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SEP 4 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)

REFERENCES:
1) Telecon between PECo (J. T. Robb, D. R. Helwig) and NRC (J. N. Ridgley, J. Wilson) on 8/16/84
2) Meeting between PECo and NRC on August 17, 1984

Dear Mr. Schwencer:

This letter transmits information discussed in the reference meeting and the reference telecon.

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 August 1984 . Responses to questions are provided in accordance with discussions at the reference 2 meeting.

Also attached is a revised response to FSAR Question 410.70. This revised response, stamped draft, will be incorporated into the FSAR, in the revision scheduled for September 1984, exactly as it appears on the attachment.

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We trust that this information will assist you in closing open item 2.

Very truly yours,

JW Gallagher
for
JS Kemper

ARD/dg/08308401
Attachments
See Attached Service List

cc: Judge Lawrence Brenner (w/enclosure)
Judge Peter A. Morris (w/enclosure)
Judge Richard F. Cole (w/enclosure)
Troy B. Conner, Jr., Esq. (w/enclosure)
Ann P. Hodgdon, Esq. (w/enclosure)
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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)

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QUESTION 410.70 (Section 9.2.6)

Provide the basis for concluding that the design temperature for the ESW and RHRSW will not be exceeded using only tornado and tornado missile protected structures, systems and components.

RESPONSE

As described in Section 9.2.6, the ultimate heat sink at Limerick is an excavated spray pond with a surface area of 9.9 acres. Four spray networks, each having 50% capacity for shutdown of two units, are provided.

Details of the spray pond excavation and finished grading are shown in Figures 3.8-55, 3.8-56, and 3.8-57. The general arrangement of the spray pond, spray networks, and spray pond pump structure is shown in Figure 9.2-6. The layout of the spray networks is shown in Figure 9.2-7.

As discussed in Section 3.5.1.4, all essential structures, systems, and components related to the ESW system, RHRSW system, and the UHS are protected from the effects of tornadoes and tornado missiles. Protection of the spray networks from tornado missiles is provided by location of the network piping and sprays below the surrounding grade and by physical separation of the networks:

a. In all but the spillway area, the surrounding grade is in excess of El. 260 ft. while the top of the sprays are at El. 258 ft and the spray network piping is between El. 253 ft 05 in. and El. 256 ft 8 in.

b. The closest branches of adjacent spray networks are separated by 65 ft.

c. The supply piping to adjacent networks is separated by 215 ft.

d. The networks are located at a minimum distance of 72 ft from the edge of the pond.

The use of elevational differences and physical separation to provide protection of the spray pond networks from tornado missiles is justified by the following considerations:

a. Only two spray networks are required for the safe shutdown of both units.

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b. The only active failure that can compromise the operability of a spray network is failure of its supply valve (HV-57-032A, B, C, or D). These valves may be manually operated to isolate damaged networks or to initiate the use of undamaged networks if their controls or motors are inoperable.

c. The physical arrangement of the spray networks precludes the possibility that large missiles can damage more than one spray network due to trajectory considerations. Multiple missiles of sufficient energy and distribution to substantially damage multiple networks are unlikely. Network piping varies in size from the 30-in. diameter supply headers to the 2-in. diameter piping at the extreme ends of the distribution branches. Network piping wall thickness varies from 0.337 to 0.500 in.

d. The loss of some sprays in a network does not result in substantial loss of heat removal capability for the entire network (each network contains 240 spray nozzles).

e. The design thermal performance of the spray pond is based on conservative design values of initial pond temperature and meteorology as described in Section 9.2.6.4. For all expected conditions, the margin in thermal performance would be considerably greater than the 10% margin demonstrated under design conditions. INSERT 1

f. Interconnections are provided that allow the use of the cooling towers as a heat sink for ESW and RHRSW systems. Such operation may be initiated from the control room or locally by manual operation.

It is unlikely that tornado winds would compromise the heat removal capability of the spray pond networks, or the cooling towers, to the extent that safe shutdown of the units would be affected. As described in Section 3.5.1.4, the spray networks have been designed to withstand design basis tornado winds. While not specifically designed to withstand design basis tornado winds, the cooling tower shell and supporting structure have been designed to withstand the following wind loading when either operating or dry:

Elev. Above Grade (ft)	Wind Velocity (mph)
30	90
150	113
200	118
300	125
400	130
500	135

The cooling towers are expected to provide sufficient heat removal capability for the safe shutdown of the units even in the event that the tower fill is extensively damaged.

g. The loss of more than two spray networks and the coincident loss of the cooling towers due to tornado missiles is unlikely due to physical separation of the cooling towers and the spray pond. The cooling towers are located approximately 600 feet from the nearest portion of a spray network.

The likelihood of tornado winds and/or missiles affecting the safe shutdown capability of the cooling towers and spray networks at the same time is quite remote when the above described design factors are considered together with the variation in tornado intensity along its path length and width (NUREG/CR-2944, Tornado Damage Risk Assessment, Reinhold & Ellingwood, Brookhaven National Labs., Sept. 82).

h. Tornado missiles are an insignificant contributor to plant risk because of the low frequency of occurrance of tornadoes in this region (EROL Section 2.3.1.2.2) and the low likelihood of damaging missiles if one were to occur.

Even if the safe shutdown capability of the cooling towers and spray networks were compromised by tornado effects, use of the cooling tower basin~~s~~ and/or UHS in a "cooling pond type" mode would allow substantial time for spray network repair. INSERT 2

INSERT 3

j. Plant procedures will address the various contingent actions available to the operators to deal with degraded UHS conditions. As indicated in the above discussions, substantial time is available for corrective operator actions.

INSERT 4

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INSERT 1

In fact, for average meteorological conditions a single spray network is sufficient for the removal of the heat rejected from both units, for at least a 24 hour period.

INSERT 2

Under design basis conditions of initial pond temperature and meteorology, it would take approximately 6 hours for the pond to reach its 95°F design temperature ~~limit~~. | △1 However, it is unlikely that such design basis conditions would accompany a tornadoe. Under average conditions it would take approximately 10 hours to reach this limit. Additionally, the rate of heat rejection from the safe

shutdown unit(s) can be reduced somewhat by depressurizing the reactor at a slower rate than 100°F per hour as assumed in the design basis analysis. The time interval expected to be available is considered adequate to complete any required repairs. Additionally, continued operability of all essential equipment would be expected beyond the spray pond "design" temperature of 95°F | △1

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INSERT 3
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i. IN THE REMOTE POSSIBILITY THAT THE HEAT REMOVAL CAPABILITY OF THE SPRAY POND NETWORKS AND THE COOLING TOWERS IS COMPROMISED, AND THAT REPAIRS CANNOT BE COMPLETED BEFORE THE DESIGN TEMPERATURE OF THE SPRAY POND IS REACHED, A "ONCE THROUGH" MODE OF COOLING CAN BE IMPLEMENTED. IN THIS MODE OF OPERATION, COOL WATER FROM THE COOLING TOWER BASINS IS SUPPLIED TO THE SPRAY POND PUMPHOUSE WET PITS, ESW AND RHRSW PUMP THIS WATER THROUGH THE PLANT, THE WATER IS RETURNED TO THE SPRAY POND AND IS ALLOWED TO DISCHARGE OVER THE BLOWDOWN WEIR AND STORM SPILLWAY.

