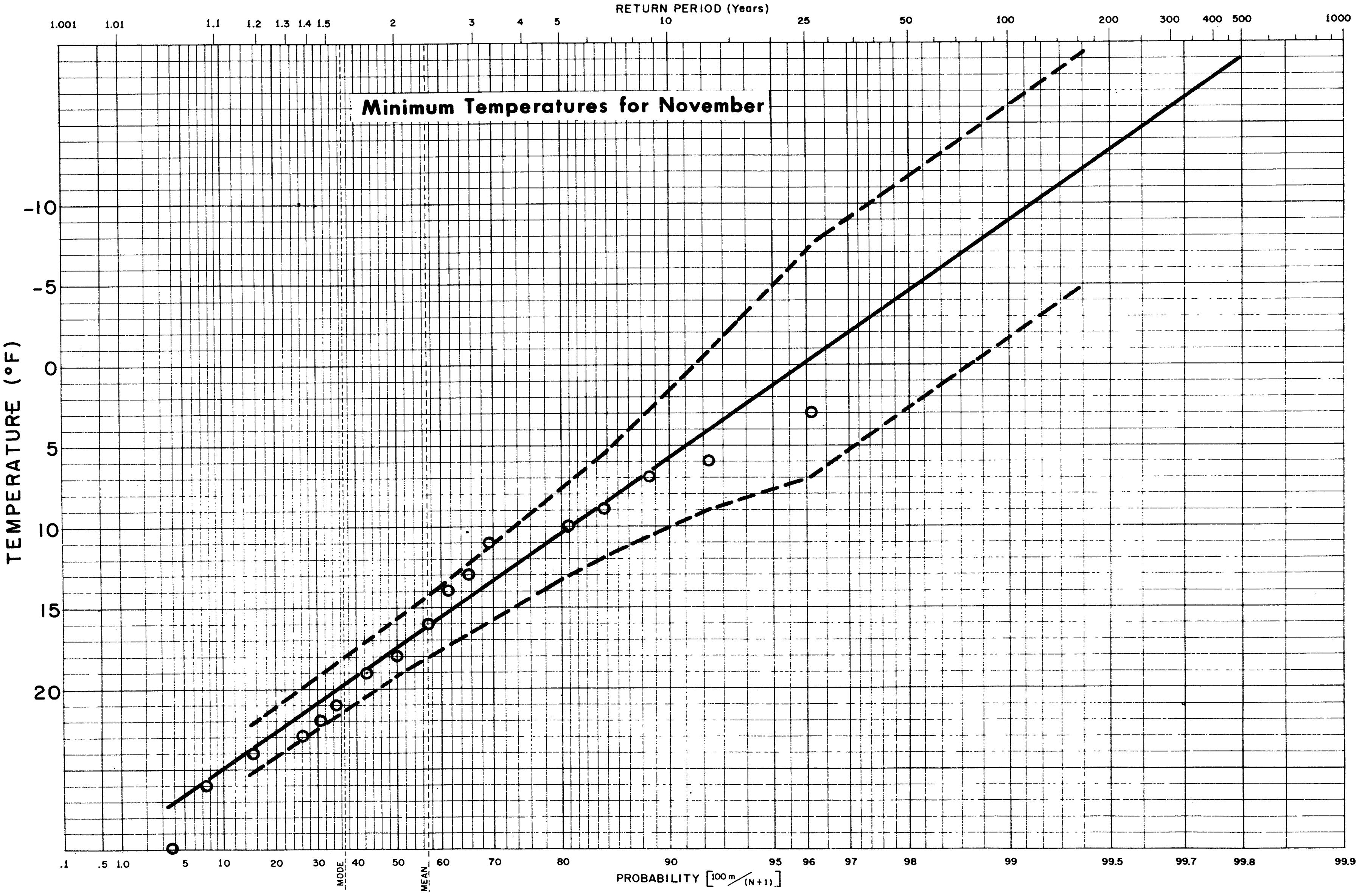


Fig. 15. Probability and return period of minimum temperatures during November.

