1.0 Purpose

The purpose of this white paper is to provide a reasonable protection evaluation of the BWR Hardened Containment Vent System (HCVS) against the external hazard of wind-borne missiles that cause an Extended Loss of AC Power (ELAP) or a Loss of the Ultimate Heat Sink (LUHS). The evaluation will be used to meet the following requirements of NEI 13-02:

> *5.1.1.6 Tornado and wind loading and missile impacts are required to be considered for portions of the HCVS.*
>
> *5.1.1.6.1 Current design of the structure is acceptable regarding wind and missile protection for portions of the HCVS enclosed within a seismic category 1 (or equivalent) building/enclosure or through the plants existing elevated release point (e.g., meteorological stack)*
>
> *5.1.1.6.2 Reasonable protection evaluations per the guidance in NEI 12-06 as endorsed by JLD-ISG-12-001 for Order EA-12-049 should be performed for portions of the HCVS not covered in 5.1.1.6.1 above.*

Note that NEI 13-02 refers to NEI 12-06 for the identification and evaluation of external hazards for the HCVS. As such, this white paper may be used for HCVS evaluations with respect to both the FLEX and HCVS orders.

- The evaluation does not address the issue of HCVS piping that could fall and damage design basis equipment required during a high wind event. Licensees should address such potential interactions within established design and licensing processes.
- The evaluation does not address damage to the HCVS piping and components due to high-wind induced failures of structure or equipment above or besides the HCVS. Licensees should assess plant specific arrangements of structures and equipment for potential wind-related concerns other than the potential missiles addressed in this paper.
- The evaluation does not address any design considerations, such as wind loading, ice, or heat, other than wind-borne missiles. Licensees should include such considerations in their design and licensing process as applicable to the HCVS.

This evaluation concludes that there is reasonable assurance that the HCVS will continue to function during the plant response to a wind-borne missile generated ELAP or LUHS given the following assumptions:

1. Piping and components external to any missile-protected structure and less than 30 feet above grade are evaluated and, unless otherwise justified in plant-specific OIPs, protected from large and small missiles.
2. Piping and components external to any missile-protected structure and greater than 30 feet above grade conform to the following:
    a. The target area of the HCVS components is less than 300 ft^2,
    b. The size and robustness of the exposed HCVS s are substantial (e.g., steel piping versus small tubing or plastic piping),
    c. There is no source of obvious potential missiles in the proximity of the exposed HCVS components (such as an unrestrained material lay down area).

3. Licensees consider guidance in FLEX, or other procedures, to restore venting capability in the event the HCVS is damaged. Restoration could include cutting pipe below damaged section. This location may have to be below the release height requirements otherwise imposed.
4. Licensees verify that if hurricanes are screened in for FLEX (see NEI-12-06), that the site procedures recommend a plant shut down prior to hurricane arrival on-site.

2.0 Background

The guidance of NEI 12-06, Section 7 provides steps to assess the impact of severe storms with high winds that can be applied to the assessment of missiles on HCVS. The steps recognize that the challenge presented by high winds is site-specific, and is a function of the site layout, plant design, and potential high wind hazards. High winds may be caused by hurricanes, extreme straight winds and tornadoes (including tornado missiles). An external wind event that would require the use of FLEX or which would proceed to cause a severe accident, would involve failure of the following:

- Offsite Power, and
- All onsite Emergency Power, or
- Loss of the Ultimate Heat Sink

The NEI 12-06 applicable steps can be summarized as follows:

1) Determine the applicability of wind conditions. This determination involves a screening process used to identify whether the site should address high wind conditions. This is discussed also in NEI 13-02, Section D.1:

   D.1.2: References in this guidance to the criteria contained in NRC endorsed FLEX guidance, NEI 12-06, invoke those Order EA-12-049 criteria, such as the screened-in criteria for hazards for establishing boundary conditions applicable to compliance with Order EA-13-109 not the reverse.

2) Characterize the applicable high wind hazards: NEI 12-06 provides guidance on the expected wind conditions and challenges that would be expected for a specific site. This characterization recognizes the fact that, for hurricanes, significant notice will be available before a severe impact at a site, allowing for advance actions and equipment staging, while advance staging for a tornado impact is not likely.