SUFFICIENT MAKEUP WATER CAN BE SUPPLIED TO THE COOLING TOWER BASINS TO SUSTAIN CONTINUOUS OPERATION IN THIS MODE FROM EITHER THE SCHUYLKILL RIVER OR PERKIOMEN CREEK MAKEUP WATER SUPPLY SYSTEMS.

THE SCHUYLKILL RIVER MAKEUP PUMPHOUSE IS LOCATED APPROXIMATELY 1500 FEET FROM THE NEAREST COOLING TOWER, MAKING IT UNLIKELY THAT THE PUMPHOUSE WOULD BE DAMAGED BY A TORNADO WHICH WOULD ALSO COMPROMISE THE SPRAY POND NETWORKS AND THE COOLING TOWERS. THIS PUMPHOUSE IS POWERED FROM THE 2300 VOLT PLANT SERVICES SWITCHGEAR. THIS SWITCHGEAR CAN BE FED USING OFFSITE POWER FROM FROM EITHER OF THE TWO OFFSITE PLANT SUBSTATIONS VIA UNDERGROUND LINES. THE TWO SUBSTATIONS ARE APPROXIMATELY 2000 FEET APART, MAKING IT HIGHLY UNLIKELY THAT BOTH SUBSTATIONS WOULD BE DISABLED BY A TORNADO WHICH WOULD ALSO COMPROMISE THE SPRAY POND NETWORKS AND THE COOLING TOWERS.

THE PUMPING STATION PROVIDING THE PERKIOMEN MAKEUP SUPPLY IS LOCATED AT A DISTANCE OF APPROXIMATELY 8 MILES FROM THE PLANT SITE. BECAUSE OF THIS SEPARATION, A TORNADO CANNOT DAMAGE BOTH THE COOLING TOWERS AND SPRAY POND AT THE SITE, AND THE PERKIOMEN PUMP HOUSE. POWER TO THE PUMPHOUSE IS SUPPLIED FROM TRANSMISSION LINES WHICH DO NOT ORIGINATE FROM ORI WHICH ARE NOT LOCATED IN PROXIMITY TO THE LIMERICK SITE. THE PUMPING STATION IS POWERED DIRECTLY FROM CROMBY GENERATING STATION AND FROM THE NORTH WALES SUBSTATION VIA THE 138 KV 130-30 TRANSMISSION LINE.

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INSERT 4

If UHS capability was lost for such a long period of time that conditions degraded considerably, the plant emergency procedures would direct the use of equipment which would achieve a safe, stable state regardless of UHS capability.

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

"LIMERICK GENERATING STATION UHS EXTREME WIND HAZARD ANALYSIS"

August 1984

Q1. Document the basis for concluding that the analysis is a conservative, rather than a realistic one. The discussion should address all stages of the analysis presented in the NUS report. It is requested in particular, that the conservatisms associated with the tornado characteristics of length, width, and gradation of intensity within the path, and the treatment of the uncertainties in those characteristics, be addressed.

Response

The Limerick UHS analysis was performed using the TORMIS methodology (with enhancements to facilitate scoring of compound cooling tower and network failures) and plant specific inputs on missile and target data. The TORMIS methodology (1,2), on the basis of NRC review (3), has been judged to be acceptable. In addition, the recommended provisions for additional conservatisms contained in the NRC's SER have been explicitly addressed in the TORMIS analysis of Limerick. These recommendations include (a) consideration of tornado characteristics for both broad regions and small areas; (b) use of the original Fujita, F-scale windspeeds; (c) increased near ground windspeed profile; and (d) use of a site-specific missile population. The following discussion summarizes our assessments of the conservatisms, realisms, and uncertainties in this analysis by topical area. Consistent with the TORMIS methodology, this documentation is presented for the following basic areas:

1. Tornado Hazard Risk
2. Missile Characteristics
3. Missile Transport
4. Damage Criteria
5. Probability Models and Simulation Methodology

Also discussed are the conservatisms in the assumed relationship between degradation of UHS performance and exceeding 10CFR100 exposure guidelines.

Table 1 summarizes this assessment and is supported by the following brief discussions in areas of particular interest. References 1 and 2 provide additional supporting details.

1. Tornado Hazard Risk

The tornado wind hazard analysis component of the methodology is conservative based on the treatment of classification errors, random encounter errors, annual reporting trend, reporting efficiency, and target size. In addition, the original F-scale windspeeds were used in the Limerick study, although the F-scale assignment technique, photogrametric data, and storm damage evidence suggests lower windspeeds as being more realistic (cf. Refs. 4 through 12).

The tornado hazard methodology accounts for path length intensity variation from F-scale assessments of 150 storms, as summarized in Table 2 which is taken from Reference 2 with data from References 13 through 17. These path length damage gradations are assigned over path lengths of several miles and hence are based on a sufficiently large area to assess storm intensity variation. Storm life cycle variation is also well documented in the literature via motion picture and still photography of tornadoes (e.g., Refs. 18 through 20). It is emphasized that TORMIS does not use the DAPPLE

Table 1. Summary of TORMIS realisms/conservatisms - Limerick UHS analysis

Topical area	Parameter/submodel	Basis	Discussion/uncertainties	Conservatism/realism factor (quantified, if possible where 1.0 = realistic)
1. Tornado Hazard Risk				
a. Methodology	Annual reporting trend	Select maximum backward 8-10 yr average	Increase of 41% over 29 yr Region C average.	Conservative (1.4)
	Reporting efficiency	Model with parameter judgments	31% increase in Region C.	Conservative (1.31)
	Direct classification error, Random encounter error	Models with parameter judgments	Increase F5 frequency by 176% in Region C.	Conservative (~2.76)
	Path length intensity variation	150 tornadoes (5 outbreaks)	Realistic, also consistent with other evidence based on photos and motion pictures, and meteorological aspects of tornado life cycles.	Realistic
	Target size	Probability theory	Increase strike probability by up to a factor of 10 over models that neglect target size for target areas $>10^6$ sf.	Conservative (~2-5)
	Windmodel	Photogrammetric studies, fluid mechanics, sensitivity analyses	Realistic to conservative. Near ground windfield enhanced per TER review comments.	Realistic
	F-Scale windspeeds	Judgment	Use original F-scale windspeeds.	Conservative
b. Data	Occurrence rate	Region C	No significant difference between Region C and site 2° square.	Realistic
	Path length, width, and direction	Region C	No significant difference on path direction variable with 2° square.	Realistic
Overall				Conservative
2. Missile characteristics data	Types of missiles	Plant survey	22 types; includes NRC spectrum	Realistic
	Number of missiles	Plant survey	118,973 zone origin; 3,097 structure origin	Very conservative
	Location of missiles	Plant survey	19 zones, 3 structures	Realistic
	Heights of missiles	Plant survey	Uniform between min and max heights; no credit taken for site slope.	Conservative
	Restraints of missiles	Plant survey	All treated as minimally restrained	Conservative
Overall				Conservative

Table 1. Summary of TORMIS realisms/conservatisms - Limerick UHS analysis (continued)

