BOUNDING GENERIC RISK ASSESSMENT FOR SELECTED PLANT SYSTEMS, PORTIONS OF WHICH ARE NOT PROTECTED FROM TORNADO-GENERATED MISSILES

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EXECUTIVE SUMMARY

Several licensees have self-identified non-conformances with their tornado missile protection licensing basis. This risk assessment supports an integrated risk-informed decision regarding: (1) whether these non-conformances represent an immediate safety concern such that the Nuclear Regulatory Commission (NRC) must take prompt action; and, (2) if not an immediate safety concern, to provide insights regarding a reasonable time for licensees to achieve compliance. This risk assessment, therefore, is one part of the integrated decision process and addresses whether acceptable levels of risk are maintained.

This study uses tornado strike hazard curves to provide a bounding estimate of the initiating event frequency (IEF) of a damaging tornado missile in each of three tornado regions as defined in NUREG/CR-4461 (Reference 1). It then uses the Standardized Plant Analysis Risk (SPAR) models for selected plants to analyze failures of systems, structures and components (SSCs) that have typically been found to not meet the licensing basis for tornado missile protection.

The main conclusion from this study is that the non-conformance with tornado missile protection issue does not rise to the level of adequate protection or require immediate plant shutdown because the risk is bounded by the IEF of 4E-4 per year even in the most severe tornado region, which is well below the 1E-3 per year threshold provided in the Office of Nuclear Reactor Regulation (NRR) Office Instruction LIC-504, “Integrated Risk-Informed Decision-Making Process for Emergent Issues” (Reference 2).

It is also concluded that the duration for this issue to result in an incremental conditional core damage probability (ICCDP) of 5E-5, another guideline from reference 2, is longer than a year. This risk study is judged to be conservative and, therefore, a longer time period than indicated in some of the calculations could be used.

Because a bounding estimate of the IEF is assumed, and the conditional core damage probabilities (CCDPs) from this study are judged to be very conservative, it is concluded that this issue is not risk-significant. This issue may be characterized as related primarily to regulatory compliance. Therefore, the NRC staff may exercise judgment in choosing a time frame for requiring licensees to address their plant-specific issues and come into conformance.

Although an immediate safety concern has not been identified based on the results of this risk evaluation and the issue appears to not be risk significant, NRC should require licensees to put appropriate compensatory measures in place until the non-conformances have been addressed.

INTRODUCTION

Issue Statement

In the early 2000's several licensees self-identified non-conformances with their tornado missile protection licensing basis. In addition, since 2005 the NRC has been performing Component Design Bases Inspections, which have provided examples of plant tornado missile licensing basis non-conformances at some facilities.

This risk assessment supports an integrated risk-informed decision (see Ref. 2) regarding: (1) whether these non-conformances represent an immediate safety concern such that NRC must take prompt action; and, (2) if not an immediate safety concern, to provide insights regarding a reasonable time for licensees to achieve compliance.

Background

Nuclear power plants are required to provide protection for safety-related SSCs from the effects of tornadoes, including tornado missiles. The methods for providing this protection are described in the plant licensing basis, typically contained in the final safety analysis report or updated final safety analysis report.

In the late 1970's and early 1980's, several licensees identified components that did not conform to their licensing basis for tornado missile protection. Some licensees requested NRC approval of the TORMIS methodology developed by the Electric Power Research Institute (EPRI). The NRC approved the TORMIS methodology in 1983. Some licensees incorporated this methodology or other probability methodologies into a license amendment request in order to modify their licensing basis and come into conformance. These probabilistic methodologies demonstrated that the probability of tornado missile damage to these nonconforming components was sufficiently low, such that no tornado missile protection was required. Other licensees incorporated protective measures to bring the plant into conformance with the licensing basis.

Relation to Risk-Informed Decision-Making

As set forth in NRR Office Instruction LIC-504 (Ref. 2), risk-informed decision-making employs five key principles:

1. Compliance with regulations unless an exemption is requested
2. Maintaining adequate safety margins
3. Maintaining adequate defense-in-depth

4. Any risk increases are small and commensurate with the Commission's Safety Goal Policy Statement
5. Performance measurement strategies (may include compensatory measures) are in place to monitor the chosen decision

This risk assessment, therefore, is one element of the integrated decision process.

RISK ASSESSMENT

Method/Approach

A detailed risk assessment is not feasible for this issue for several reasons, including:

- Specific non-conforming SSCs would need to be identified for each plant, or a comprehensive list that spans all affected plants would be needed.
- Site-specific tornado missile hazard curves would need to be developed.
- Individual target fragilities to various missiles would need to be developed.
- Tornado missiles could impact equipment credited in the PRA whether or not such equipment is required to be protected from tornado missiles on all SSCs credited in the PRA.
- The SPAR models would have to be modified to analyze tornado missile risk. This could include new event trees, changes to offsite power recovery models, equipment repair probabilities, human error probabilities, and so forth.

