NEI 13-02 [Rev. 0]

INDUSTRY GUIDANCE FOR COMPLIANCE WITH ORDER EA-13-109

BWR Mark I & II Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions

November 2013

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Nuclear Energy Institute

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1. INTRODUCTION

The nuclear energy industry and the NRC share a common challenge of ensuring prevention and mitigation strategies are available to maintain safety in the face of unlikely and extreme events. An approach that focuses on diverse and flexible mitigation capability will provide additional defense-in-depth safety enhancement against a range of extreme events, some of which cannot be forecasted.

The importance of reliable operation of hardened vents during conditions involving loss of active containment heat removal has been reinforced by the lessons learned from the accident at Fukushima Dai-ichi. Hardened vents have been in place in U.S. plants with BWR Mark I containments for many years but design variances exist across the industry with regard to the capability of the vents for a broad spectrum of events. Generally, BWR Mark II containments do not currently have hardened vent paths. The NTTF 90-day report [Ref. 6] indicated hardened vent designs that were AC independent to operate with limited operator actions from the control room are necessary. Therefore, Order EA-12-050 [Ref. 2] required hardened containment venting systems in BWR facilities with Mark I and Mark II containments on the basis that they are needed to provide reasonable assurance of adequate protection of public health and safety.

Subsequently the original Order was rescinded and replaced with a new order to require a severe accident capable containment vent on the basis that it provides a cost-justified substantial safety improvement beyond what is needed to provide reasonable assurance of adequate protection of public health and safety. Order EA-13-109 [Ref. 1] was issued to expand the set of design and quality requirements originally imposed by EA-12-050 to ensure that venting functions are available during postulated severe accident conditions. Because EA-12-050 has been rescinded and its requirements are now reflected in Order EA-13-109, licensees are no longer expected to comply with the requirements of Order EA-12-050, including any applicable time lines for submission of integrated plans, or for completion dates for implementation.

The severe accident Hardened Containment Venting System (HCVS) Order contains historical information and decision making insights in sections I, II and III that provide useful information, but do not contain the legally binding actions which licensees are required to comply with, which are in sections IV and Attachment 2.

1.1 Purpose

The purpose of this guidance is to assist nuclear power reactor licensees with the identification of measures needed to comply with the requirements of Order EA-13-109, “Order Modifying Licenses with Regard to Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions” [Ref. 1]. This guidance provides an acceptable method for satisfying those requirements; however, licensees may propose other methods for satisfying these requirements.

Incorporation of the lessons learned from the March 11, 2011 Fukushima Dai-ichi Accident is a key element in the foundation of requirements and guidance associated with the scope of work required in response to Order EA-13-109, which is prefaced by the following statement:

> *"The events at the Fukushima Dai-ichi nuclear power plant following the March 2011 earthquake and tsunami highlight the possibility that events such as rare natural phenomena could challenge the traditional defense-in-depth protections related to preventing accidents, mitigating accidents to prevent the release of radioactive materials, and taking actions to protect the public should a release occur. At Fukushima Dai-ichi, limitations in time and unpredictable conditions associated with the accident significantly hindered attempts by the operators to prevent core damage and containment failure. In particular, the operators were unable to successfully operate the containment venting system. These problems, with venting the containments under the challenging conditions following the tsunami, contributed to the progression of the accident from inadequate cooling of the core leading to core damage, to compromising containment functions from overpressure and over-temperature conditions, and to the hydrogen explosions that destroyed the reactor buildings (secondary containments) of three of the Fukushima Dai-ichi units. …The events at Fukushima reinforced the importance of reliable operation of hardened containment vents during emergency conditions, particularly for smaller containments such as the Mark I and Mark II designs …"*

To address this event with the rest of the nuclear industry, there are many regulatory and industry recommendations and changes to be considered. Many of these are documented in the following:

- NRC Near Term Task Force 90 Day Report, [Ref. 6]
- NRC SRM/SECY 11-0124 - Recommended Actions to be taken Without Delay From The Near-Term Task Force Report, [Ref. 7]
- NRC – SRM/SECY 11-0137 - Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned, [Ref. 8]

The primary objectives of the industry response scope of work derived from these documents resulted in NEI 12-06, revision 0, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide [Ref. 20], for implementation of NRC Order EA-12-049, Mitigation Strategies for Beyond-Design-Basis External Events (FLEX), [Ref. 4. Many of these cornerstones will be utilized in this guidance document for addressing NRC Order EA-13-109 even though they did not originally extend to venting capabilities under severe accident conditions.

The industry is committed to continuous improvement of nuclear safety. Some applicable continuous improvement work items from lessons learned from the Fukushima Daiichi event are listed below:

a) Confirm or establish effective coping measures to address the vulnerability of onsite and offsite AC power systems to common mode failures resulting from external and internal events, including beyond design basis events.

b) Confirm the external events that formed the basis for plant designs exceed credible hazards based on historical data and current models (floods, high winds, seismic events, etc.) or revise the design bases and change the plants, as necessary to accomplish the revised design bases.

c) Confirm or establish effective primary containment protective strategies that can manage post-accident conditions, including such factors as elevated pressures and hydrogen generation from fuel damage more extensive than original design bases, including use of hardened venting, etc. as appropriate.

d) Confirm or establish effective integrated strategies to provide for system based response for events and/or severe accidents involving multiple reactors at a site (i.e., integrate Emergency Operating Procedures (EOPs), Severe Accident Management Guidelines (SAMGs), Abnormal Operating Instructions (AOIs), Extreme Damage Mitigation Guidelines (EDMGs), etc.).

e) Provide for support during extended emergencies involving infrastructure loss, including fuel supplies, coordination of offsite resources, communications, near site living requirements and transportation, etc.

f) Share and participate with other stakeholders to co-develop responses, improve acceptance and consensus, and minimize development costs.

g) Establish Regional Response Centers (RRC) with multiple sets of site response equipment and long term coping equipment for preventing fuel damage from an Extended Loss of AC Power (ELAP) event.

1.2 HCVS Guiding Principles

Hardened vents have been in place in U.S. plants with BWR Mark I containments for many years but a variance exists with regard to the capability of the vents for a broad spectrum of events. BWR Mark II containments have containment venting capability but they typically are not hardened vent paths. Therefore, hardened containment venting systems in BWR facilities with Mark I and Mark II containments were required by the NRC (Order EA-12-050) on the basis that they are needed to enhance protection of public health and safety.

On June 6, 2013, the US NRC rescinded Order EA-12-050 and issued a new order, EA-13-109, expanding the requirements of the original order to include requirements for the reliable hardened vent to be capable of operation during severe accident conditions. The new order is applicable to all operating BWR licensees with Mark I and Mark II containments issued under Title 10 of the Code of Federal Regulations (10 CFR), Part 50, “Domestic Licensing of Production and Utilization Facilities.”

The original Order EA-12-050 required that all boiling water reactor (BWR) Mark I and Mark II containments have a reliable hardened vent to remove decay heat from the containment and maintain containment pressure within acceptable limits following events that result in the loss of active containment heat removal capability or prolonged station blackout (SBO), i.e., Extended Loss of AC Power (ELAP). The original order did not include requirements relating to severe accident service for the hardened containment venting system (HCVS); rather, the HCVS was only required to be able to support strategies related to the prevention of core damage under a wide range of plant conditions. JLD-ISG-2012-02, "Compliance with Order EA-12-050, Reliable Hardened Containment Vents" [Ref. 5] provided the Interim Staff Guidance (ISG) for implementation of Order EA-12-050.

All licensees subject to Order EA-12-050 provided integrated plans for the design and implementation of reliable hardened containment vents by February 28, 2013. In SRM-SECY-12-0157, "Staff Requirements - SECY-12-0157, "Consideration Of Additional Requirements For Containment Venting Systems For Boiling Water Reactors With Mark I And Mark II Containments" [Ref. 3], the Commissioners directed the staff to revise Order EA-12-050 to require the upgrade or replacement of the reliable hardened vents required by Order EA-12-050, with a containment venting system designed and installed to remain functional during severe accident conditions.

EA-13-109 requires that BWRs with Mark I or Mark II containments ensure that in addition to pre-core damage venting capability, the HCVS also provides a reliable hardened venting capability from the wetwell and drywell under severe accident conditions, including those involving a breach of the reactor vessel by molten core debris. However, EA-13-109 also allows a reliable containment venting strategy that makes it unlikely that a licensee would need to vent from the containment drywell as an acceptable alternate to the drywell vent. The severe accident capable HCVS is intended to keep the originally required function of the HCVS, which is to help prevent severe accidents from occurring, and to add the capability of operating during a severe accident conditions. The wetwell and drywell vent pathways are not required to be in operation at the same time.

The development and implementation of the severe accident capable HCVS consists of two phases. The first phase consists of providing a venting system from the containment wetwell that meets the functional, quality, and programmatic requirements listed in subsequent sections of this guide. The second phase is associated with capabilities to vent from the drywell during severe accident conditions and involves either installing a venting system or developing a reliable strategy to limit the possible need to vent from the containment drywell during severe accident conditions. Thus the wetwell and drywell vent pathways will not be required to be installed concurrently. Appendix C outlines the methodology licensees may use to evaluate the alternate containment venting strategy to a drywell vent path.

1.3 Procedure Interface

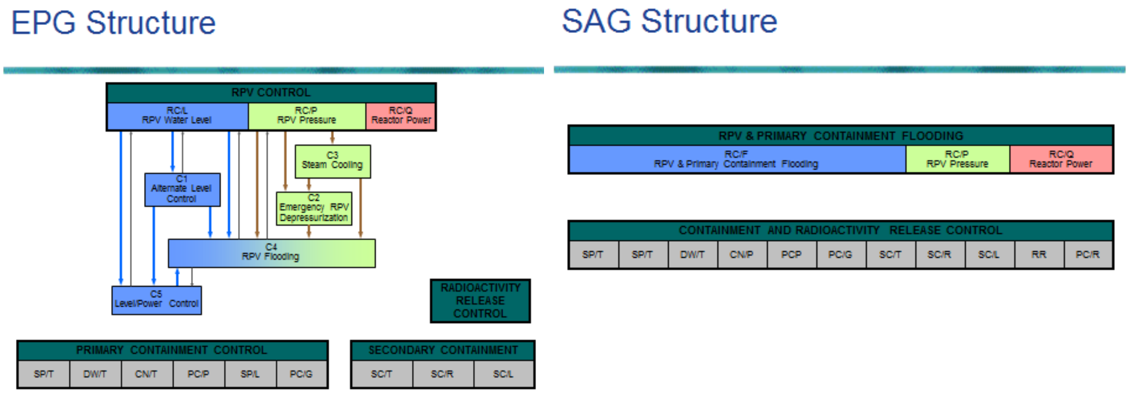
This section is intended to provide information on the accident management features of the suite of procedures needed to respond to symptoms present in a Beyond Design Basis Event (BDBE). Inclusion of this information does not intend to provide any express or implied endorsement of Emergency Procedure Guidelines/Severe Accident Guidelines (EPG/SAG) or other details presented in this section. If any conflicts arise between the discussion in this section and the criteria stated in Order EA-13-109, then the criteria in the Order takes precedence over the direction in EPGs/SAGs.

Command and Control for accident response is governed by the suite of Emergency Preparedness guidelines and procedures. Containment heat removal and pressure control functions are, and have always been, manually initiated at BWR facilities. Therefore, the use of procedures to direct the use of installed systems has existed well before the development of either order. The HCVS is also initiated manually and therefore requires procedural direction to initiate venting for containment heat removal and containment pressure control.

Use of the HCVS is governed by the plant specific Emergency Operating Procedures (EOPs), severe accident management guidelines (SAMGs), and Emergency Preparedness procedures. The EOPs provide direction, based on symptomatic containment conditions, to initiate use of installed vent paths from containment to assure adequate core cooling has been maintained for prevention of fuel damage. The SAMGs provide direction for use of hardened vents for the purpose of containment pressure control after adequate core cooling has been lost.

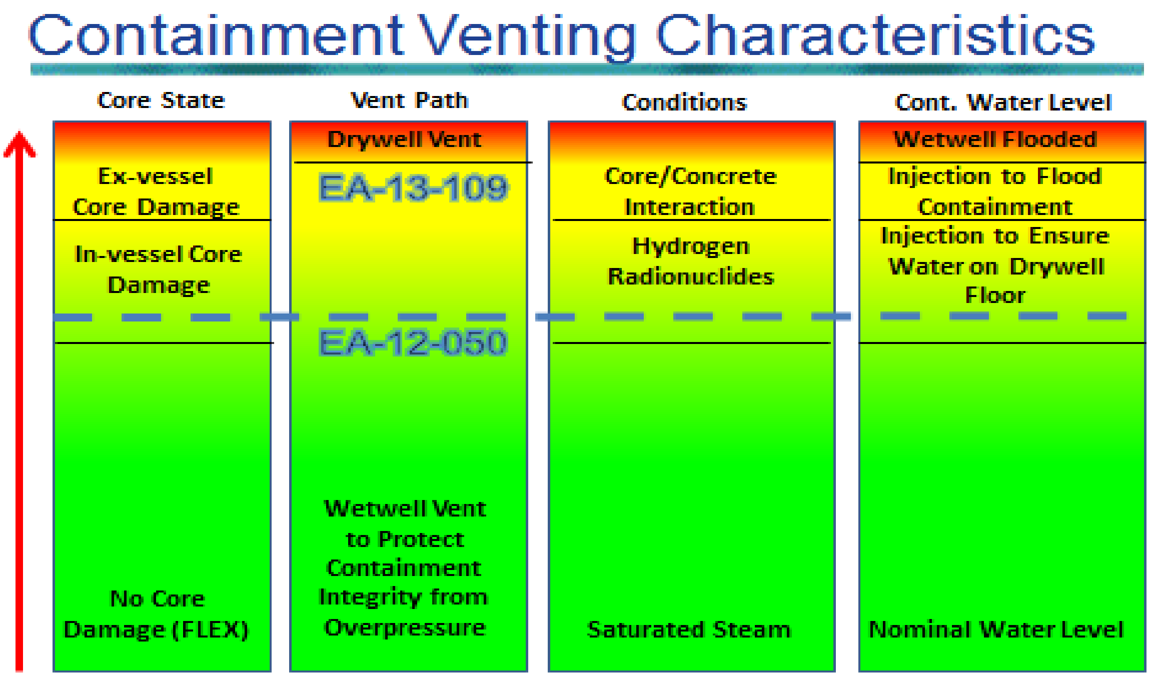
HCVS reliability does not only depend upon the design of the HCVS, but also the procedural guidance directing use based on containment parameters. The importance of reliable operation of hardened vents during conditions involving loss of containment heat removal capability is well established and this understanding has been reinforced by the lessons learned from the accident at Fukushima Dai-ichi. Understanding the procedural interface and direction in determining HCVS design criteria is essential

The plant specific procedures are based upon the Boiling-Water Reactor Owners Group BWROG generic Emergency Procedure Guidelines/Severe Accident Guidelines (EPGs/SAGs), whose organizational structure is diagramed below:



Utilities currently have implemented Revision 2 of the EPG/SAGs, but Revision 3 has been published and includes the lessons learned from Fukushima Dai-ichi.

The BWROG standard emergency procedure guidelines and severe accident guides (EPG/SAGs) (Revision 2 and 3) both provide direction for BWR Mark I and II plants to leave EPG/SAGs flowcharts (into recovery actions) at any point where adequate containment heat removal methods are in effect as on the following illustration of containment venting characteristics (i.e., they are not predisposed to have to use drywell venting.)



Containment Venting Characteristics

Core State	Vent Path	Conditions	Cont. Water Level
	Drywell Vent		Wetwell Flooded
Ex-vessel Core Damage	EA-13-109	Core/Concrete Interaction	Injection to Flood Containment
In-vessel Core Damage		Hydrogen Radionuclides	Injection to Ensure Water on Drywell Floor
No Core Damage (FLEX)	EA-12-050 Wetwell Vent to Protect Containment Integrity from Overpressure	Saturated Steam	Nominal Water Level

Revision 3 of the EPG/SAGs enhanced the flow of information from revision 2 using lessons learned from the Fukushima event. The information presented is representative of the structure in Revision 3.

From the plant specific EOPs developed from the EPGs, use of a hardened vent is directed:

- before primary containment pressure reaches the primary containment overpressure limit defined by the Primary Containment Pressure Limit (PCPL),
- if lower containment pressure is necessary to provide RPV injection; if suppression pool approaches saturation conditions and can no longer effectively condense steam discharged from RCIC; or
- to limit total offsite dose by venting steam prior to experiencing fuel damage.

From the plant specific SAMGS developed from the SAGs, use of a hardened vent is directed:

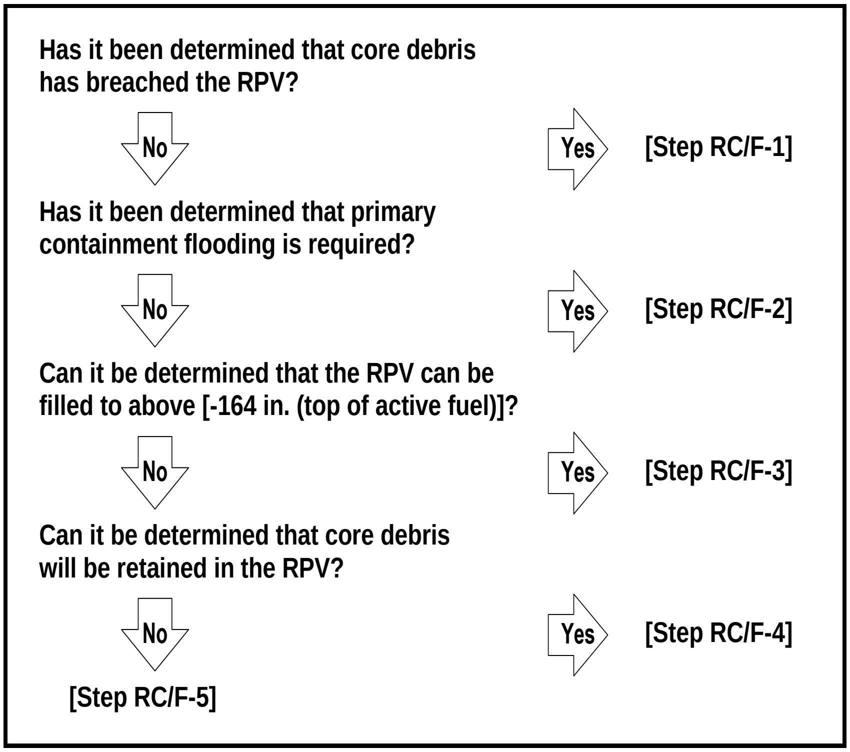
- Before primary containment pressure reaches the primary containment overpressure condition defined by (PCPL);
- To facilitate RPV injection or containment injection; or
- To remove combustible gases from primary and secondary containment.