Topical area	Parameter/submodel	Basis	Discussion/uncertainties	Conservatism/realism factor (quantified, if possible where 1.0 = realistic)
3. Missile transport methodology	Aerodynamics	Wind tunnels tests; cross flow analogy	Realistic	Realistic
	Trajectory model	Orientation dependent; drag, lift, side forces	Realistic; conservative relative to 3-D drag models.	Realistic
	Air density	Data	Increased by 5% over ambient to reflect entrained particles.	Conservative (1.05)
	Injection methodology	Maximum-transport criterion; comparisons to field data	See Ref. 1, 2	Conservative
	Windmodel	Data; sensitivity analysis	Conservative relative to multivortex model; realistic compared to Fujita, TRW models; peak winds modeled as steady winds.	Realistic
Overall				Conservative
4. Plant model and damage criteria	Targets	Plant design	Realistic; conservative for networks	Conservative
	Damage criteria - networks	Two failure modes considered; single missile failure criteria	Very conservative; each missile assumed to hit most fragile component; single missile breaking off 1 spray arm causes loss to entire network.	Conservative (~2.0-10.0+)
	Damage criteria - cooling towers	a. missile damage to distribution flume, riser pipes, curb wall	See report	Conservative
		b. Wind damage to shell; design loads, safety factors, G. Gulf performance	Use of center point Windspeed	Realistic Realistic
Overall				Conservative

Table 1. Summary of TORMIS realisms/conservatisms - Limerick UHS analysis (continued)

Topical area	Parameter/submodel	Basis	Discussion/uncertainties	Conservatism/realism factor (quantified, if possible where 1.0 = realistic)
5. Probability models and simulation methodology	Random variables	Full distributions to represent variability and uncertainties	Realistic to conservative	Realistic
	Multiple missile probability model	Subpopulation; union combination	Very conservative; assumes all missiles from a zone contribute equally	Very conservative
	Multiple target probability	Probability theory	Exact	Realistic
	Confidence intervals	Sample mean is normally distributed	Conventional assumption	Realistic
Overall				Conservative

Rated Tornado Intensity	Tornado Group	No. Tornadoes	Path Lengths (mi)						
			Total	<F0	F1	F2	F3	F4	F5
F1	April 3-4,1974	31	295.0	169.0	126.0				
	Red River Valley	1	7.0	3.8	3.2				
	Grand Gulf	2	14.6	8.9	5.7				
	Totals	34	316.6	181.7	134.9				
F2	April 3-4,1974	30	360.5	82.5	123.0	155.0			
	Red River Valley	5	108.0	43.0	44.0	21.0			
	Grand Gulf	2	13.5	6.6	3.3	3.6			
	Bossier City	3	39.1	14.1	13.1	11.9			
	Totals	40	521.1	146.2	183.4	191.5			
F3	April 3-4,1974	35	710.0	65.0	171.0	225.0	249.0		
	Red River Valley	2	31.0	15.8	6.8	5.6	2.8		
	Grand Gulf	2	31.8	3.4	10.6	15.9	1.9		
	Bossier City	1	9.5	2.4	3.5	3.0	0.6		
	Cabot, Ark.	1	15.0	6.5	3.0	4.2	1.3		
	Totals	41	797.3	93.1	194.9	253.7	255.6		
F4	April 3-4,1974	24	858.0	116.0	133.0	229.0	182.0	198.0	
	Red River Valley	2	86.0	14.0	16.0	35.5	13.0	7.5	
	Grand Gulf	2	26.0	6.8	5.1	4.9	8.5	0.7	
	Bossier City	1	6.8	2.0	0	2.0	1.6	1.2	
	Totals	29	976.8	138.8	154.1	271.4	205.1	207.4	
F5	April 3-4,1974	6	302.0	40.0	31.0	57.0	73.0	56.0	45.0
F1-F5	Totals	150	2,913.8	599.8	698.3	773.6	533.7	263.4	45.0

Table 2. Path length intensity variation data

index as developed by Abbey and Fujita (21). The TORMIS treatment of path length variation is more conservative than that in Ref. 21 as discussed on pages I-92, I-93 of Ref. 2.

Uncertainties in the path length data can be obtained by calculating the variance of each F-scale category for the mapped storms. The greatest uncertainty occurs for the smallest sample size, which is F5. The 95% confidence interval produces about a factor of 1.8 uncertainty on the mean. This factor is small compared to the conservatisms in the analysis.

A quantitative demonstration of the conservatisms in the analysis and an overall test of the tornado hazard model can be obtained from comparison of results to those of other models; in particular, the NRC developed hazard curve (Ref. 22) for Limerick. Figure 1 compares the tornado hazard curve developed using the TORMIS methodology (Figure 3-3a of NUS-4507, Ref. 23) with the NRC curve. The curve used in the Limerick tornado wind and missile analysis represents the frequency with which the windspeed at any point on the target exceeds the specified velocity is very conservative relative to the NRC curve over the entire range of windspeeds of concern. The curve is a factor of 7 to 10 more conservative than the NRC curve for speeds less than about 260 mph. Hence, on the basis of this quantitative comparison, the TORMIS tornado hazard methodology and results for the Limerick analysis are conservative. Had the NRC curve been used in the Limerick UHS analysis, the F4 tornado contribution to the failure criteria would have been a factor of 10 less and the F5 contribution a factor of 2 less. The final results in the NUS-4507 (Ref. 23) would then be:

	As Reported TORMIS Hazard Curve	Updated with NRC Hazard Curve
Event T	6.6×10^{-7}	8.2×10^{-8}
Event V	7.9×10^{-7}	1.1×10^{-7}

In summary, the tornado hazard curve used in NUS-4507 is very conservative relative to the NRC curve which was developed using different assumptions but which is also believed to be conservative.

2. Missile Characteristics

As indicated in Table 1 and documented in the report, two separate plant surveys were used to gather the data for the missile characteristics at Limerick. Over 120,000 potential missiles, with 22 types representing a wide variety of objects (including the NRC spectrum), were postulated for the TORMIS analysis. The heights of these missiles were conservatively postulated and all missiles were treated as minimally restrained for optimal transport. The number of missiles correspond to a heavy construction period and would be expected to be reduced significantly over the majority of the plant life. Typical mature plant missile populations are in the range of 5000 to 30,000. Hence, the missile characteristics used in this analysis are very conservative, based on the numbers and types of missiles and their treatment as being unrestrained.

