PHILADELPHIA ELECTRIC COMPANY
2301 MARKET STREET
P.O. BOX 8699
PHILADELPHIA, PA. 19101
(215) 841-4502

JOHN S. KEMPER
VICE-PRESIDENT
ENGINEERING AND RESEARCH

SEP 11 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 & 2 Additional Information for Auxiliary Systems Branch Regarding SER Open Issue #2 (Tornado Missile Effects on Ultimate Heat Sink)

REFERENCE: Meeting between PECo and NRC on August 17, 1984

Dear Mr. Schwencer:

This letter completes the transmittal of information discussed in the reference meeting.

Attached is a document entitled, "Responses to Questions and Requests for Additional Information on NUS-4507 Report 'Limerick Generating Station UHS Extreme Wind Hazard Analysis'", dated September 1984".

With this transmittal, all information necessary for the closing of SER open item 2, has been provided.

Very truly yours,

John S. Kemper

ARD/dg/08308401

Attachments

See Attached Service List

B001
1/1

cc:	Judge Lawrence Brenner	(w/enclosure)
	Judge Peter A. Morris	(w/enclosure)
	Judge Richard F. Cole	(w/enclosure)
	Judge Christine N. Kohl	(w/enclosure)
	Judge Gary J. Edles	(w/enclosure)
	Judge Reginald L. Gotchy	(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)
	Ms. Maureen Mulligan	(w/enclosure)
	Charles W. Elliot, Esq.	(w/enclosure)
	Zori G. Ferkin, Esq.	(w/enclosure)
	Mr. Thomas Gerusky	(w/enclosure)
	Director, Penna. Emergency Management Agency	(w/enclosure)
	Angus R. Love, Esq.	(w/enclosure)
	David Wersan, Esq.	(w/enclosure)
	Robert J. Sugarman, Esq.	(w/enclosure)
	Martha W. Bush, Esq.	(w/enclosure)
	Spence W. Perry, Esq.	(w/enclosure)
	Jay M. Gutierrez, Esq.	(w/enclosure)
	Atomic Safety & Licensing Appeal Board	(w/enclosure)
	Atomic Safety & Licensing Board Panel	(w/enclosure)
	Docket & Service Section	(w/enclosure)
	Mr. James Wiggins	(w/enclosure)
	Mr. Timothy R. S. Campbell	(w/enclosure)

RESPONSES TO QUESTIONS AND REQUESTS FOR
ADDITIONAL INFORMATION ON
NUS-4507 REPORT

"LIMERICK GENERATING STATION UHS EXTREME WIND HAZARD ANALYSIS"

September 1984

Q.6 What is the value of the hurricane and straight wind speeds at an elevation of 33 ft. which correspond to the nominal failure of the cooling towers? Can it be shown that the probability of failure of the cooling towers due to missiles borne by straight winds and hurricanes with speeds less than this value is negligible when compared to a frequency of 10^{-6} per year?

Response

The vulnerability of the cooling towers and spray network components to hurricane and straight winds has been analyzed using the TORMIS methodology. This analysis has proceeded in 5 steps:

1. Develop profiles for hurricane and straight wind gusts.
2. Evaluate cooling tower failure for hurricane and straight winds.
3. Refine hurricane and straight-wind frequency curves.
4. Modify TORMIS for hurricane and straight-wind simulations.
5. Perform simulations and analyze TORMIS results.

The following paragraphs summarize the methods and results of each of the steps, consistent with the discussions in the August 17 review meeting. A conservative analysis has been made using the worst case missile and wind directional characteristics.