For the purpose of this evaluation, bounding conservative assumptions were made to support a regulatory position for one to several generic populations of plants depending on their geographic tornado zone. The main steps in the chosen approach are detailed below:

1. Use tornado strike hazard curves from Ref. 1 and information from Ref. 3 to provide a bounding estimate of the IEF of a damaging tornado missile in each of three tornado regions.
2. Determine whether an immediate safety concern is indicated, assuming that the bounding IEF results in core damage.
3. Apply a "target size reduction factor" (assumed) to account for targets being smaller that assumed in reference 1.
4. Refine the analysis by using SPAR models to gain insights into core damage probability given failure of SSCs assumed to be non-complying as follows:
    - Choose a sample of plants in the region with highest tornado hazard

- Use the internal events loss of offsite power (LOOP) event tree for the analysis
- Remove credit for offsite power recovery; solve the event tree to determine the "base case" CCDP given LOOP and no offsite power recovery
- Fail selected systems (i.e., systems assumed to be unprotected from tornado missiles) and calculate the new CCDP
- Calculate the increase in CCDP and multiply by the bounding IEF from step 1 above to estimate the delta CDF attributable to some SSCs not being protected from tornado missiles

5. Perform selected sensitivity analyses.
   - Sensitivity of delta CDF to an assumed "target size reduction factor"
   - Sensitivity of delta CDF to one or more base-cases that assume failure of non-safety-related equipment from tornado missiles
6. Determine the duration that the analyzed, non-compliant SSCs could remain in that condition before the ICCDP reaches some appropriate threshold.

<u>Acceptance Guidelines</u>

NRR Office instruction LIC-504 (Ref. 2) provides several risk metrics that can be used to indicate when an issue might require immediate shutdown of a plant to provide reasonable assurance of adequate protection of public health and safety. The CDF metric was chosen as the appropriate one for this issue. LIC-504 states that a CDF on the order of 1E-3 per year or higher might indicate that an immediate safety concern exists.

LIC-504 also states that an ICCDP greater than 5E-5 might indicate that immediate action is required to reduce risk. This metric is judged not to be appropriate for determining whether the tornado missile non-conformances represent an immediate safety concern. However, this metric is useful in determining the duration that an assumed non-conforming condition can exist before the ICCDP reaches the 5E-5 value.

In summary, two risk acceptance guidelines from LIC-504 are used in this study:

- CDF < 1E-3 per year for assessing whether the issue represents an immediate safety concern
- ICCDP = 5E-5 for determining what non-complying duration would be required in order to reach this level

<u>Assumptions, Precautions and Limitations</u>

The risk assessment documented in this report is of a bounding nature. The upper bound on core damage risk from tornado missiles is set at the frequency at which a tornado with wind speeds in excess of 75 mph would hit a plant in the most severe tornado region in the U.S. This IEF was obtained by using documented sources of information (Refs. 1 and 3) and therefore provides a reasonable upper bound for the risk.

The application of a “target size reduction factor,” while it has logical appeal, presents several problems: without specific knowledge of the actual non-conforming conditions for a given site, it cannot be concluded that the width of the targets, in the aggregate, is less than or equal to 10 percent of the building width assumed in reference 1. More importantly, it is not clear that such a ratio is appropriate. However, no credit is taken for targets that are partially shielded by buildings, and the fragility of the target is not considered at all. A 10 percent reduction in the strike probability is assumed because the analysis is very conservative in other ways; still, such an assumption should be tested and verified when specific non-conformances are evaluated.

The SPAR model analyses are problematic as well. Use of a PRA model tends to add credibility to a risk analysis, even though, in this case, the model was not developed to analyze tornado missiles. A representative existing event tree was chosen (LOOP) for these analyses, and reasonable assumptions were made (such as not crediting offsite power recovery), but the approach is simplistic at best. As it turns out, the SPAR results show that, under the conservative assumptions made in this study, CCDP given a non-recoverable LOOP and complete loss of selected SSCs approaches 1.0 in many cases. Therefore, it is unlikely that this part of the analysis will result in regulatory decisions that are based on overly optimistic risk numbers.

Note that this risk assessment is intended as one input into the LIC-504 integrated risk-informed decision-making process. Other factors, including defense-in-depth and safety margins, need to be factored into any decision on the tornado missile issue.

The assumptions employed in this study include the following:

- The “hazard-fragility” approach is not employed due to resource and schedule constraints.
- The variability of tornado strike frequency over a year was not taken into account. For some locations, there may be a couple of months during the year when almost all tornadoes have occurred in the past.
- Configuration-specific risk was not considered. For example, performance of online maintenance on certain systems during peak tornado periods could result in much greater risk exposure than an average risk might indicate.
- The mission time for the PRA was not extended from the 24-hour time period. While recovery of offsite power was not credited in this analysis, the failure-to-run probabilities are based on a 24 hour mission time.