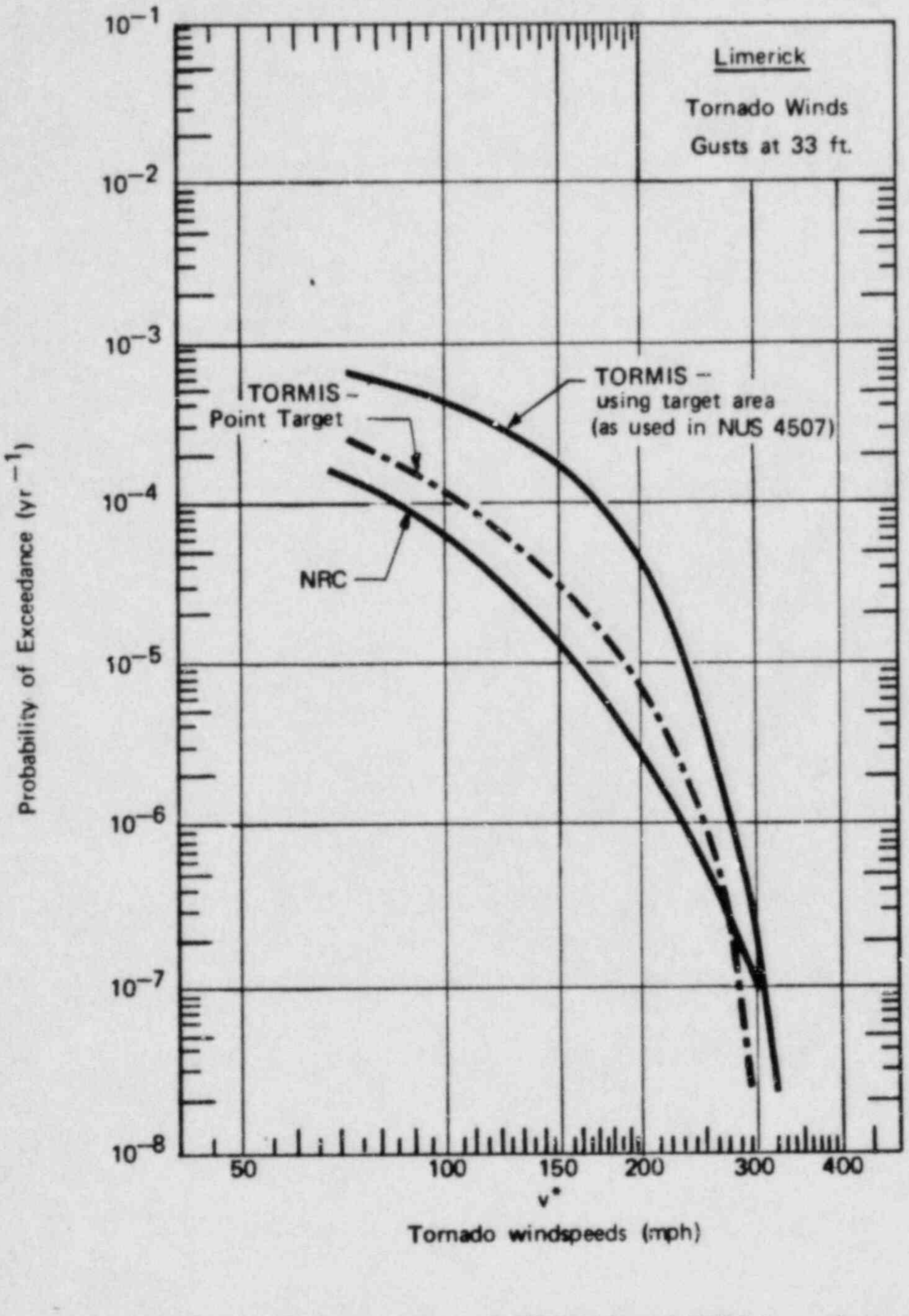

Figure 1. Comparison of TORMIS and NRC hazard curves.

3. Missile Transport Methodology

The TORMIS missile transport methodology represents the state-of-the-art for tornado missile trajectory calculations. Following is a list of some important features of the methodology:

- The aerodynamic models have been developed using static wind tunnel test data.
- The trajectory model includes drag, lift, and side forces and has been shown (Ref. 1, 2, 24) to be more conservative than the conventionally used point mass drag models.
- Drag, side and lift force aerodynamic coefficients are increased by 20, 30 and 40% respectively, to conservatively reflect near ground effects when the missiles are near the ground surface (Ref. 1).
- The TORMIS methodology is the only model to account for entrained dust particles by increasing ambient air density (and hence the aerodynamic forces on the missiles).
- The missile injection methodology uses a maximum transport criterion in which the missiles are released to the moving windfield at peak aerodynamic force.
- The tornado windfield model has been shown to be robust with respect to other models (including a multivortex model) in a missile transport sensitivity analysis (Ref. 2, 25).
- The windfield is conservatively non-zero at the ground surface and rises quickly in the near-ground domain.
- Comparisons of missile transport to field data indicate that the TORMIS methodology predicts the type of transport expected of missiles and debris in tornado windfields (Ref. 2).

The model is very conservative relative to other tornado missile transport models and somewhat conservative in an absolute sense.

4. Damage Criteria

With the exception of the spray pond networks, the Limerick plant was modeled using geometric and material property values essentially identical to the plant design. For the spray pond network, a very conservative model was used. Each network was enclosed by a rectangular box (or control volume) that was used to assess missile impact probability and damage to the network components.

The damage criteria used for the networks are very conservative since:

- Each missile that hits the control volume is assumed to hit a spray arm and the thinnest wall distribution pipe.
- Both pipe perforation and spray arm failure modes were evaluated for each missile impact.

- A single missile is assumed to be capable of damaging an entire network.

This treatment is very conservative, by a factor of 10 or more.

The damage criteria used for cooling towers included both missile damage to critical tower components and wind pressure damage to the hyperbolic shell. The missile damage criterion is conservative on the basis of the missile characteristics used, transport methodology, and the single missile damage criteria. The cooling tower wind damage criterion is very conservative as discussed in detail in response to Q3.

5. Probability Models and Simulation Methodology

The probability models and simulation techniques used in TORMIS vary from realistic to conservative. Probability models are used to characterize uncertainties and variabilities consistent with the available data. The multiple missile calculations are very conservative, based on the subpopulation approach and union damage criteria. The confidence intervals show the effect of limited Monte Carlo sample size and are calculated in the conventional manner.

6. Impact of Degradation of UHS Performance

As indicated in paragraph 4 above, the Limerick UHS analysis assumed that any missile passing through the control volume with sufficient velocity to damage the weakest component of a spray network will result in a complete and unrecoverable loss of the network's heat removal capability. When at least 3 out of 4 networks are so lost and both cooling towers are lost (2 units operating) or when all networks are lost and the unit 1 cooling tower is lost (only unit 1 is operating) it is assumed that damage to the core occurs and the 10CFR100 exposure guidelines are exceeded.

This is a very conservative approach for the reasons described in response to FSAR question 410.70. Additionally, it is conservative to assume that all core damage events associated with degraded UHS performance would result in doses approaching 10CFR100 guidelines.

7. Summary

Overall, the TORMIS analysis of the Limerick UHS is felt to be extremely conservative. There are uncertainties in the data and models, and hence uncertainties in the final results. However, there are no areas where the methodology is known to be unconservative. There are a number of areas, identified in Table 1 and discussed above, where the methodology is clearly conservative, either by virtue of comparisons to other results (wind hazard) or through intentional efforts to simplify the modeling where realistic models would be far too complicated (e.g., missile injection and damage criteria). Estimates of the magnitude of these conservatisms can be summarized as follows:

Wind Hazard Analysis	2-10
Missile Characteristics	2-10

Missile Transport Methodology	2-3
Damage Criteria	5-20
Probability Models and Simulation Methodology	2-3
Impact of UHS Damage	5-20

These are subjective estimates based on comparison with the results, features of the TORMIS methodology, and the margin to exceedance of 10CFR100 limits. Based upon these estimates, the Limerick results are clearly conservative for tornado wind and missile effects. The conservatisms are thus judged to be significant and would be expected to exceed a factor of 10 with high confidence.

We believe the conservatisms above provide reasonable qualitative assurance that the frequency of exceeding 10CFR100 guidelines is lower than the values derived in NUS-4507.

Q2. Provide documentation of some intermediate results to substantiate that significantly fewer tornadoes affect both the towers and the spray pond than the spray pond alone.

Response

Table 3, summarizes the base case probability estimates for the 6 events scored in the Limerick TORMIS analysis. Events Q and R correspond to spray pond network damage, irrespective of the cooling towers, in which Event Q is damage to at least 3 out of 4 networks and Event R corresponds to damage to all 4 networks. These results indicate that damage to the spray pond networks by tornado missiles is about 100 times more likely than damage to both networks and cooling towers (compare 7×10^{-5} to 7×10^{-7} per year for rupture of spray arm failure mode). This difference is due principally to (1) the separation distances between the network and the cooling towers, and (2) the tower failure windspeed. The centers of the towers are about 1,000 ft south of the center of the networks. F1, F2, and F3 tornadoes are not, in general, strong enough or wide enough to encompass the towers with winds > 135 mph (at 33 ft) and also to generate missiles which damage at least 3 of the 4 networks. Table 3 demonstrates that F1, F2, and F3 tornadoes did not contribute to the combined tower failure and network damage events, but that tornadoes of these intensities are capable of damaging the networks. Hence, the noncontribution of the lower F-scales to the combined damage events is a major reason for the differences in damage probabilities when both towers and networks are considered.