Containment venting per the procedures and guidelines should be coordinated with evacuation procedures and timed to take advantage of favorable meteorological conditions. It should be coordinated to take advantage of suppression pool scrubbing as much as possible.

For venting using EOPs the wetwell vent is expected to be used to protect containment and will be venting mostly saturated steam, while Primary Containment Water level and pressure will be maintained to preserve the Pressure Suppression Capability of the Containment. This could include venting to protect steam driven systems being used to provide adequate core cooling or to limit the total offsite dose if it is expected that fuel damage may occur.

Once fuel damage occurs and transfer to plant specific SAMGs is made, containment venting will depend on other plant conditions. Only two steps in plant specific SAMGs require containment flooding, steps RC/F-1 and RC/F-2. The remaining steps seek to maintain Pressure Suppression Capability (which means suppression pool water is maintained in an extended range but not flooding containment). Containment venting could be used to restore Pressure Suppression Capability by lowering containment pressure. The SAMGS do not mandate Drywell venting for all conditions.

The following graphic shows the SAMG decision block and briefly describes the conditions each step implements:



RC/F-1 RPV breached. Submerge debris and flood containment.

RC/F-2 Pressure Suppression Capability not maintained or Primary system break. Cool debris and flood containment.

RC/F-3 Re-flood RPV above TAF. Maintain Pressure Suppression Capability.

RC/F-4 Debris expected to remain in RPV. Cool debris and maintain Pressure Suppression Capability.

RC/F-5 Debris may melt through RPV. Containment may fail. Maximize RPV injection. Maintain Pressure Suppression Capability.

To summarize, containment venting is addressed in plant specific EOPs for prevention of core damage. After core damage cannot be prevented, plant specific SAMGs address mitigation of core damage. The basis for these actions is documented in the BWROG EPG/SAG Rev. 3 Appendix B, Technical Basis, and the Technical Support Guidelines, Rev. 0. Hardened containment vent designs should include a review of any pending procedure changes that could influence the design, such as the EPG/SAG Revision 3 directions for use of containment vents.

1.4 Overview

This industry guidance has been developed to provide an integrated set of considerations for the design and implementation of a severe accident capable hardened containment venting system (HCVS). This guidance is organized in the following manner:

Section 2: Description of the Wetwell boundary conditions to be applied to the design of HCVS including the applicable severe accident conditions, the design boundary conditions and operational assumptions, and the role of mitigation strategy capabilities implemented under EA-12-049 “Order Modifying Licenses with Regard to Requirements For Mitigation Strategies For Beyond-Design-Basis External Events,” [Ref. 4]

Section 3: Description of the Drywell boundary conditions to be applied to the design of HCVS including the applicable severe accident conditions, the design boundary conditions and operational assumptions.

Section 4: Guidance on the design considerations for the HCVS including vent path design, vent operation and monitoring, support systems for sustained operations, protection from flammable gas ignition, other design requirements such as environmental qualification, seismic and external hazard design and quality requirements.

Section 5: Guidance on meeting the programmatic requirements associated with the order.

Section 6: Guidance on the operational considerations for the HCVS including procedural guidance and training related to the operator actions required for use of the HCVS and the testing and inspection of the HCVS and associated components. Operations consideration for the HCVS including environmental considerations, procedures, allowed out of service time, and testing.

Section 7: Template for Overall Integrated Plan Submittal and six month status updates

Section 8: References

Appendices: Appendices are provided to elaborate on specific aspects of the guidance including a glossary of key terms, a cross-reference roadmap of order requirements, assessment of need for a dry well vent, FLEX interfaces, generic letter 89-16 interfaces, methods for defining plant-specific severe accident operator doses and source terms, and design approaches to address control of flammable gases.

Licensees may propose other methods for satisfying the requirements of Order EA-13-109. The NRC staff can review such methods and determine their acceptability on a case-by-case basis.

2. WET WELL VENT BOUNDARY CONDITIONS FOR VENT DESIGN AND OPERATION

Boiling-Water Reactors (BWRs) with Mark I and Mark II containments shall have a reliable, severe accident capable hardened containment venting system (HCVS). The HCVS includes a severe accident capable wetwell venting system, and may also, depending on the approach taken for Phase 2 of Order EA-13-109, include a severe accident capable drywell venting system. Because the implementation can be in two phases, and the fact that the containment conditions that exist at the initiation of venting from the wetwell and drywell may be different, this document separates the boundary conditions for design and operation between wetwell and drywell into two separate sections. Boundary conditions used in design of HCVS shared components, instrumentation and piping is included in this Section and in Section 4.1.

Under Phase 1 of Order EA-13-109, Licensees with BWR Mark I and Mark II containments shall design and install a HCVS, using a vent path from the wetwell to remove decay heat, vent the containment atmosphere (including steam, hydrogen, carbon monoxide, non-condensable gases, aerosols, and fission products), and control containment pressure within acceptable limits. The HCVS shall be designed for those accident conditions (before and after core damage) for which containment venting is relied upon to reduce the probability of containment failure, including accident sequences that result in the loss of active containment heat removal capability during an extended loss of alternating current (AC) power (ELAP). The HCVS shall meet the requirements of Sections 4, 5, and 6 of this document.

Under Phase 2 of Order EA-13-109, Licensees with BWR Mark I and Mark II containments shall either, (1) design and install a HCVS, using a vent path from the containment drywell, that meet the requirements in Sections 3 through 6 or, (2) develop and implement a reliable containment pressure control and cooling strategy using the guidance provided in Appendix C of this document that demonstrates it is unlikely that a licensee would need to vent from the containment drywell before alternate reliable containment heat removal and pressure control is reestablished to meet the requirements in Section B.2 of the Order. [This revision of NEI 13-02 provides guidance information for Phase 1 and overview information for Phase 2.]

The requirements of Order EA-12-050 addressed the use of the HCVS for both prevention of core damage and protection of the containment from overpressure failure during a Beyond Design Basis Event (BDBE) that do not progress to core damage and severe accident conditions. Unlike conditions resulting from postulated plant events, severe accidents, by their very nature, are an effectively unbounded class of events. Although reactors licensed under 10CFR52 have certain regulatory requirements related to severe accident capabilities, the extension of regulatory requirements to design features required for severe accident conditions is unique for existing reactors licensed under Part 50. This unique aspect of Order EA-13-109 calls for very clear definition of the boundary conditions to be applied to the design and operational considerations required to implement the HCVS. The purpose of this section is to clearly outline these boundary conditions and the key terms used in relation to the conditions associated with a severe accident capable vent.

Two key functional aspects of the HCVS involve the prevention of containment over-pressurization for events that do not result in core damage and for events where severe accident conditions exist.

A key guiding principle regarding the design of the HCVS is defining conditions that are consistent with the capability of the containment to withstand severe accidents. This document will define the design parameters of the HCVS equipment, including that of a drywell vent, with the understanding that the HCVS design parameters should provide margin to meet the EA-13-109 order language of "The design is not required to exceed the current capability of the limiting containment components".

2.1. Wetwell HCVS Use for Design Basis

Use of the HCVS during design basis accident or other events (DBE) is not assumed nor required.

2.2. Wetwell HCVS Use for Beyond Design Basis External Events (BDBEEs)

A spectrum of Beyond Design Basis Events (BDBE) or Beyond Design Basis External Events (BDBEE) may be postulated; however, in the context of the HCVS, the design and operation in response to such events is not intended to be constrained to a specific set of scenarios or timelines. Rather, the considerations for the HCVS are defined to provide a broad functional capability for the prevention of containment over-pressurization prior to core damage and mitigation of containment over-pressure conditions that may exist after core damage.

2.2.1. BDBE are events that involve assumptions and failures that exceed those associated with DBEs but may not be considered severe accidents.

2.2.2. Certain beyond design basis events such as an extended loss of AC power (ELAP) can result in the loss of active containment heat removal capability.

2.2.2.1. Plant actions to address an ELAP are contained in the plants response to NRC Order EA-12-049, commonly referred to as FLEX. An ELAP itself is not considered a severe accident since use of FLEX prevents core damage. However, if ELAP is not mitigated a severe accident with core damage and vessel breach may evolve.

2.2.3. The primary design objective of the HCVS is to provide sufficient venting capacity to prevent a long-term overpressure failure of the containment by restoration and maintenance of containment pressure below the primary containment design pressure and the primary containment pressure limit (PCPL).

2.2.4. The HCVS venting pressure for a BDBE may be driven by conditions created during BDBEs, such as to lower pressure to use a low pressure portable pump or to control containment conditions to allow continued use of installed equipment such as installed steam-driven equipment that discharges to the Suppression Pool/Torus during loss of containment cooling and may be using the suppression pool as a water source and thus also the cooling medium for pump components.

2.3. Wetwell HCVS Use during Applicable Severe Accident Conditions

The primary severe accident use of the HCVS is to protect the containment from over-pressure failure caused by the increase in containment pressure from steam, non-condensable gases, and elevated containment temperature following severe core damage. For the purposes of this order, the severe accident is caused by loss of active containment heat removal capability or failure to mitigate an ELAP. The conditions include both scenarios in which all core debris is cooled in-vessel (similar to the accident at TMI-2) and scenarios in which core debris breaches the reactor coolant boundary and relocates into containment, with some of the core debris remaining within the reactor vessel. Increased temperature resulting from severe accidents may impact the pressure retention capability of containment penetration seals, particularly the drywell head gasket. The performance of the HCVS in response to a severe accident is intended to minimize, as far as reasonably practicable, uncontrolled releases of radionuclides and combustible gases to the environment external to the containment by preventing containment over-pressure failure.

The HCVS would also be used as an element of the Plant procedures to maintain the Pressure Suppression Pressure function of the containment prior to RPV breach by controlling suppression pool/torus pressure and level. Additionally, venting of non-condensable gases from containment can reduce the challenge to containment integrity from stratified gas temperature effects on the drywell head gasket.

2.3.1. Realistic assumptions (i.e. not bounding) may be used to determine the initial conditions for design of the HCVS, e.g., Suppression Pool initial temperature, DW initial temperature, use of heat sinks in analysis models. These initial condition assumptions are consistent with the starting point for order EA-12-049, in response to an ELAP.

2.4. Wetwell Vent Design Boundary Conditions

The potential scope of possible severe accident conditions is essentially unbounded. In some scenarios, severe accident containment conditions can compromise containment integrity for reasons other than over-pressurization, (e.g., drywell shell melt-through in Mark Is, extremely high temperature effects on drywell head seal leakage or other postulated containment failure modes). The unbounded nature of severe accident conditions calls for a more reasonable design philosophy; the HCVS capability should exceed the current capability of the limiting containment components or meet the conditions under which it is required to operate. Four primary parameters are defined for use in defining the HCVS component capability; Pressure, Temperature, Radiation and Hydrogen/CO Concentration.

Order Reference: 1.2.10 – The HCVS shall be designed to withstand and remain functional during severe accident conditions, including containment pressure, temperature, and radiation while venting steam, hydrogen, and other non-condensable gases and aerosols. The design is not required to exceed the current capability of the limiting containment components.

2.4.1. Depending on the HCVS design, the HCVS may have three distinct portions.

2.4.1.1. a portion that only supports wetwell venting,

2.4.1.2. a portion that only supports drywell venting, and

2.4.1.3. a portion that is shared by both.

2.4.1.3.1. The drywell generally has the most limiting boundary conditions, so the drywell boundary condition parameters described below are recommended for the shared portions of the HCVS.

2.4.2. The use of the HCVS is provided in Industry Guidance and adopted on a plant-specific basis through the use of flowcharts and procedures.

2.4.2.1. In the plant procedures, the highest pressure used for venting to control (restore and maintain) pressure is based on the plant-specific Primary Containment Pressure Limit (PCPL).

2.4.2.1.1. When designated herein, the most bounding PCPL for design of components is PCPL-C, which is based on the pressure capability of containment.

2.4.2.1.2. PCPL(-C) is selected as the boundary condition for the design pressure of the HCVS components, instrumentation and piping. It is expected that the capability of HCVS components and piping will be greater than the design boundary conditions.

2.4.3. During a severe accident, temperature of gases in the wetwell and drywell will differ due to insufficient removal of decay heat from fission products resulting in superheat or non-saturated conditions in the drywell.

2.4.3.1. The suppression pool/wetwell of a BWR Mark I/II containment can be considered to be in a saturated condition.

2.4.3.2. The plant-specific PCPL determination provides a temperature range for the suppression pool of 70ºF to 350ºF.

2.4.3.3. Therefore, the design temperature for the wetwell vent portions of the HCVS are recommended to be based on the 350ºF upper bound of the EPG/SAG bases document which is above the saturation temperature corresponding to typical PCPL values.

2.4.4. For the drywell, the plant-specific PCPL is within a drywell temperature range of 100ºF - 545ºF.

2.4.4.1. The PCPL and 545ºF, is recommended as the design pressure and temperature for the drywell vent system and any common and shared portions of the vent line. For portions of the vent line past the 1st primary containment isolation valve (PCIV) an auditable analysis may justify lower values. (This guidance is providing design pressure and temperature for the drywell vent system to address the possibility that the wetwell vent system associated with Phase I may share piping and components with the drywell vent portion associated with Phase 2. Although the drywell vent system will be addressed under Phase 2. Licensees should consider the impact of the selected design conditions on other performance and operating aspects that may be required of the drywell vent system during the Phase 2 analysis and evaluations, as further discussed below.)

2.4.4.1.1. The postulated boundary of severe accident conditions could exceed the recommended design envelope of the drywell vent as evidenced by the Fukushima events and supported by various studies prior to Fukushima. In that event, the HCVS should have the capability to continue to perform its function at more extreme conditions. Inherent margins above design of the components, such as higher plastic failure temperatures provide assurance of this capability (reference Figure 2.1.)

2.4.4.1.2. The HCVS capability at extreme conditions should consider all potential aspects of vent usage and operation under severe accident conditions, including but not limited to drywell floodup and protection of drywell head seal from over-pressure and associated over-temperature induced gross leakage; which is accomplished by maintaining containment pressure below the lower of containment design pressure or PCPL.

Notes:

- The Switzerland Regulator imposed a vent design pressure of 150% of containment design pressure or 66% of failure pressure via HSK-AN-2026.
    - A European BWR uses 150°C (302°F) as the design temperature for its vent system.
- Not all BWR Containment, Drywell Sprays and Suppression Pools are sized and/or configured similarly depending on NSSS provider and construction timeline.
- These vent design parameters are associated with a particular configuration and severe accident mitigation strategy that is intended to protect the containment pressure retaining capability.

2.4.4.2. As pictorialized in Figure 2-1, which illustrates the representative margin of the containment based on the design envelope, extending the DW HCVS vent design values to PCPL and 545°F (from point 1 to point 2 on the diagram) provides an assurance that margin is maintained in the DW head region by selecting this design point for the DW vent.

Selection of this design point (PCPL and 545°F) could provide margin to avoid gross drywell head seal leakage (as illustrated by comparing point 3 to point 4 on the diagram).

Phase 2 activities should be informed by analysis/calculations and filtering strategies Rulemaking that show system designs and use of operating procedures provide reasonable confidence against drywell head seals gross leakage; realizing that pressure control and the temperature in the upper drywell region have an influence on drywell head seal leakage. This Phase 1 guidance and the recommended values (PCPL, 545ºF) adequately address the pressure/temperature design values for those portions of the HCVS that may be common to both wetwell and drywell vents.

The basis of Figure 2.1 is a compilation of various test and engineering evaluations that are publically available on the integrity of containment, e.g., SOARCA, NUREG/CR-2442, NUREG/CR-5334, NUREG/CR-3234, NUREG/CR-4064, DE-ACO4-76DP00789 [Ref. 9, 11 – 15].

The HCVS operational procedures should provide direction such that containment pressures are controlled. This capability of pressure control should be shown to provide containment pressure and associated temperature margin below the ultimate failure prediction for gross drywell head seal leakage.

2.4.4.2.1. The green, blue and light blue highlighted regions of the diagram show the dominant items contributing to loss of containment for that range of temperatures and pressures based on the containment design bases grey box.

2.4.4.2.2. The red area of the diagram shows the region where there is high likelihood that significant containment compromise will occur based on the containment design values (point 1).

2.4.4.2.3. The failure predictions for gross drywell head seal leakage from over-pressure/over-temperature, individually or in combination, shall be based on Figure 2.1 compilation basis and any other available data and research on the subject matter.