(1) Wind Profile

The wind profile in homogeneous terrain is given by the logarithmic law

$$U_{3600}(z) = U_{3600}(10)\,\frac{\ln(z/z_0)}{\ln(10/z_0)} \qquad (1)$$

where $U_{3600}(z)$ = mean hourly horizontal velocity at height z and z = 10 m is the reference height. For roughness length z_0 = 1 m, the mean hourly wind profile at Limerick can be approximated by

$$U_{3600}(z) = 0.434\, U_{3600}(10)\, \ln(z) \quad . \qquad (2)$$

This mean hourly profile is adjusted to a 2 sec gust profile using a 2.22 gust factor for rough terrain (see Sachs, Ref. 1). With a constant gust component with height,

$$U_2(z) = U_{3600}(z) + 1.22\ U_{3600}(10) \qquad (3)$$

where $U_2(z)$ is the 2 sec gust at height z. From Eqs. 2 and 3 and the relation $U_2(10) = 2.22\ U_{3600}(10)$,

$$U_2(z) = U_2(10)[0.55 + 0.1955 \ln z] \ . \qquad (4)$$

Defining $C_2(z) = U_2(z)/U_2(10)$, the normalized hurricane and straight wind gust profile for Limerick is:

z(ft)	z(m)	C(z)
10	3	0.77
33	10	1.00
100	30	1.22
250	76	1.40
500	152	1.53

This profile is used in the TORMIS simulations of hurricane and straight winds and in the following windspeed failure analysis for the cooling tower shell.

(2) Cooling Tower Failure Windspeed

The hurricane and straight winds expected to fail the cooling towers at Limerick have been estimated using the above profile. Using the procedure outlined in the response to Question 3, the calculated failure windspeed is 135 mph at 10 m. This 10 m windspeed corresponds to windspeeds of about 190 mph at tower mid height. The method of calculating the buckling loads of shell structures is given in Ref. 2.

(3) Hurricane and Straight Wind Frequencies

The hurricane and straight-wind curves in NUS-4507 [3] were developed from published data. In the August 17 review meeting, it was agreed that the hurricane hazard curve was conservative for Limerick. Hence, this curve is used

for the hurricane wind and missile simulations. To perform these simulations over the entire range of windspeeds, it has been necessary to extend the curve beyond the windspeed exceedance probabilities from the published data in Batts, Russell, and Simiu [4]. The results of this extension of the hurricane curves are presented in Subsection (a).

For the straight wind curves presented in NUS-4507 [3], it was agreed in the August 17 review meeting that these curves reflect the 1 meter roughness at Limerick. In the rederivation of these curves, it was also suggested by the NRC that the Harrisburg, PA frequencies be used in this reanalysis. Subsection (b) presents the results of this analysis.

(a) Hurricane Frequencies

From NUS-4507, the 2-sec gust hurricane windspeeds of 70, 78, and 102 mph correspond to annual exceedance probabilities of 2×10^{-2}, 1×10^{-2}, and 5×10^{-4}, respectively. Batts, Russell, and Simiu [4] found that the best-fitting distributions for hurricane winds is the 3 parameter Weibull distribution

$$P(V > V^*) = \exp\left[-\left(\frac{V^*-\mu}{\sigma}\right)^{\gamma}\right] .$$

In a subsequent paper, Batts [5] indicates that the best-fitting tail length parameter γ for coastal mileposts near Limerick are about $\gamma = 2$ to $\gamma = 4$ with $\gamma = 3$ for milepost 2400, the closest landfall position relative to Limerick. Using $\gamma = 3$, the Weibull parameters μ and σ are determined as $\mu = -54.01$ and $\sigma = 79.35$. The resulting windspeed exceedance probabilities at 10 meters are:

V^* (2-sec Gust)	$P(V > V^*)$ (yr^{-1})
70	$2.2x10^{-2}$
78	$1.0x10^{-2}$
90	$2.5x10^{-3}$
102	$5.0x10^{-4}$
120	$2.6x10^{-5}$
135	$1.4x10^{-6}$
145	$1.4x10^{-7}$
155	$1.2x10^{-8}$
165	$7.4x10^{-10}$

These frequencies are identical to the 78 and 102 mph data and are slightly conservative for the 70 mph data point in NUS-4507 [3]. The resulting curve in given in Fig. 1.

(b) Straight-Wind Frequencies

The Harrisburg, PA Airport data [6] has been used to develop an updated straight wind frequency curve for Limerick. The Harrisburg windspeeds are conservative relative to those at Philadelphia Airport in Ref. 6. The procedure used to develop these updated frequencies is summarized below:

1. Convert the extreme fastest-mile speeds in Ref. 6 to mean hourly speeds, assuming a roughness length z_0 = 0.07 m for Harrisburg.