- The annual probability of a tornado missile striking a target may be reduced by the ratio of the target width to the 200 foot building width assumed in reference 1.
- It is assumed that the tornado missile target set is no wider than 20 feet; i.e., the target size reduction factor (the above ratio) is 10 percent.
- The SPAR model LOOP event tree, with credit for offsite power recovery removed, provides a reasonable representation of tornado missile risk.
- Safety-related SSCs that comply with the tornado missile requirements do not fail as a result of tornado missiles.
- Safety-related SSCs that do not comply with those requirements are assumed to fail with certainty for any tornado with wind speeds greater than 75 mph that hits that SSC.
- Any non-safety equipment that might fail from a tornado missile is assumed to fail in both the base case analysis and the analysis of non-compliant, safety-related SSCs.
- SPAR models allow recovery of emergency diesel generators (EDGs) (with a fairly pessimistic basic event probability). This credit was retained in the analysis as a surrogate for post-tornado actions that might be taken to restore the failed system. (For example, for a crimped EDG exhaust, plant staff could cut off the pipe and restore the function.)

Conservative assumptions have been used in order to address limitations with the use of full-power, internal events SPAR models. SPAR models and results had to be adjusted to account for conditions arising from a tornado missile strike.

<u>Tornado Missile Hazard</u>

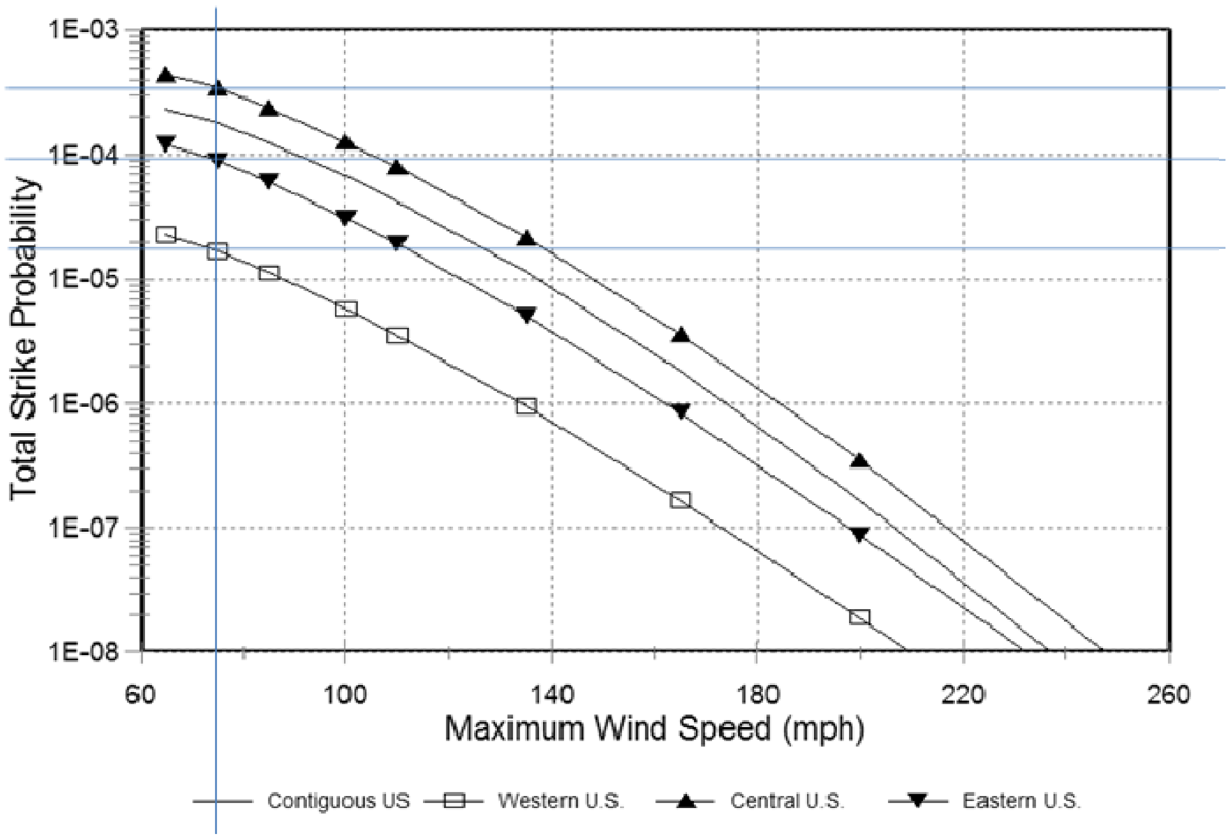
NUREG/CR-4461 (Ref. 1) provides Figure 5-1, entitled “Comparison of Conditional Wind Speed Probabilities Calculated for the Contiguous United States and for the Western, Central, and Eastern Regions.”