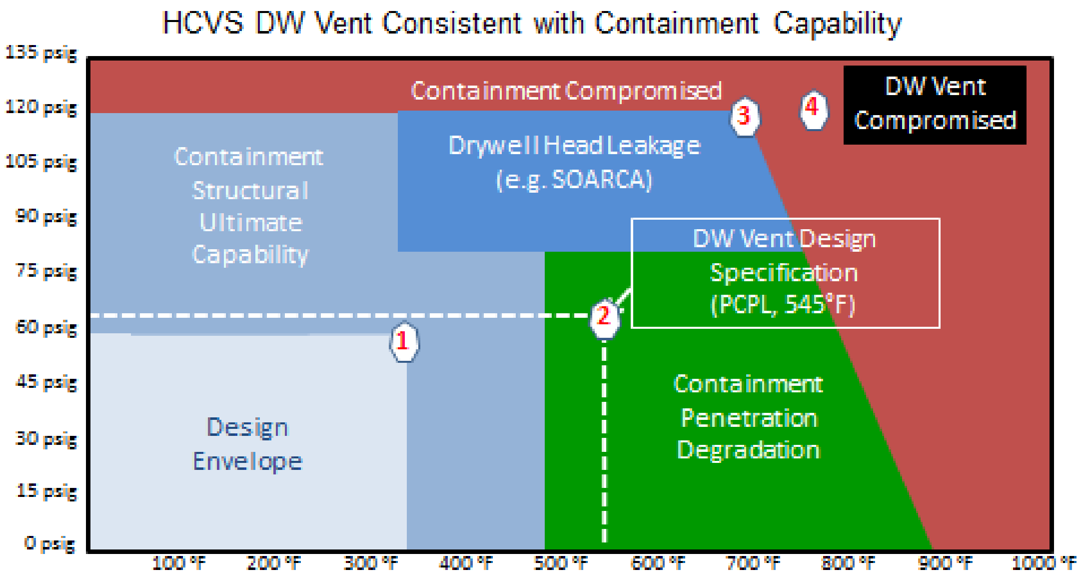

HCVS DW Vent Consistent with Containment Capability

Figure 2-1

2.4.4.3. The selection of the DW HCVS vent design values to PCPL and 545°F does not imply that the DW vent should be operated at this value since elevated temperatures and pressures increase the probability of DW head gasket compromise, which should be avoided.

2.4.5. The order drives two options regarding design of the HCVS for flammable mixtures; ensure that the flammability limits of gases passing through the system are not reached or to design for detonation.

2.4.5.1. Designing for detonation is addressed in Appendix H.

2.4.5.2. The exclusion of oxygen is an acceptable method to ensure that flammability limits are not reached.

2.4.5.3. Hydrogen gas (and other combustible gases) is a product of the core damage process as a result of chemical reactions involving zirconium and steam (or steel and steam) and Molten Corium Concrete Interaction (MCCI).

2.4.5.3.1. Depending on the scenario, vent operating cycles and the timing of vent use, the volume fraction of hydrogen can vary widely.

2.4.5.3.2. Based on information in Appendix H, consideration of a hydrogen concentration range of 0% to 6% is recommended (see NUREG C/R-2475/NUREG C/R-6524, GE SIL 643) [Ref. 17, 18 and 19].

2.4.5.3.3. Hydrogen is flammable at above 8% in many references and as low as 4% in other references.

2.4.5.3.4. Purging is an acceptable method for keeping the flammable concentration below 8%

2.4.6. The recommended boundary conditions for the severe accident capable vent are summarized in Table 2-1 below:

Severe Accident Capable Vent Design Parameter Boundary Conditions

Boundary Parameter	Wetwell Vent Path	Drywell Vent/ Shared Paths
Containment Design Pressure	For Sizing Design use the **Lesser** of Design Pressure or PCPL For Pressure Rating use the **Higher** of Design Pressure or PCPL	
Containment Design Temperature	350 ^{o}F	545^{o}F

Table 2-1

2.4.6.1. Selection of values that are more conservative than the above recommended values is acceptable (i.e., higher design pressures and temperatures).

2.4.6.2. Less restrictive bases than the above recommended values require a plant-specific technical justification.

2.4.7. The piping, valves, and the valve actuators should be designed to withstand the dynamic loading resulting from the actuation of the system, including piping reaction loads from valve opening, resultant loads from SRV operation, potential for water hammer from accumulation of steam condensation, and hydrogen detonation, if applicable, during multiple venting cycles.

2.5. Vent Operation Assumptions

The vent must be capable of operation during an extended loss of AC power (ELAP) and under conditions that may exist during a severe accident.

Order Reference: 1.2.6 – The HCVS shall be capable of operating with dedicated and permanently installed equipment for at least 24 hours following the loss of normal power or loss of normal pneumatic supplies to air operated components during an extended loss of AC power.

2.5.1. Severe accident conditions within the containment require consideration of accessibility and stay time issues using the methodologies in Appendix F and G. Sections 4.2.5 and 4.2.6 provide the requirements for design.

3. DRY WELL VENT BOUNDARY CONDITIONS FOR VENT DESIGN AND OPERATION

3.1. Drywell HCVS Use for Design Basis
3.2. Drywell HCVS Use for BDBEEs
3.3. Drywell HCVS Use during Applicable Severe Accident Conditions
3.4. Drywell Vent Design Boundary Conditions
3.5. Drywell Vent Operation Assumptions

4. DESIGN CONSIDERATIONS

The purpose of the reliable HCVS is to enhance the capability of BWRs with Mark I and II containments to preserve containment capability in a wide spectrum of possible beyond design basis accident conditions including the presence of ex-vessel core debris, controlling containment pressure within acceptable limits by venting the containment atmosphere including steam, hydrogen, non-condensable gases, aerosols, and fission products. As described in Section 2, the HCVS will be designed for those accident conditions for which containment venting is relied upon to prevent containment failure; including accident sequences that result in the loss of active containment heat removal capability or extended loss of AC power (ELAP). This section describes the design considerations applicable to the design and implementation of a plant-specific HCVS.

4.1. Vent Design Criteria

4.1.1. Vent Thermal Design and Capacity

The primary design objective of the HCVS is to provide sufficient venting capacity to prevent a long-term overpressure failure of the containment by keeping the containment pressure below the lower value of either PCPL or containment design pressure, and maintaining Pressure Suppression Capability such that the safety relief valves (SRVs) can be opened and closed as required by plant conditions. Operational functionality of these valves will ensure the capability to depressurize the RPV to permit injection of low head injection systems and to maintain the containment pressure boundary.

Order Reference: 1.2.10 – The HCVS shall be designed consistent with containment pressures and temperatures during severe accident conditions as well as dynamic loading resulting from system actuation. The design is not required to exceed the current capability of the limiting containment components.

Order Reference: 1.2.1 – The HCVS shall have the capacity to vent the steam/energy equivalent of 1 percent of licensed/rated thermal power (unless a lower value is justified by analyses), and be able to maintain containment pressure below the primary containment design pressure and the primary containment pressure limit (PCPL).

4.1.1.1. Key issues to be addressed in the Vent Thermal Design and Capacity requirements are:

4.1.1.1.1. Consideration of containment venting to support mitigation strategies for BDBEE including ELAP conditions.

4.1.1.1.2. Ability of the vent system to operate under the expected pressures and temperatures of the containment.

4.1.1.1.2.1. The key consideration would be design temperature of the drywell vent components and instrumentation.

4.1.1.1.3. Sizing considerations for the wetwell and drywell vent.

4.1.1.1.3.1. A wet well vent sized under conditions of constant heat input at a rate equal to 1 percent of rated thermal power and containment pressure equal to the lesser of the PCPL or containment design pressure, the exhaust-flow through the wetwell vent would be sufficient to prevent the containment pressure from increasing.

4.1.1.1.3.2. The suppression pool/torus suppression capacity is typically sufficient to absorb the decay heat generated during at least the first three hours following the shutdown of the reactor with the suppression pool as the source of cooling. The decay heat is typically less than 1 percent of rated thermal power following this three hour period and continues to decrease to well under 1 percent thereafter.

4.1.1.1.3.2.1 Licensees shall have an auditable engineering basis for the decay heat absorbing capacity of their suppression pools, venting pressure and associated decay heat value.

4.1.1.1.3.2.2. Licensees may justify use of decay heat rates of less than 1 percent for purposes of vent sizing capability if analyses demonstrate that containment pressure can be maintained below the lower of design pressure or PCPL (Wetwell or drywell).

4.1.1.1.3.3. In cases where plants were granted, have applied, or plan to apply for power uprates, the decay heat value selected should correspond to the uprated thermal power.

4.1.1.1.3.4. The basis for the venting capacity should give appropriate consideration of where venting is being performed from (i.e., wetwell or drywell) and the difference in pressure between the drywell and the suppression chamber.

4.1.1.1.3.5. Vent sizing for multi-unit sites must take into consideration simultaneous venting from all the units, and ensure that venting on one unit does not negatively impact the ability to vent on the other units. This includes ensuring any shared portions of the vent can pass the cumulative flow requirements

4.1.2. Multipurpose Penetration Use

Order Reference: 1.2.3 – The HCVS shall include design features to minimize unintended cross flow of vented fluids within a unit and between units on the site.

Order Reference: 2.1 – The HCVS vent path up to and including the second containment isolation barrier shall be designed consistent with the design basis of the plant. These items include piping, piping supports, containment isolation valves, containment isolation valve actuators and containment isolation valve position indication components.

4.1.2.1. Key issues to be addressed regarding multipurpose penetration and containment isolation barriers use are:

4.1.2.1.1. Exception to GDC 56, 10 CFR 50.12 submittal.

4.1.2.1.1.1. Each HCVS containment penetration must have two in-series PCIVs as required by GDC 56.

4.1.2.1.1.1.1. Although GDC 56 stipulates that one valve should be inside containment and the other outside containment, both PCIVs on each HCVS containment penetration may be installed outside containment and as close as reasonably possible to the penetration.

4.1.2.1.1.1.2. Locating a power operated valve inside containment that must open and remain operable following a beyond design basis severe accident decreases the reliability of any valve and operator (including motive air and DC instrumentation and controls) located inside the containment.

4.1.2.1.2. The rational for locating the PCIVs as close as reasonably possible to the containment penetration is to comply with the applicable GDCs.

4.1.2.1.2.1. It limits the amount of the HCVS flow path that is part of the containment penetration boundary.

4.1.2.1.2.2. Minimizing the amount of new containment penetration piping limits the risks to containment integrity. Any piping that is part of the containment penetration boundary must be designed to the appropriate criteria (typically, protected from pipe whip, jet impingement, missiles, and be designed to ASME Section III class 2 with the added requirement for low stresses during design basis operation of the plant to preclude having to postulate pipe break or pipe cracks).

4.1.2.1.2.2.1. New piping and valves should be evaluated for both Design Basis events and Beyond Design Basis Events as separate evaluations.

4.1.2.1.2.2.2. Boundary conditions and loads associated with the Beyond Design Basis event do not have to be included or considered in Design Basis Calculations.

4.1.2.1.2.2.3. Qualification for piping/valves associated with the BDBE may include both different loading combinations and allowed stresses.

4.1.2.1.2.3. Locating the PCIVs close to the containment penetration restricts the possibility for practical local-manual operation; Section 4.2 discusses design features that will increase remote-manual operation.

4.1.2.1.3. GDC 56 stipulates that the valves must be either locked-closed or have automatic closure.

4.1.2.1.3.1. The intent of automatic isolation is to ensure that penetrations that may be open to the containment atmosphere during normal operation (e.g., nitrogen inerting, nitrogen purging) are closed when containment integrity is required.

    - 4.1.2.1.3.2. Automatic isolation of the HCVS valves on a containment isolation signal is possible, but it would be redundant since these valves are required to be closed during all anticipated modes of operation that could require containment isolation. (Except during the period required for operation when the containment isolation signals are to be defeated to allow HCVS operation)
    - 4.1.2.1.3.3. Also, automatic isolation would unnecessarily complicate valve opening if HCVS is required.
    - 4.1.2.1.3.4. To support not providing locked-closed valves or automatic isolation, an option is new PCIVs that are normally-closed valves that have a fail-closed mode (i.e., AOVs).
    - 4.1.2.1.3.5. These valves shall have remote-manual operation, but with a key-lock on the control switch to prevent inadvertent opening.
- 4.1.2.1.4. As required by GDC 54, these penetrations “shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits.”
    - 4.1.2.1.4.1. The periodic PCIV testing frequency is dictated by the unit’s Technical Specifications.
    - 4.1.2.1.4.2. Periodic rupture diaphragm testing frequency shall be based on manufacturer recommendations, if the rupture diaphragm is used as a relied upon penetration barrier
    - 4.1.2.1.4.3. However, testing at any time may be required if a valve or rupture diaphragm reliability issue arises.
    - 4.1.2.1.4.4. Therefore, the HCVS flow path can be credited for being closed and remaining closed during all design basis transients and accidents.

4.1.3. Routing Considerations

Order Reference: 1.1.4 – The HCVS controls and indications shall be accessible and functional under a range of plant conditions, including a severe accident environment, extended loss of AC power**,** and inadequate containment cooling.

4.1.3.1. Key issues to be addressed regarding routing considerations are listed in Appendices F & G on source term and dose considerations and Section 4.2 for operator “residence time”.

4.1.4. Multi-Unit Interfaces

System cross-connections or shared Unit vent exhaust flow paths present a potential for steam, hydrogen, and airborne radioactivity leakage to other areas of the plant and to adjacent units at multi-unit sites if the units are equipped with common vent piping. At Fukushima, an explosion occurred in Unit 4, which was in a maintenance outage at the time of the event. Although the facts have not been fully established, a likely cause of the explosion in Unit 4 is that hydrogen leaked from Unit 3 to Unit 4 through a common venting system.

Order Reference: 1.2.3 – The HCVS shall include design features to minimize unintended cross flow of vented fluids within a unit and between units on the site.”

4.1.4.1. HCVS design should provide design features to minimize the cross flow of vented fluids and migration to other areas within the plant or to adjacent units at multi-unit sites.

4.1.4.1.1. A design that is free of physical and control interfaces with other systems eliminates the potential for any cross-flow is one way to satisfy this requirement.

4.1.4.1.2. Examples of acceptable means for minimizing cross flow are the use of valves, “leak-tight” dampers, and check valves.

4.1.4.1.3. Pressurizing with inert gas between system boundary valves could also be used (provided sufficient gas exists to support this during the required sustained operation period).

4.1.4.1.4. Other means are acceptable with a site specific justification based on the component parameters.

4.1.4.1.5. Any HCVS flow path interface should be designed to remain closed or automatically close upon the initiation of the HCVS and remain closed for as long as the HCVS is in operation.

4.1.4.1.5.1. If Operator actions are required for confirming/changing state of interfacing valves, then validation of the action using normal plant validation methods should be included in the HCVS plant procedures.

4.1.4.1.6. The environmental conditions (e.g. pressure, temperature) at the flow path interface locations during venting operations should be evaluated to ensure that the interface will remain sufficiently leak-tight.

4.1.4.1.7. If power is required for the interfacing valves to move to isolation position, it should be from power sources meeting the same standards and qualifications as the vent valves.

4.1.4.1.8. Leak tightness of any such barriers should be periodically verified by testing as described in Section 6 of this document.

4.1.5. Release Point

The HCVS release to outside atmosphere should be at an elevation higher than adjacent plant structures. (Refer to Section 5 for discussion of qualification details)

Order Reference: 1.2.2 – The HCVS shall discharge the effluent to a release point above main plant structures.

4.1.5.1. Release through existing plant meteorological stack(s) is acceptable.

4.1.5.2. If the release from HCVS is through a stack different than the plant meteorological stack, the elevation of the stack should meet the following criteria:

4.1.5.2.1. Be higher than the nearest power block building or structure.

4.1.5.2.2. The release point should be situated away from ventilation system intake and exhaust openings or other openings that may be used as natural circulation ventilation intake flow paths during a BDBEE (e.g., to prevent recirculation of the releases back into the buildings.)

4.1.5.2.3. The release stack or structure exposed to outside should be designed or protected to withstand missiles that could be generated by the external events that screen in for the plant site using the guidance in NEI 12-06 as endorsed by JLD-ISG-12-01 [Ref. 21] (See Section 5 for details).

4.1.6. Leakage Criteria

The HCVS design should address the reduction of Hydrogen Gas flammability in the vent pipe through the use of steam suppression (Reference Appendix H and reference NUREG C/R-2475/NUREG C/R-6524, GE SIL 643 [Ref 17, 18 and 19],) nitrogen inerting or the exclusion of oxygen.

Order Reference: 1.2.3 – The HCVS shall include design features to minimize unintended cross flow of vented fluids within a unit and between units on the site.

Order Reference: 1.2.12 – The HCVS shall be designed to minimize the potential for hydrogen gas migration and ingress into the reactor building or other buildings.

4.1.6.1. Design for Leakage during HCVS Operation:

4.1.6.1.1. HCVS line inerting

4.1.6.1.1.1. The HCVS up to the second containment isolation valve should be either nitrogen inerted or be “steam inerted” such that any hydrogen gases within the containment or vent pipe remain below the hydrogen gas flammability limit (See NUREG/CR-2475).

4.1.6.1.1.2. The HCVS pipe beyond the final isolation valve used to initiate/cease venting should be designed for deflagration/detonation due to potential for oxygen intrusion resulting from steam condensation following HCVS vent closure or have the capability of being purged prior to the vent drawing in oxygen.

4.1.6.1.2. HCVS line oxygen exclusion

4.1.6.1.2.1. The exclusion of oxygen as an acceptable alternative to either inerting with steam or nitrogen or making the piping detonation/deflagration proof. An example of this approach is maintaining the line pressure above atmosphere to the last discharge isolation valve.

4.1.6.1.2.2. The HCVS pipe beyond the isolation valves should be able to tolerate a detonation/deflagration or have a purge system that would either keep oxygen out of the system or reduce hydrogen concentration below flammability limits following vent cycles.

4.1.6.2. Design for Leakage in interfacing piping to HCVS:

The HCVS pipe beyond the interfacing piping isolation valve should meet the provisions of Section 4.1.4.1.

4.1.7. Protection from Flammable Gas Ignition

Protection from flammable gas ignition should utilize principles found in NUREG/CR-2475. Additional information is provided in Appendix H of this document. The evaluation of gas ignition is to document the capability of the HCVS piping to maintain integrity should deflagration or detonations occur. Deformation of the pipe is acceptable given the integrity and continued functional capability of the vent system is shown to be maintained.

Order Reference: 1.2.11 – The HCVS shall be designed and operated to ensure the flammability limits of gases passing through the system are not reached; otherwise, the system shall be designed to withstand dynamic loading resulting from hydrogen deflagration and detonation.

4.1.7.1. Design for Deflagration/Detonation

Most plants have a UFSAR evaluation of the Offgas flow path for detonation potential that evaluates piping for this issue. This method can be similarly used to evaluate the HCVS design. Methods of designing the HCVS piping/components/ instrumentation against flammable gas detonation/deflagration are discussed in Appendix H. Susceptible portions of the piping should be determined based on where oxygen can be drawn into the piping/interfacing piping.

