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JUL 27 1984

Mr. A. Schwencer, Chief
Licensing Branch No. 2
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Limerick Generating Station, Units 1 and 2 Additional Information for Auxiliary Systems Branch (ASB) Regarding SER Open Issue #2 (Tornado Missile Effects on Ultimate Heat Sink).

References: (1) Letter, J. S. Kemper to A. Schwencer, dated March 22, 1984 ("Analysis of Tornado Missile Effects on Ultimate Heat Sink").
(2) Meeting Notice for June 15, 1984, R. E. Martin to A. Schwencer, dated June 8, 1984.

File: GOVT 1-1 (NRC)

Dear Mr. Schwencer:

Enclosed are responses to your questions and comments concerning our analysis transmitted in reference (1). Your questions and comments were attached to the reference (2) meeting notice and were further clarified in the 6/15/84 PECO/NRC meeting.

We conclude that the attached responses do not affect the results of the reference (1) analysis. We trust that this additional information will assist you in the resolution of SER open issue #2.

Sincerely,

JW Gallagher for JS Kemper

JHA/gra/07178405

cc: See Attached Service List

B001 1/1

cc: Judge Lawrence Brenner (w/enclosure)
Judge Richard F. Cole (w/enclosure)
Troy B. Conner, Jr., Esq. (w/enclosure)
Ann P. Hodgdon, Esq. (w/enclosure)
Mr. Frank R. Romano (w/enclosure)
Mr. Robert L. Anthony (w/enclosure)
Charles W. Elliot, Esq. (w/enclosure)
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Director, Penna. Emergency Management Agency (w/enclosure)
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Jay M. Gutierrez, Esq. (w/enclosure)
Atomic Safety & Licensing Appeal Board (w/enclosure)
Atomic Safety & Licensing Board Panel (w/enclosure)
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Martha W. Bush, Esq. (w/enclosure)
Mr. James Wiggins (w/enclosure)
Mr. Timothy R. S. Campbell (w/enclosure)
Ms. Phyllis Zitzer (w/enclosure)
Judge Peter A. Morris (w/enclosure)

RESPONSE TO
QUESTIONS AND COMMENTS CONCERNING REPORT NUS-4507
LIMERICK GENERATING STATION, ULTIMATE HEAT SINK EXTREME
WIND HAZARD ANALYSIS

JULY 1984

Q1. Hurricane Winds

The hurricane wind statistics proposed in the Report are based on the assumption that the friction coefficient accounting for terrain roughness is 0.45 (p. 3-3, first paragraph). It is noted in NWS 23 (Schwerdt, et al., 1979), from which this coefficient is taken, that the value of 0.45 was based upon the factor observed at Brookhaven National Laboratory, "considered a rough site" (Schwerdt, et al., 1979, p. 268).

The roughness at Brookhaven has been estimated to be of the order of $z_o = 1.00$ m, owing, notably, to the presence of wooded areas (see I. A. Singer, et al., "The Micrometeorology of the Turbulent Flow Field in the Atmospheric Boundary Surface Layers," in Proceedings of the International Research Seminar on Wind Effects on Buildings and Structures, Vol. 1, University of Toronto Press, 1968, pp. 557-594). On the other hand, the terrain roughness at Limerick appears to be lower, i.e., $z_o = 0.4$ m (see Appendix A). it would then follow that the friction coefficient, rather than being 0.45, would have a value close to the average of the values 0.45 and 0.78 (see Figure 15.4 of NWS 23, attached herewith), i.e., 0.61, say. Use of this factor would increase the hurricane wind speeds at Limerick by about 35 percent. This would cause a shift to the right of the curves in Figures 3-1(a) and 3-3(b) of the Report, even if gust factors with values less than 2.2 were used for the 2-sec wind.

What is the effect of such a shift upon the frequencies of exceeding 10 CFR Part 100 limits?

Response

At a meeting held between the NRC staff and its consultant, and PECo and its consultants on June 15, 1984, the NRC staff and its consultant agreed that the appropriate friction coefficient had been used in NUS-4507.

Appendix A

Table A1 shows wind speeds measured at Limerick (from Table 3-1 of the Report), and wind speeds at the Philadelphia Airport.

The friction velocity is given by the expression

$$U_* = U^{hourly}(z)/2.5\,\ell n\,(z/z_o).$$

At the Philadelphia Airport (open terrain, $z_o = 0.05$ m)

$$u_*^P = 41.17/2.5\,\ell n\,(30 \times 0.3048/0.005) = 3.11 \text{ mph.}$$

If the roughness length at Limerick was $z_o = 0.4$ m, then

$$u_*^L = 29/2.5\,\ell n\,30 \times 0.3048/0.4 = 3.706 \text{ mph.}$$

and $u_*^L/u_*^P = 1.19$. This ratio is consistent with experimental results given in (Bietry, et al., "Mean Wind Profiles and Change of Terrain Roughness," <u>J. Struct. Div.</u>, ASCE, October 1978) for $z_o = 0.4$ m or so ($u_*/u_*^{open} = 1.15$ for $z_o = 0.3$m; $u_*/U_*^{open} = 1.33$ for $z_o = 1$m; $U_*/U_*^{open} = 1.46$ for $z_o = 2.5$ m).