Regulatory Guide 1.76 (Ref. 3) states: “Wind velocities in excess of 34 m/s (75 mph) are capable of generating missiles from objects lying within the path of the tornado wind and from the debris of nearby damaged structures … [the] event sequence typically includes a wind-based occurrence in the plant vicinity in excess of 34 m/s (75 mph), existence and availability of missiles in the area, injection of missiles into the wind field, suspension and flight of those missiles, impact of the missiles with safety-related structures, and resulting damage to critical equipment.”

Therefore, a bounding estimate of the IEF for damaging tornado missiles can be taken as the annual strike probability of a tornado with wind speeds in excess of 75 miles per hour. The figure below is reproduced from Figure 5-1 of reference 1; the line at 75 mph was added to facilitate reading the appropriate probabilities from the graph.

Based on the above, the annual probability of a tornado strike generating damaging missiles (i.e., exceeding 75 mph) for each tornado region is:

Western U.S.	< 2E-5 per year
Eastern U.S.	< 1E-4 per year
Central U.S.	< 4E-4 per year



Plants Selected for Analysis

NUREG/CR-4461 (Ref. 1) breaks the U.S. into three tornado regions, with the first one (Central U.S.) having the highest tornado hazard. Seven nuclear power plants in NRC Region III were selected for this analysis, because they all fall in the Central U.S. tornado region. The seven plants include both boiling and pressurized water types and reactors from each of the major nuclear reactor vendors. The SPAR models for these plants were used for the risk analysis as documented in Table 1, below.

Table 1: Information Taken Directly from SPAR Models - Selected NRC Region III Plants[1]

Plant	Type	Event Tree[2]	SPAR Ver.	SPAR Date	Base CDF[3]	IEF[4]
Byron	W 4-loop	LOOPWR	8.25	8/25/2009	1.67E-07	3.91E-03
Clinton	BWR-6	LOOPWR	8.17	(not given)	2.61E-06	4.83E-03
Davis Besse	B&W	LOOP	8.19	7/8/2008	5.26E-07	2.84E-02
Fermi	BWR-4	LOOPWR	8.20	7/29/2009	1.40E-07	4.83E-03
Kewaunee	W 2-loop	LOOP	8.20	7/8/2008	3.71E-06	2.84E-02
Palisades	CE	LOOP	8.20	8/8/2009	2.57E-06	2.84E-02
Quad Cities	BWR-3	LOOPWR	8.18	9/14/2009	5.21E-07	4.83E-03

Note 1: All plants in this table are in the most severe tornado area ("Region 1" of RG 1.76)
Note 2: Some SPAR models have a separate "weather related LOOP" tree (LOOPWR)
Note 3: CDF is only for the LOOP or LOOPWR tree for that model
Note 4: Initiating event frequency is the one corresponding to the CDF shown

Chosen Missile Targets for Base Cases and Non-Conforming SSCs

A sample of actual non-conforming SSCs for some of the nuclear power plants on this list was obtained in order to understand, from a generic perspective, the types of failures that should be assumed in this risk assessment. After reviewing this information, the analyst chose loss of service water (ESW) and loss of all EDGs as the cases to be analyzed using the Saphire computer code and the SPAR models, as shown in Table 2, below.

Table 2: Analysis Base Cases and Assumed Non-Complying SSCs

Plant	Actual Non-Conformances[1]	Cases Analyzed	Remarks
Byron	Essential Service Water: • Cooling Towers • Piping • Blowdown pit Well Water piping	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate storage tank fails	Base case 2
		• Unit 1 EDGs fail	
		• Unit 1 EDGs fail • Unit 2 EDGs fail	
		• ESW fails	
Clinton	Not Available	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate system fails • Firewater system fails	Base case 2
		• EDGs fail	
		• ESW fails	
Davis Besse	• CCW • AFW • 4160 v buses	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate storage tank fails	Base case 2

Table 2: Analysis Base Cases and Assumed Non-Complying SSCs			
Plant	Actual Non-Conformances[1]	Cases Analyzed	Remarks
	• 480 v buses • DC buses • Battery chargers • EDGs • Service water	• No offsite power recovery • Station Blackout Diesel fails	Base case 3
		• EDGs fail	
		• ESW fails	
Fermi	Large list of penetrations, doors, walls, etc. but no indication of what SSCs are affected	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate system fails • Firewater system fails	Base case 2
		• No offsite power recovery • Combustion Turbines fail	Base case 3
		• EDGs fail	
		• Emergency Equipment service water fails	
		• ESW fails	
Kewaunee	EDG exhaust vents	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate storage tank fails	Base case 2
		• No offsite power recovery • Technical Support Center Diesel fails	Base case 3
		• EDGs fail	
		• Service Water system fails	
Palisades	Not Available	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate storage tank fails	Base case 2
		• No offsite power recovery • Non-safety diesel fails	Base case 3
		• EDGs fail	
		• ESW fails	
Quad Cities	EDG intake and exhaust	• No offsite power recovery	Base case 1
		• No offsite power recovery • Condensate system fails • Firewater system fails	Base case 2
		• No offsite power recovery • Station blackout Diesels fail	Base case 3
		• Unit 1 EDGs fail	
		• Unit 2 EDGs fail	
		• All EDGs fail	
		• ESW fails	