4.1.7.2. Purge systems to reduce gas concentrations below flammability limits.

Use of a purge system in sections of pipe susceptible to air intrusion from intermittent HCVS operation can also be used to minimize detonation/deflagration potential.

4.1.7.3. Design Systems to Prevent Detonation/Deflagration

Design of the HVCS may include features that prevent air/oxygen backflow into the discharge piping. Use of design features in sections of pipe susceptible to air intrusion from intermittent HCVS operation can also be used to minimize detonation/deflagration potential.

4.1.7.4. Combination of loads

The design of the HCVS may require that it withstand the dynamic loading resulting from hydrogen deflagration/detonation. For design purposes, the HCVS is not required to consider assumed simultaneous loads that would not be present or occur during the venting of hydrogen (e.g. seismic loads).

4.1.8. Combined Drywell/Wetwell Vent pipe Design considerations

4.1.8.1. Depending on the HCVS design, the HCVS may have three distinct portions or flow paths;

4.1.8.1.1. A portion that only supports wetwell venting,

4.1.8.1.2. A portion that only supports drywell venting, and

4.1.8.1.3. A portion that is shared by both.

4.1.8.2. The drywell generally has the most limiting boundary conditions, so the drywell boundary condition parameters described in Sections 2.4.4 are recommended for the shared portions of the HCVS, unless lower values are justified.

4.1.8.3. Examples of reasons for lower temperature values include heat loss through piping and dead-legged piping (for example, WW vent piping when DW vent is being used)

4.1.9. Fault/Failure Evaluations

The table below provides an example of a Failure Evaluation that will be included in the Overall Integrated Plan. The table details the HCVS system interactions with design and operation for potential failures and alternate actions. It should not be construed from inclusion of this table in this guide, that the HCVS should be designed as a single failure proof system due to the low probability of a Severe Accident BDBEE. However, licensees should give consideration for low cost measures to provide enhanced reliability of the vent system.

SAMPLE: Failure Evaluation Table

Functional Failure Mode	Failure Cause	Alternate Action*	Failure with Alternate Action Impact on Containment Venting?
Fail to Vent (Open) on Demand	Valves fail to open/close due to loss of normal AC power	Switch power supply to inverter backed AC power	No
	Valves fail to open/close due to loss of one train of inverter backed AC power	Align power supply to alternate inverter	No
	Valves fail to open/close due to complete loss of DC batteries (long term)	Recharge batteries with FLEX provided generators considering severe accident conditions	No
	Valves fail to open/close due to loss of normal pneumatic air supply	No action needed, valves are provided with accumulator tanks which are sufficient for up to 5 actuations in a 24 hour period	No
	Valves fail to open/close due to loss of alternate pneumatic air supply (long term)	Recharge accumulator tanks with N_2 bottles and/or portable air compressors. Replace bottles as needed.	No
	Valve fails to open/close due to SOV failure	Heroic Action needed	Yes

4.2 Vent Operation and Monitoring

The importance of reliable operation of hardened vents during conditions involving loss of containment heat removal capability is well established and this understanding has been reinforced by the lessons learned from the accident at Fukushima Dai-ichi. This sub-section describes the design considerations relative to the HCVS operation and monitoring.

By nature, some BDBEEs create a need to initially operate the vent manually (either locally or from remote stations) and the design concepts espoused in this document protect that operational capability. Due to the multiple functions provided by the vent path, a single set of passive features (e.g., Rupture Diaphragms) cannot achieve all of the operational functions, therefore operator actions are required. The challenges found in operating the vents at Fukushima have been addressed by this guidance as have the required actions to complete multiple functions (e.g. FLEX heat removal venting, normal plant venting, intermittent venting in severe accidents, post severe accident venting for combustible gas control). Based on this, the design elements proposed by this guidance (as listed below) do not require specific new requirements to minimize operator actions to address the ability to operate vents as required for ELAP and severe accident conditions.

4.2.1 Protection from Inadvertent Actuation

The design of the HCVS should incorporate features, such as control panel key-locked switches, locking systems, rupture diaphragms, or administrative controls to prevent the inadvertent opening of the vent.

a. The system should be designed to preclude inadvertent actuation of the HCVS due to any single active failure.

b. The design should consider general guidelines such as single point vulnerability and spurious operations of any plant installed equipment associated with HCVS.

c. Use of Administrative controls on energizing the HCVS controls can also be a part of the acceptable plan to minimize impact on Current Licensing Basis (CLB) controls.

Order Reference: 1.2.7 - The HCVS shall include means to prevent inadvertent actuation.

4.2.1.1 One or more of the following criteria are acceptable approaches for inadvertent actuation features of the HCVS.

4.2.1.1.1 Rupture diaphragm in the HCVS flow path

4.2.1.1.2 Key lock for HCVS valve switches

4.2.1.1.3 Administrative Controls for energizing HCVS components/controls

4.2.1.1.4 Interface with Technical Specification Components (such as current primary containment isolation valve (PCIV) controls).

4.2.1.2 Meeting design features and the above criteria will show compliance with separation of controls from negative impact on CLB equipment and methods to demonstrate reasonable prevention of inadvertent actuation of the system.

4.2.1.3 Prevention of inadvertent actuation, while important for all plants, is essential for plants relying on containment accident pressure (CAP) to provide adequate net positive suction head to the emergency core cooling system (ECCS) pumps. Plants that rely on CAP should have an evaluation that specifically addresses the design considerations for minimizing inadvertent actuation interaction. This evaluation may include a combination of design features and administrative controls.

4.2.2 Required HCVS Controls Primary Control and Monitoring Location

The preferred location for remote operation and control of the HCVS is from the main control room. However, alternate locations to the control room are also acceptable.

Order Reference: 1.2.4 - The HCVS shall be designed to be manually operated during sustained operations from a control panel located in the main control room or a remote but readily accessible location.

Order Reference: 1.2.8 - The HCVS shall include means to monitor the status of the vent system (e.g., valve position indication) from the control panel required by 1.2.4. The monitoring system shall be designed for sustained operation during an extended loss of AC power.

4.2.2.1 The control location should take into consideration the following:

4.2.2.1.1 The ability to open/close the valves multiple times during the event, i.e., sustained operations.

4.2.2.1.1.1 Licensees should determine the number of open/close cycles necessary during the first 24 hours of operation and provide supporting basis consistent with the plant-specific containment venting strategy.

4.2.2.1.1.2 Sustained operational requirements may continue beyond the capacity of the installed HCVS system motive force (air/nitrogen) make-up, power supply changes or both, i.e., beyond the first 24 hours.

4.2.2.1.1.3 Sustained operations provisions should continue until 7 days or a shorter period of time if an alternative method of containment heat removal is put in place by using installed or portable equipment (e.g., a means of shutdown cooling aligned directly to the RPV, drywell or suppression pool.) The alternate method of containment heat removal should not rely on the HCVS (i.e., the HCVS isolation valves should be able to remain closed such that releases and cross unit or system interface leakages are no longer a concern.)

4.2.2.1.1.4 During Sustained Operation, the containment barrier is initially manually controlled by the plant staff/ERO during containment heat removal operations (either by containment venting or alternative measures) to prevent further fuel damage. This manual containment heat removal allows RPV injection by use of RCIC or external water supplies (reduced containment pressure may be required.)

4.2.2.1.1.5 Severe accident venting to remove containment heat should be stopped as soon as possible to fully restore the containment function so that the containment source term barrier is available (i.e., no substantial leakage through containment components.) Thus allowing design barriers to be maintained for potential degrading core conditions.

4.2.2.1.2 The temperature and radiological conditions that operating personnel may encounter both in transit and locally at the controls.

4.2.2.1.2.1 This should include the impacts on initial release of post severe accident source term and impacts of vent piping related heat up in areas with little or no ventilation on the controls/controlling station. Alternatives may be used, such as providing features to facilitate manual operation of valves from remote locations or relocating/reorienting containment vent valves.

4.2.2.1.3 Availability of permanently installed HCVS equipment, including any connections required to supplement the HCVS operation during an ELAP (e.g., electric power, N_2/air) should be consistent with the staff's guidance in JLD-ISG-2012-01 for Order EA-12-049 with consideration of severe accident conditions.

4.2.2.1.4 The controls/control location design should preclude the need for operators to move temporary ladders or operate from atop scaffolding to access the HCVS valves or remote operating locations.

4.2.2.1.5 HCVS valve position indication should be available at the primary controlling location.

4.2.2.1.6 HCVS valve position indicators should be capable of operating under the temperature/radiation conditions existing at the valve locations.

4.2.2.1.7 HCVS valve position indicators and indications should be powered from sources that will be available during the appropriate mission time of the HCVS system. The mission time may vary by component but the cumulative mission time for credited components and instrumentation performing a required installed plant HCVS equipment function should be no less than the first 24 hours post event.

4.2.2.1.8 HCVS system should include indications of effluent temperature. Permanently installed gauges that are at, or nearby, the HCVS control panel is an acceptable method to address this item.

4.2.2.1.9 The HCVS system should include indications for the Containment Pressure and Wetwell level for determination of vent operation. These indications may be either at the primary controlling location (order criteria 1.2.4) for the HCVS or at another location with communication to the HCVS controlling location. Use of existing control room indications is adequate and these instruments do not need to be powered by the HCVS battery system.

4.2.2.1.10 Considerations for alternative approaches for system status instrumentation must provide sufficient information and justification for alternative approaches and be submitted to the NRC for approval.

4.2.2.2 The following criteria are acceptable approaches for HCVS Primary Controls and Monitoring location:

4.2.2.2.1 Requirement for sustained operation of the HCVS

4.2.2.2.2 Requirements for assessment of temperature and radiological condition

4.2.2.2.3 Reasonable protection of required equipment

4.2.2.2.4 Required design criteria for indications

4.2.2.3 Meeting design features and the above criteria will show compliance with Primary Controls and Monitoring location requirements (including instrumentation).

4.2.3 Alternate Remote Operation {Alternate/Local Valve Control Location}

During an ELAP, manual operation/action from alternate control locations may become necessary to operate the HCVS. As demonstrated during the Fukushima event, the valves lost motive force including electric power and pneumatic air supply to the valve operators, and control power to solenoid valves.

a. If direct access and local operation of the valves is not feasible due to temperature or radiological hazards, licensees should include design features to facilitate remote manual operation of the HCVS valves. This could include means such as reach rods, chain links, hand wheels, alternative control locations, and portable equipment to provide motive force as needed (e.g., air/N_2 bottles, diesel powered compressors, and DC batteries).

   Note, throughout this section portable equipment will not be relied upon until 24 hours after event initiation.

Order Reference: 1.2.5 - The HCVS shall, in addition to the requirements of 1.2.4, be capable of manual operation (e.g., reach-rod with hand wheel or manual operation of pneumatic supply valves from a shielded location), which is accessible to plant operators during sustained operations.

4.2.3.1 The HCVS design should consider the following elements to facilitate remote manual operation:

4.2.3.1.1 An assessment of temperature and radiological conditions that operating personnel may encounter both in transit and locally at the local or alternate control location.

4.2.3.1.1.1 Include radiological conditions associated with post severe accident source terms and impacts of vent piping related heat up in areas with little or no ventilation on the local or alternate control location.

4.2.3.1.1.2 Alternatives such as providing features to facilitate manual operation of valves from remote locations or relocating/reorienting the valves may be used.

4.2.3.1.1.3 Consider that local-manual access to PCIVs for an ELAP event may not be feasible due to high temperature or radiation levels in the Reactor Building since they will be located near a containment penetration.

4.2.3.1.1.4 The connections between the valves and portable equipment should be designed for quick deployment.

4.2.3.1.1.5 If a portable motive force (e.g., air or N_2 bottles, DC power supplies) is used in the design strategy, licensees should provide reasonable protection of that equipment consistent with the staff's guidance in JLD-ISG-2012-01 for Order EA-12-049 considering severe accident conditions.

4.2.3.1.1.6 The Local Controls/Alternate Valve Control Location design should preclude the need for operators to move temporary ladders or operate from atop scaffolding to access the HCVS valves or remote operating locations.

4.2.3.2 The following criteria are acceptable approaches for HCVS Local Controls/Alternate Valve Control Location:

4.2.3.2.1 Supply an alternate method of HCVS valve operation

4.2.3.2.2 Assessment of temperature and radiological conditions

4.2.3.2.3 Reasonable protection of required equipment

4.2.3.2.4 Required design criteria for indications

4.2.3.2.5 Criteria for manual opening of HCVS and Interfacing AOVs

4.2.3.2.6 Criteria for operation of HCVS and Interfacing MOVs

4.2.3.3 Meeting design features and the above criteria will show compliance with local controls/alternate control location requirements (including instrumentation).

4.2.4 Vent Monitoring

Plant operators must be able to readily monitor the radiological conditions that exist during venting operations of the HCVS at all times.

Order Reference: 1.2.9 - The HCVS shall include a means to monitor the effluent discharge for radioactivity that may be released from operation of the HCVS. The monitoring system shall provide indication from the control panel required by 1.2.4 and shall be designed for sustained operation during an extended loss of AC power.

4.2.4.1 The HCVS design should provide a means to allow plant operators to readily determine, or have knowledge of, the following system parameters:

4.2.4.1.1 HCVS vent valves position (open and closed).

4.2.4.1.2 HCVS vent pipe radiation levels. The range of the instrument should be consistent with the dose rates anticipated during severe accident venting. The use of a multi-range instrument that will span the expected dose rates is acceptable.

4.2.4.1.2.1 The effluent discharge radiation monitor is required to provide additional knowledge of HCVS operation not as a required change for Emergency Preparedness off-site dose functions.

4.2.4.1.3 Other important information includes the status of supporting systems, such as availability of electrical power and pneumatic supply pressure.

4.2.4.1.3.1 Monitoring by means of permanently installed gauges or meters that are at, or nearby, the HCVS control panel or in the Control Room with communication to the HCVS control panel is acceptable.

4.2.4.1.4 The HCVS system should include indications for the Containment Pressure and Wetwell level for determination of vent operation. These indications may be either at the local controls/alternate control location for the HCVS systems or at another location with communication to the Primary Controls location or local controls/alternate control location.

4.2.4.1.5 Alternative approaches for system status instrumentation may be considered with appropriate justification provided for alternative approaches.

4.2.4.2 The means to monitor system status should support sustained operations during an ELAP, and be designed to operate under environmental conditions that would be expected following a loss of containment heat removal capability and an ELAP. “Sustained operations” beyond the first 24 hours may include the use of portable equipment to provide an alternate source of motive force to components used to monitor HCVS status.

Note: Additional instrumentation required to comply with Order EA-12-049 as discussed in NEI 12-06 may be useful in support of HCVS operation, but are not required for HCVS functionality.

4.2.4.3 Instrument reliability should be demonstrated via an appropriate combination of design, analyses, operating experience, and/or testing of HCVS components for the conditions described in Section 2 of this guide.

4.2.4.3.1 Selection of HCVS components should consider ease and simplicity of design so that maintenance and calibration during system operation is not necessary. This design consideration should avoid the need for intrinsically safe instruments.

4.2.4.4 The following criteria are acceptable approaches for HCVS monitoring:

4.2.4.4.1 Requirements to monitor HCVS vent pipe conditions including radiological releases, vent pipe pressure and temperature.

4.2.4.4.2 Sustained operation of HCVS vent pipe condition instrumentation and other required indications during an ELAP condition (limiting analysis).

4.2.4.4.3 Requirements for assessment of radiological, temperature and pressure conditions in the area of HCVS monitoring instruments.

4.2.4.5 Meeting design features and the above criteria will show compliance with HCVS monitoring.

4.2.5 Operational Hazards

Order Reference: 1.1.2 - The HCVS shall be designed to minimize plant operators' exposure to occupational hazards, such as extreme heat stress, while operating the HCVS system.

Order Reference: 1.1.3 - The HCVS shall also be designed to account for radiological conditions that would impede personnel actions needed for event response.

4.2.5.1 HCVS controls should be located in areas where sustained operation is possible accounting for expected temperatures and radiological conditions in the HCVS vent pipe and attached components without extreme heat stress or radiological over exposure to the operators.

4.2.5.1.1 HCVS operation must be possible without placing the operators in dose fields above those allowed by the ERO guidance to conduct local equipment operation. The use of shielding and other radiological dose control actions may provide acceptable radiation levels for operator access

4.2.5.1.2 HCVS operating locations (Primary/Alternate) must account for the expected lack of ventilation that is encountered during an ELAP event.

4.2.5.1.3 HCVS operating locations should not place the operators in areas above the maximum safe entry points in the applicable plant safety manual/guidance.

4.2.5.1.4 HCVS controls should be located in areas where sustained operation is possible accounting for radiological conditions in the HCVS vent pipe and attached components (instrumentation) within allowed doses per the ERO guidance to the operators for non-heroic actions. These conditions should include estimation of the impact during an ELAP event and following core damage required vent operations.

4.2.5.1.5 The HCVS vent pipe routing and shielding must be considered for other actions required of the plant staff/ERO during the event should venting be required during severe accident conditions. Guidance for the allowable dose fields/dose during required actions with the source term in the HCVS vent pipe would be the limits prescribed in the ERO guidance.

Note: Any deviation from the above can be considered provided justification is submitted.

4.2.5.2 The following criteria are acceptable approaches for HCVS operational hazards at local controls/primary and alternate control locations:

4.2.5.2.1 Temperature conditions at the HCVS proposed operating stations meet plant safety manual/guidance or justification is provided to the Staff.

4.2.5.2.2 Radiological conditions at the HCVS proposed operating stations meets ERO allowable dose guidance or justification is provided.

4.2.5.2.3 Other plant actions required by the plant staff/ERO should account for the expected radiological conditions caused by HCVS vent pipe routing with severe accident source term release through the HCVS vent pipe. The expected limits imposed on the dose/dose field from the ERO guidance should be used for these actions.

4.2.5.3 Meeting design features and the above criteria will show compliance with HCVS operational hazards at Primary Controls and Local/Alternate Valve Control Locations.

4.2.6 Designed to minimize Operator Actions

HCVS system should be designed to maximize the probability of successful operator action to operate vents when required.

Order Reference: 1.1.1 - The HCVS shall be designed to minimize the reliance on operator actions.