2. Compute the friction velocity u_{*ref} from the relation:

$$u_{*ref} = \frac{U_{3600}(z,z_0)}{2.5 \ln(z/z_0)}$$

3. Compute the friction velocity u_* for a roughness length z_0 = 1 m from

$$u_* = p\, u_{*ref}$$

where p = 1.33 [7].

4. Compute the mean hourly speeds for z_0 = 1 meter

$$U_{3600}(z,z_0 = 1) = 2.5\, u_* \ln(z/1)$$

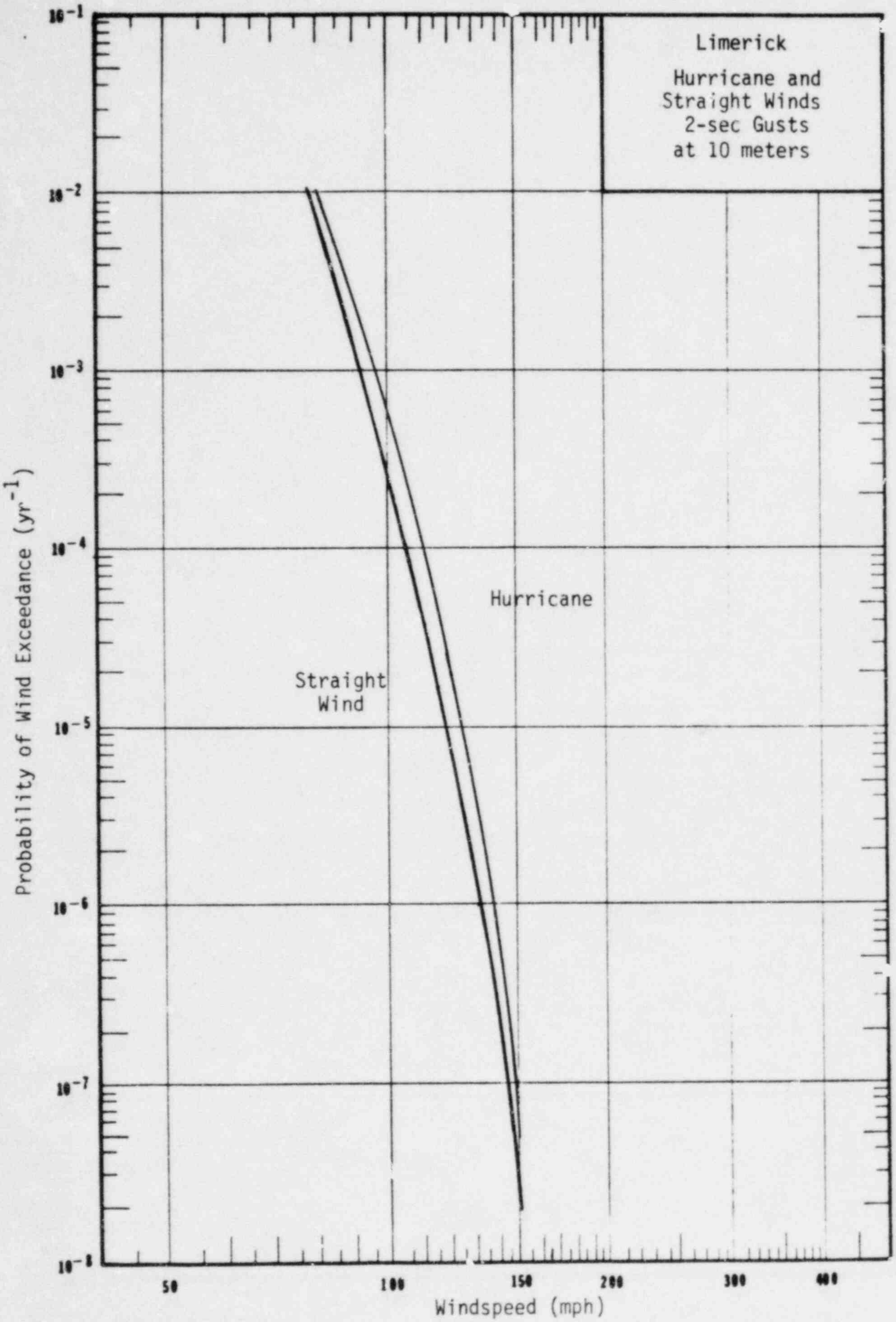

Figure 1. Limerick Hazard Curves for Hurricane and Straight Winds

5. Convert the mean hourly speeds to 2-sec gusts from

$$U_2(z,z_0 = 1) \approx 2.22\ U_{3600}(z,z_0 = 1)$$

where the peak gust factor of 2.22 is taken from Sachs [1] for rough terrain.

Table 1 summarizes these calculations and the resulting windspeeds for exceedance probabilities $1\text{x}10^{-1}$ to $1\text{x}10^{-6}$ per year. Figure 1 illustrates the straight-wind frequencies. These windspeeds correspond to 2-sec gusts, which are conservatively assumed to be of sufficient duration to fail the cooling towers.

(4) TORMIS Modifications

The TORMIS computer code uses a translating three dimensional tornado windfield model to simulate the effects of a tornado moving through a plant site. The plant model, missile characteristics, injection and transport models, and damage criteria are independent of the windfield specification and thus, are valid for any severe windfield. Hence, with selected changes to TORMIS, the methodology is applicable to wind and missile analysis for straight wind and hurricane effects. These changes and the validation procedures used are described in the following paragraphs.