Notes:
1. Some of these non-conformances are historical may have already been addressed
2. CCW = Component Cooling Water

Table 2: Analysis Base Cases and Assumed Non-Complying SSCs			
Plant	Actual Non-Conformances[1]	Cases Analyzed	Remarks
3. AFW = Auxiliary Feedwater			

Analysis and Results

An upper bound core damage frequency estimate is provided by the initiating event frequency for tornadoes with wind speeds in excess of 75 miles per hour hitting a site, as wind speeds below this value are not expected to produce missiles that can damage nuclear power plants. As shown above, under the discussion of tornado hazards, this results in the following upper bounds for core damage frequency for plants in each of the three tornado regions defined in NUREG/CR-4461 (Ref. 1):

Western U.S. < 2E-5 per year
Eastern U.S. < 1E-4 per year
Central U.S. < 4E-4 per year

The hazard curves from reference 1 assume a "… characteristic horizontal dimension of a finite structure, assumed to be 200 [feet] …" This risk assessment assumes that the strike probability can be reduced by some factor for targets smaller than 200 feet wide. For this study, a 10 percent factor was used to account for the assumption that non-complying SSCs are likely no wider than 20 feet on average. Note that, because this factor is directly applied to the bounding IEF, the sensitivity of the results is linearly dependent on this factor. That is, a factor of ten larger (i.e., no reduction due to the size of the targets) will result in a ten-time increase in the delta CDF and a ten-time shorter duration to reach the ICCDP threshold.

The next step in the analysis is to estimate the increase in risk attributable to having SSCs that do not comply with the corresponding requirements for tornado missile protection. The SPAR model LOOP event tree was assumed to be the most applicable for these analyses. The approach is to remove credit for offsite power recovery, solve the LOOP event tree, and divide the resulting CDF by the LOOP IEF that was used in the SPAR model. This provides the CCDP given a non-recoverable loss of offsite power event. This CCDP provides "base case 1" for each of the plants in this analysis.

The next step is to analyze the assumed non-compliant plant. At least two cases were analyzed for each plant: loss of the EDGs and loss of ESW. Additional cases were considered for some plants as shown in Table 2; for example, when credit could be taken for cross-tying EDGs from a sister unit. The base case CCDP was subtracted from the CCDP from these analyses to obtain the increase in CCDP (given a tornado missile) because of the noncompliant SSCs.

The final estimate for the increase in CDF for each case was computed by multiplying the bounding IEF for Central U.S. (4E-4/year), the assumed "target size reduction factor" (0.1), and

the delta CCDP. The duration until the ICCDP threshold would be reached was found by dividing that increase in CDF into the ICCDP threshold (5E-5).

There are several problems with the simplified risk assessment approach described above, beyond the use of the extremely conservative tornado IEF. Probabilistic risk assessment (PRA) studies are intended to be realistic to the extent practicable. An implicit assumption in the approach used here is that the safety-related SSCs that comply with the tornado missile protection requirements have a zero chance of failing due to tornado missiles, and that the non-complying SSCs will fail with certainty. More significantly, however, the non-safety-related equipment that is modeled in the PRA should also be treated probabilistically rather than assuming none of them fails (or all of them fail) from the tornado missiles. (Refer to *Assumptions, Precautions and Limitations*, above, for more information.)

A simplified approach was employed to partially address this concern with the non-safety equipment. One or two additional base case analyses were performed for each plant, where selected non-safety equipment was assumed failed. These are included in the new base cases (as well as in the analysis of the non-conforming SSCs) because such failures can impact the delta risk.

For the boiling water reactors (BWRs), the second base case failed both condensate and firewater. For the pressurized water reactors (PWRs), the second case failed the condensate storage tank. When a plant had a non-safety source of alternating current power, such as a station blackout (SBO) diesel or internal combustion turbine generator, it was failed as a third base case.

The SPAR model versions that were used in this analysis are presented in Table 1. The software used was Saphire 8, Version 8.0.9, Build 0 (05/29/2013). The results of these analyses are presented in the tables in Attachment 1. In addition, the maximum values of CCDP, ΔCDP, and ΔCDF for each plant are provided. Also, the minimum calculated duration to reach the ICCDP threshold of 5E-5 is also shown.

The results of these analyses show that the CCDP given certain failure of EDGs or ESW can equal or be very near 1.0. These CCDPs are considered conservative for a number of reasons, including:

- Any tornado with winds greater than 75 miles per hour will generate missiles capable of impacting the non-conforming SSCs ("targets").
- Missiles so generated will impact the target with certainty.
- The target will fail if any missile impacts it.
- The failure mode of the SSC struck by the missile is one that renders that SSC non-functional. (For example, if a missile strikes an EDG exhaust that is non-compliant

with the tornado missile requirements, the exhaust is assumed to fail in a manner that fails the EDG.)