4.2.6.1 Design features consistent with this approach include:

- 4.2.6.1.1 Environmental considerations
  - 4.2.6.1.1.1 Heat stress impact on ability to vent
  - 4.2.6.1.1.2 Radiological condition impact on ability to vent
- 4.2.6.1.2 Sustained operational capability
  - 4.2.6.1.2.1 Independent 24 hour electrical and pneumatic supplies.
  - 4.2.6.1.2.2 The system will be capable of multiple valve cycles during the first 24 hour period without the need to recharge pneumatic or electrical power supplies.
- 4.2.6.1.3 Ease of vent valve operation
  - 4.2.6.1.3.1 Readily accessible under all operational conditions (e.g., accessible location without need for ladders or scaffolds)
  - 4.2.6.1.3.2 Operation achievable at a localized location.
  - 4.2.6.1.3.3 Operation does not require the use of jumpers or lifted leads to defeat valve interlocks.
  - 4.2.6.1.3.4 System comprised of installed equipment. No need for system or component disassembly/reassembly.

4.2.6.2 The following criteria are acceptable approaches for HCVS minimize operator actions that could prevent vent operations when required:

- 4.2.6.2.1 Compliance with other sections of this guidance as listed above.

4.2.6.3 Meeting design features and the above criteria will show compliance with HCVS to minimize operator actions that could prevent vent operations when required.

5. PROGRAMMATIC CONTROLS

5.1. Environmental Conditions

The HVCS is required to be capable of functioning during severe accidents in which the containment function is not compromised by the severe accident conditions. The HCVS equipment is designed to provide reasonable assurance of operation in the severe accident environment for which it is intended to function and over the time span for which it is needed. However, the environmental requirements of 10CFR50.49 are design basis regulatory requirements and as such are not applicable under severe accident conditions.

Order Reference: 1.2.10 – The HCVS shall be designed consistent with containment pressures and temperatures during severe accident conditions as well as dynamic loading resulting from system actuation. The design is not required to exceed the current capability of the limiting containment components.

5.1.1. The resultant design conditions for the HCVS equipment to provide reasonable protection to assure functionality may be different for the wetwell vent and/or the drywell vent, thus the following environmental conditions should be considered in the design of the system:

5.1.1.1. The limiting wetwell conditions are assumed to be 350°F and 80 psig based on the saturation temperature at the drywell failure pressure.

5.1.1.2. The drywell conditions are assumed to be 545°F and 80 psig corresponding to the temperature and pressure at which the drywell head may exhibit some leakage. Although some range of temperatures above this may be encountered due to stratification in areas of the drywell, the HCVS equipment should be designed using a temperature of 545°F consistent with the boundary conditions as detailed in Section 2 of this document.

5.1.1.3. Drywell radiological conditions should be consistent with the conditions assumed in the plant's current licensing basis (CLB) for a major accident. (i.e., the most severe design basis accident during or following which the equipment is required to remain functional, including the radiation resulting from recirculating fluids for equipment located near the recirculating lines and including dose-rate effects.)

5.1.1.3.1. Such accidents have generally been assumed to result in substantial meltdown of the core with subsequent release of appreciable quantities of fission products (e.g., Technical Information Document (TID) 14844, "Calculation of Distance Factors for Power and Test Reactor Sites (March 1962)," or NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants" consistent with the current design basis of the plant.) Refer to Appendix G for further details.

5.1.1.3.2. The evaluation of HCVS functionality should consider the potential conditions resulting from accidental events, whether postulated, hypothesized or otherwise identified, which do not exceed the conditions resulting from any credible accident as identified in the plant's CLB.

5.1.1.4. If the drywell vent and wetwell vent are interconnected, interaction between the two vent flow paths should be considered although only one flow path is required to be operated at any one time.

5.1.1.5. Environmental effects of the areas traversed by the system should be considered in both standby and operating conditions.

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.

5.1.1.7. The system should be designed to provide reasonable assurance of operation for up to 7 days consistent with the sustained operation definition.

5.2. Seismic and External Hazard Conditions

Order Reference: 2.1 – The HCVS vent path up to and including the second containment isolation barrier shall be designed consistent with the design basis of the plant. These items include piping, piping supports, containment isolation valves, containment isolation valve actuators and containment isolation valve position indication components.

Order Reference: 2.2 – All other HCVS components shall be designed for reliable and rugged performance that is capable of ensuring HCVS functionality following a seismic event. These items include electrical power supply, valve actuator pneumatic supply and instrumentation (local and remote) components.

5.2.1. HCVS components including instrumentation should be designed, as a minimum, to meet the seismic design requirements of the plant.

5.2.2. Components including instrumentation that are not required to be seismically designed by the design basis of the plant should be designed for reliable and rugged performance that is capable of ensuring HCVS functionality following a seismic event. (reference ISG-JLD-2012-01 and ISG-JLD-2012-03 [Ref. 22] for seismic details.)

5.2.3. The components including instrumentation external to a seismic category 1 (or equivalent building or enclosure should be designed to meet the external hazards that screen in for the plant as defined in guidance NEI 12-06 as endorsed by JLD-ISG-12-01 for Order EA-12-049.

5.3. Quality Requirements

Order Reference: 2.1 – The HCVS vent path up to and including the second containment isolation barrier shall be designed consistent with the design basis of the plant. These items include piping, piping supports, containment isolation valves, containment isolation valve actuators and containment isolation valve position indication components.

Order Reference: 2.2 – All other HCVS components shall be designed for reliable and rugged performance that is capable of ensuring HCVS functionality following a seismic event. These items include electrical power supply, valve actuator pneumatic supply and instrumentation (local and remote) components.

5.3.1. HCVS components including instrumentation should, as minimum, meet the quality design requirements of the plant, ensuring HCVS functionality.

5.3.1.1. The HCVS up to and including the second isolation valve is designed to the same quality requirements of the connected system.

5.3.1.2. HCVS elements that are not covered by 5.3.1.1 should be reliable and rugged to ensure HCVS functionality following a seismic event

5.3.1.3. Additionally, non-safety equipment installed to meet the requirements of Order EA-13-109 must be implemented so that they do not degrade the existing safety-related systems

5.3.1.4. Design quality requirements and supporting analysis documentation should be auditable, consistent with generally accepted engineering principles and practices, and controlled within the configuration document control system

5.4. Maintenance Requirements

Order Reference: 1.2.13 – The HCVS shall include features and provision for the operation, testing, inspection and maintenance adequate to ensure that reliable function and capability are maintained.

5.4.1. HCVS equipment should be initially tested or other reasonable means used to verify performance conforms to the design and operational requirements.

5.4.2. Validation of source manufacturer quality is not required.

5.4.3. The HCVS maintenance program should ensure that the HCVS equipment reliability is being achieved in a manner similar to that required for FLEX equipment. Standard industry templates (e.g., EPRI) and associated bases may be developed to define specific maintenance and testing.

5.4.3.1. Periodic testing and frequency should be determined based on equipment type and expected use (further details are provided in Section 6 of this document).

5.4.3.2. Testing should be done to verify design requirements and/or basis. The basis should be documented and deviations from vendor recommendations and applicable standards should be justified.

5.4.3.3. Preventive maintenance should be determined based on equipment type and expected use. The basis should be documented and deviations from vendor recommendations and applicable standards should be justified.

5.4.3.4. Existing work control processes may be used to control maintenance and testing.

5.4.4. HCVS permanent installed equipment should be maintained in a manner that is consistent with assuring that it performs its function when required.

5.4.4.1. HCVS permanently installed equipment should be subject to maintenance and testing guidance provided to verify proper function.

5.4.5. HCVS non-installed equipment should be stored and maintained in a manner that is consistent with assuring that it does not degrade over long periods of storage and that it is accessible for periodic maintenance and testing.

6. OPERATIONAL CONSIDERATIONS

6.1. Operator Actions

During the extended loss of AC power condition at the Fukushima Dai-ichi units, operators faced many challenges while attempting to restore adequate core cooling in addition to complications associated with controlling containment pressure via the containment venting system. The difficulties faced by the operators related to operation of the containment venting system included the location of their vent valves, ambient temperatures and radiological conditions, loss of all alternating current electrical power, loss of motive force to open the vent valves, and exhausting DC battery power. The use of a hardened containment vent provides an important method of containment heat removal which can become necessary for an ELAP/loss of Ultimate Heat Sink (UHS) event. Indirectly, an elevated containment pressure may prevent the injection from a low head water supply to the RPV. Operator actions are a vital part of normal and off-normal plant activities and are expected to play an important role in mitigation of beyond design basis external events. It is fully recognized that operator actions will be needed to implement the EA-13-109 severe accident capable HCVS; however, the licensees should consider design features for the system that will minimize the need and reliance on operator actions to the extent possible during a variety of plant conditions, as further discussed in this guidance. Actions should be simple and easily accomplished with direct feedback to indicate when the action is successfully accomplished.

The HCVS should be designed to be operated from a control panel located in the main control room or a remote but readily accessible location. The HCVS should be designed to be fully functional and self-sufficient with permanently installed equipment in the plant, without the need for portable equipment or connecting thereto, until such time that on-site or off-site personnel and portable equipment become available. At least one method of operation of the HCVS should be capable of operating with permanently installed equipment for at least 24 hours during the extended loss of AC power. The system should be designed to function in this mode with permanently installed equipment providing electrical power (e.g., DC power batteries or electrical or pneumatic operation) valve motive force (e.g., N_2/air cylinders). The HCVS operation in this mode depends on a variety of conditions, such as the cause for the extended loss of AC power (e.g., seismic event, flood, tornado, high winds), severity of the event, and time required for additional help to reach the plant, move portable equipment into place, and make connections to the HCVS. The system should be designed to function in this mode for a minimum duration of 24 hours with no operator actions required or credited to replenish electrical power and pneumatic supplies. Operator action is expected to perform system alignment and monitoring functions from either the primary (1.2.4) or alternate (1.2.5) locations as needed for event mitigation. To ensure continued operation of the HCVS beyond 24 hours, licensees may credit manual actions, such as moving portable equipment to supplement electrical power and valve motive power sources.

For the period of sustained operation beyond the initial 24 hours after event initiation, the licensee should consider the number and complexity of actions and the cumulative demand on personnel resources that are needed to maintain hardened vent functionality as a result of design limitations. The use of supplemental portable power or pneumatic sources may be acceptable if the supplemental power or pneumatic source is readily available, could be quickly and easily moved into place, and installed through the use of pre-engineered quick disconnects, and the necessary human actions were identified along with the time needed to complete those actions. Conversely, supplemental power sources that require a qualified electrician or mechanic to temporarily wire into the panel or connect to a piping system would not be considered acceptable because its installation requires a series of complex, time-consuming actions in order to achieve a successful outcome.

6.1.1. Feasibility and Accessibility

During an extended loss of AC power, the drywell, wetwell (torus or suppression pool), and nearby areas in the plant where HCVS components including instrumentation are expected to be located will likely experience elevated temperatures due to inadequate containment cooling combined with loss of normal and emergency building ventilation systems. In addition, installed normal and emergency lighting in the plant may not be available. Licensees should take into consideration plant conditions expected to be experienced during applicable beyond design basis external events when locating valves, instrument air supplies, and other components including instrumentation that will be required to safely operate the HCVS system. Components required for manual operation should be placed in areas that are readily accessible to plant operators, and not require additional actions, such as the installation of ladders or temporary scaffolding, to operate the system.

6.1.1.1. The design strategy should evaluate potential plant conditions and use acquired knowledge of these areas to provide input to system operating procedures, training, the choice of protective clothing, required tools and equipment, and portable lighting. The evaluation should include considerations such as, how temperatures would elevate due to extended loss of AC power conditions and the lighting that would be available following beyond design basis external events. Use of handheld or portable lighting is acceptable.

6.1.1.2. The design of the HCVS should account for radiological conditions resulting from the beyond design basis external event including dominant severe accident impacts. During the Fukushima event, personnel actions to manually operate the containment vent valves were impeded due to the location of the valves in the torus (suppression pool) rooms. The HCVS should be designed to be placed in operation by operator actions at a control panel, located in the main control room or in a suitable alternate location (Requirements 1.2.4 and 1.2.5). The design of the severe accident capable HCVS system will take into account the radiological conditions that may be encountered during system operation. The use of shielding and locating components having significant source term away from system control stations where the system will be operated are the primary means available to control operational dose. Additional means of minimizing potential radiological dose to the operators may include, but are not limited to:

6.1.1.2.1. Simplification of operator actions needed to initiate, control and isolate the system including replenishment of electrical power and pneumatics during the sustained operational period.

6.1.1.2.2. Use of rupture diaphragms are an acceptable component to address inadvertent actuation and leakage, but require operator action to initiate venting at lower pressures than the rupture diaphragm setting. Thus the ability to open the vent path by reasonable operator actions must be addressed if rupture diaphragms are installed in the HCVS.

6.1.1.2.3. Minimizing the time operators need to spend at the vent controls or monitoring locations during system operation under severe accident conditions.

6.1.1.2.4. Minimizing the number of operators needed to operate and maintain the system functional under severe accident conditions.

6.1.1.2.5. Developing a strategy to rotate operators through the various venting actions to minimize the dose received by any one operator.

6.1.1.3. In response to Generic Letter (GL) 89-16, a number of facilities with Mark I containments installed vent valves in the torus (suppression pool) room, near the drywell, or both. Licensees may continue to use these venting locations or select new locations, provided that the requirements of this guidance document are satisfied.

6.1.1.4. The HCVS improves the chances of mitigating a core damage accident by removing heat from containment and lowering containment pressure. Radiological and thermal impacts to the plant from the HCVS within the plant and at the location of the external release could impact the event response from on-site operators and off-site help arriving at the plant. An adequate strategy to minimize radiological consequences that could impede personnel actions should include the following:

6.1.1.4.1. Provide permanent radiation shielding where necessary to facilitate personnel access to valve controls that allow manual operation of the valves at a remote manual location. Other alternatives to facilitate personnel access besides radiation shielding can be utilized, such as:

6.1.1.4.1.1. Provide features to facilitate manual operation of valves from remote locations, as discussed further in this guidance.

6.1.1.4.1.2. Locate the vent valves in areas that are significantly less challenging to operator access/actions.

6.1.1.5. In accordance with Requirement 1.2.10 and 1.2.11, the HCVS should be designed for pressures that are consistent with the higher of the primary containment design pressure and the primary containment pressure limit (PCPL), for specification purposes, as well as including dynamic loading resulting from system actuation and hydrogen deflagration or detonation if the gases passing through the system cannot be maintained below flammability limits. The capacity for venting should be based on the lower pressure value because the flow characteristics are more limiting at the lower pressure. In addition, the system should minimize leakage. As such, ventilation duct work (i.e., sheet metal) should not be utilized in the design of the HCVS. Licensees should perform appropriate testing, such as hydrostatic or pneumatic testing, to establish the leak-tightness of the HCVS. System actuation should consider the dynamics of the driving force for the venting such as the pressure fluctuations from SRV actuations, etc.

6.1.1.6. The HCVS release to outside atmosphere should be at an elevation higher than adjacent power block plant structures. Release through existing plant metrological stacks is considered acceptable, provided the guidance under

Requirements 1.2.3 and 1.2.11 are satisfied. If the release from HCVS is through a vent stack different than the plant metrological stack, the elevation of the stack should be higher than the nearest power block building or structure. The routing should be such that radiological conditions resulting from operation of the HCVS would allow event response by the on-site operators and off-site help arriving at the plant without requiring heroic actions.

6.1.1.7. The required Operator actions to operate the HCVS under the design conditions required by Order items 1.1.2 and 1.1.3 at the plant specified operating locations need to be evaluated.

6.1.1.7.1. The operations should be feasible for the control locations for conducting the operations under the beyond design basis external event conditions. These expected conditions can be obtained from available generic or plant-specific accident analysis.

6.1.1.7.2. The timing of the operations should be taken into consideration (e.g., operation of the equipment during the worst source term release is not required if the station could be accessed prior to the release and after the release for control of radiological dose) for this accessibility/feasibility evaluation.

6.1.1.7.3. Guidance is supplied in Appendix D, F,E and G of this guide for this evaluation. Elements of the evaluations can utilize NUREG 1921/1852 [Ref. 23 and 24] guidance and/or procedural controls.

6.1.1.8. Environmental conditions and effects on operators need to be considered during event response and sustained operation timelines.

6.1.2. Procedural Guidance

6.1.2.1. Procedures to operate, test, and maintain the severe accident capable HCVS during ELAP conditions should include the following elements:

6.1.2.1.1. HCVS operation including system startup, shutdown and off-normal conditions.

6.1.2.1.2. HCVS standby status verification.

6.1.2.1.3. System out of service controls.

6.1.2.1.4. Location of system components and equipment lineups (may be part of other plant system procedures).

6.1.2.1.5. HCVS instrumentation available that supports HCVS operation.

6.1.2.1.6. Directions for sustained operation using portable equipment and supplies, which supports HCVS operation.

6.1.2.1.7. Storage location of portable equipment.

6.1.2.1.8. Equipment testing and maintenance.

6.1.2.1.9. CAP is credited by some (typically earlier) plants to meet RG 1.1 in a LOCA. Specifically CAP in a LOCA is credited to ensure that the ECCS pumps have adequate NPSH. LOCA is a DBE. If applicable, the nexus between containment accident pressure (CAP) and the ECCS and containment heat removal pump net positive suction head during a design basis LOCA (DBLOCA) and how an inadvertent opening of the vent valve could have an adverse impact on the operation of those pumps. For an ELAP event a LOCA is not considered and ECCS pumps are not available. The HCVS design should ensure that inadvertent opening of the vent path in a DBE is not credible. The procedures should also address the precautions that should be taken to assure adequate net positive suction head before restarting those pumps upon restoration of onsite or offsite power during an ELAP event.