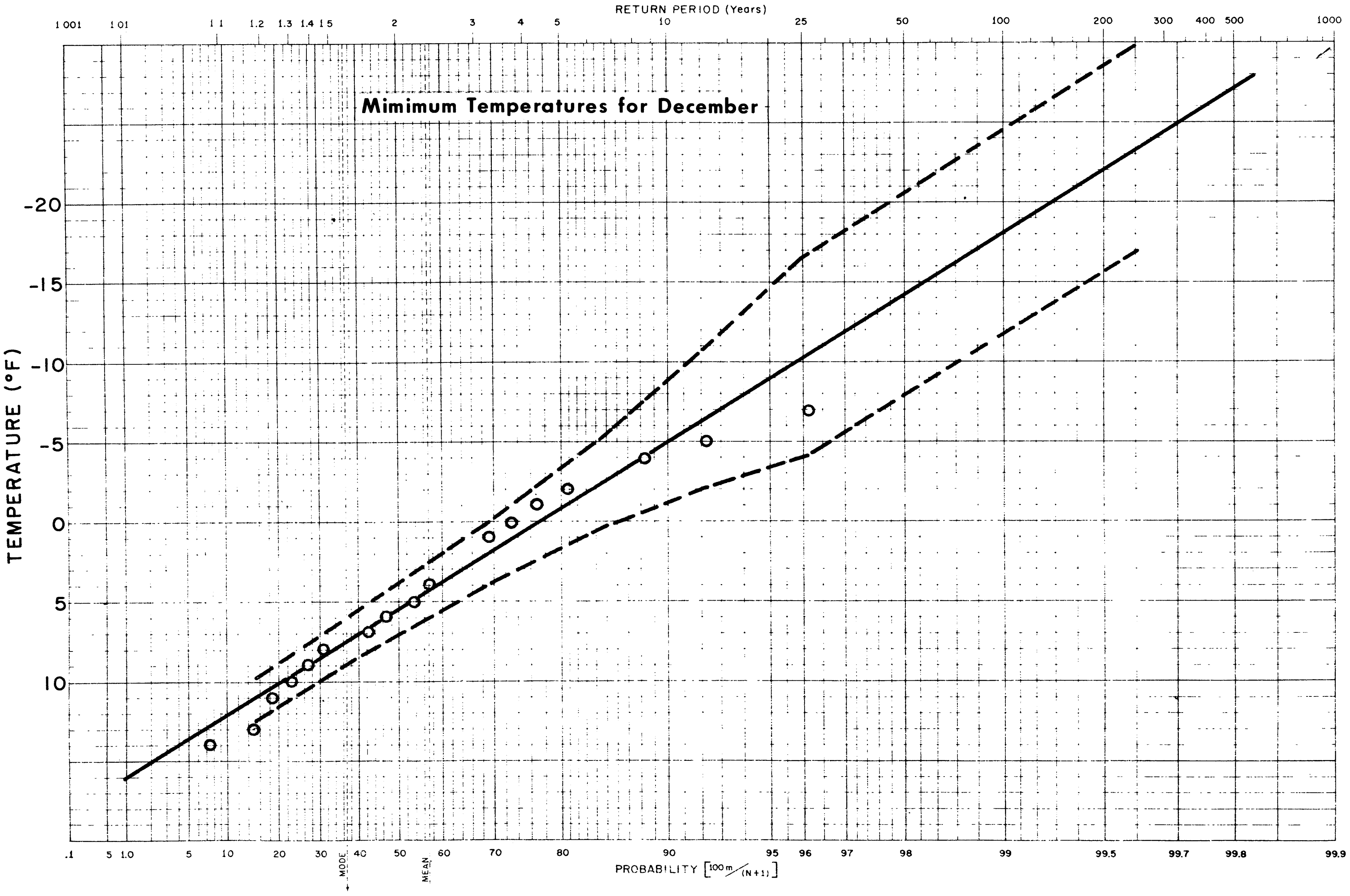


Fig. 16. Probability and return period of minimum temperatures during December.