A total of five modifications were made to the TORMIS code. First, the vector DIRREG (REGION, I), I = 1,2,...,7 was added to the input list after the integer REGION. This allows an arbitrary distribution of storm directions to be read in as input rather than the use of the default tornado direction distribution for the specified NRC region.

The second change was to the TORSTR subroutine that samples the storm characteristics. The portion of TORSTR that sample tornado length, width, offset and windspeed characteristics (rotational and translational windspeed parameters) was replaced by a simple specification of straight-wind storm

TABLE 1. STRAIGHT-WIND GUST FREQUENCIES AT LIMERICK

Annual Exceedance Probability	Harrisburg, PA Fastest-mi $U_f(10,0.07)$	Harrisburg, PA Mean-Hourly $U_{3600}(10,0.07)$	Harrisburg, PA Friction Velocity u_{*ref}	Limerick Friction Velocity u_*	Limerick Mean-Hourly $U_{3600}(10,1)$	Limerick 2-sec Gust $U_2(10,1)$
10^{-1}	56.1	45.6	3.68	4.89	28.1	62.4
10^{-2}	70.6	56.5	4.55	6.05	34.8	77.3
10^{-3}	84.8	66.3	5.34	7.10	40.9	90.8
10^{-4}	98.9	76.1	6.13	8.15	46.9	104.1
10^{-5}	113.1	86.3	6.96	9.26	53.3	118.3
10^{-6}	127.2	96.4	7.77	10.34	59.5	132.1

characteristics. Storm length and width were arbitrarily set at large values, TPL = 150 mi and TPW = 100,000 ft, respectively. The storm horizontal velocity at 33-ft elevation, V_{33}, was sampled from a stepwise truncated Weibull distribution according to

$$V_{33} = \mu + \sigma \left\{ - \ln \left[e^{-\left(\frac{a-\mu}{\sigma} \right)^{\gamma}} - \xi \left[e^{-\left(\frac{a-\mu}{\sigma} \right)^{\gamma}} - e^{-\left(\frac{b-\mu}{\sigma} \right)^{\gamma}} \right] \right] \right\}^{1/\gamma},$$

where μ, σ, and γ are the Weibull parameters defined previously, a and b are the lower and upper windspeeds of the interval being sampled, and ξ is a pseudo random number sampled from the unit interval.