6.1.2.2. HCVS procedures should be developed and implemented in the same manner as other plant procedures.

6.1.2.3. HCVS procedures for operation need to be validated for operator usability/accessibility and should address the following functional operations:

6.1.2.3.1. With power on normal power sources. [no ELAP]

6.1.2.3.2. With backup power and from local manual location/alternate remote location during conditions of ELAP/loss of UHS with no core damage for containment heat removal AND containment pressure control (PCPL). [FLEX]

6.1.2.3.3. With backup power and from local manual location/alternate remote location during conditions of ELAP/loss of UHS with core damage and vessel breach for containment heat removal AND containment pressure control (PCPL). [Severe Accident Capable Vent]

6.1.2.4. Coordination with guidance and procedures

The Licensee should verify that the procedures for HCVS operation are coordinated with other procedures. The following relationships should be evaluated to address this coordination:

6.1.2.4.1. Coordinate EOPs and SAGs with hardened containment vent operation on normal power sources (no ELAP)

6.1.2.4.2. Coordinate Abnormal Operating Procedures (AOPs), EOPs, SAGs and FLEX Support Guidelines (FSGs) with hardened containment vent operation on normal and backup power and from primary and alternate locations during conditions of ELAP/loss of UHS with no core damage. System use is for containment heat removal AND containment pressure control

6.1.2.4.3. Coordinate SAGs with HCVS operation on normal and backup power and from primary and alternate locations during conditions of ELAP/loss of UHS with core damage and vessel breach. System use is for containment heat removal AND containment pressure control (PCPL) with potential for combustible gases.

6.1.2.4.4. Coordinate administrative controls for FLEX and HCVS equipment allowed outage times and compensatory actions.

6.1.2.5. Demonstration with other Post Fukushima measures

The Licensee should demonstrate use in drills, tabletops, or exercises for HCVS operation as follows:

6.1.2.5.1. Hardened containment vent operation on normal power sources (no ELAP).

6.1.2.5.2. During FLEX demonstrations (as required by EA-12-049: Hardened containment vent operation on backup power and from primary or alternate location during conditions of ELAP/loss of UHS with no core damage. System use is for containment heat removal AND containment pressure control.

6.1.2.5.3. HCVS operation on backup power and from primary or alternate location during conditions of ELAP/loss of UHS with core damage. System use is for containment heat removal AND containment pressure control with potential for combustible gases (Demonstration may be in conjunction with SAG change).

6.1.3. Training

6.1.3.1. All personnel expected to operate the HVCS should receive initial and continuing training in the use of plant procedures developed for system operations when either normal or backup power is available and during ELAP/loss of UHS conditions consistent with the specific elements of the plant's training program.

6.1.3.2. The training should be refreshed on a periodic basis consistent with the procedure control process at the plant site or when procedural related changes occur to the HCVS.

6.1.3.3. Training should also ensure that specific guidance and procedures that direct HCVS Operation is referenced and used in formulation of the training (e.g., EOPs, FSGs, SAGs,).

6.1.3.4. When determining the required HCVS training a "task analysis" or similar site acceptable process should be used.

6.1.3.5. Training for use of any FLEX equipment in a support role will be governed by the actions developed for compliance with order EA-12-049.

6.1.3.5.1. The use of a Systematic Approach to Training (SAT) based training program to determine required training and frequency may be used to demonstrate compliance with the training requirements of Order EA-13-109 in lieu of the specific elements defined in 6.1.3.1 through 6.1.3.4.

6.2. Testing and Inspection of HCVS.

6.2.1. The HCVS design should provide a means (e.g., drain valves, pressure and temperature gauge connections) to periodically test system components including instrumentation, including exercising (opening and closing) the vent valve(s).

6.2.2. Primary and secondary containment required leakage testing is covered under existing design basis testing programs.

6.2.3. The HCVS outboard of the containment boundary should be tested to ensure that vent flow is released to the outside with minimal leakage, if any, through the interfacing boundaries with other systems or units.

6.2.3.1. The testing method can either individually leak test interfacing valves or test the overall leakage of the HCVS volume by conventional leak rate testing methods.

6.2.3.2. The test volume should envelope the HCVS between the outer primary containment isolation barrier and the last isolation point from the plant buildings, including the volume up to the interfacing valves.

6.2.3.3. The test pressure should be based on the HCVS design pressure. Methods for testing system boundary leakage should be consistent with the licensee's design basis for these tests (e.g., permissible leakage rates for the interfacing valves should be within the requirements of American Society of Mechanical Engineers Operation and Maintenance of Nuclear Power Plants Code (ASME OM) – 2009, Subsection ISTC – 3630 (e) (2) [Ref. 25], or later edition of the ASME OM Code.)

6.2.3.4. When testing the HCVS volume, allowed leakage should not exceed the sum of the interfacing valve leakages as determined by the licensee's test program (e.g., ASME OM Code).

6.2.3.5. For HCVS designs that contain interfacing valves between the HCVS and an isolated system, i.e. systems that do not vent to atmosphere. An assessment of the impact of cumulative leakage past interfacing valves into an isolated system should be performed. The results of the assessment should be used in establishing the leakage limits for interfacing valves between the HCVS and the isolated system(s).

6.2.3.5.1 When interfacing components including instrumentation are found to be degraded such that the HCVS function cannot be assured, then an entry into the plants Corrective Action Program shall be made to address the cause(s) of the non-functionality of the HCVS and prevent recurrence.

6.2.4. Licensees should implement the following operation, testing and inspection requirements for the HCVS to ensure reliable operation of the system.

Testing and Inspection Requirements

Description	Frequency
Cycle the HCVS valves and the interfacing system valves not used to maintain containment integrity during operations.	Once per operating cycle
Perform visual inspections and a walkdown of HCVS components.	Once per operating cycle
Test and calibrate the HCVS radiation monitors.	Once per operating cycle
Leak test the HCVS.	(1) Prior to first declaring the system functional; (2) Once every three operating cycles thereafter; and, (3) After restoration of any breach of system boundary within buildings.
Validate the HCVS operating procedures by conducting an open/close test of the HCVS control logic from its control panel and ensuring that all interfacing system valves move to their proper (intended) positions.	Once per every other operating cycle

6.3. Allowed out of service time for HCVS

6.3.1. The unavailability of equipment and applicable connection that directly performs an HCVS function should be managed such that HCVS functionality is maximized. The primary control and monitoring elements (1.2.4) and alternate valve control elements (1.2.5) of HCVS operation will normally be functional in Modes 1, 2 and 3. However the HCVS is not a single failure proof system, and as such the primary and alternate methods of HCVS operation do not imply system redundancy.

6.3.1.1. If the primary control and monitoring elements or alternate valve control elements of HCVS render operation of the HCVS non-functional, those elements may be out of service for periods of up to 90 consecutive days without any compensatory actions.

6.3.1.2. If the primary control and monitoring elements and alternate valve control elements of HCVS render operation of the HCVS non-functional, those elements may be out of service for periods of up to 30 consecutive days without any compensatory actions.

6.3.1.3. If the allowed out of service times described in 6.3.1.1 and/or 6.3.1.2 above are exceeded, then through the plant corrective action program determine:

6.3.1.3.1. The cause(s) of the non-functionality, 6.3.1.3.2. The actions to be taken and the schedule for restoring the system to functional status and prevent recurrence, and

6.3.1.3.3. Initiate action to implement appropriate compensatory actions.

6.3.2. The HCVS system is functional when piping, valves, instrumentation and controls including motive force necessary to support system operation are available. Since the system is designed to allow a primary control and monitoring or alternate valve control by Order criteria 1.2.4 or 1.2.5, allowing for a longer out of service time with either of the functional capabilities maintained is justified. A shorter length of time when both primary control and monitoring and alternate valve control are unavailable is needed to restore system functionality in a timely manner while at the same time allowing for component repair or replacement in a time frame consistent with most high priority maintenance scheduling and repair programs, not to exceed 30 days unless compensatory actions are established per 6.3.1.2.

6.3.3. The system functionality basis is for coping with beyond design basis events and therefore plant shutdown to address non-functional conditions is not warranted. However, such conditions should be addressed by the corrective action program and compensatory actions to address the non-functional condition should be established. These compensatory actions may include alternative containment venting strategies or other strategies needed to reduce the likelihood of loss of fission product cladding integrity during design basis and beyond design basis events even though the severe accident capability of the vent system is degraded or non-functional. Compensatory actions may include actions to reduce the likelihood of needing the vent but may not provide redundant vent capability.

6.3.4. Applicability for allowed out of service time for HCVS for system functional requirements is limited to startup, power operation and hot shutdown conditions when primary containment is required to be operable and containment integrity may be challenged by decay heat generation.

7. REPORTING REQUIREMENTS

Licensees shall promptly start implementation of the requirements in Attachment 2 to Order EA-13-109, *Order Modifying Licenses with regard to Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions*, upon NRC issuance of the associated final interim staff guidance (ISG) for each Phase (reference section IV.B of Order EA-13-109). In accordance with NRC Order EA-13-109 the following reporting requirements are established.

7.1. Submittal Guidance

7.1.1. All Licensees shall notify the Commission if they are unable to comply with any of the Phase 1 requirements or if any of the Phase 1 (wetwell vent) requirements would adversely affect the safe and secure operation of the facility within twenty (20) days of the issuance date of the final ISG for Phase 1, The notification shall provide the Licensee's justification for seeking relief from or variation of any specific requirement. Reference EA-13-109 C.1 & 2.

7.1.2. All Licensees shall notify the Commission if they are unable to comply with any of the Phase 2 requirements or if any of the Phase 2 (drywell vent) requirements would adversely affect the safe and secure operation of the facility within twenty (20) days of the issuance date of the final ISG for Phase 2, The notification shall provide the Licensee's justification for seeking relief from or variation of any specific requirement. Reference EA-13-109 C.3 & 4.

7.1.3. All Licensees shall, by June 30, 2014, submit to the Commission for review an Overall Integrated Plan (OIP) including a description of how compliance with the Phase 1 (wetwell vent) requirements will be achieved. Reference EA-13-109 D.1.

7.1.4. All Licensees shall, by December 31, 2015, submit to the Commission for review an updated OIP including a description of how compliance with the Phase 2 (drywell vent) requirements will be achieved. Reference EA-13-109 D.2.

7.1.5. All Licensees shall provide status reports at six (6)-month intervals following submittal of the Phase 1 (wetwell vent) OIP which delineates progress made in implementing the requirements of Order EA-13-109. Reference EA-13-109 D.3.

7.1.5.1. The issuance of the revision to the OIP which includes Phase 2 scope from 7.1.4 can substitute for the six (6)-month status report due on December 31, 2015.

7.1.5.2. The six (6)-month status reports beginning in 2016 shall include both Phase 1 and 2 scope.

7.1.5.3. Once Phase 1 scope is complete the six (6)-month status reports will only update Phase 2 items and leave the Phase

1 items as historical until compliance with both Phase 1 and 2 scope is complete.

7.1.6. All Licensees shall report to the Commission when full compliance with the requirements for Phase 1 and Phase 2 are achieved. Reference EA-13-109 D.4.

7.2. Overall Integrated Plan Template

The Overall Integrated Plan should include a complete description of the HCVS strategies, including important operational characteristics. The level of detail generally considered adequate is consistent to the level of detail contained in the Licensee's Final Safety Analysis Report (FSAR).

7.2.1. The OIP should provide the following information:

7.2.1.1. Extent to which this guidance, NEI 13-02, is being followed including a description of any alternatives to the guidance

7.2.1.2. A milestone schedule of planned actions

7.2.1.3. Description of the strategies and guidance to be developed to meet the requirements contained in Attachment 2 of the Order

7.2.1.4. Operational characteristics contained in this document, NEI 13-02 are being met.

7.2.1.5. Description of how the design features contained in section 4 of this guide are being met for the appropriate phase

7.2.1.6. Description of major installed and portable components used in the strategies, the applicable reasonable protection for the portable equipment, and the applicable maintenance requirements for the HCVS equipment.

7.2.1.7. Description of major system components including instrumentation, including applicable quality requirements

7.2.1.8. Description of the steps for the development of the necessary procedures, guidance, and training for the HCVS strategies including modifications to meet the requirements contained in this document, NEI 13-02.

7.2.1.9. Conceptual sketches, as necessary to indicate equipment which is installed or equipment hookups necessary for the strategies.

7.2.1.9.1. A preliminary or draft piping and instrumentation diagram (P&ID) or a similar diagram that shows system components including instrumentation and interfaces with plant systems and structures is acceptable piping and instrumentation diagrams should be included in the OIP, while as-built

P&IDs will be available upon completion of plant modifications

7.2.1.9.2. A preliminary or draft electrical/air motive force functional connection sketch should be included in the OIP.

7.2.1.10. Description of how the portable HCVS equipment will be available to be operable during BDBEE and Severe Accident events as defined in this document, NEI 13-02.

7.2.2. Phase 1, wetwell vent OIP shall be submitted by June 30, 2014 that should include a description of how compliance with the “Phase 1” requirements described in Attachment 2 of the Order will be achieved within the required schedule.

7.2.2.1. The Phase 1 OIP should include the items delineated in section 7.1.1 as well as the following items:

7.2.2.1.1. A description of how the design objectives contained in section 2 of this guide, NEI 13-02 are met

7.2.2.1.2. When applicable to a specific Licensee, include details on how this issue will be addressed for all situations when CAP credit is required

7.2.2.2. An industry template will be provided that defines the essential information for this submittal.

7.2.3. By December 31, 2015, a revision of the Phase 1 OIP including a description of the approach to the Phase 2 requirements described in Attachment 2 of the Order will be achieved within the required schedule shall be submitted.

7.2.3.1. The Phase 2 OIP revision should address the items delineated in section 7.1.1 as it relates to Phase 2 as well as the following items:

7.2.3.1.1. A description of how the design objectives contained in section 3 of this guide, NEI 13-02 are met

7.2.3.1.2. When applicable to a specific Licensee, include details on how this issue will be addressed for all situations when CAP credit is required

7.2.3.2. A justification for meeting Phase 2 via conditions allowed in Phase 2 B.2 option from the Order and delineated in Appendix C of this guide can replace the criteria from 7.2.3.1 above

7.2.3.3. An industry template will be provided that defines the essential information for this submittal (revision).

7.3. Six (6)-Month Updates

7.3.1. The 6-month status submittal should delineate progress made in implementing the requirements of the Order and include the following information

7.3.1.1. An update of the milestone schedule from the OIP

7.3.1.2. A brief summary of the milestones from the OIP completed in the preceding six-month period

7.3.1.3. Changes to the compliance method as stated in the OIP or OIP revision

7.3.1.3.1. Revisions to the OIP detailed implementation details that follow the criteria of NEI 13-02 and comply with the Order requirements need not be submitted to the NRC, but should be documented for inspection after compliance is obtained.

7.3.1.4. Changes to the compliance schedule as required by the Order or revised in other NRC communication on this topic

7.3.1.5. Provide update of any open items from the OIP, RAIs or Draft SER.

7.3.2. The 6-month status submittal should not be a revised OIP except for the December 31, 2015 update which could be replaced with the Phase 2 OIP revision submittal.

7.3.3. An industry template will be provided that defines the essential information for the 6-month status submittal.

8. REFERENCES

1. USNRC, Order EA-13-109, “Order Modifying Licenses with Regard to Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions,” June 6, 2013 (ADAMS Accession No. ML13143A321).
2. USNRC, Order EA-12-050, “Order Modifying Licenses with Regard to Reliable Hardened Containment Vents,” March 9, 2012 (ADAMS Accession No. ML12054A694).
3. USNRC, SRM SECY-12-0157, “Staff Requirements - SECY-12-0157, ”Consideration Of Additional Requirements For Containment Venting Systems For Boiling Water Reactors With Mark I And Mark II Containments”, March 19, 2013 (ADAMS Accession No. ML13078A017).
4. USNRC, Order EA-12-049, “Order Modifying Licenses with Regard to Requirements For Mitigation Strategies For Beyond-Design-Basis External Events,” March 12, 2012 (ADAMS Accession No. ML12054A735).
5. USNRC, JLD-ISG-2012-02, Revision 0, “Compliance with Order EA-12-050, Reliable Hardened Containment Vents”, Interim Staff Guidance, September 29, 2012 (ADAMS Accession No. ML 12229A475).
6. USNRC – SECY-11-0093, “Near Term Task Force 90 Day Report”, (ADAMS Accession No. ML111861807).
7. USNRC – SRM SECY-11-0124, “Recommended Actions to be taken Without Delay From The Near-Term Task Force Report”, (ADAMS Accession No. ML112911571).
8. USNRC – SRM SECY-11-0137, “Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned”, (ADAMS Accession No. ML113490055).
9. NUREG-1935, State-of-the-Art-Reactor Consequence Analysis (SOARCA) Report (ADAMS Accession No. ML12332A057/ML12332A058)
10. "Mark I Containment Severe Accident Analysis." Prepared for the Mark I Owners Group, Chicago, IL: Chicago Bridge & Iron, NA-CON, April 1987
11. NUREG/CR-2442 U.S. Nuclear Regulatory Commission, Division of Technical Information & Document Control, “Reliability Analysis of Steel Containment Strength”, Grieman, L.G. et al., June 1982.
12. NUREG/CR-5334, “Severe Accident Testing of Electrical Penetration Assemblies”, Clauss, D.B., November 1989
13. NUREG/CR-3234; SAND83-0538, “The Potential for Containment Leak Paths Through Electrical Penetration Assemblies Under Severe Accident Conditions”, Wayne Sebrell, dated July 1983.
14. NUREG/CR-4064, "Structural Response of Large Penetrations and Closures for Containment Vessels Subjected to Loadings Beyond Design Basis," R.F. Kulak et al., February, 1985

15. NUREG/CR-4944, “Containment Penetration Elastomer Seal Leak Rate Tests”, Bridges T.L., July 1987.
16. DE-ACO4-76DP00789, "Performance of Seals and Gaskets Under Severe Accident Conditions," Koenig L., Sandia National Laboratory, pp. 174-180.
17. NUREG/CR-2475, Hydrogen Combustion Characteristics Related to Reactor Accidents (ADAMS Ascension No. ML071700446)
18. NUREG/CR-6524, The Effect of Lateral Venting on Deflagration-to-Detonation Transition in Hydrogen-Air-Steam Mixtures at Various Initial Temperatures (ADAMS Ascension No. ML071650492)
19. General Electric Nuclear Energy Services Information Letter, GE SIL 643, Potential for Radiolytic Gas Detonation, dated June 14, 2002
20. NEI 12-06 Rev 0, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide (ADAMS Ascension No. 12221A205)
21. USNRC, JLD-ISG-2012-01, Revision 0, “Compliance with Order EA-12-049, Order Modifying Licenses with Regard to Requirements for Mitigating Strategies for Beyond-Design-Bais External Events”, Interim Staff Guidance, August 29, 2012 (ADAMS Accession No. ML 12229A174)
22. USNRC, JLD-ISG-2012-03, Revision 0, “Compliance with Order EA-12-051, Reliable Spent Fuel Pool Instrumentation”, Interim Staff Guidance, August 29, 2012 (ADAMS Accession No. ML 12221A339)
23. NUREG-1921, EPRI/NRC-RES Fire Human Reliability Analysis Guidelines (ADAMS Ascension No. ML093350494)
24. NUREG-1852, Demonstrating the Feasibility and Reliabilityof Operator Manual Actions in Response to Fire (ADAMS Ascension No. ML073020676)
25. ASME OM-2009, Operation and Maintenance of Nuclear Power Plants

APPENDIX A – GLOSSARY OF TERMS

This glossary provides definitions of key terms used in this guidance document and an acronym listing.