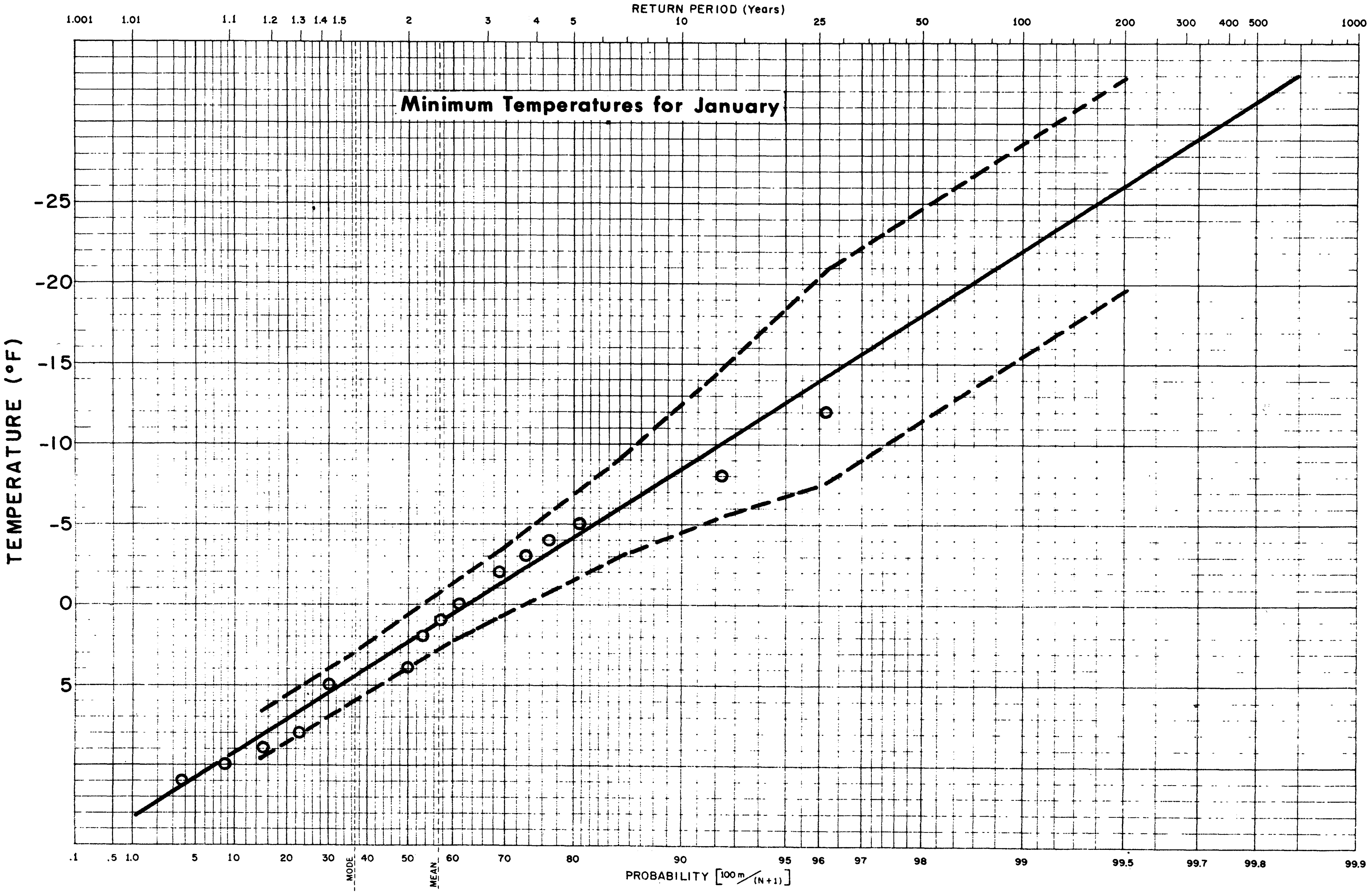


Fig. 17. Probability and return period of minimum temperatures during January.