3) Protection of equipment: The likely direction of the wind or tornado path, physical separation of the offsite power, safe shutdown equipment, and mitigation equipment is considered. This evaluation includes the consideration for orientation of the equipment including consideration of the surrounding buildings and the wind exposure expected. In general, tornadoes travel from the west or west-southwesterly direction resulting in the highest exposure from that direction.
   - The FLEX strategy is designed to ensure that “a single event would not damage all FLEX mitigation equipment…” This NEI 12-06 evaluation approach is the basis for

> the HCVS evaluation required by NEI 13-02 discussed above. The general approach for FLEX of providing redundant, separated capabilities to address tornado hazards is not applicable to HCVS, which is treated similar to installed, protected equipment.

As discussed in NEI 13-02, Section 5.1.1.6 (shown above), the HCVS piping contained within existing structures (a seismic category 1 (or equivalent) building/enclosure) is generally considered missile protected. As such, the evaluation below applies to the HCVS piping and components that are outside any seismic Category I or equivalent structure, and that are more than 30 feet above grade.

3.0 Reasonable Protection Evaluation

The following discussion applies to the likelihood that a wind-generated ELAP event will also result in a tornado missile damaging the HCVS such that containment venting through the HCVS is not possible. As noted above, such a wind event must result in failure of all offsite power, all onsite AC emergency power, and then also damage the HCVS such that containment venting is prevented.

> Per Reference 1, large mass tornado missiles, such as an automobile, are not considered credible above an elevation 30 feet above all grade levels near the plant structures (e.g., within 300 yards). Plants must provide a site-specific tornado missile evaluation of any HCVS piping or components that are outside a seismic Category I or equivalent structure if they are less than 30 feet above grade as this white paper does not include evaluation of such piping or components. If a portion of the HCVS is inside a non-missile protected structure and is below 30 feet above grade, that portion should also be evaluated for missile protection similar to any portion that is external to any structure.

3.1 <u>Likelihood of a Wind-Generated ELAP</u>

Following the 2011 Fukushima Daiichi event, numerous studies were performed on the potential for an external-event ELAP. Some of these were supported by previously published evaluations [6] or evaluations already underway such as NUREG/CR-7005 [5] (Comparing high winds for hurricanes and tornadoes). The previous analyses [6, 9, 10] have concluded that a wind-generated ELAP core damage event is unlikely with a probability below 1E-06 events/year (or lower). Wind damaging both offsite power and all safe shutdown equipment is considered unlikely, and on the order of 1E-06/year or lower, depending on the site [6, 9, 10].

Figures 7-1 and 7-2 of NEI 12-06 show the peak wind speed gusts for locations within the United States at 1E-06/year. The bases for the figures are NUREG/CR-7005 [5] and NUREG/CR-4461 [4] respectively, which are used to support RG 1.76 [1]. The contour maps and the supporting analysis show the likelihood of a beyond-design-basis (BDB) wind event is on the order of 1E-06/year or lower for most plants. Coastal plants can see a more likely event from a hurricane, which is discussed below.

A more recent analysis is documented in the ESBWR Design Control Document [Reference 2, NEDO-33201]. The ESBWR analysis looked at the national average frequencies for tornadoes and hurricanes. (Note that older guidance documents refer to the Fujita (F) Scale and newer guidance refers to the Enhanced Fujita (EF) Scale for wind speed ranges based on expected damage; see Table 2.1 in Reference 4) The results of this analysis are summarized as follows:

1) Tornado of EF2/3 is estimated as 9.7E-05/year. This is not expected to affect safe shutdown (SSD) equipment for existing plants, other than offsite power.
2) Tornado of EF4 or above is estimated as 5E-06/year. This could affect SSD equipment for existing plants. Damage to multiple trains of SSD is unlikely.
3) Hurricanes greater than 196 mph wind speeds are considered less likely than the EF4 tornado.

Conservatively assuming for existing BWRs that an EF4 can affect the offsite power and some SSD equipment, the likelihood of a tornado-generated ELAP is shown to be well below 5E-06/year based on generic data used for the ESBWR calculation for the initiating event frequency. Overall, the above is used to arrive at the estimate that the likelihood of a wind-generated ELAP is on the order of 1E-06/ or lower for most plants since the high winds would have to disable offsite power as well as the installed emergency diesel generators. The discussion below will demonstrate that the additional failure of HCVS piping, when needed, will be well below this for plants where the exposed HCVS piping is greater than 30 foot above grade.