On the other hand, if the roughness length at Limerick was $z_o = 1.0$ m (i.e., close to the roughness of the Brookhaven site), then

$$u_*^L = 29/2.5\ \ n\ 30 \times 0.3048/1.0 = 5.24$$

and

$$u_*^L/u_*^P = 1.68 > 1.33.$$

It is concluded that the wind speeds measured at Limerick and at the Philadelphia Airport are not compatible with the hypothesis that $z_o = 1.0$ m.

Table A1. Wind Speeds at Limerick and at Philadelphia Airport, in MPH

	Limerick	Philadelphia Airport		
	30 ft. elev. (hourly speed)	20 ft. elev. (fastest-mile speed)[a]	30 ft. elev. (fastest-mile speed)[a]	30 ft. elev. (hourly speed)[b]
	(1)	(2)	(3)	(4)
1972	30	43	47	38
1973	27	47	51	42
1974	28	40	44	36
1975	30	47	51	42
1976	32	50	55	45
1977	27	49	54	44
Mean	29 mph		—	41.17 mph

[a]From Extreme Wind Speeds at 129 Stations in the Contiguous United States, NBS BSS 118, 1979.

[b]Based on Wind Effects on Structures by E. Simiu and R.H. Scanlan (Eq. 2.3.30, p. 62) and the assumption $z_o = 0.05$ m (open terrain).

A schematic portrayal of adjustments is shown in figure 15.4. The k_e values shown are for overwater wind speeds $\geq$ 73 kt (135 km/hr). Figure 15.2 shows that k_e varies with wind speed < 73 kt.