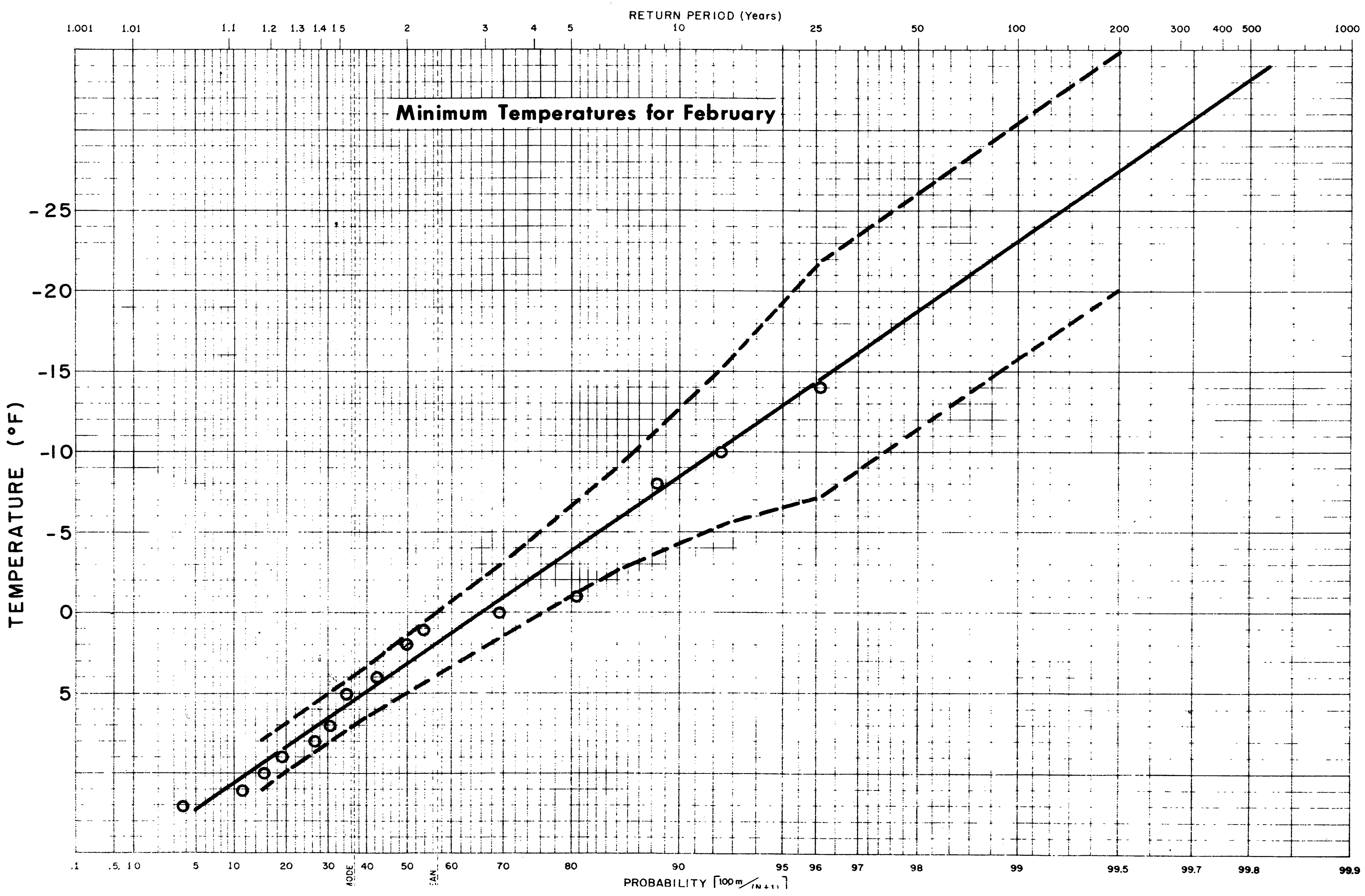


Fig. 18. Probability and return period of minimum temperatures during February.