The probability of separate cooling tower failure due to tornado windspeeds can be estimated from Figure 1 attached to the response to Q.1. Using the curve for point targets, the probability of V > 135 mph at 33 ft. is about 4×10^{-5} per year. The curve provided in Ref. 22 shows that this probability is lower by a factor of 2, or about 2×10^{-5} per year.

Additional intermediate outputs have been generated from the TORMIS outputs to illustrate the capabilities of different F-scales to damage networks and cooling towers. Table 4 summarizes the relative frequency of network damage given a tornado strike on the target area. These results show a trend of increasing likelihood of more than 1 network being damaged with increasing F-scale. It is emphasized that these results are estimates based upon Monte Carlo simulations and hence are subject to statistical variability. As in all statistical simulations, these estimates would improve and show smoother trends with increasing sample size. However, statistical theory provides a basis for computing confidence intervals on the mean values from finite sample sizes using the estimated sample variances (e.g., see Ref. 26). These calculations are performed in TORMIS to show the effect of finite sample size and are summarized in Table 3. Table 5 illustrates the same trend for separate cooling tower failures. The higher F-scales are much more likely to damage 1 or 2 towers, given a strike on the total target area (which includes the spray networks). It is noted that Table 5 includes both wind and missile damage. The tower damage probability for the F1 category is the missile damage failure mode.

Table 3. Base case probability estimates by event and network damage criteria

Network Damage Criterion	Tornado Intensity	Probability Estimates $\hat{P}(A) = \hat{P}^{M}(A\|I_\ell)\ P(I_\ell)$ (per year)					
		Event Q ($\geq 3/4\ W_1$)[1]	Event R ($4/4\ W_1$)	Event T ($4/4\ W_1 \cap 1/1\ C_1$)	Event U ($4/4\ W_1 \cap \geq 1/2\ C_1$)	Event V ($\geq 3/4\ W_1 \cap 2/2\ C_1$)	Event X $V \cup (4/4\ W_1 \cap 1/2\ C_1)$
Missile Entrance	F1[2]	1.0×10^{-5}	2.0×10^{-6}	*[3]	*	*	*
	F2	6.5×10^{-5}	4.2×10^{-5}	*	*	*	*
	F3	2.0×10^{-5}	3.6×10^{-6}	*	*	*	*
	F4	1.1×10^{-5}	7.2×10^{-6}	2.2×10^{-6}	2.2×10^{-6}	9.3×10^{-7}	2.2×10^{-6}
	F5	1.0×10^{-6}	7.5×10^{-7}	2.3×10^{-7}	2.5×10^{-7}	1.6×10^{-7}	2.6×10^{-7}
	All	1.1×10^{-4}	6.2×10^{-5}	2.4×10^{-6}	2.4×10^{-6}	1.1×10^{-6}	2.5×10^{-6}
	95% Conf. Bounds[4]	$\{3.4\times10^{-5}, 1.9\times10^{-4}\}$	$\{0, 1.3\times10^{-4}\}$	$\{1.0\times10^{-7}, 4.7\times10^{-6}\}$	$\{1.2\times10^{-7}, 4.7\times10^{-6}\}$	$\{0, 2.6\times10^{-6}\}$	$\{2.0\times10^{-7}, 4.8\times10^{-6}\}$
Rupture of Spray Arm $V_1' > (V_1')_j$*	F1	1.6×10^{-8}	*	*	*	*	*
	F2	4.7×10^{-5}	3.5×10^{-5}	*	*	*	*
	F3	9.4×10^{-6}	2.9×10^{-7}	*	*	*	*
	F4	5.9×10^{-6}	2.8×10^{-6}	6.2×10^{-7}	6.2×10^{-7}	7.2×10^{-7}	1.2×10^{-6}
	F5	7.6×10^{-7}	3.5×10^{-7}	3.9×10^{-8}	3.9×10^{-8}	7.2×10^{-8}	9.6×10^{-8}
	All	6.6×10^{-5}	3.9×10^{-5}	6.6×10^{-7}	6.6×10^{-7}	7.9×10^{-7}	1.3×10^{-6}
	95% Conf. Bounds	$\{0, 1.4\times10^{-4}\}$	$\{0, 1.1\times10^{-4}\}$	$\{0, 1.4\times10^{-6}\}$	$\{0, 1.4\times10^{-6}\}$	$\{0, 2.2\times10^{-6}\}$	$\{0, 2.8\times10^{-6}\}$
Perforate Pipe Wall	F1	*	*	*	*	*	*
	F2	3.5×10^{-5}	2.2×10^{-8}	*	*	*	*
	F3	7.3×10^{-6}	*	*	*	*	*
	F4	2.0×10^{-6}	4.7×10^{-7}	2.9×10^{-7}	2.9×10^{-7}	7.2×10^{-7}	1.0×10^{-6}
	F5	2.3×10^{-7}	1.2×10^{-7}	4.7×10^{-8}	4.7×10^{-9}	1.0×10^{-8}	1.5×10^{-8}
	All	4.5×10^{-5}	6.2×10^{-7}	2.9×10^{-7}	2.9×10^{-7}	7.3×10^{-7}	1.0×10^{-6}
	95% Conf. Bounds	$\{0, 1.1\times10^{-4}\}$	$\{0, 1.3\times10^{-6}\}$	$\{0, 8.6\times10^{-7}\}$	$\{0, 8.6\times10^{-7}\}$	$\{0, 2.1\times10^{-6}\}$	$\{0, 2.5\times10^{-6}\}$

[1] $\geq 3/4\ W_i$ 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] The F-scale occurrence rates do <u>not</u> reflect non-tornadic winds.

[3] * indicates no event successes were obtained in the TORMIS simulation.

[4] 95% two-sided confidence interval reflecting uncertainty in Monte Carlo method.

Table 4. Conditional probability of network damage given tornado strike

F-scale intensity	Number of networks damaged					Total
	0	1	2	3	4	
F1	0.97	0.03	(a)	(a)	0.0	1.00
F2	0.79	0.08	0.01	0.07	0.05	1.00
F3	0.85	0.02	0.08	0.05	(a)	1.00
F4	0.55	0.18	0.16	0.07	0.04	1.00
F5	0.60	0.10	0.12	0.12	0.06	1.00

[a] Denotes a conditional probability estimate greater than 0 but less than 0.005.

Table 5. Conditional probability of cooling tower failure given tornado strike

F-scale intensity	Number of towers damaged			
	0	1	2	Total
F1	0.98	0.02	0.0	1.00
F2	0.70	0.17	0.13	1.00
F3	0.50	0.42	0.08	1.00
F4	0.51	0.18	0.31	1.00
F5	0.59	0.11	0.30	1.00

Q3. The failure criterion adopted for the cooling towers is that the cooling towers fail if the windspeed exceeds 140 mph at the center of the tower, at mid-height. It is possible that a portion of the tower can experience wind speeds in excess of 140 mph while the center of the tower does not. Discuss the significance of this with respect to any potential lack of conservatism, that is, should the 140 mph windspeeds just touching the tower be the conservative failure criterion?