- If an SSC has any non-compliant feature, total failure of all trains of that SSC occurs (i.e., 100% correlation among trains of the affected systems).
- Candidate SSCs for this analysis were SSCs with a high risk importance (e.g., ESW and EDGs).
- No credit is given for equipment added as a result of NRC orders resulting from the terrorist attacks on September 11, 2001
- No credit is given for the industry's "FLEX" equipment or other post-Fukushima equipment

The results, then, do not derive any significant benefit from the SPAR model analyses, but rather are determined by the bounding IEF (4E-4 / year) and the assumed "target size reduction factor" (0.1). As the tables show, the estimated increase in CDF from tornadoes is as high as 4E-5 per year and the duration to reach an ICCDP of 5E-5 as short as 1.3 years.

CONCLUSIONS

This risk assessment supports the following conclusions:

- The non-conformance with tornado missile protection issue does not rise to the level of adequate protection or require immediate plant shutdown because the risk is bounded by the IEF of 4E-4 per year even in the most severe tornado region, which is well below the 1E-3 per year threshold.

- The duration for this issue to result in an ICCDP of 5E-5 is longer than a year. While the analysis calculates durations as short as 1.3 years, which derives from the IEF and the assumed target size reduction factor, the many conservatisms in this study should support a longer time period than the value calculated by simply using a conditional core damage probability of 1.0.

It should be noted that a number of licensees have successfully been granted license amendments to accept tornado missile non-conformances based on computer simulations that showed a very small annual probability of a tornado missile strike on any of the non-conforming SSCs (i.e., less than 1E-6). While one must be careful extrapolating from such cases to the entire population of nuclear power plants with non-conforming SSCs, these studies at least demonstrate the conservatisms used in this study.

Because a bounding estimate of the IEF is assumed, and the conditional core damage probabilities (CCDPs) from this study are judged to be very conservative, it is concluded that this issue is not risk-significant. This issue may be characterized as related primarily to

regulatory compliance. Therefore, the NRC staff may exercise judgment in choosing a time frame for requiring licensees to address their plant-specific issues and come into conformance.

Although an immediate safety concern has not been identified based on the results of this study, and the above conservatisms imply that the issue is not risk significant, NRC should require licensees to put appropriate compensatory measures in place until the non-conformances have been resolved. Example compensatory measures could include (but are not be limited to):

- Contingency plans in case of failure of non-protected SSCs during a tornado;
- Consideration of tornado missile risk when scheduling online maintenance. For example, online maintenance of SSCs that are important to risk given an extended loss of offsite power should be scheduled during periods of historically low tornado activity to the extent possible; and,
- Housekeeping measures to reduce the potential for missiles.

Each licensee should be expected to propose compensatory measures appropriate for the specific non-conformances at their site.

REFERENCES

1. NUREG/CR-4461, “Tornado Climatology of the Contiguous United States,” Revision 2, U.S. Nuclear Regulatory Commission, February 2007 (ADAMS Accession No. ML070810400)
2. NRR Office Instruction LIC-504, “Integrated Risk-Informed Decision-Making Process for Emergent Issues,” Revision 3, U.S. Nuclear Regulatory Commission, April 12, 2010, (ADAMS Accession No. ML100541776)
3. Regulatory Guide 1.76, “Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,” Revision 1, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007 (ADAMS Accession No. ML070360253)

ATTACHEMENT 1: RISK ASSESSMENT RESULTS TABLES

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Table A1: Analyses for Byron: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	4.68E-07	1.20E-04				no offsite power recovery
U1 EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B	4.57E-04	1.17E-01	1.17E-01	4.67E-06	10.7	
U1/U2 EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B + EPS-DGN-FS-2A + EPS-DGN-FS-2B	1.19E-03	3.04E-01	3.04E-01	1.22E-05	4.1	EDG recovery is still allowed
ESW	ESW*	3.91E-03	1.00E+00	1.00E+00	4.00E-05	1.3	Saphire reports CDF higher than IEF (5.24E-3) due to retaining non-minimal cutsets (system generated failure event - TRUE) is not set to true and subsumed.
Base Case 2	OEP-XHE-X?-NR* + AFW-TNK-FC-CST1	1.09E-04	2.79E-02				no offsite power recovery + condensate storage tank fails
U1 EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B	5.62E-04	1.44E-01	1.16E-01	4.63E-06	10.8	
U1/U2 EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B + EPS-DGN-FS-2A + EPS-DGN-FS-2B	1.30E-03	3.32E-01	3.05E-01	1.22E-05	4.1	
ESW	ESW*	3.91E-03	1.00E+00	9.72E-01	3.89E-05	1.3	(same problem as case 1 ESW above)
	Maximum value =	3.91E-03	1.00E+00	1.00E+00	4.00E-05	1.3	= Minimum years