3.2 <u>Likelihood of Wind-Generated Missile Damage to HCVS Piping</u>

The likelihood of the HCVS piping more than 30 feet above grade being damaged such that it cannot perform its vent function is evaluated below. In the evaluation, some use is made of risk-informed decision making concepts (using generic estimates and general discussions appropriate for this evaluation):

- The evaluation is per the endorsed reasonable protection evaluation of NEI 12-06, and therefore meets the current regulation.
- The actual protection of the plant from tornados involves multiple trains of safety-related Systems, Structures, and Components, the HCVS is only used when all those have failed.
- The HCVS is only used for BDB Events (BDBE), the calculated safety-margin for the plant is unaffected.
- The plant's calculated Core Damage Frequency (CDF) does not rely on BDBE equipment such as the HCVS In addition, since the HCVS is not an accident initiator and is only used in a very low probability BDBE, any change in CDF that extends to BDBEs would be very small. Additional risk evaluations [13] have likewise shown that the margins between broader metrics related to offsite releases and the NRC's established safety goals are not significantly impacted by assumptions related to the performance of the HCVS.

The tables below illustrate missile-induced failure likelihood (as a function of F-scale tornado) of a 16" diameter pipe 230' long. The missile strike probabilities are taken from the TORMIS Manual [3]. The conditional probability (i.e. conditional upon the tornado strike frequency) of losing functionality of the vent pipe due to a tornado missile impact (assuming it is not designed against missiles) is considered extremely low due to the low probability of the tornado itself and the small overall strike area of the HCVS piping (see below). Calculations for specific plants have shown impact on specific targets (not all ELAP targets) to be on the order of 1E-06 to 1E-07 [11, 12]. This is obtained by multiplying the plant-specific tornado frequency for each tornado classification by the missile strike probability from TORMIS (or a similar computer code).

The strike area of a single generating unit for a wind generated missile is calculated as follows:

- Pipe width ~ 1.3 feet (for the largest expected pipe ~ 16"), assumed the pipe presents a rectangular surface to the wind since it will be attached to the side of a building and thus one side is shielded from missiles.
- Pipe length ~ 230 feet (external to Seismic Cat 1 structures)
- Target Area = ~300 ft^2

Table 3-1

Probability of Failure From Tornado Generated Missiles for F-Scale 2 to 6

Lower Bound Estimate

Component	Target Area (ft^2)	Available Missiles	F Scale	Missile Flux ψ (per missile per ft^2 per tornado)	Missile Strike Probability (per tornado)	Assumed Conditional Probability of Failure	Probability of Component Failure (per tornado)
Exposed Vent Pipe	300	5000	2	5.9E-11	8.9E-05	1	8.9E-05
			3	2.0E-10	3.0E-04	1	3.0E-04
			4	2.3E-10	3.5E-04	1	3.5E-04
			5	8.7E-10	1.3E-03	1	1.3E-03
			6	1.3E-09	2E-03	1	2E-03

Table 3-2

Probability of Failure From Tornado Generated Missiles for F-Scale 2 to 6

Bounding Estimate

Component	Target Area (ft^2)	Available Missiles	F Scale	Missile Flux ψ (per missile per ft^2 per tornado)	Missile Strike Probability (per tornado)	Assumed Conditional Probability of Failure	Probability of Component Failure (per tornado)
Exposed Vent Pipe	300	50000	2	5.9E-11	8.9E-04	1	8.9E-04
			3	2.0E-10	3.0E-03	1	3.0E-03
			4	2.3E-10	3.5E-03	1	3.5E-03
			5	8.7E-10	1.3E-02	1	1/3E-02
			6	1.3E-09	2E-02	1	2E-02

The above table does not account for other factors discussed below, including the lower probability of being damaged when the piping is located 30 feet above the ground. The conditional failure probability of the vent during the most severe tornado (F6 tornado) is equal to or lower than the reasonably expected or base failure rate of the vent function. In other words, the failure rate of the vent due to mechanical issues, power issues, or operator action failure probabilities associated with the vent is equal to or higher than the failure rate of losing the non- protected vent during a severe tornado. This is a very conservative evaluation given the assumed failure probability of 1 due to a missile strike. Given the HCVS piping is typically being built from robust piping, the piping will withstand many of the missile strikes predicted, including those from smaller objects (a larger percentage of the estimated site missiles listed above) or at low velocity. Therefore, providing additional missile protection for the subject portions of the HCVS system 30-feet above grade would not significantly improve the reliability or availability of the venting function for dealing with external events.

The above calculation with respect to target area demonstrates the small probability that HCVS piping will be struck by a missile generated by the same wind event that disabled all offsite and onsite AC emergency power. By including an assumed failure probability of 1 in the calculation, any strike is assumed to result in failure. However, any missile also has the possibility of striking the HCVS piping or

component in a manner that does not result in failure of the vent function. This could be a glancing blow that does not significantly damage the HCVS, or could be a direct normal hit that severs the HCVS piping. In both of these scenarios, the HCVS function would be retained. Therefore, the actual failure probability associated with a single missile strike is considerably less than 1.