A.1 Definitions:

These definitions have been made consistent with other external definitions, to the degree possible, but the definitions herein represent the expressed intent of the terms as used in this guidance.

Active Function: A function that requires mechanical motion or a change of state (e.g., the closing of a valve or relay contacts or the change in state of a transistor

Beyond Design Basis Requirements: Provide reasonable confidence in a flexible operational capability for responding to an unbounded class of event conditions

Containment: For the purpose of this guidance, the principal enclosure that acts as a leak-tight barrier, to prevent the release of radioactive material from the structure, system, and component (SSC) containing the radioactive material under DBE conditions.

Current Design Basis Requirements: Provide a high level of assurance of design capability to address a defined set of event conditions

Elevated Release: Release of steam outside the reactor building and other critical buildings necessary for safe shutdown

Hardened Containment Vent System (HCVS): A group of physically interconnected components including instrumentation that together perform the specified design function as defined by Order EA-13-109 and this guide.

Hardened Pathway:

- Release of steam, hydrogen or radionuclides at an elevation above the reactor building roof.
- A vent pathway designed to withstand pressures consistent with existing containment design and avoid steam impacts within the Reactor Building.
- A vent pathway designed to withstand PCPL pressures and avoid hydrogen or radionuclide releases or re-entrainment within unacceptable locations such as the Reactor Building or Control Building.
- New venting capability should not change the design basis. The vent capability should be seismically and flooding informed, analogous to risk-informed. The containment function must be protected.

Mission Time: The operational or available time a component is required to perform its function. This time may vary by component but the cumulative mission time for credited components including instrumentation performing a required installed plant HCVS equipment function should be no less than the first 24 hours post event. Multiple pieces of equipment may be used to obtain the required time duration, such as two (2) half (1/2) size accumulators to obtain the required 24 hours of installed capacity.

Passive Function: A function that is not an active function (e.g., the pressure-retaining function of a valve, a structural element, pipe support, cable, etc. that is not required to change position in order to perform its design function).

Performance Based: Performance objectives for the design of hardened vents to ensure reliable operation and ease of use (both opening and closing) during a prolonged SBO, ELAP

Primary Containment Pressure Limit (PCPL): Defined in Rev 4 BWROG EPGs in order to maintain containment integrity

Public: For the purpose of this guidance, all individuals outside a geographic boundary within which public access is controlled and activities are governed by the operator of a reactor nuclear facility.

Redundant Equipment or System: Equipment or system that duplicates the essential function of another piece of equipment or system to the extent that either may perform the required function regardless of the state of operation or failure of the other.

Regulatory Requirement: For the purpose of this guidance, a requirement stemming directly, or indirectly, from a regulation established by a regulatory agency (e.g., the Code of Federal Regulations (CFR), or an NRC license).

Reliable: Capable of performing its required function in the desired manner under all the relevant conditions and on the occasions or during the time intervals when it is required so to perform. [Source: A.E. Green and A.J. Bourne, Reliability Technology, Wiley-Interscience, 1972.] The vent can be used when needed by procedures, and be usable across a spectrum of events to include both prevention and mitigation of severe core damage

Seismically Reliable and Rugged Performance: A term used to describe the design of components including instrumentation beyond the second containment isolation barrier to ensure that the HCVS is able to remain functional following a design basis seismic event. While the design and construction must meet the plant's design basis earthquake seismic requirements, licensees may use commercial grade components and materials beyond the second containment isolation barrier. Thus, licensees are not required to qualify piping, supports and other related components in accordance with NRC requirements for safety related structures, systems, and components, including Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," for this portion of the system.

Severe Accident: An accident that involves extensive core damage and fission product release into the reactor vessel and containment with potential release to the environment. Severe accidents include both scenarios in which all core debris is cooled in-vessel (similar to the accident at TMI-2) and scenarios in which core debris breaches the reactor coolant boundary and relocates into containment, with some of the core debris remaining within the reactor vessel.

Severe Accident Hardened Containment Vent System

- The containment venting function should presume the occurrence of significant core damage and the presence of hydrogen. (This is a defense-in-depth requirement and should be considered one of the missions of the hardened vent system)
- The vent should be capable of operation to limit pressure to the PCPL, and to permit depressurization at any time, for example, to enable low pressure coolant injection into the RPV
- Operators should be able to vent containment from the wetwell and drywell(if chosen as the Phase 2 option) using permanently installed equipment under prolonged SBO conditions, ELAP
- Venting system should minimize the use of common systems between units and not interfere with the operation of other safety and non-safety equipment

Single Failure: A random failure (e.g., single component failure or operator error) and its consequential effects, in addition to an initiating occurrence, which result in the loss of capability of a component to perform its intended function. Fluid and electrical systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor (2) a single failure of any passive component (assuming active components function properly) results in a loss of capability of the system to perform its safety function(s).

Sustained Operation: The ability to operate 7 days or a shorter time if an alternative method of containment heat removal is put in place by using installed or portable equipment (e.g., a means of shutdown cooling aligned directly to the RPV, drywell or a means of suppression pool cooling). Use of the Hardened Containment vent should not be the means of containment heat removal after this time. Some containment source term control is inherent with the longer term (>7 day or alternate means) containment heat removal function; however, addressing site source term control functionality will be governed by the ERO Recovery actions versus activities associated with NEI 13-02 or Order EA-13-109. This definition does not apply to Order EA-12-049 phase 1, 2, or 3 equipment unless the equipment is repurposed under Order EA-13-109.

A.2 Acronyms and Abbreviations

Acronym	Description
AC	Alternating Current
AOP	Abnormal Operating Procedure
AOV	Air Operated Valve
ASME	American Society of Mechanical Engineers
BDBE	Beyond Design Basis Event
BDBEE	Beyond Design Basis External Event
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners' Group
CAP	Containment Accident Pressure
CLB	Current License Basis
DBE	Design Basis Event
DBLOCA	Design Basis Loss of Coolant Accident
DC	Direct Current
DW	Drywell
ECCS	Emergency Core Cooling System
EDMG	Extreme Damage Mitigation Guideline
ELAP	Extended Loss of AC Power
EOP	Emergency Operating Procedure
EPGs	Emergency Procedure Guidelines
EPRI	Electric Power Research Institute
ERO	Emergency Response Organization
FSG	FLEX Support Guideline
GDC	General Design Criteria
GE	General Electric
HCVS	Hardened Containment Vent System
ISG	Interim Staff Guidance
LOCA	Loss of Coolant Accident
LUHS	Loss of Ultimate Heat Sink
MCCI	Molten Corium Concrete Interaction
MOV	Motor Operated Valve
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
NTTF	Near Term Task Force
OIP	Overall Integrated Plan
P&ID	Piping and Instrumentation Diagram
PCIV	Primary Containment Isolation Valve
PCPL	Primary Containment Pressure Limit
PSP	Pressure Suppression Pressure
RAI	[NRC] Request for Additional Information
RCIC	Reactor Core Isolation Cooling
RPV	Reactor Pressure Vessel

Acronym	Description
RRC	Regional Response Center
SAGs	Severe Accident Guidelines
SAMG	Severe Accident Management Guidelines
SAT	Systematic Approach to Training
SBO	Station Blackout
SER	[NRC] Safety Evaluation Report
SOV	Solenoid Operated Valve
SRV	Safety Relief Valve
TMI	Three Mile Island
TOC	Table of Contents
UFSAR	Updated Final Safety Analysis Report
UHS	Ultimate Heat Sink

APPENDIX B – ROADMAP OF ORDER REQUIREMENTS

The purpose of this appendix is to provide a cross-reference of the requirements contained in the revised Order EA-13-109 against the requirements of the original Order EA-12-050 and identifies where the requirements are addressed in this guidance document.

B.1 Structure of Roadmap

Table B-1 lists each requirement of Order EA-13-109, "Order Modifying Licenses With Regard To Reliable Hardened Containment Vents Capable Of Operation Under Severe Accident Conditions" [Ref. B-1] against the requirements of the original Order [Ref. B-2] and the appropriate section in this document.

B.2 References

B.2.1 USNRC, Order EA-13-109, "Order Modifying Licenses with Regard to Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions," June 6, 2013 (ADAMS Accession No. ML13143A321).

B.2.2 USNRC, Order EA-12-050, "Order Modifying Licenses with Regard to Reliable Hardened Containment Vents," March 12, 2012 (ADAMS Accession No. ML12054A696).

Table B-1

Roadmap of Technical Requirements from Revised EA-12-050

EA-13-109 Order Requirement	Changes from EA-12-050	NEI 13-02 Applicable Guidance
HCVS Performance Objectives (Phase I)		
A.1.1.1 - Minimize the reliance on operator actions	No changes	4.2.6
A.1.1.2 - Minimize operators' exposure to occupational hazards	No changes	4.2.5, 6.1.1
A.1.1.3 – Account for radiological conditions that would impede event response	Wording change from "minimize radiological consequences" to "account for radiological consequences"	4.2.5, 6.1.1, Appendix F, Appendix G
A.1.1.4 – Accessible controls and indications	New Item, Specified in order item previously in ISG. "The HCVS shall be accessible and functional under a range of plant conditions, including a severe accident environment, extended loss of AC power and inadequate containment cooling"	4.1.3, Appendix F, Appendix G
HCVS Design Features		
A.1.2.1 - Capacity to vent 1 percent of thermal power	Added, "and the primary containment pressure limit (PCPL)." to end of sentence.	4.1.1
A.1.2.2 - Discharge the effluent to a release point above plant structures	No changes but renumbered (1.2.9 in EA-12-050)	4.1.5
A.1.2.3 - Design features to minimize cross flow	No changes but renumbered (1.2.6 in EA-12-050).	4.1.2, 4.1.4, 4.1.6
A.1.2.4 - Operation from control panel for sustained operations	Similar wording as 1.2.2 in EA-12-050, but included the definition of "sustained operation" in a footnote.	4.2.2

Table B-1

Roadmap of Technical Requirements from Revised EA-12-050

EA-13-109 Order Requirement	Changes from EA-12-050	NEI 13-02 Applicable Guidance
A.1.2.5 – Alternate manual operation capability	New Item, adds additional capability for system operation for defense in depth, not redundancy.	4.2.3
A.1.2.6 - Operation with permanently installed equipment for 24 hours	New Item, added prior ISG item. "The HCVS shall be capable of operating with dedicated and permanently installed equipment for at least 24 hours following the loss of normal power or loss of normal pneumatic supplies to air operated components during an extended loss of AC power."	2.5, 4.2.2, 4.2.6, 6.1
A.1.2.7 – Prevention of inadvertent actuation	No changes but renumbered (1.2.3 in Order EA-12-050).	4.2.1
A.1.2.8 – Monitoring of vent status from control panel	No substantive changes but renumbered (1.2.4 in Order EA-12-050). Added, "from the control panel installed in accordance with requirement 1.2.4"	4.2.2
A.1.2.9 - Means to monitor the effluent discharge	No substantive changes but renumbered 1.2.5 in Order EA-12-050). Added, "from the control panel installed in accordance with requirement 1.2.4"	4.2.4

Table B-1

Roadmap of Technical Requirements from Revised EA-12-050

EA-13-109 Order Requirement	Changes from EA-12-050	NEI 13-02 Applicable Guidance
A.1.2.10 - Design for severe accident & dynamic conditions	Significant changes from 1.2.8 in Order EA-12-050. Added design conditions to account for severe accident service of the HCVS to include temperature, radiation and combustible gas. Design consistent with limiting containment components.	2.3, 2.4, 4.1.1, 5.1
A.1.2.11 - Flammability control	New item related to hydrogen control. "The HCVS shall be designed and operated to ensure the flammability limits of gases passing through the system are not reached; otherwise, the system shall be designed to withstand dynamic loading resulting from hydrogen deflagration and detonation."	4.1.7, 4.1.7.1, 4.1.7.2, Appendix H
A.1.2.12 - Designed to minimize hydrogen gas migration	New item related to hydrogen control programs. "The HCVS shall incorporate strategies for hydrogen control that minimizes the potential for hydrogen gas migration and ingress into the reactor building or other buildings.	4.1.6, Appendix H
A.1.2.13 - Operation, testing, inspection and maintenance	No changes, renumbered (1.2.7 in Order EA-12-050).	5.4, 6.2

Table B-1

Roadmap of Technical Requirements from Revised EA-12-050

EA-13-109 Order Requirement	Changes from EA-12-050	NEI 13-02 Applicable Guidance
Quality Standards		
A.2.1 – Design basis of containment isolation function	No changes.	5.3
A.2.2 - Reliable and rugged performance	No changes.	5.2, 5.3
Programmatic Requirements		
A.3.1 - Develop, implement, and maintain procedures	No significant changes. Changed prolonged SBO to extended loss of AC power.	6.1.2, 6.1.2.1
A.3.2 - Train appropriate personnel	No significant changes. Changed prolonged SBO to extended loss of AC power.	6.1.3
Drywell Vent Functional Requirements (Phase 2)		
B.1.1 Meet performance objectives, design features, quality requirements, and programmatic requirements	New guidance on Drywell venting.	3
B.1.2 Justify confidence drywell vent is not necessary	New guidance on Drywell venting.	Appendix C

APPENDIX C – ASSESSMENT OF NEED FOR DRYWELL VENT

The purpose of this appendix is to provide a repeatable process for determining whether a drywell vent is needed under element B of the order. The idea behind providing a plant-specific example is two-fold: (1) help NRC see how it works so they can accept the methodology and (2) help utilities better understand how to apply it.

C.1 Methodology for Evaluating the Need for a Drywell Vent (Later)

C.2 Example Plant-specific Evaluation of the Need for a Drywell Vent (Later)

C.3 References (Later)

APPENDIX D – INTERFACE WITH FLEX

Order EA-13-109 calls for very clear definition of the boundary conditions to be applied to the design and operational considerations required to implement the HCVS associated with a severe accident capable vent. Compliance with NRC Order EA-12-049, FLEX is clearly a mitigation strategy for a BDBEE without core damage.

D.1. Interaction Between Order EA-12-049 and EA-13-109

D.1.1. Complying with Order EA-13-109 using components allocated to FLEX do not change the compliance methods or requirements for all aspects of complying with Order EA-12-049 using FLEX.

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.

D.1.3. Use of specific elements of FLEX to comply with Order EA-13-109 require only those specific elements to have additional criteria as defined in this guidance applied to ensure the credited function is available to meet the design, operational and maintenance criteria contained in this guide. The most likely FLEX functions that could be used for compliance to EA-13-109 are makeup air to the HCVS system connections (either primary or alternate control locations) and requisite power (either AC or DC) to either primary or alternate valve operating stations

D.1.3.1. Connections, staging and deployment for portable equipment and support functions must comply with Order EA-13-109 requirements as clarified in this guidance.

D.1.3.2. Connections, staging and deployment established for FLEX do not have to be applicable for compliance with Order EA-13-109. If this is the case then additional actions are required to provide compliance with Order EA-13-109 requirements as clarified in this guidance.

D.1.4. For ELAP and Loss of Ultimate Heat Sink (LUHS) BDBE that do not have core damage, FLEX analysis determines the timing for containment venting under Order EA-12-049 (ELAP/LUHS) conditions.

D.1.4.1. For ELAP and LUHS BDE that do not have core damage, FLEX will supply the analysis and method of water addition to the RPV. It also supplies AC/DC power and Key Parameter instrumentation, as defined in NRC endorsed guidance NEI 12-06 independent of HCVS

D.2. Onsite Portable Equipment Use

D.2.1. The HCVS may use on-site FLEX Phase 2 portable equipment as replenishment source for motive air

D.2.2. The HCVS may use on-site FLEX Phase 2 portable equipment as source of reliable DC power

D.2.3. The HCVS may use on-site FLEX Phase 2 portable equipment as source of AC power

D.2.4. The HCVS may use required FLEX Key Parameter instruments for monitoring Suppression Pool (Torus)/DW parameters such as those listed in section 4.2.2.1.9.

D.2.5. The HCVS may use FLEX Phase 1 or 2 Safety Support Functions strategies, as defined in the plant's FLEX OIP, for habitability in HCVS areas

D.3. Offsite Portable Equipment Use

D.3.1. The HCVS may use off-site FLEX Phase 3 portable equipment for any longer term actions which they are capable of addressing

D.3.2. The HCVS may use any available off-site portable equipment for any longer term actions which they are capable of addressing

D.3.3. These sets of off-site equipment will have to perform the functions identified in other sections of this document and only have to address the radiological, and habitability conditions expected to be present at the location and time of connection. With severe accident conditions other setup/connections may be necessary due to associated radiological and habitability concerns.

D.3.4. Accessibility and deployment conditions under the Order EA-13-109 conditions expected at the time of deployment and use should be addressed when determining the appropriate usability of portable equipment.

APPENDIX E – INTERFACE WITH GENERIC LETTER 89-16, INSTALLATION OF A HARDENED WETWELL VENT

The purpose of this appendix is to provide a clear understanding of the interface between Generic Letter 89-16, Installation of a Hardened Wetwell Vent, and order EA-13-109, Reliable Hardened Containment Vents Capable of Operation Under Severe Accident Conditions.