The third change involved the windfield model. The tornado windfield model was replaced by the model:

UT(1) = 0 (Radial Component)
UT(2) = 0 (Tangential Component)
UT(3) = 0 (Vertical Component)
UTRAN = $V_{33}[0.55+0.1955 \ln (0.3048\, z^{*})]$, (Translational Windspeed)
where z^{*} is in feet and $z^{*} = z$ if $z > 1$ ft or
$z^{*} = 1.000001$ if $z \leq 1$ ft.

The fourth change was a replacement of the calculation of maximum windspeed at the cooling towers (VELT) during storm passage by the simple statement

VELT = UTRAN

where UTRAN is determined as above at z^{*} = ZTD, the specified height on the cooling tower at which the windspeed is to be evaluated.

The last change to TORMIS involved simplification of the injection model. Since at a given height the windspeed is constant with time, it is not necessary to calculate the storm center position for optimum release of the missile at peak aerodynamic force. Thus, the TORMIS injection model was replaced by the simple model that S = 0, i.e., the nominal storm center track position is even with the missile (in the offset, track position frame) at injection.

After making the above changes, sample runs of the code were made in which storm directions were forced to be in one of two octants, by proper specification of the vector DIRREG, and a number of missiles were flown for each storm. The storm characteristics were then checked to verify that they were properly determined. The missile trajectory and impact points were observed to lie along lines roughly parallel to the line of storm movement. This is the expected behavior in which the missiles travel in vertical planes parallel to the storm direction (lift and side forces can lead to minor out of plane movement).

In order to further verify the code, two minor changes were made in order to run ballistic test cases (constant drag, no lift and side forces) with a vertically uniform windfield. In the first case, the drag coefficient was set to zero ($C_D = 0$) and the resulting trajectory was a straight-line drop to the ground, as expected. In the second case, the drag coefficient was set to unity ($C_D = 1$) for a six-inch pipe injected at 161.8 ft elevation. The impact position and velocity were checked by independent calculation using a simple ballistic trajectory model and agreement was obtained.

(5) Simulations and Results

A sequential procedure has been used to analyze the effects of hurricanes and straight winds on the Limerick UHS. First, separate simulations were made to validate the use of N-S directions as the most conservative wind directions for missile damage to the spray pond networks. Second, the risk from hurricane winds using the hurricane frequency curve in Fig. 1 and N-S wind directions was evaluated. The third step was to estimate the risks from straight winds using N-S wind directions. The results of these analyses are presented in the following paragraphs.

(a) Wind Direction

The 4 spray networks at Limerick are aligned along an E-W axis, see Fig. 4-3 of Ref. 3. Since loss of the UHS at Limerick requires damage to at least 3 out of 4 networks, missiles must be transported into at least 3 out of 4 networks. Winds blowing from the N or S octants result in the shortest run-up distances to each network and, hence, are much more likely to damage at least 3 out of 4 networks. Winds blowing from other directions have to transport missiles much farther to reach all 4 networks. For example, winds blowing in an E-W direction have to transport missiles about 800 feet to reach the 4^{th} network (transport is predominantly along the wind vector direction for straight winds and hurricanes). Hence, the damage criteria and orientation of the networks suggests the N-S direction as the conservative worst case analysis for wind directions at Limerick.

As a validation of this concept, two independent simulations were run for hurricane winds in the 135-150 mph interval. The following conditional probability of missile entrance given hurricane strike were obtained:

	Conditional Probabilities	
Wind Direction	Events Q, V, X	Events R, T, U
N-S Winds:	0.74	0.36
E-W Winds:	0.04	0

Hence, N-S winds are more than an order of magnitude more likely to transport missiles into at least 3 out of 4 networks than E-W winds. For the network damage criteria, the N-S wind direction produces conditional probability estimates of about 0.12 and 0.02 for Events Q, V, X, and R, T, U, respectively. The E-W wind direction simulation produced no damages for these events out of 40 storms. Hence, these results quantify the conservatisms inherent in the N-S wind direction simulation for the Limerick plant.