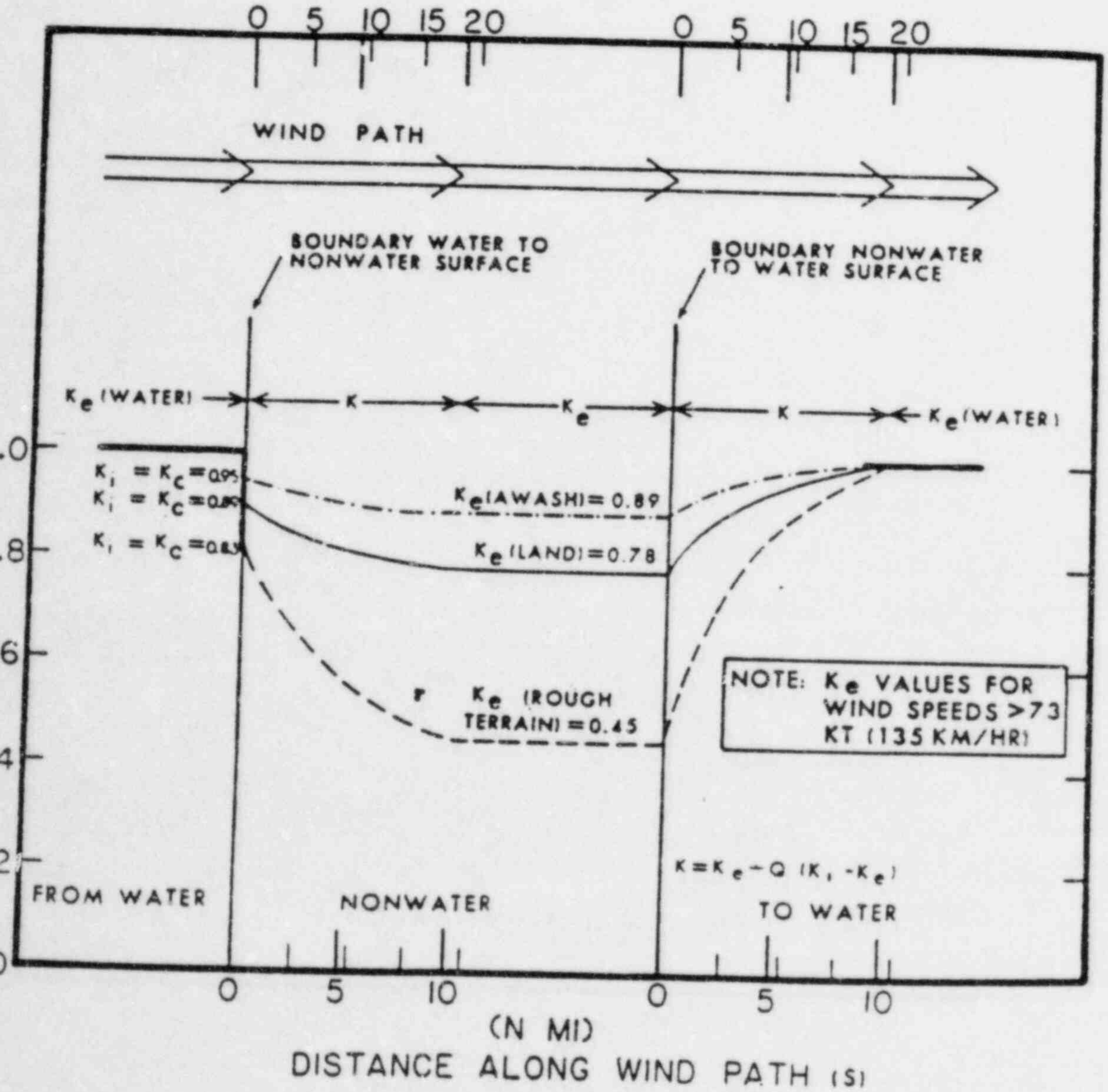


Figure 15.4. Schematic of nearshore frictional adjustments.

Q2. Sampling Errors in Estimation of Extreme "Straight" and Hurricane Winds

The probability distribution of extreme "straight" winds is estimated in the Report on the basis of a sample of only ten largest yearly wind speed data. The precision of the estimates based on a 10-data sample is, as a rule, unsatisfactory. For example, in the case of the Philadelphia Airport, the method of moments yields, for the estimated 2000-yr wind based on a 10-data sample, the 95 percent confidence interval 83.2±23.0 mph (fastest mile) - see Extreme Wind Speeds at 129 Stations in the United States, NBS BSS 118, P. 235. The precision of the estimates would increase by a factor of $(23/10)^{1/2} = 1.52$ if all the 23 data available for the Philadelphia Airport station were used.

Sampling errors also are inherent in hurricane wind speed estimates (see Batts, et al., "Sampling Errors in estimation of Extreme Hurricane Winds," J. Str. Div., ASCE, October 1980, pp. 2111-2115).

What is the expected effect of accounting for sampling errors in estimating "straight" and hurricane wind speeds upon the estimated frequencies of exceeding 10 CFR Part 100 limits?

Response

(a) Straight Winds. The estimation of extreme straight winds for Limerick is not based solely on the 10 year site records. As noted in the report, (p. 3-5) site data was available; hence it was prudent to consider this information along with longer record data from surrounding stations. These extreme winds based on the site record are given in Table 3-2 of the report, which also states (p. 3-5): "In view of the limited 10-year history of Limerick extremes and the use of a constant peak gust factor (which tends to minimize the variance of the extreme gusts), additional comparisons have been made to published data from surrounding NWS stations. Reading and Philadelphia, Pennsylvania, are the closest stations. . . ."

The Philadelphia data [from Changery, 1982] that was used is based on 28 years of record and the Reading data [also from Changery, 1982] is based on 56 years of record. Note that the Changery data leads to higher estimates of straight winds than that given in NBS BSS 118, which was alluded to in the review comments. For example, the 1,000 yr return period wind for Philadelphia Airport is 89 mph compared to 80 mph in NB BSS 118. The combined use of Philadelphia (28 yrs), Reading (56 yrs) and Limerick (10 yrs) data was used in arriving at a conservatively shifted mean curve (Limerick→Reading).

It was indicated in the review meeting that the NRC staff had used the Harrisburg, Pennsylvania, data (39 years of record) curve in its preliminary investigation of Limerick. This curve produces windspeeds very similar to the Reading data. The effect of sampling error for the straight wind frequencies is illustrated in Figure 1

for the Reading data based on an equivalent 28 years of record, which is one-half of the actual record length at Reading. Hence, the sampling errors are effectively increased by $\sqrt{2}$ to account for extrapolation to the site. A family of curves is plotted based on normally distributed errors, which were computed using the method of moments. This family of curves is plotted at $\{\hat{\mu} - 1.76\hat{\sigma}, \hat{\mu} - 0.859\hat{\sigma}, \hat{\mu}, \hat{\mu} + 0.859\hat{\sigma},$ and $\hat{\mu} + 1.76\hat{\sigma}\}$, which are the expected value locations of a discretized normal density with probabilities 0.1, 0.2, 0.4, 0.2, and 0.1, respectively.

In the review meeting, it was suggested that the effects of sampling uncertainties could be evaluated in a Bayesian scheme by integrating over the sampling distributions of the parameters of a Type I extreme value distribution, an appropriate distribution for extreme wind speeds. For small sample sizes, work by Rojiani and Wen shows that in this scheme an increase in the exceedance probability results for a fixed sampling mean and standard deviation. However, since Limerick extreme winds have been extrapolated from surrounding sites with records from 29 to 56 years, the issue of small sample sizes is less significant than the question suggests. The curves in Fig. 1 are judged to be representative of the uncertainties in the straight windspeed frequencies at Limerick. The range spanned by these curves is larger than the variability estimated in the Rojiani and Wen paper between the sample sizes of 30 and ∞.