Note that the calculation of Table 3-1 does not include any specific sources for the tornado-borne missiles. Rather, the TORMIS spectrum includes missiles of all sources and therefore would include such items as roof ventilation components, staged equipment or spare components stored in the plant environs.

The above calculation is applicable to any rugged component associated with the HCVS, including the piping, hangers and an installed check valve. However, components more easily damaged, such as components using instrument tubing, may be damaged by small missiles or even the wind event itself. As such, these non-rugged components are not part of the evaluation in this white paper.

3.3 <u>Damage to components above 30 feet</u>

The spectrum of potential missiles that may be generated during a tornado are listed in RG 1.76, Table 2 [1]. Tables 3-1 and 3-2 above provide a lower and upper bound estimate for missile strikes for missiles of all sizes. But above 30 feet, a strike by heavier missiles is less likely. Smaller object strikes would be more common, but would not be expected to damage HCVS piping due to their low mass. A strike from an automobile or similar large object in or around the nuclear power plant site would be the most likely wind-generated missile to damage the HCVS piping. However, and as discussed above, most HCVS piping exits missile-protecting structures above 30 feet from the ground. The RG 1.76[1] evaluation of automobile-like missiles concludes that such a large missile is not considered to strike at elevations above 30 feet.

Automobiles are the most damaging type of missile we would typically expect at a site, but is not postulated to damage HCVS piping which exits existing site structures above 30 feet above all grade levels near the plant structures. RG 1.76 [1] only requires consideration of such large kinetic energy missiles for targets at elevations less than 30 feet.

The Reactor Building (RB) and other surrounding buildings may generate missiles from damaged sheet metal siding. Such siding is typical in BWR RB designs from the refueling floor level and above. These sheet metal panels are also typically designed to blow out in a tornado, as such are a likely missile, and therefore are evaluated herein separately. The sheet metal is typically assumed to be 4 ft. x 8 ft., 100 pounds [8], although heavier sheet metal is possible. Damage to HCVS piping can be calculated to occur using standard damage approaches [7], but only if the sheet metal strikes the piping normal to the pipe (directly on edge) with the sheet metal at or near 225 mph. However, sheet metal, when carried by wind, will most likely travel oriented perpendicular to the wind and strike a target with a glancing blow versus normal. Even a few degrees off normal will cause the sheet metal to glance off the HCVS pipe. Per [7], a less rigid missile such as sheet metal will crumple upon impact, rather than transfer significant energy to the HCVS component. And as has been stated, a more rigid missile, without striking the pipe directly at its centerline, would tend to glance off the pipe expending much less energy (from its own momentum) upon impact. Given the low probability of the sheet metal becoming a missile, accelerating

to sufficient speed in a short distance, remaining 30 feet above ground, remaining rigid, and striking the HCVS piping on edge, this sheet metal missile is not considered likely to damage the HCVS piping. Likewise, the sheet metal alone does not serve as an effective barrier for tornado protection and therefore any portions of the HVAC with only sheet metal between it and the outside environment should be treated as exposed.

3.4 Overall Likelihood of Damage due to a Tornado Missile

When the consideration for the size/mass of the missile likely to impact the HCVS piping greater than 30 feet above grade is combined with the missile strike probabilities in tables 3-1 and 3-2, it can be concluded that damage that would disable the vent function to a 300 ft^2 target from missiles is unlikely. Overall, the frequency of the HCVS piping located 30 feet above grade being damaged by a tornado-generated missile is likely to be significantly below the Tables 3-1 and 3-2 estimates above when accounting for the tornado frequencies.

3.5 Wind-Generated Missiles from Hurricanes

Wind-generated missiles from hurricanes are also possible and may result in ELAP events on the order of a tornado-generated ELAP discussed in 3.1 above for some coastal plants. However, due to the long time for preparation, a plant facing a large hurricane will likely shut down and prepare for a possible ELAP event using established weather-related procedures before the hurricane arrives. Preparation would also involve advanced staging to minimize the possible effects of an ELAP resulting from a hurricane. Site-specific guidance may include, for example, that if high winds, hurricane, or tornado activity is forecasted for the site or likely to occur, then walk-downs of the site would be performed to identify items and take action to reduce the potential threat of projectiles in high wind situations. As a result, a hurricane-generated ELAP event is considered much less likely than a tornado-generated ELAP event and even less likely is the potential need for containment venting to support decay heat removal or protection of the primary containment given the preparation time available for hurricanes. However, staging in preparation for a tornado is considered unlikely.