Response

The actual failure criterion employed was that the horizontal windspeed at 33 ft above grade exceeded 135 mph at the center of the cooling tower. As discussed in Q5, this is essentially equivalent to the windspeed exceedance of 140 mph at tower midheight.

The significance of the use of the center of the tower as a reference point can be addressed in two parts:

a. What is the chance that a part of the tower sees winds greater than 135 mph, given that the center experiences winds less than 135 mph?

b. How important are local pressure variations in height and width relative to the expected mode of tower failure in tornadoes?

These issues are discussed separately in the following paragraphs.

1. Windspeed Exceedance of Edge of Tower

In order to assess the likelihood that some part of the cooling tower might experience winds in excess of 135 mph at 33 ft elevation when the windspeed at the center is less than 135 mph, $P(V_m \geq 135 | V_0 \leq 135)$, a TORMIS simulation was performed with additional check points on windspeed exceedance. As shown in Figure 2 five points were chosen at 75 ft spacing and 33 ft elevation in a vertical plane containing the center line of the tower and normal to the tornado direction of travel. One thousand tornadoes were simulated in each of the F2-F5 intensity levels and the maximum horizontal windspeed V_0 at tower center (point 0) on each cooling tower for each tornado was calculated. For each tornado for which V_0 did not exceed 135 mph, the maximum windspeeds, V_1 through V_4, at the other points were calculated. Letting V_m be the maximum of these ($V_m = \max\{V_i\}$, $i = 1,2,3,4$) the scoring of one of seven mutually exclusive and collectively exhaustive events was as follows:

1. $P(V_m < 135 | V_0 \leq 135)$
2. $P(135 \leq V_m < 145 | V_0 \leq 135)$
3. $P(145 \leq V_m < 155 | V_0 \leq 135)$
4. $P(155 \leq V_m < 165 | V_0 \leq 135)$
5. $P(165 \leq V_m < 175 | V_0 \leq 135)$
6. $P(175 \leq V_m < 185 | V_0 \leq 135)$
7. $P(V_m \geq 185 | V_0 \leq 135)$

Here $P(V_\ell \leq V_m < V_h | V_0 \leq 135)$ is the probability that V_m is in the interval $[V_\ell, V_h)$, given that $V_0 \leq 135$ mph.

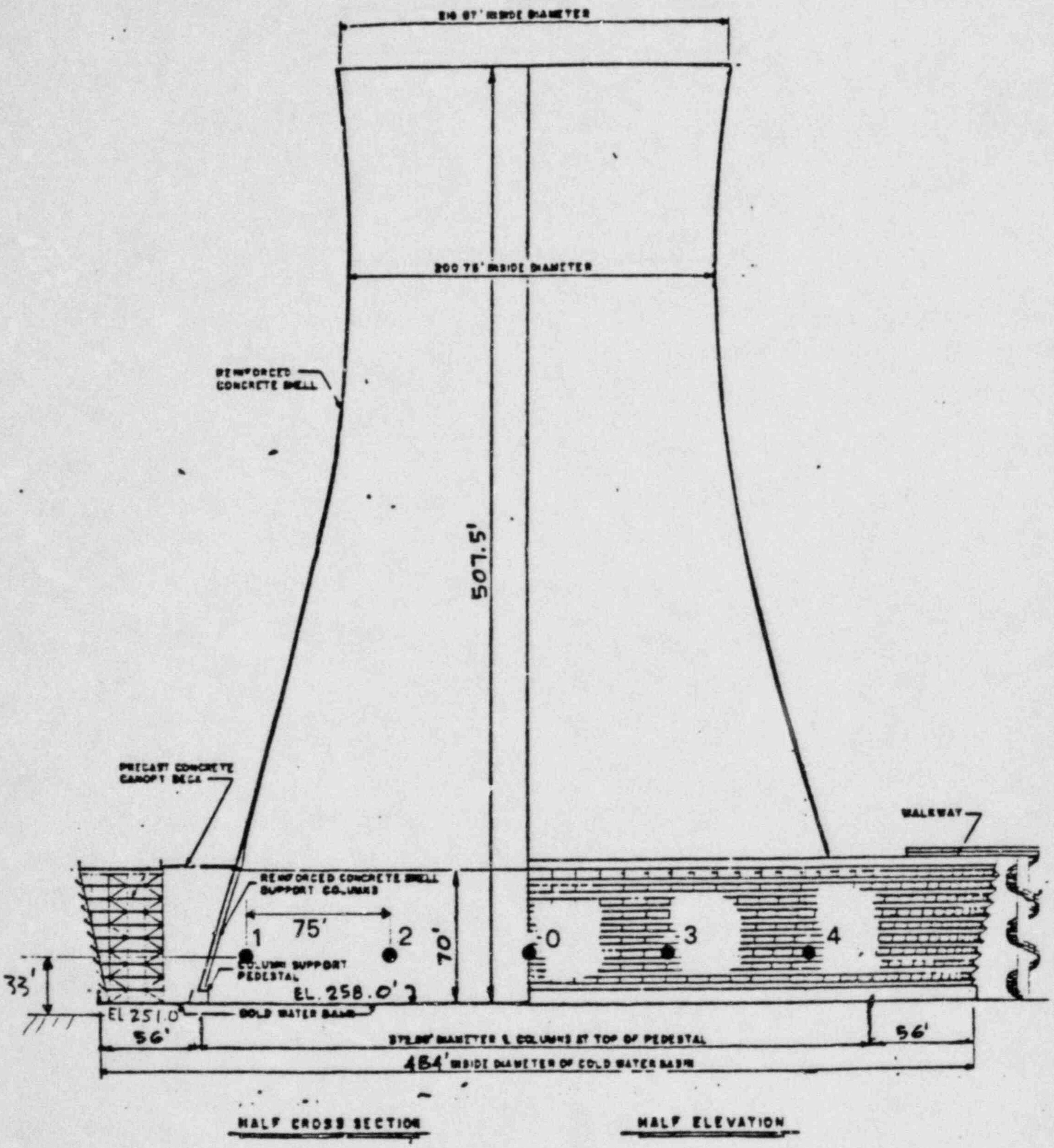

Figure 2. Points at which Horizontal Windspeeds Were Calculated

From these results the following estimates, averaged over both cooling towers were constructed:

1. $P(V_0 \leq 135)$, the probability that the tower center point would experience windspeeds less than or equal to 135 mph;

2. $P(V_0 > 135)$, the complementary probability that the tower center would experience windspeeds greater than 135 mph; and

3. $P(V_m \geq V_\ell | V_0 \leq 135)$, the probability that any of the other points 1-4 would experience windspeeds greater than V_ℓ, given that the center point windspeed was not greater than 135 mph, for V_ℓ = 135, 145, 165, 175 and 185 mph.

Table 6 summarizes these results. They indicate that only 3, 12, 14, and 14 percent of F2, F3,F4, and F5 tornadoes, respectively, would produce winds in excess of 135 mph on the tower given that the center of tower experience winds $\leq$ 135 mph. For V_m to significantly exceed 135 mph, say $V_m \geq 165$ mph, these probabilities are 0, 0.04, 0.08, and 0.07, respectively. Hence, these results indicate that the error introduced by using tower center point is not significant, considering the other conservatisms in the analysis.