(b) Hurricanes. Uncertainties in the hurricane curve for Limerick can be estimated using the results of the Batts et al. study. The following estimates of error are used:

	Standard Deviations, σ	
	$P(v>V^*) = 1x10^{-2}$	$P(v>V^*) = 2.5x10^{-3}$
1. Monte Carlo Sample	0.08	0.08
2. Δp R Distributions	0.03	0.04
3. K coefficient	0.05	0.08
4. Surface Friction	0.03	0.03
5. Observational Errors	0.05	0.08
6. Storm Decay	0.02	0.02

Assuming that the results are linear and independent in these errors, the combined error can be estimated by summing the variance of each error source. One obtains $\hat{\sigma}_t = 0.117$ for $P(v>V^*) = 1x10^{-2}$ and $\hat{\sigma}_t = 0.15$ for $P(v>V^*) = 2.5x10^{-3}$. These uncertainites are plotted in fig. 2 for a discretized normal distribution with probabilities 0.1, 0.2, 0.4, 0.2, and 0.1. These uncertainties demonstrate a wider distribution than that estimated for the straight winds and thus tend to dominate the straight wind curves.

(c) Effect of Sampling Errors. These uncertainties in straight wind and hurricane frequencies influence the estimation of the cross-over windspeeds; i.e., the windspeeds at which the separate straight

wind, hurricane, and tornado curves cross. The mean cross-over speed of 105 mph estimated in the report would not be significantly affected. However, these uncertainties introduce a range of cross-over windspeeds. If one neglects uncertainty in the tornado curve, the family of cross-over windspeeds that results are approximately:

Probability	Hurricane Cross-Over Speed	Straight Wind Cross-Over Speed
P = 0.1	79 mph	86 mph
P = 0.2	90 mph	95 mph
P = 0.4	105 mph	102 mph
P = 0.2	115 mph	110 mph
P = 0.1	128 mph	122 mph

At speeds less than these, the hurricanes and straight winds dominate. These speeds correspond to 10 m gusts and would be expected to increase somewhat with height. However, the above speeds do not reflect uncertainties in the tornado curve, which would tend to decrease these speeds at similar probability levels.

On the basis of the reported TORMIS simulations, and the above estimates of cross-over windspeeds sampling errors do not effect the Event T and V probabilities. The results indicate that only the most severe winds (i.e., F4 and F5 tornadoes) are capable of damaging both spray pond and towers. Hence, a shift in the cross-over windspeeds due to sampling uncertainties would not be significant unless the cross-over speed exceeded about 140 mph, the tower failure speed.