(b) Hurricane Simulations

A plant-specific hurricane wind and missile simulation using TORMIS has been made. The windfield profile, hurricane windspeed frequency curve, and 135 mph tower failure speed at 10 m were used in these simulations. The missile characteristics, plant targets, and damage criteria are the same as documented in NUS-4507 [3]. The windspeed intervals and numbers of storms simulated were:

Windspeed Interval (mph)	Hurricane Strike Probability (yr^{-1})	Number of Storms
90-105	2.2×10^{-3}	700
105-120	2.9×10^{-4}	300
120-135	2.5×10^{-5}	80
135-150	1.3×10^{-6}	40
150-165	4.1×10^{-8}	40

Within each windspeed interval, the windspeeds were sampled from a Weibull distribution using the parameters developed previously.

The results of the simulations are given in Table 2. The estimated probability for Event T (damage criteria for one unit operating) is 3×10^{-8} per year and 1.7×10^{-7} per year for event V (damage criteria for two units operating). These frequencies are dominated by winds in the 135-150 mph interval. At lower windspeeds the towers do not fail by either wind or missiles. At higher windspeeds, the contribution to the total failure probability is negligible. For example, the probability of $V > 165$ mph for hurricane winds is 7.4×10^{-10} per year. Conservatively assuming a conditional damage probability of unity, the contribution is no greater than 7.4×10^{-10}, which is several orders of magnitude less than the event damage probabilities in Table 2.

TABLE 2. HURRICANE WINDSPEED SIMULATIONS

Network Damage Criterion	Hurricane Windspeed Intervals	Probability Estimates $\hat{P}(A) = \hat{P}^N(A \mid I_\ell)\, P(I_\ell)$ (per year)					
		Event Q ($\geq 3/4\ W_i$)[1]	Event R ($4/4\ W_i$)	Event T ($4/4\ W_i \cap 1/1\ C_i$)	Event U ($4/4\ W_i \cap \geq 1/2\ C_i$)	Event V ($\geq 3/4\ W_i \cap 2/2\ C_i$)	Event X $V \cup (4/4\ W_i \cap 1/2\ C_i)$
Missile Entrance	90-105	2.5×10^{-4}	2.6×10^{-5}	*[2]	*	*	*
	105-120	9.3×10^{-5}	1.9×10^{-5}	*	*	*	*
	120-135	1.3×10^{-5}	5.5×10^{-6}	*	*	*	*
	135-150	9.8×10^{-7}	4.7×10^{-7}	4.7×10^{-7}	4.7×10^{-7}	9.8×10^{-7}	9.8×10^{-7}
	150-165	3.7×10^{-8}	1.8×10^{-8}	1.8×10^{-8}	1.8×10^{-8}	3.7×10^{-8}	3.7×10^{-8}
	All	3.5×10^{-4}	5.2×10^{-5}	4.9×10^{-7}	4.9×10^{-7}	1.0×10^{-6}	1.0×10^{-6}
	95% Conf. Bounds[3]	$\{3.0\times10^{-4}, 4.1\times10^{-4}\}$	$\{3.3\times10^{-5}, 7.0\times10^{-5}\}$	$\{3.0\times10^{-7}, 6.8\times10^{-7}\}$	$\{3.0\times10^{-7}, 6.8\times10^{-7}\}$	$\{8.4\times10^{-7}, 1.2\times10^{-6}\}$	$\{8.4\times10^{-7}, 1.2\times10^{-6}\}$
Rupture of Spray Arm $V_i' > (V_i')_J$*	90-105	*	*	*	*	*	*
	105-120	1.0×10^{-6}	*	*	*	*	*
	120-135	8.8×10^{-7}	*	*	*	*	*
	135-150	1.6×10^{-7}	2.7×10^{-8}	2.7×10^{-8}	2.7×10^{-8}	1.6×10^{-7}	1.6×10^{-7}
	150-165	9.6×10^{-9}	3.1×10^{-9}	3.1×10^{-9}	3.1×10^{-9}	9.6×10^{-9}	9.6×10^{-9}
	All	2.1×10^{-6}	3.0×10^{-8}	3.0×10^{-8}	3.0×10^{-8}	1.7×10^{-7}	1.7×10^{-7}
	95% Conf. Bounds	$\{4.4\times10^{-7}, 3.6\times10^{-6}\}$	$\{0, 8.4\times10^{-8}\}$	$\{0, 8.4\times10^{-8}\}$	$\{0, 8.4\times10^{-8}\}$	$\{4.6\times10^{-8}, 2.9\times10^{-7}\}$	$\{4.6\times10^{-8}, 2.9\times10^{-7}\}$
Perforate Pipe Wall	90-105	*	*	*	*	*	*
	105-120	*	*	*	*	*	*
	120-135	*	*	*	*	*	*
	135-150	*	*	*	*	*	*
	150-165	*	*	*	*	*	*
	All	*	*	*	*	*	*
	95% Conf. Bounds						