2. Tower Failure

In NUS-4507 a windspeed of 135 mph at 33 ft. was used as the failure criterion of the cooling tower, based on a report from Bechtel Power Corporation. A more detailed analysis has been made of the capacity of the cooling towers at Limerick to withstand tornado winds. The tornado wind profile given in response to Question 5 was used in this analysis. This profile provides for essentially uniform winds above 33 feet.

Figure 3 shows the symmetric wind pressure distribution on the cooling tower used in the analysis of tower response to extreme winds. This distribution has been verified on "as built" towers. For the Limerick towers, the original buckle or failure of the tower occurs at theta equal to 71° at an elevation of two hundred feet above the point where the shell starts.

The calculated failure windspeed is 180 mph at 33 feet. This windspeed has been estimated by integrating the wind loads on the tower and accounting for the dead load of the reinforced concrete shell.

If the maximum tornado wind velocity occurs at a point other than at theta equals zero degrees, the pressure distribution is non-axisymmetric and the maximum pressure coefficient at zero degrees is less than 1.56 as shown on the figure. The coefficients are slightly higher for angles of theta greater than zero. They are not very much greater because the coefficient normal to the shell is used in the structural analysis. These deviations create minor negligible differences in the compressive stress at the critical points because the stress is an integrated value over the height of the tower. The deviations could also cause torsion on the shell. The shell has a very high torsional stiffness, and thus this effect is negligible.

Table 6. Windspeed exceedance probabilities at tower center and at the point of maximum windspeed, by tornado F-scale

	F2	F3	F4	F5
$P(V_0 \leq 135 \mid F_i)$	0.98	0.82	0.70	0.66
$P(V_0 > 135 \mid F_i)$	0.02	0.18	0.30	0.34
$P(V_m > 135 \mid V_0 \leq 135; F_i)$	0.03	0.12	0.14	0.14
$P(V_m > 145 \mid V_0 \leq 135; F_i)$	0.01	0.10	0.12	0.10
$P(V_m > 155 \mid V_0 \leq 135; F_i)$	(a)	0.06	0.09	0.08
$P(V_m > 165 \mid V_0 \leq 135; F_i)$	(a)	0.04	0.08	0.07
$P(V_m > 175 \mid V_0 \leq 135; F_i)$	(a)	0.02	0.06	0.06
$P(V_m > 185 \mid V_0 \leq 135; F_i)$	(a)	0.01	0.05	0.05

[a] No success in TORMIS simulations.

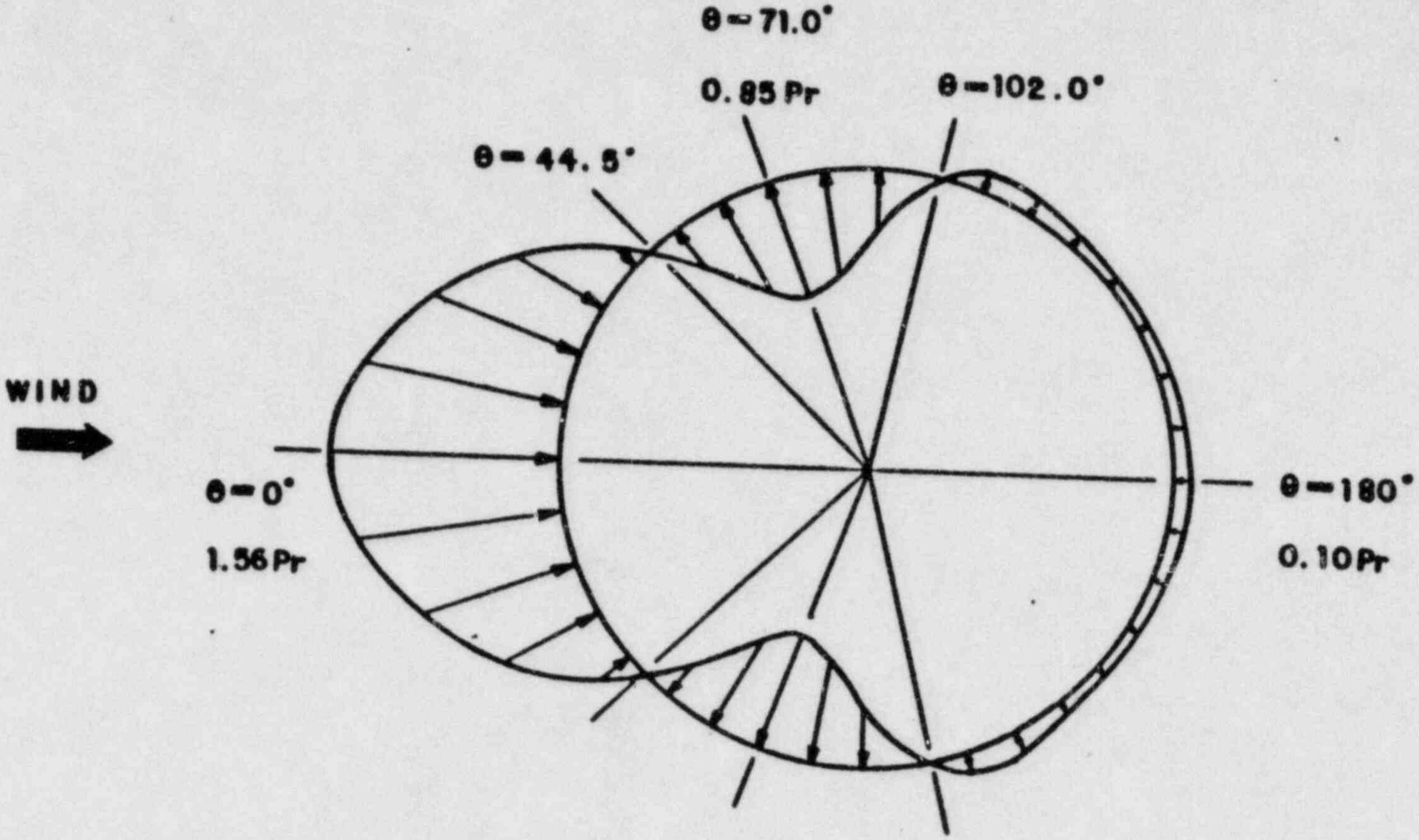

Figure 3. Pressure Distribution on a Cooling Tower

The use of the 135 mph failure criterion is significantly conservative on the basis of this analysis of tower capacity. The probability of exceedance of windspeeds of 180 mph is a factor of about 4 lower than that of exceeding 135 mph.

Q4. Discuss why vortex shedding or the venturi effect are not significant contributors to failure of the cooling towers.

Response

The assumed failure criteria for the cooling towers for straight winds and winds of hurricane origin is discussed more fully in response to Question 6 in which the failure speed at 33 ft is given as 135 mph. The windspeed profile used in this evaluation is that given by the expression:

$$U(Z) = U(10)\left[0.55 + .1955\ln Z\right]$$

where:

Z = height above ground (meters)
$U(10)$ = horizontal windspeed at 10 meters (33 ft)
$U(Z)$ = horizontal windspeed at Z meters

The effects of vortex shedding and the venturi effect were investigated to determine the significance of these effects at or below the assumed failure point of the towers.

a. A maximum vortex shedding frequency was calculated using (1)a Strouhal number of .3, (2) a velocity representative of the top of the tower (305 ft/sec) corresponding to the assumed failure speed at 10 meters of 135 mph, and (3) a minimum tower diameter of 200 ft. The frequency of vortex shedding for this condition is .46 Hz. The natural frequency of the tower in the first beam mode is about 3 Hz.