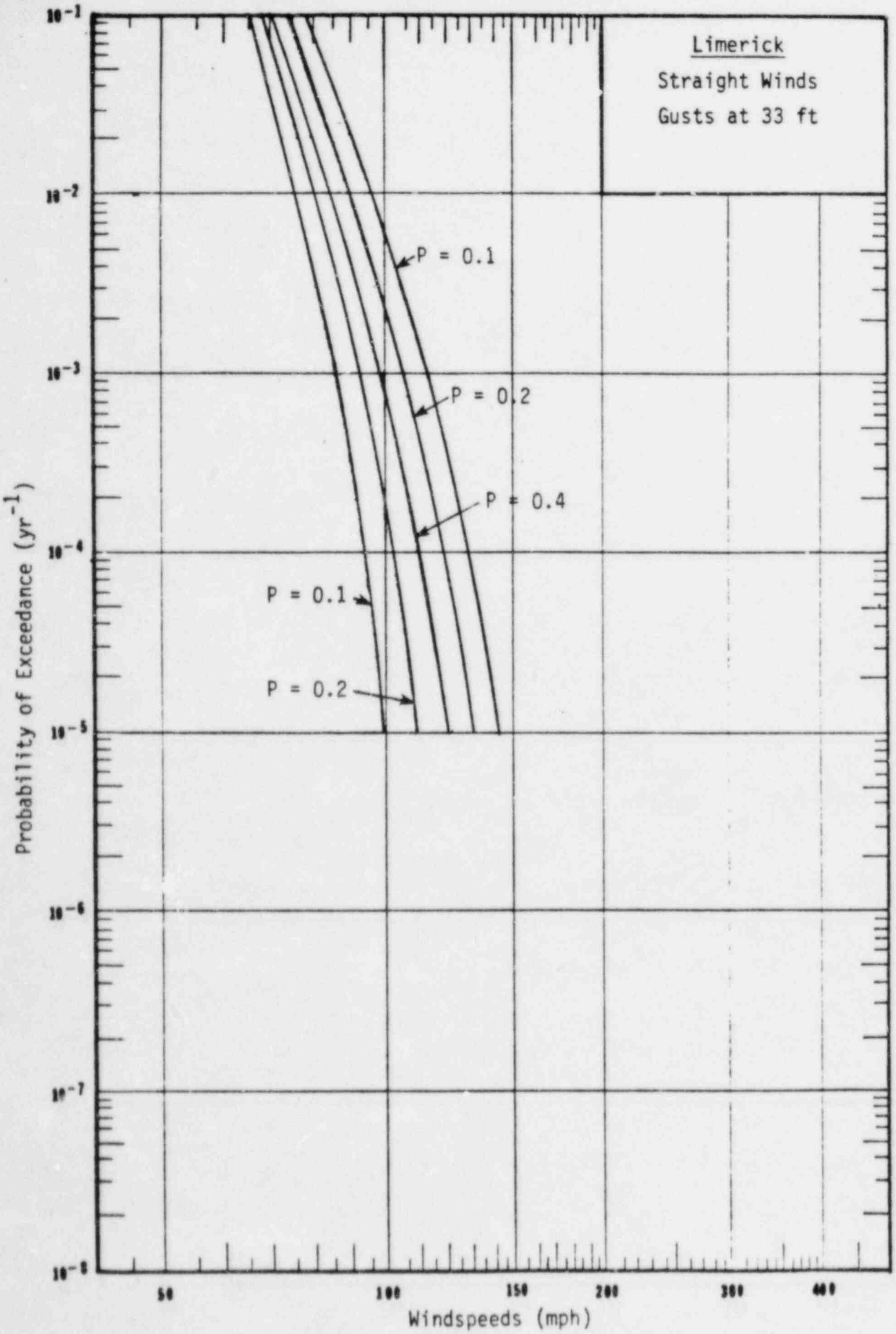


Figure 1. Straight Wind Hazard Curves

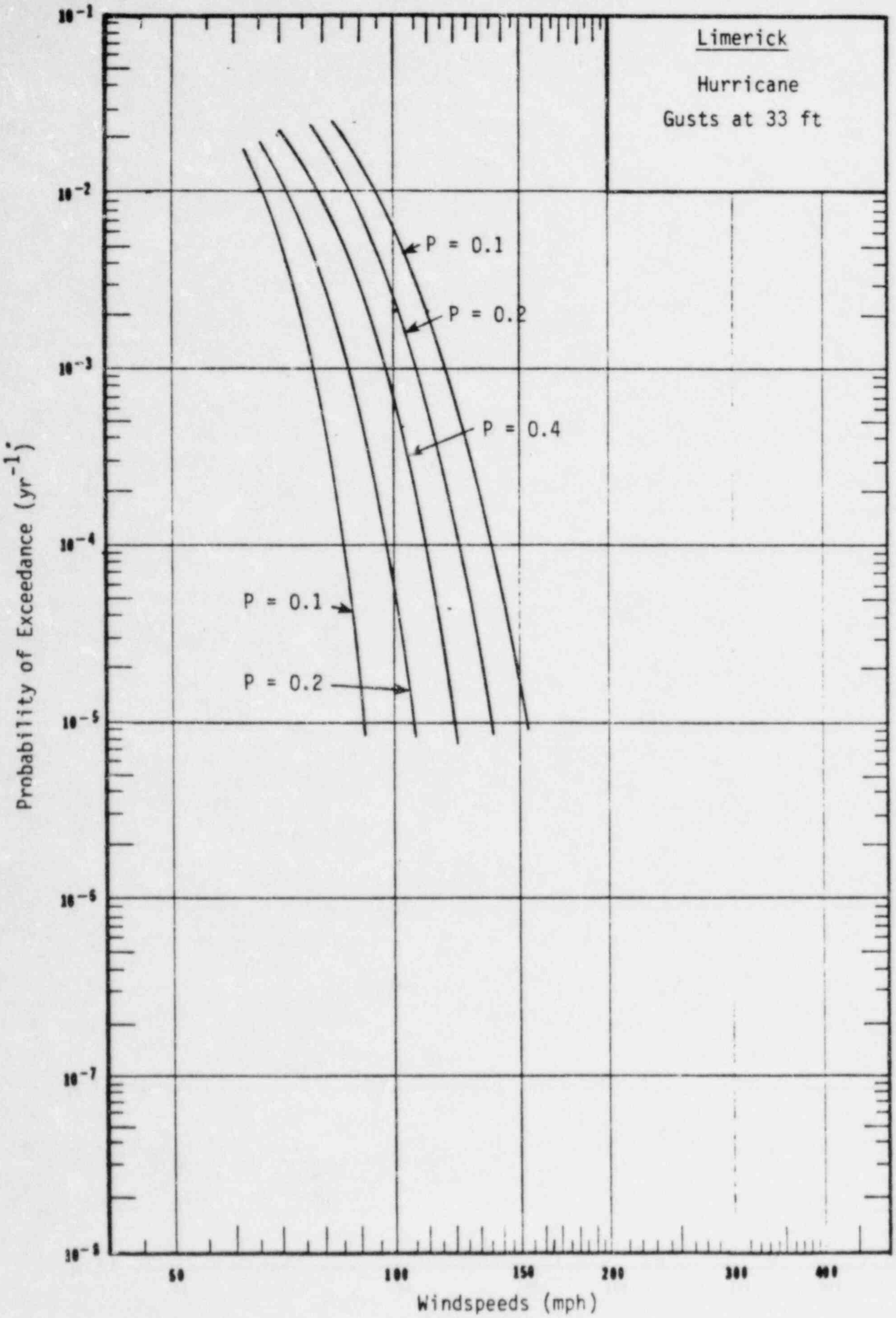


Figure 2. Hurricane Hazard Curves

Q3. Area Used in Calculation of Tornado Wind Speed Frequencies

It is indicated on p. 3-10 of the Report that the area used in estimating tornado wind speed frequencies (the target area) consists of an envelope enclosing the spray pond networks and cooling towers. An explanation is requested as to: (a) why the target area does not consist of the entire missile origin area, rather than of the above mentioned envelope, and (b) what would be the effect of such an extension of the target area upon the estimates of the frequency of exceeding 10 CFR Part 100 limits.

Response

The TORMIS methodology treats both the area of the target and the missile origin area in the tornado missile calculation. Two aspects of the modeling are relevant to this question: (1) how is a tornado strike defined and (2) what missile origin areas are used for each simulated strike.

A union definition of tornado strike is used [Twisdale, 1983], which defines a tornado strike if any one point of the target lies within the tornado windfield damage path. The tornado strike simulation accounts for missiles being propelled outside of the tornado damage path boundary, as explained in EPRI NP-769 [Twisdale, 1978]. Briefly, a study was performed to determine the chance of missiles being transported outside the tornado damage path width boundaries, which are assumed to correspond to 73 mph damage threshold windspeeds ($F \geq F1$ intensity). The results in EPRI NP-769 indicate that narrow, high intensity (F4 and F5) tornadoes could propel missiles outside the damage path width (W_t). Hence in the TORMIS methodology, an effective path width, W_{te}, is defined for purposes of determining target and missile strike probabilities:

$$W_{te} = 440 + 0.56W_t \quad , W_t < 1000 \text{ ft}$$

Thus, a minimum effective tornado width of 4 0 feet is used for F4 and F5 tornadoes with a linear transition to $W_t \geq 1000$ ft.