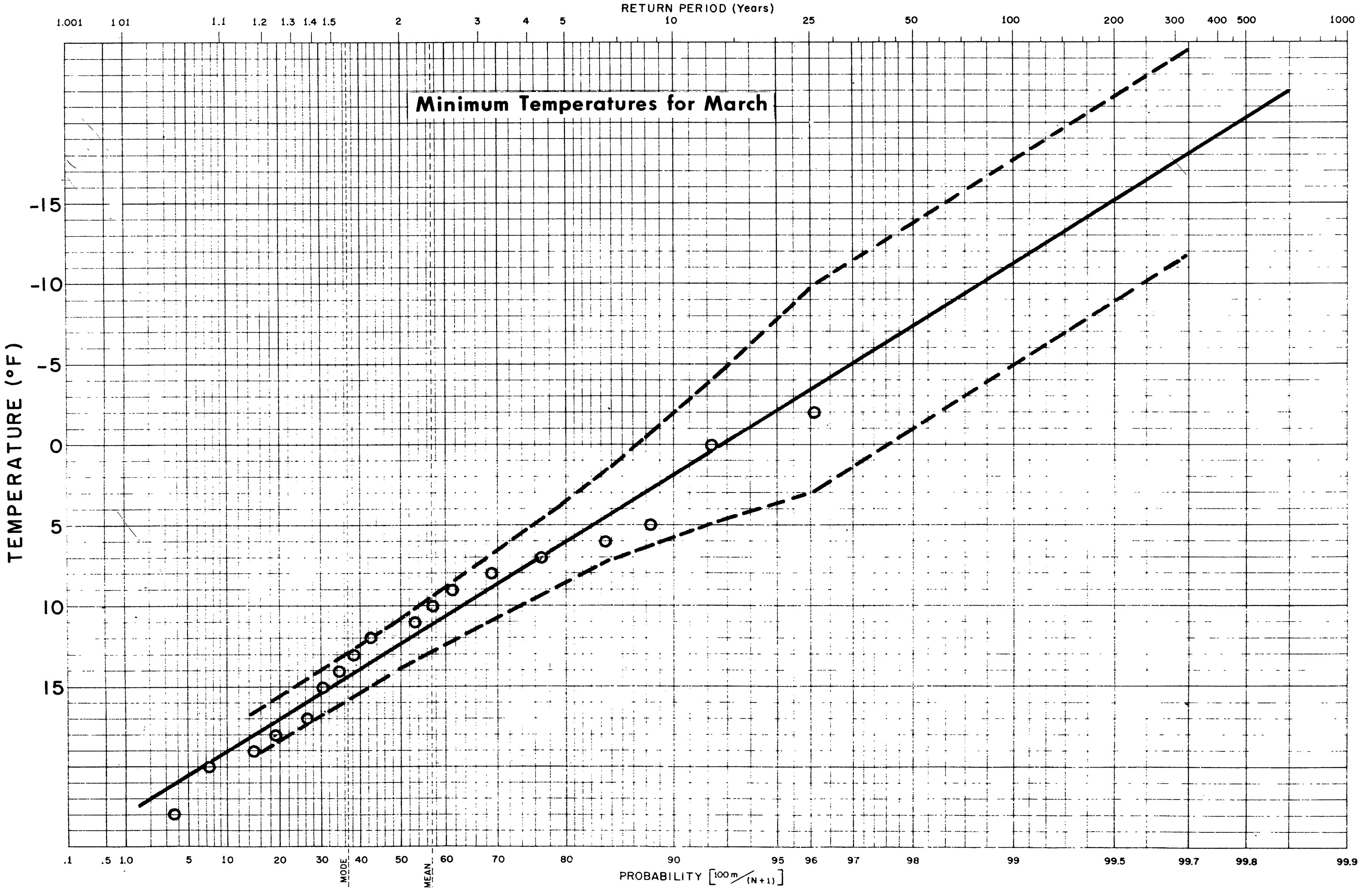


Fig. 19. Probability and return period of minimum temperatures during March.

V. SUMMARY OF DIFFUSION STUDIES

A diffusion study was carried out at the plant site during 1959-1960. Details of instrumentation, days when measurements were made and computed values of Sutton's parameters, C_z and C_y, are found in Refs. 11-13. The emphasis was on measurements when diffusion was likely to be poor, and accordingly several experiments were carried out under inversion conditions.

The method utilized in the analysis of data from the diffusion experiments was to assume a value of Sutton's n and then to compute C_y and C_z from the observed tracer particle counts. The value of n was adjusted until the values of C_y and C_z were consistent with theory and with other known observations. The results are summarized in Table X.

TABLE X

MEAN COMPUTED VALUES OF C_z AND C_y AT THE ENRICO FERMI PLANT SITE

Day	n	$\bar{C}_z$	$\bar{C}_y$
6 August 1959 (run No. 1)	0.25	0.15	0.38
27 November 1959	0.20	0.14	0.64
4 February 1960	0.30	0.08	0.54
3 April 1960	0.30	0.09	0.61
8 May 1960	0.20	0.13	0.44
25 June 1960	0.23	0.14	0.37

Mass balance studies in which the measured mass of tracer material emitted per unit time from the source was compared with the measured mass of tracer material passing per unit time through vertical planes normal to the wind at various distances downwind from the source confirmed the validity of the experimental techniques used.

On the basis of the diffusion studies, several facts are apparent. The first and most important one is that a lake breeze induced inversion does not limit diffusion as much as one might anticipate at first sight. Both the experiments of 4 February 1960 and of 3 April 1960 were held under a lake breeze inversion condition. Using the relatively low value of 0.30 for Sutton's n, the vertical diffusion coefficient C_z is small, as anticipated, but the horizontal diffusion coefficient, C_y, is larger than would be expected. Increasing n to a more reasonable value for an inversion, say n = 0.50, gives values of C_z and C_y that are larger than any acceptable values of the Sutton parameters. The conclusion then is that the mean values of the computed $\overline{C}_y$ and $\overline{C}_z$ are showing the integrated effects of changes or transitions in the diffusion regime as the tracer is carried inland.