Based on this discussion, the most likely missile-initiated ELAP is from a tornado event.

3.6 Site Specific Considerations

As discussed in NEI 12-06 and above, considerations for location direction of the wind or tornado, and physical separation of the offsite power, safe shutdown equipment, and mitigation equipment should be included in any site-specific use of the results of this white paper. For the HCVS, this would include a qualitative consideration of the location and orientation of the HCVS piping to the equipment discussed above.

Additionally, site specific grading and elevations should be considered for potential impact to the HCVS. For example, for a site with potential missiles located above the site grade (e.g., hill side next to the site containing potential missiles such as automobiles, structures, equipment, or other unsecured objects), a

tornado-generated missile above 30 feet above grade is more likely. Additional protection or means to limit missile generation (such as prohibit material staging when high wind events are more likely) may be warranted in that case.

Site-specific arguments may be used above those provided in this evaluation. The following are examples of such site-specific considerations: the location of the HCVS piping in comparison to the offsite power and EDGs, HCVS protection from the Reactor Building (RB) or surrounding buildings, the angle that would be required in order to strike the HCVS piping, the ability of the HCVS piping to survive most missile strikes, location of surrounding grade (discussed above) or other factors.

In addition to the small strike area associated with the exposed HCVS components relative to the overall site area, HCVS components may be afforded some protection from wind-borne missiles by site structures. For example, a vent pipe routed external to the RB, is protected from missiles coming from the direction of the RB. This is true even if the intervening structure is not a missile-resistant structure because any structure can serve to deflect or otherwise slow missiles such that they have a lower likelihood of damaging the HCVS components. The protection afforded by intervening structures is in addition to the low probability of the missile strike calculated in section 3.2 and further reduces the risk below that calculated in section 3.2.

Site-specific arguments related to plant configurations, protection from adjacent structures, changes to plant procedures, surrounding grades and other factors not bounded by the generic evaluation in this paper should be provided in the overall integrated plans for the design, installation, and maintenance of the HCVS.

4.0 Conclusions

Based on the above information, it may be concluded that the HCVS is unlikely to be damaged in a manner that prevents containment venting by a wind-generated missile from the same wind event that generates an ELAP or LUHS. For those plants with HCVS systems enveloped by the assumptions in the generic evaluation in Section 3, reference to this paper in their overall integrated plan is sufficient to address the issue of wind-borne missiles for Order EA-13-109 and the containment venting functions of Order EA-12-049. For plants with HCVS systems not bounded by the generic evaluation in Section 3, the overall integrated plans should provide additional discussion for the affected portions of the HCVS system and describe either the protection provided against wind-borne missiles or an evaluation of why such protection is not needed.

5.0 References

1) RG 1.76, Revision 1, US NRC, Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants, March 2007
2) NEDO-33201 Rev 2, Section 14, GE Hitachi Nuclear Energy, ESBWR High Winds Risk.
3) TORMIS Manual, Prepared by Carolina Power and Light for the Electric Power Research Institute, EPRI, NP-768, May 1978
4) NUREG/CR-4461, US NRC, “Tornado Climatology of the Contiguous United States, February 2007

5) NUREG/CR-7005, US NRC, “Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants,” November 2011.
6) NUREG-1150, US NRC, “Severe Accident Risks: An assessment for Five U.S. Nuclear Power Plants,” December 1990.
7) BC-TOP-9A, Bechtel Topical Report Design of Structures for Missile Impact, Revision 2, September 1974, ML14093A217.
8) Updated FSAR, Brunswick Steam Electric Plant Units 1 and 2, Revision. 24
9) NUREG/CR-7110-1 “State-of-the-Art Reactor Consequence Analyses Project, Volume 1: Peach Bottom Integrated Analysis.” U.S. Nuclear Regulatory Commission, Washington, DC. 2012
10) NUREG/CR-7110-2 “State-of-the-Art Reactor Consequence Analyses Project, Volume 2: Surry Integrated Analysis.” U.S. Nuclear Regulatory Commission, Washington, DC. 2012.
11) DC Cook, License Amendment Request to Permit Use of PRA Techniques to Evaluate the Need for Tornado-Generated Missile Barriers, June 8, 2000.
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13) EPRI Technical Report 3002003301, “Technical Basis for Severe-Accident Mitigating Strategies.”