The TORMIS methodology treats all the missiles in the tornado damage path ($W_{te} \times L_t$ where L_t is the tornado path length) for each simulated strike. Objects outside the 73 mph path boundary for a simulated tornado strike are not evaluated. Some light weight debris in this region would be displaced, but one would not expect such debris impact to be a risk contributor for nuclear power plant targets. In general, it is felt that observations and photos of damage and debris translation with peak winds < 73 mph support this assumption. In addition, trajectory simulations of near ground missiles predict little or no transport of typical plant missiles for such low windspeeds. For the Limerick spray pond networks, missiles originating outside the 73 mph windfield would also have to fly over 150-200 feet to reach the networks within the pond area. Hence, there would be no effect of an extension of the target area for tornado strike or the consideration of missiles outside 73 mph boundary on the estimated frequency of exceeding 10 CFR Part 100.

Q4. Effect of High Winds Upon Spray Pond Network Pipes

For the sake of completeness, brief calculations should be included indicating the magnitude of stresses induced in distribution pipes and their connections by winds assumed to be acting in a direction normal to the 200 ft side of the pond.

Response

The spray pond network piping has been assessed for tornado wind pressures. The maximum resulting pipe stresses are less than the stresses for a railroad blast which are acceptable as shown below.

The maximum wind pressure is calculated based on the following assumptions/parameters:

Pressure on pipe = $C_D q$

C_D = Coefficient of drag, from empirical data, based on Reynolds number, $(\rho/\mu)VD$

q = dynamic wind pressure; $0.002558V^2$, from FSAR section 3.3.2

V = wind velocity: 360 mph = 528 ft/sec, from FSAR section 3.3.2

D = pipe diameter; 30, 18, 10, 6, 4 and 2 inches

μ/ρ = kinematic viscosity; 1.6×10^{-4} ft^2/sec, based on air at 14.7 psia, 65°F. Note that μ/ρ will decrease if water becomes entrained in the air stream but this will not affect C_D.

$Re \geq 5X10^5$ (for all diameters)

$C_D \cong 0.4$ at $Re \geq 2 \times 10^5$

$$\text{pressure} = 0.002558(360)^2(.4)\ (1/144) = .92 \text{ psi}$$

The equivalent static pressure from a railroad blast is 1.125 psi, which is greater than the pressure from tornado wind loads which is 0.92 psi. Equivalent static pressure from rail road car blast is calculated using the methodology contained in reference 2.2-1 of the FSAR. Therefore, the railroad blast governs, and the resulting blast loads and pipe stresses are discussed below.