[1] These events correspond to $\geq 3/4\ W_i$ denotes damage to at least 3 out of 4 networks; $4/4\ W_i$ denotes damage to all 4 networks; $1/1\ C_i$ denotes damage to cooling tower 1; $\geq 1/2\ C_i$ denotes damage to at least 1 out of 2 cooling towers; and $2/2\ C_i$ denotes damage to both cooling towers.

[2] * indicates no event successes were obtained in the TORMIS simulations.

[3] 95% two-sided confidence interval reflecting uncertainty in Monte Carlo method.

(c) Straight-Winds

The effects of straight winds on the UHS and cooling towers at Limerick can be conservatively estimated from the results in Table 2. The entries for each windspeed interval are adjusted by the ratio of occurrence rate of straight winds to hurricane winds. From Fig. 1 and the preceeding table, the straight wind frequencies and adjustment factors are approximately:

Windspeed Interval (mph)	Straight Wind Frequency (yr-1)	Occurrence Rate Adjustment
90-105	1.5×10^{-3}	0.69
105-120	7.2×10^{-5}	0.25
120-135	7.5×10^{-6}	0.30
135-150	4.8×10^{-7}	0.37
150-165	$\sim1.8\times10^{-8}$	0.44

When the missile damage probabilities (rupture of spray arm failure mode) in Table 2 are multiplied by these straight wind adjustment factors, one obtains:

Event	Damage Probability (yr^{-1})
Q	5.8×10^{-7}
R,T,U	1.1×10^{-8}
V,X	6.3×10^{-8}

These frequencies are based on a conservative analysis that assumes all straight winds blow in the worst case N-S directions.

The total damage probabilities for hurricane and straight-winds for events T and V are:

Event	Damage Probability (yr^{-1})
T	4.1×10^{-8}
V	2.3×10^{-7}

These values are significantly less than 10^{-6} per year and therefore meet the applicable criteria. The average frequency over the lifetime of the plant for hurricane and straight winds is $1/40[5(4.1 \times 10^{-8}) + 35(2.3 \times 10^{-7})] = 2.1 \times 10^{-7}\ yr^{-1}$. This may be compared to the like frequency for tornadoes of $7.7 \times 10^{-7}\ yr^{-1}$ given on p. 5-13 of Ref. 3.

References

1. P. Sachs, Wind Forces in Engineering (Second Edition), Pergamon Press, New York, 1978.

2. K. P. Buchert, Buckling of Shell and Shell-Like Structures, K. P. Buchert and Assoc., 1973.

3. T. B. Bitowf, et al., "Limerick Generating Station - Ultimate Heat Sink Extreme Wind Hazard Analysis," NUS-4507, NUS Corp., Gaithersburg, Maryland, March 1984.

4. M. E. Batts, L. R. Russell and E. Simiu, "Hurricane Wind Speeds in the United States," Journal of the Structural Division, Vol. 106, No. ST10, October 1980.

5. M. E. Batts, "Probabilistic Description of Hurricane Wind Speeds," Journal of the Structural Division Vol. 108, No. ST7, July 1982.

6. E. Simiu, M. J. Changery and J. J. Filliben, "Extreme Wind Speeds at 129 Stations in the Contiguous United States," NBS Building Science Series 118, U.S. Department of Commerce, March 1979.

7. J. Biétry, C. Sacré and E. Simiu, "Mean Wind Profiles and Change of Terrain Roughness," Journal of the Structural Division, Vol. 104, No. ST10, October 1978.