The fact that there is usually either a heat source or a heat sink present near the plant site, i.e., land and lake temperatures are usually different, resulting in density gradient which causes movement of the air. This movement ensures that adequate diffusion takes place most of the time.

During the course of the diffusion study program, the contractor requested that the authors furnish diffusion coefficients to them for use in a study of the evaluation of a hypothetical contained accident at the Enrico Fermi reactor. Table XI is a table of the submitted values used in the hypothetical study.

TABLE XI

DIFFUSION PARAMETERS USED IN AN EVALUATION OF A HYPOTHETICAL CONTAINED ACCIDENT AT THE ENRICO FERMI REACTOR

Lapse Rate	Diffusion Parameters		
	n	$C_z(m^{n/2})$	$C_y(m^{n/2})$
Inversion	0.55	0.08	0.40
Weak Lapse	0.25	0.35	0.40
Strong Lapse	0.20	0.40	0.40

At first glance, these values do not seem to compare well with the values in Table X which were computed from the diffusion study observations. There are several reasons for this apparent discrepancy. It is known that the values of the diffusion parameters vary with sampling time. The recommended values from Table XI are to be used for sampling times on the order of one hour since the problem is that of atmospheric diffusion after leakage into the atmosphere from the containment vessel. In essence then, any problem for which the values from Table XI should be used is a problem concerning a continuous source. An instrument for measuring the concentration in the plume would be exposed to the plume passing over it for a period of hours. On the other hand, the sampling periods during the diffusion study ranged from 15 sec to 1 min. The result is that the computed values of the diffusion coefficients from the diffusion study will be applicable to such a problem as when a puff passes over the sampler in a matter of several minutes. Thus the recommended parameters from Table XI differ from the values in Table X because of sampling time.

The values that were used in the computations of the leakage from the containment vessel had to be conservative, that is, the computed concentrations had to be higher than those actually observed or expected to be observed. At first glance, it can be said that as C_z and C_y decrease the computed concentration increases. If the values of C_z and C_y in Table XI are smaller than those in Table X, then the computed concentrations will be high and thus conservative. It is noted that C_y in Table XI is, in fact, lower than the values of C_y from Table X. This is not true of C_z, however. The difference is due to the sampling time; the method of airplane sampling used prevents corresponding differences in C_y. The values of C_z recommended in Table XI are in good agreement with hourly values based upon other field experiments.[14] The value of n should also be looked at for conservatism. As n gets larger, the computed concentrations get larger, too. The values of n in Table XI are either the same or larger than the assumed values in Table X. In summary, then, the recommended values of Sutton's parameters in Table XI are generally conservative.

VI. STACK DESIGN

Meteorological criteria were used in determining the stack design factors of location, height, diameter, and effluent velocity.[15] Effluent temperature and emission rate were fixed prior to the meteorological computations. Maximum surface concentrations were computed under various meteorological conditions. Those conditions were fumigation (Types I and III), looping of the plume, aerodynamic downwash, trapping, and deposition. The percentage of the time that such meteorological conditions were anticipated to occur was discussed, based upon the meteorological observations made at the plant site.

VII. GENERAL CONCLUSIONS

The Enrico Fermi Atomic Power Plant is located on flat land at the western end of Lake Erie. The level of the land does not rise over 30 ft for a distance of 5 miles from the site or more than 100 ft for 20 miles from the site. Thus there is no physical trapping of the air as in a river valley. The presence of the lake and the flatness of the land contribute to above-average wind speeds and to relatively infrequent calm conditions. The yearly average wind speed at 102 ft above ground level is 12.4 mph. The wind speed averages 4 mph or greater 96% of the time. These winds provide good dilution potential for any airborne contaminant.

There is a lake-breeze-induced inversion of limited vertical extent and of short duration which reduces diffusion for 1 to 2 miles inland from the plant. Advective inversions as measured at the shore line tower occur mainly with on-shore winds. Most of the time, however, these inversions are broken up by mechanical or thermal turbulence before the air has advanced more than a mile or two inland. Diffusion improves rapidly as these inversions are destroyed. In addition, the wind speed during inversion conditions is higher than is normally found, being 10.2 mph on the average.

In summary, the diffusion characteristics of the site are representative of those along a typical western shoreline of one of the Great Lakes. From a meteorological viewpoint there is no reason to disqualify the Enrico Fermi Site as a nuclear reactor location. In fact, there are several meteorological factors, such as prevailing winds from the SSW through the WNW and the lack of calm conditions, that tend to favor this location.

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