Table A2: Analyses for Clinton: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	1.29E-05	2.67E-03				no offsite power recovery
EDGs	EPS-DGN-FS-DG1A + EPS-DGN-FS-DG1B + EPS-DGN-FS-DG1C	4.08E-03	8.45E-01	8.42E-01	3.37E-05	1.5	
ESW	SSW*	4.08E-03	8.45E-01	8.42E-01	3.37E-05	1.5	PSW & SSW; SWS system code not used. Plant service water is non-safety-related per FSAR.
Base Case 2	OEP-XHE-X?-NR* + CDS* + FWS*	2.57E-05	5.32E-03				no offsite power recovery + no condensate + no fire water system
EDGs	EPS-DGN-FS-DG1A + EPS-DGN-FS-DG1B + EPS-DGN-FS-DG1C	4.83E-03	1.00E+00	9.95E-01	3.98E-05	1.3	Saphire reports 4.92E-3; cutsets appear minimal. Small event approximation appears to be the cause.
ESW	SSW*	4.83E-03	1.00E+00	9.95E-01	3.98E-05	1.3	Saphire reports 4.92E-3; cutsets appear minimal. Small event approximation appears to be the cause.
	Maximum value =	4.83E-03	1.00E+00	9.95E-01	3.98E-05	1.3	= Minimum years

Table A3: Analyses for Davis Besse: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	4.28E-06	1.51E-04				no offsite power recovery
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12	1.25E-03	4.40E-02	4.39E-02	1.75E-06	28.5	
SWS	SWS*	1.27E-03	4.47E-02	4.46E-02	1.78E-06	28.0	
Base Case 2	OEP-XHE-X?-NR* + AFW-TNK-FC-CST311	1.60E-05	5.63E-04				no offsite power recovery + condensate storage tank fails. There are 2 CST's - logic shows either will fail that source of AFW supply
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12	3.75E-05	1.32E-03	7.57E-04	3.03E-08	1651.2	Apparent Saphire error – additional failure of CST has reduced risk several orders of magnitude
SWS	SWS*	2.84E-02	1.00E+00	9.99E-01	4.00E-05	1.3	
Base Case 3	OEP-XHE-X?-NR* + EPS-DGN-FS-SBO	7.91E-05	2.79E-03				No offsite power recovery + SBO diesel fails
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12	2.03E-02	7.15E-01	7.12E-01	2.85E-05	1.8	
SWS	SWS*	2.03E-02	7.15E-01	7.12E-01	2.85E-05	1.8	
	Maximum value =	2.84E-02	1.00E+00	9.99E-01	4.00E-05	1.3	= Minimum years

Table A4: Analyses for Fermi: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	1.47E-07	3.04E-05				no offsite power recovery
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12 + EPS-DGN-FS-DG13 + EPS-DGN-FS-DG14	1.34E-04	2.77E-02	2.77E-02	1.11E-06	45.1	
ECW	ECW*	1.53E-07	3.17E-05	1.24E-06	4.97E-11	1006250.0	emergency equipment SW
ESW	ESW*	1.35E-04	2.80E-02	2.79E-02	1.12E-06	44.8	Emergency SW
Base Case 2	OEP-XHE-X?-NR* + CDS* + FWS*	5.00E-06	1.04E-03				no offsite power recovery + no condensate + no fire water system
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12 + EPS-DGN-FS-DG13 + EPS-DGN-FS-DG14	1.71E-04	3.54E-02	3.44E-02	1.37E-06	36.4	
ECW	ECW*	5.11E-06	1.06E-03	2.28E-05	9.11E-10	54886.4	
ESW	ESW*	1.71E-04	3.54E-02	3.44E-02	1.37E-06	36.4	
Base Case 3	OEP-XHE-X?-NR* + EPS-CTG*	5.62E-07	1.16E-04				no offsite power recovery + no combustion turbines
EDGs	EPS-DGN-FS-DG11 + EPS-DGN-FS-DG12 + EPS-DGN-FS-DG13 + EPS-DGN-FS-DG14	3.98E-03	8.24E-01	8.24E-01	3.30E-05	1.5	
ECW	ECW*	6.02E-07	1.25E-04	8.28E-06	3.31E-10	150937.5	
ESW	ESW*	3.98E-03	8.24E-01	8.24E-01	3.30E-05	1.5	
	Maximum value =	3.98E-03	8.24E-01	8.24E-01	3.30E-05	1.5	= Minimum years

Table A5: Analyses for Kewaunee: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	3.19E-05	1.12E-03				no offsite power recovery
EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B	7.57E-03	2.67E-01	2.65E-01	1.06E-05	4.7	EDG 1 + "swing" EDG
SWS	SWS*	7.57E-03	2.67E-01	2.65E-01	1.06E-05	4.7	
Base Case 2	OEP-XHE-X?-NR* + AFW-TNK-FC-CST1	1.15E-04	4.05E-03				no offsite power recovery + condensate storage tank fails
EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B	2.48E-02	8.73E-01	8.69E-01	3.48E-05	1.4	
SWS	SWS*	2.48E-02	8.73E-01	8.69E-01	3.48E-05	1.4	
Base Case 3	OEP-XHE-X?-NR* + EPS-DGN-FS-TSC	7.38E-05	2.60E-03				no offsite power recovery + TSC diesel fails
EDGs	EPS-DGN-FS-1A + EPS-DGN-FS-1B	1.84E-02	6.48E-01	6.45E-01	2.58E-05	1.9	
SWS	SWS*	1.84E-02	6.48E-01	6.45E-01	2.58E-05	1.9	
	Maximum value =	2.48E-02	8.73E-01	8.69E-01	3.48E-05	1.4	= Minimum years