   Therefore, for all velocities less than the assumed tower failure speed, it is concluded that vibrational stresses induced by vortex shedding would not be significant and need not be considered further.

b. The effect of the constriction of flow between the cooling towers has been investigated and the effects on either tower are judged to be small for all wind speeds of interest at or below the failure speed used in the analysis for all angles of approach. This conclusion is based on the actual tower spacing and an examination of the pitch to diameter ratios corresponding to the straight wind failure profile and the diameter of the towers at various elevations.

Q5. What is the value of the tornado wind speed at an elevation of 33 ft which corresponds to the nominal failure of the cooling towers? Are the results of the simulations in the NUS report compatible with these values?

Response

The nominal tower failure speed used in the TORMIS simulations was actually 135 mph at 33 ft. Hence, the simulation results are identically consistent with this value. As discussed in the response to Question 3, item 2, this is a significantly conservative value relative to the assessed failure speed of 180 mph at 33 ft. for tornado winds

NUS-4507 reported a tower failure speed of 140 mph at tower midheight. This speed, on the basis of published TORMIS wind profiles (2), is consistent with the 135 mph at 33 ft and was reported on that basis. Figure 4 illustrates this profile variation of tornado windspeed with height. The midheight speed was reported since it was felt that midheight was a more useful engineering reference than 33 ft for towers of 500 ft height. Considering the practical aspects of predicting tower failure, the TORMIS tornado wind profile can be treated as essentially uniform above 33 ft.

As a further validation of the windspeed variation with height, the TORMIS results have been further evaluated to determine what typical variation in the vertical profile results from variation in tornado parameters and offsets inherent in the probabilistic TORMIS analyses. The vertical profile of the maximum horizontal windspeed at a given offset depends largely on the relative contributions of the radial and tangential components at the time that the maximum occurs. The radial component increases with height z to a maximum and then exponentially falls off while the tangential component unimodally approaches the free-field value at the top of the boundary layer. These components and the translational velocity are vectorially added to obtain the net horizontal windspeed at a given horizontal and vertical position. Thus, there is not a fixed ratio between the maximum horizontal windspeeds at 250 ft and 33 ft elevations for a given offset. However, the variations are not significant, as documented below.

To estimate the expected range of values of the 250-ft windspeed corresponding to 135 mph at 33 ft, the vortex rotational velocity at the core radius as a function of elevation was estimated using the TORMIS windfield model. For a core radius R = 515 ft, the maximum rotational velocity at z_0 = 33 ft is $V_{max} = U_{r\theta}(R, z_0)$ = 300 mph, the magnitude of the ratio of radial of tangential windspeeds at (R, z_0) is $\gamma = 0.6947$, the tornado width is W = 10,460 ft and the translational velocity is U_T = 65 fps. The ratio of rotational velocity at R and z = 250 ft to that at R and z = 33 ft is $U_{r\theta}(R,250)/U_{r\theta}(R,33) = 310/300 = 1.033$. The rotational velocity at the core radius is not necessarily the maximum horizontal windspeed that the towers would see, but this ratio of rotational velocities is one measure of the vertical variation of the windfield model. On this basis, the horizontal velocity at 250 ft corresponding to 135 mph at 33 ft would be (135)(1.033) = 139.5 mph.

We also evaluated the ratio of maximum horizontal windspeeds at z = 250 ft and z = 33 ft at various offsets for 1,000 tornadoes sampled randomly from

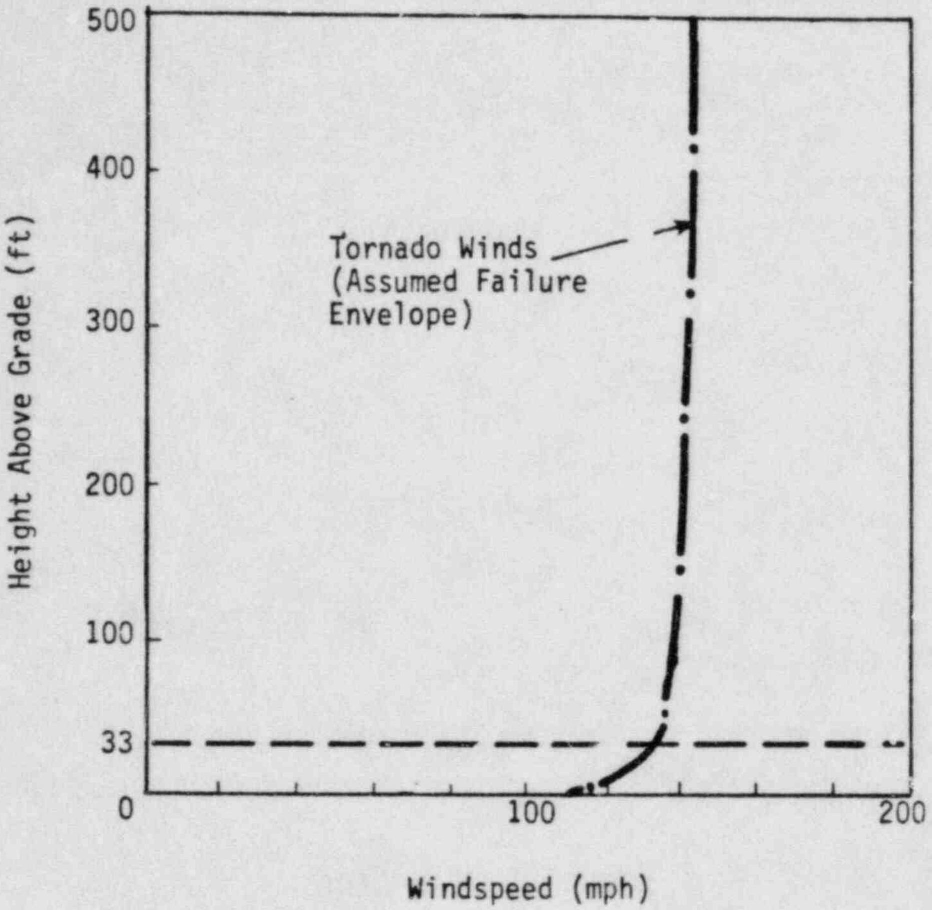

Figure 4. TORMIS Tornado Wind Profile Corresponding to Tower Failure

each of the F2, F3, F4 and F5 intensity categories. The mean values and standard deviations of these ratios are as shown below:

	F2	F3	F4	F5	All
V_{250}/V_{33}	0.968	1.018	1.013	0.999	1.000
$\sigma(V_{250}/V_{33})$	0.0022	0.0033	0.0026	0.0028	0.0055

These results were obtained from simulations at various offsets, including large offsets where the windspeeds are dominated by the translational velocity, and thus do not show much vertical variation. Hence, the above ratios may be slightly small for estimating windspeeds at 250 ft corresponding to tower failure windspeeds of 135 mph at 33 ft. For example, the average ratio of five F3 tornadoes, selected at random, whose maximum windspeeds at 33 ft were between 119 and 159 mph (i.e., near the 135 mph value) was $V_{250}/V_{33} = 1.048$. On this basis, the 250 ft windspeed corresponding to 135 mph at 33 ft would be 141.5 mph.

Thus, it has been concluded that maximum horizontal windspeeds at tower midheight would generally be between 134 and 142 mph when the maximum windspeeds at 33 ft were 135 mph. The results reported in NUS-4507 are consistent with these values.

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