The pressure from a railroad blast results in a maximum pipe stress of 9600 psi. This maximum stress was determined using

Bechtel computer code ME101, which is described in FSAR section 3.9.1.2.6.1. The equivalent uniform force for the railroad blast load is as follows:

Pipe Diameter (in)	Blast load (#/ft)
30	405
18	243
10	135
6	81
4	54
2	27

The computer model assumed a uniform force, applied in the horizontal direction, perpendicular to the pipe and the spray nozzles. FSAR figures 9.2-6 and 9.2-7 show spray pond network arrangement. The bending and torsional moments resulting from the applied blast loads are used to calculate the piping stresses in accordance with the ASME code.

The railroad blast (and tornado wind) is considered to be a faulted condition load since it has a low probability of occurrence and need not be combined with seismic loads. Therefore, only equation 9D of ASME Section III needs to be satisfied:

EQN. 9D: P_D + Wt + wind $\leq$2.4 Sh, where:

P_D = maximum system pressure stress, Sh = 13700 (SA-155, GR. C55, clI)

Wt = Maximum system weight stress, Sh = 15000 (SA-106, GR. B)

EQN. 9D: 2535 + 3218 + 9600 = 15353 < 32880 psi

Based on the above evaluation, the effects of a railroad car explosion are acceptable. Therefore, the effects of tornado wind loadings on Spray pond piping are also acceptable.

Q5. Design and Failure Wind Speeds for Cooling Towers

It is indicated on p. 4-29 of the Report that the towers have been designed for a basic wind of 90 mph at 30 ft above grade and up to 135 mph at 500 ft above grade.

a. What is the Report's definition of the basic wind speed? Is it the fastest-mile wind speed over open terrain?

b. What is the precise definition of "designed for," i.e., was an allowable stress, or an ultimate stress approach used in the design of the tower for a basic wind of 90 mph?

c. What are the heights of the towers? From p. 4-7 one might infer that they are 485 ft. Is this inference correct? What does the 500 ft elevation mentioned in line 2, Section 4.4.3.1 represent? A simple sketch of the towers should be included, indicating: the elevations of the top and bottom of the towers; the curb wall; and the fill areas.

d. Is the 140 mph speed at which the towers are assumed to fail a speed averaged over 2 seconds?

Answers to these question are needed to allow the estimation of the load factor for the wind load.