Table A6: Analyses for Palisades: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Years**	**Notes**
Base Case 1	OEP-XHE-X?-NR*	1.72E-05	6.06E-04				no offsite power recovery
EDGs	EPS-DGN-FS-11 + EPS-DGN-FS-12	1.80E-03	6.34E-02	6.28E-02	2.51E-06	19.9	DG-13 is "non-safety"
SWS	SWS*	1.89E-03	6.65E-02	6.59E-02	2.64E-06	19.0	DG-13 does not appear to have SWS dependency
Base Case 2	OEP-XHE-X?-NR* + AFW-TNK-FC-CST	1.53E-03	5.39E-02				no offsite power recovery + condensate storage tank fails
EDGs	EPS-DGN-FS-11 + EPS-DGN-FS-12	3.51E-03	1.24E-01	6.97E-02	2.79E-06	17.9	
SWS	SWS*	2.84E-02	1.00E+00	9.46E-01	3.78E-05	1.3	Saphire reports 3.2E-2 and includes non-minimal cutsets.
Base Case 3	OEP-XHE-X?-NR* + EPS-DGN-FS-13	1.55E-04	5.46E-03				no offsite power recovery + non-safety DG fails
EDGs	EPS-DGN-FS-11 + EPS-DGN-FS-12	2.13E-02	7.50E-01	7.45E-01	2.98E-05	1.7	
SWS	SWS*	2.13E-02	7.50E-01	7.45E-01	2.98E-05	1.7	
	Maximum value =	2.84E-02	1.00E+00	9.46E-01	3.78E-05	1.3	= Minimum years

Table A7: Analyses for Quad Cities: Failures Shown in Addition to Corresponding Base Case

Case	Failed SPAR Basic Events	CDF	CDP	ΔCDP	ΔCDF	Years	Notes
Base Case 1	OEP-XHE-X?-NR*	2.04E-06	4.22E-04				no offsite power recovery
U1 EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12	1.80E-03	3.73E-01	3.72E-01	1.49E-05	3.4	EDG 1 + "swing" EDG
U2 EDG	EPS-DGN-FS-DG2	3.03E-05	6.27E-03	5.85E-03	2.34E-07	213.6	
All EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12 + EPS-DGN-FS-DG2	2.30E-03	4.76E-01	4.76E-01	1.90E-05	2.6	
ESW	ESW*	4.79E-04	9.92E-02	9.87E-02	3.95E-06	12.7	Fault tree shows ESW cooling EDGs, but this CDF is less than failing EDGs
Base Case 2	OEP-XHE-X?-NR* + CDS* + FWS*	1.31E-05	2.71E-03				no offsite power recovery + no condensate + no fire water system
U1 EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12	2.54E-03	5.26E-01	5.23E-01	2.09E-05	2.4	
U2 EDG	EPS-DGN-FS-DG2	1.04E-04	2.15E-02	1.88E-02	7.53E-07	66.4	
All EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12 + EPS-DGN-FS-DG2	3.24E-03	6.71E-01	6.68E-01	2.67E-05	1.9	
ESW	ESW*	7.24E-04	1.50E-01	1.47E-01	5.89E-06	8.5	same issue as above
Base Case 3	OEP-XHE-X?-NR* + EPS-DGN-FC-SBOSTRUCT	7.75E-06	1.60E-03				no offsite power recovery + SBO building fails
U1 EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12	3.04E-03	6.29E-01	6.28E-01	2.51E-05	2.0	
U2 EDG	EPS-DGN-FS-DG2	8.83E-05	1.83E-02	1.67E-02	6.67E-07	75.0	
All EDGs	EPS-DGN-FS-1 + EPS-DGN-FS-12 + EPS-DGN-FS-DG2	1.94E-03	4.02E-01	4.00E-01	1.60E-05	3.1	1157 cutsets
ESW	ESW*	1.94E-03	4.02E-01	4.00E-01	1.60E-05	3.1	755 cutsets; same CDF
	Maximum	3.24E-	6.71E-	6.68E-	2.67E-	1.9	= Minimum years

Table A7: Analyses for Quad Cities: Failures Shown in Addition to Corresponding Base Case							
Case	**Failed SPAR Basic Events**	**CDF**	**CDP**	**ΔCDP**	**ΔCDF**	**Year s**	**Notes**
	value =	03	01	01	05		