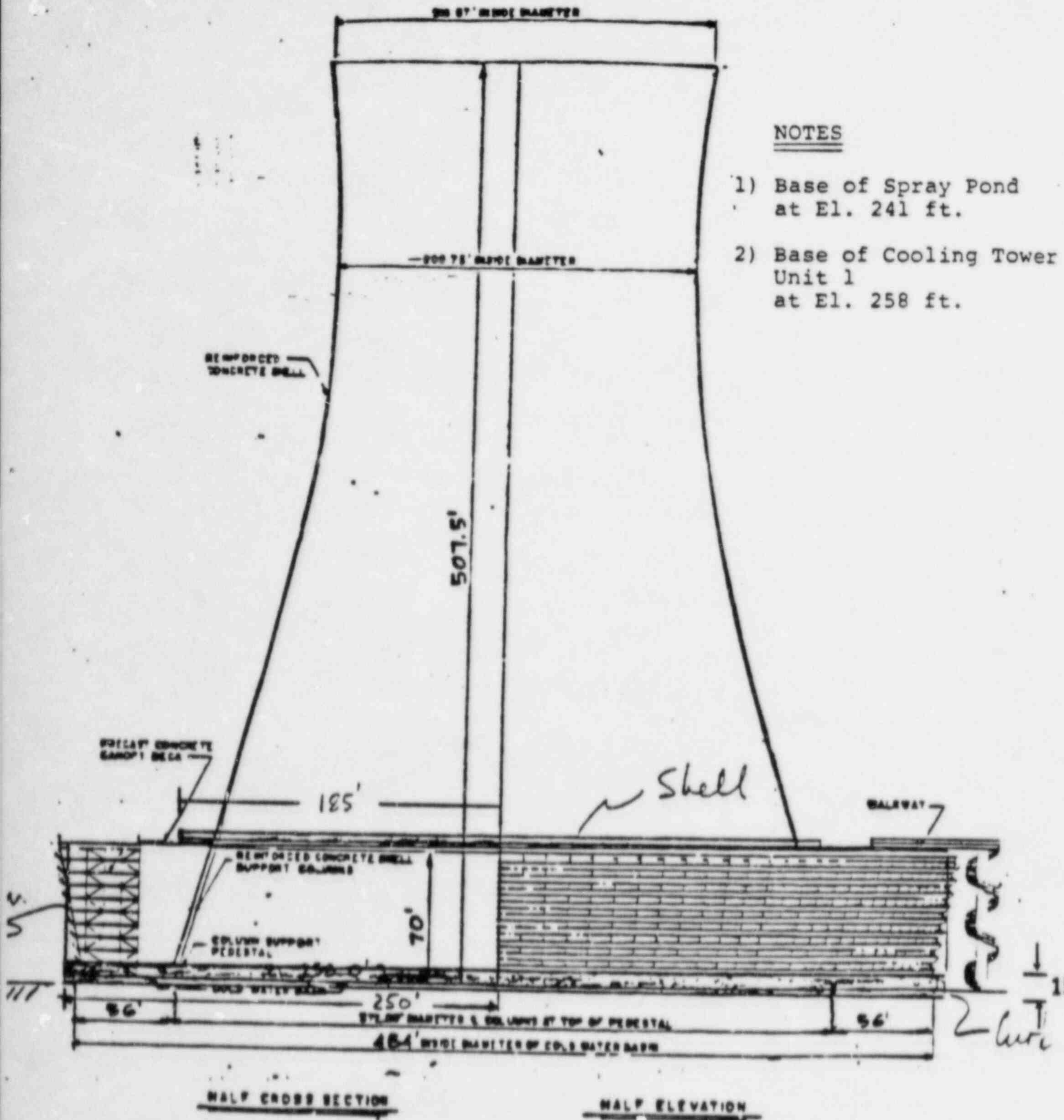
Response

a. Cooling towers are designed according to ASCE paper 3269 which defines basic winds as 50 year return period winds corresponding to fastest mile speeds at 10 meters. The wind velocity varies with height in accordance with Table 1a of the paper.

b. Allowable stress.

c. See Figure 1.

d. The TORMIS methodology conservatively simulates the peak windspeeds and tornados as steady-state winds. For example an F2 tornado with a peak wind of 150 mph (averaged over several seconds) would be simulated with a peak steady wind of 150 mph. The actual averaging time of peak tornado winds is generally felt to be on the order of several seconds since the tornado classification system is based on observations of structural damage. (Fujita assumes that the windspeeds in the F-scale are fastest quarter mile speeds.) Thus, the tower failure criteria is based on windspeeds without any explicit consideration of averaging time. If the centerline of the tower experiences windspeeds of any duration 140 mph at tower midheight the tower is assumed to fail.



NOTES

1) Base of Spray Pond at El. 241 ft.

2) Base of Cooling Tower Unit 1 at El. 258 ft.

COOLING TOWER GENERAL ARRANGEMENT

Figure 1

Q6. Equivalence Between Straight or Hurricane Winds and Tornado Winds Used in Risk Analysis

It is indicated on p. 3-13 of the Report that nontornadic winds were treated by adjusting the tornado F-scale occurrence rates according to Figure 3-3(b) and that "it will be seen later that the results of this study are insensitive to these approximations."

What is the number of the page or of the section where this is shown? Explain why this approximation is acceptable.

Response

Equivalence was not used in any fundamental sense for purposes of assessing the vulnerability of the ultimate heat sink. Since the study was primarily directed towards tornados and tornado missiles the study merely adjusted the tornado strike probabilities of F1 tornadoes so that the effects of all winds would be treated within a single calculation. In general, one would assume independence among tornado, hurricane, and straight wind events and combine the separate results according to the union rule of probability theory. However, the consideration of non-tornado winds, which was requested to be addressed by the NRC staff in the meeting of November 1983 was not taken to this detail in this study since the assumed cooling tower failure speed was significantly higher than the mean tornado cross-over speed.

In the meeting between NRC staff and PECo staff and their respective consultants on June 15, 1984, it was also pointed out that the events of interest in the Limerick Ultimate Heat Sink analysis require damage to multiple networks (3 out of 4 or 4 out of 4) and also one or both cooling towers in the same tornado strike. Since the windspeed at which a cooling tower fails is assumed in NUS-4507 to be 140 mph, winds less than 140 mph are of interest only from a missile induced failure mode of the towers. Missile induced failures of the distribution flume, curb wall and fill area were considered. In the TORMIS simulations, there were no cases in which missile damage occurred to the tower and damage to at least three networks for windspeeds less than 140 mph. In fact, only F4 and F5 tornadoes contributed to Events T and V. Since the tornado cross-over windspeed is 105 mph the results for Events T and V would not be sensitive to simulations of lower windspeeds unless the tower failure speed $<$ 105 mph.

Q7. Direction of Translation of Tornadoes

Has the probability distribution of the direction of tornado translation been accounted for in the calculations? If not, and if there is a predominant direction of tornado translation (e.g., most tornadoes moving in the northeast direction), what would be the effect of taking this factor into account on the estimated frequency of exceeding 10 CFR Part 100 limits? This question is asked because it appears, intuitively, that tornadoes moving in the northeast direction could destroy the towers and hurl missiles on the spray ponds.

Response

Yes the probability density function has been considered in the TORMIS simulations. Region C data was used [Twisdale, 1981] as summarized below:

Direction	Percent
E	40
NE	38
N	6
NW	2
W	2
SW	1
S	2
SE	9

About 80 percent of the tornadoes travel toward an E-NE quadrant.