In 1989, the NRC issued Generic Letter 89-16, "Installation of a Hardened Wetwell Vent," to all licensees of BWRs with Mark I containments to encourage licensees to voluntarily install a hardened wetwell vent. In response, licensees installed a hardened vent pipe from the wetwell to some point outside the secondary containment envelope (usually outside the reactor building). Some licensees also installed a hardened vent branch line from the drywell. Because the modifications to the plant were performed in accordance with 10 CFR 50.59, "Changes, tests and experiments," detailed information regarding individual plant configurations was not submitted to the NRC staff for review. Subsequently, the NRC has issued orders to each plant via EA-13-109 to install reliable hardened containment vents capable of operation under severe accident conditions to be implemented in two phases; Phase 1 addresses the Wetwell vent path and Phase 2 the Drywell vent path. A review of the requirements of EA-13-109 phase 1 and Phase 2 concludes the requirements of this order bounds the previous requirements of GL 89-16. As such, licensees have a basis for changing commitments to GL 89-16 in accordance with NEI 99-04, Guidelines for Managing NRC Commitment Changes.

Design Elements of GL 89-16 (based on the Pilgrim design included in 89-16)	EA-13-109 requirement equivalent or greater
Provide venting capability equal to approximately 1% decay heat	Item 1.2.1
Vent the wetwell vapor space to a suitable release point (e.g. stack, reactor building or turbine building roof).	Item 1.2.2
Provide operability independent of AC power (note 1)	Item 1.1.4
Prevent inadvertent operation	Item 1.2.7
No single operator error can actuate the system	Item 1.2.7
Provide indication of valve position in the main control room	Item 1.2.8
Piping is safety related and supported as Class I up to the vent valve	Section 2
Class II items with potential to degrade the integrity of a Class I are analyzed.	Section 2

Note 1: It was proposed in the staff recommendation in SECY 89-17 that the hardened vent isolation valves be capable of being opened from the control room under station blackout conditions beyond the then-established coping time; however, the generic letter only requested that the licensee include costs for electrical modifications in a plant-specific basis for why the vent was not cost beneficial if a vent was not voluntarily installed. The installed vents in most cases were dependent on AC power.

References: SECY 89-17

APPENDIX F – METHOD TO EVALUATE OPERATOR DOSES

The purpose of this appendix is to provide a link to information on methods that are already established in response to regulatory dose considerations for fuel damage and core ex-vessel. The approach proposed to use to evaluate operator dose under the severe accident conditions that may be present under a EA-13-109 order scenario is the information from the well-established NUREG 0737. An example of this is the Direct Shine component for Main Control Room Habitability in the NUREG is an acceptable application for Order EA-13-109. The following information provides a general overview of some of those elements for personnel not readily familiar with the NUREG and its application.

While this appendix purports using the existing regulatory basis it is understood that the severe accident conditions that may be present under a EA-13-109 order scenario are beyond design basis conditions and there is no express or implied change in the regulatory position on other guidelines because of the use of that guidance in this document.

F.1 Methodology for Computation of Operator Doses

Personnel safety and accessibility will be important during the mitigation of a severe core damage accident. Opening of a containment vent with elevated radiation levels will pose some challenges to the operating staff. Various methods for routing the vent piping can reduce the impact on plant operations. Shielding of portions of the vent pipe can also be used to reduce exposure to plant personnel.

Attenuation coefficients can be obtained for various materials such as concrete (0.181 cm^{-1}) and lead (1.289 cm^{-1}) to allow for estimating the local radiation doses to plant personnel. More sophisticated analysis tools are available to assist the plant in evaluation of radiation doses expected during the venting operation for their specific routing. Whether using sophisticated analysis tools or hand calculations, multiple release pathways must be considered when evaluating possible sources of dose for plant personnel. While selectively routing vent pathways may assist in the mitigation of radiation effects on plant personnel, the vent paths themselves must be properly shielded in order to prevent shine through the walls of the vent paths (pipe walls). Furthermore, fission products and aerosols released from the containment have the potential to escape the reactor building through a stack or other pathways, depending upon vent path routing preferences. Any radiation released from the reactor building has the potential to shine back into various compartments of the reactor building, such as the main control room. Thus, it is also important to evaluate the effects of fission products and aerosols that could have potentially been released from the reactor building. While such effects are partially dependent upon scrubbing capabilities prior to the release of any trace gases beyond the boundary of the reactor building walls, meteorological effects, such as wind patterns and precipitation, may also affect overall dose to plant personnel. Wind patterns that force fission products and aerosols to hover over the reactor building increase the amount of risk to plant personnel. Additionally, any precipitation can force airborne sources of radiation to settle on the roof of the reactor building or main control room. As previously mentioned, sophisticated analysis tools are available for calculating such effects.

F.2 Example Plant-specific Dose Calculation

Appendix G provides estimates for containment radiation levels during postulated severe core damage accidents. The above attenuation characterization can be used to estimate radiation levels due to shielding by new or existing structures to demonstrate an acceptable environment for plant staff.

For example, using the attenuation above for a one (1) foot concrete shield, a factor of 1000 reduction in the radiation level can be achieved.

F.3 References

F.3.1 Accident Source terms for Light-Water Nuclear Power Plants, NUREG-1465, February 1995

F.3.2 Clarification of TMI Action Plan Requirements, NUREG 0737, November 1980.

APPENDIX G – METHOD TO EVALUATE SOURCE TERM FOR VENT

The purpose of this appendix is to provide a link to information on methods that are already established in response to regulatory source term considerations for fuel damage and core ex-vessel. The approach proposed to use to evaluate source terms for the HCVS under the severe accident conditions that may be present under a EA-13-109 order scenarios is the information from the various documents used for similar purposes in the industry, such as, Alternative Source Term, Part 100.11, NUREG 1465, SORCA. An example of this is the use of the Source Term from the NUREG 1465 assumption of short term core relocation inside containment because it is conservative for the piping source term application for Order EA-13-109that would occur from a core damage/vessel breach scenario at a later time several hours after SCRAM. The following information provides a general overview of some of those elements for personnel not readily familiar with the NUREG and its application.

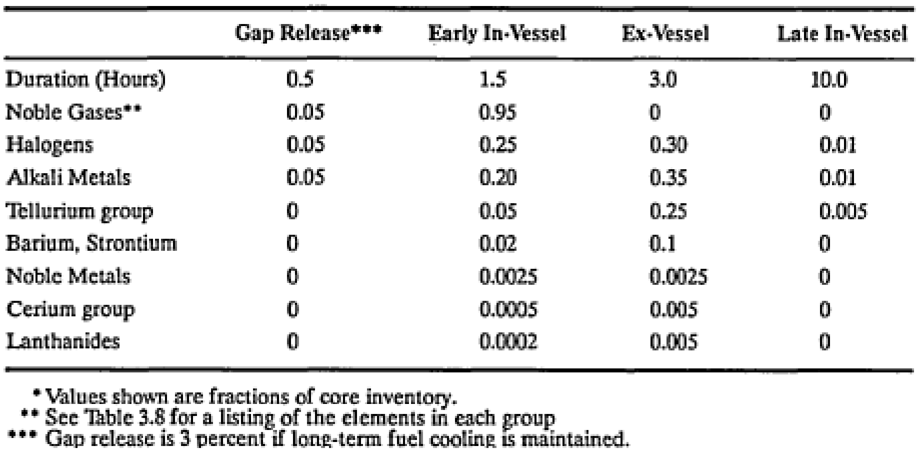
While this appendix purports using the existing regulatory basis it is understood that the severe accident conditions that may be present under a EA-13-109 order scenario are beyond design basis conditions and there is no express or implied change in the regulatory position on other guidelines because of the use of that guidance in this document

G.1 Methodology for Computation of Source Term

The U.S. NRC Response Technical Manual RTM-96 (Ref G-1) contains simple methods for estimating the radiation levels within containment during a core damage event. RTM-96 provides expected containment radiation monitor readings based on fission product inventories as defined in NUREG-1465 (Ref G-2). The source terms defined in NUREG-1465 for cladding damage and overheating damage are summarized in Table G-1:

- Cladding damage releases the gap activity, consisting of approximately 5% of the total core inventory of noble gases and volatile fission products.
- Overheating damage, corresponding to the early in-vessel release phase, releases virtually all of the remaining noble gases and larger amounts of the volatile fission products from the fuel pellets themselves—approximately 25% of the total core inventory of iodine and 20% of the cesium. Smaller amounts of less volatile products may also be released primarily tellurium, strontium, and barium. The total radionuclide content in the primary containment following overheating damage is the sum of the gap activity and early in-vessel releases.

Table G-1: Fission Product releases into Containment



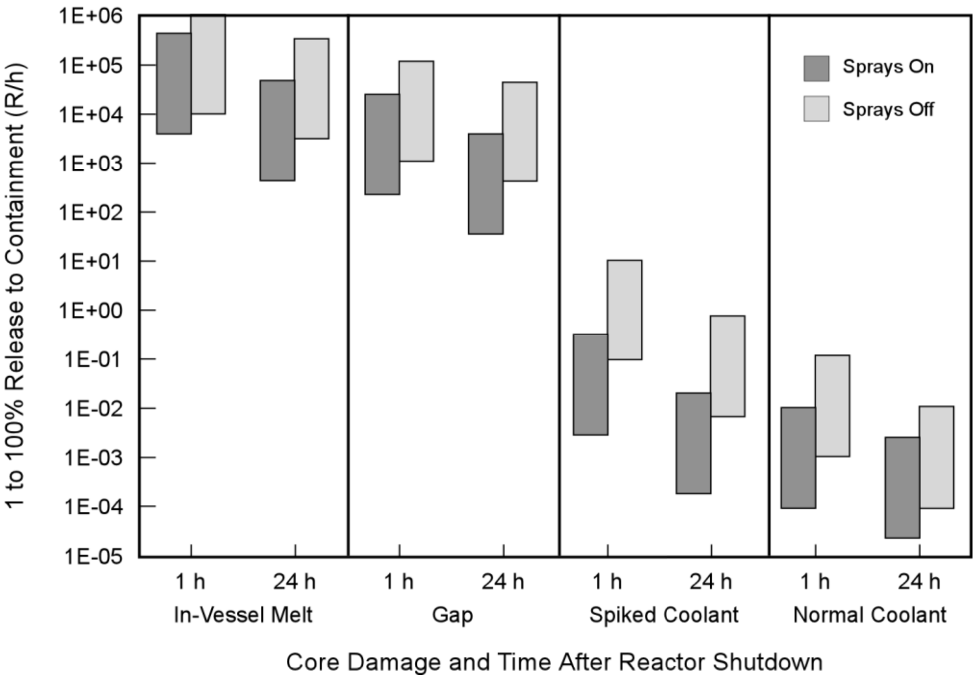
	Gap Release***	Early In-Vessel	Ex-Vessel	Late In-Vessel
Duration (Hours)	0.5	1.5	3.0	10.0
Noble Gases**	0.05	0.95	0	0
Halogens	0.05	0.25	0.30	0.01
Alkali Metals	0.05	0.20	0.35	0.01
Tellurium group	0	0.05	0.25	0.005
Barium, Strontium	0	0.02	0.1	0
Noble Metals	0	0.0025	0.0025	0
Cerium group	0	0.0005	0.005	0
Lanthanides	0	0.0002	0.005	0

* Values shown are fractions of core inventory.
** See Table 3.8 for a listing of the elements in each group
*** Gap release is 3 percent if long-term fuel cooling is maintained.

Equivalent plant-specific radiation levels may be calculated using any accepted analytical tool. Figure G-1provides representative values for the Mark I and II containment design taken from RTM-96. In general, the radiation levels associated with the onset of cladding damage are expected to be at least two orders of magnitude greater than those attributable to coolant releases and the ranges associated with overheating damage are expected to be approximately one order of magnitude greater than those for cladding damage. The cladding damage and overheating damage ranges each span approximately two orders of magnitude.

G.2 Example Plant-specific Source Term Calculation

Drywell Radiation Levels



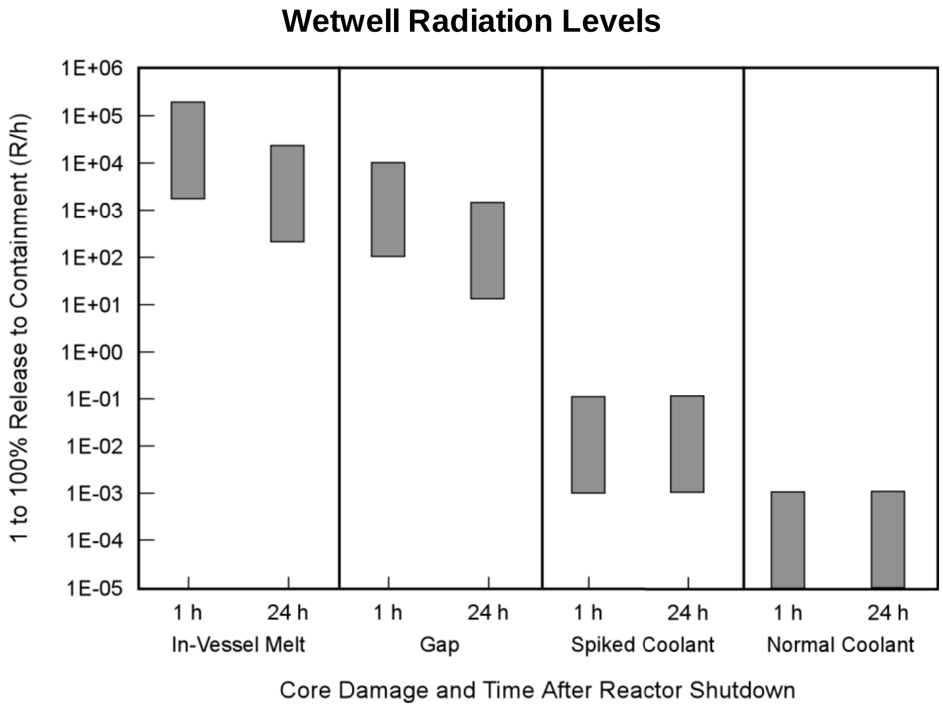


Figure G-1: Mark I/II Primary Containment Radiation Levels (Reference G-1)

The radiation monitor readings as defined in RTM-96 are assumed to provide an adequate estimate for designing the HCVS.

G.3 References

G.3.1 USNRC, “RTM-96, Response Technical Manual,” NUREG/BR-0150, Vol. 1, Rev. 4, March 1996.

G.3.2 Accident Source terms for Light-Water Nuclear Power Plants, NUREG-1465, February 1995

APPENDIX H – METHODS TO ADDRESS CONTROL OF FLAMMABLE GASES

H.1 Bases and Methodology

Order Reference: 1.2.11 – The HCVS shall be designed and operated to ensure the flammability limits of gases passing through the system are not reached; otherwise, the system shall be designed to withstand dynamic loading resulting from hydrogen deflagration and detonation.

Hydrogen will be produced as a result of core damage during a severe accident. Although not cited in the requirements section of Reference 2 (in particular Requirement 1.2.11 relative to consideration of "hydrogen deflagration or detonation"), carbon monoxide is cited as a combustible gas in the introduction paragraph to Attachment 2 to that reference. Carbon monoxide (CO) can be produced in sufficient quantities to deflagrate and potentially detonate (in a vent pipe) by the process of Molten Core Concrete Interaction (MCCI). This would occur in the most severe of accidents once the reactor vessel is breached and corium has reached (and interacted sufficiently with) the pedestal or lower liner protecting concrete. It should be noted that the potential to produce sufficient quantities of CO is dependent on the aggregate used in the drywell concrete. The chemical makeup of limestone (which contains large amounts of calcium carbonate - $CaCO_3$), will produce CO with a corium interaction. Although the amount of CO produced is relatively small as compared to hydrogen produced by gross metal-water reaction, the potential for a deflagration/detonation cannot be ruled out with limestone aggregate. Basalt based aggregate (which has no appreciable carbon constituents) will produce only minor amounts of CO due to MCCI. Therefore CO production for those plants that utilize that type of aggregate should be considered inconsequential (although a final evaluation should be made by the affected plant).

Detonation of either Hydrogen or CO is not expected to occur in containment, given existing plant controls to ensure the containment remains free of Oxygen. Detonation in the HCVS may occur if venting occurs and Oxygen is allowed to enter the HCVS discharge piping. Air/Oxygen would most likely enter the HCVS piping following a vent cycle, either through steam collapse or by rising Hydrogen leaving the HCVS piping (replaced by inflow of air).

Values are provided for the resultant pressure from a detonation. Calculations for the values presented relative to detonation pressures for hydrogen and carbon monoxide were performed based on methodology presented in Reference 15. Values given are based on resultant pressure following the passage of a detonation wave, often called the Chapman-Jouguet pressure (or C-J pressure). Using that methodology, a formula is set up involving ratios and load factors which provide a pathway to a resultant pressure based on the starting pressure at the time that the combustible gas is ignited. Deflagration to detonation transition (DDT) is assumed such that the detonations are considered with less than accepted detonable combustible gas concentration (~18% for hydrogen). Initial P_0 to P_f ratio for hydrogen is based on ratios provided in Reference 1 (ratio for carbon monoxide is based on information found in Reference 3) with dynamic load factor (DLF) based on Reference 6 (including a check that the typical resonance velocity of such a detonation in a typical vent pipe section is less than the C-J velocity of a pure stoichiometric mixture of hydrogen and oxygen). A multiplier is also utilized based on the assumption of closed ends on the pipe (although pipe elbows are not closed ends, they do present the opportunity for reflection which enhances the DDT phenomenon) as per Reference 6.

Preventing the detonation in HCVS is possible, either through design of the HCVS to ensure Oxygen is not allowed to enter the piping, or by inerting the HCVS piping after venting. If a detonation is not prevented, the piping should be designed to withstand the detonation without failing.

The size of the vent must meet the criteria cited in Section 4.1.1 of this guidance for the primary design objective of the HCVS is to prevent overpressure failure of the containment prior to core damage and subsequent to core damage. The following sections provide high level methodology and discussion on possible approaches to either prevent or withstand a detonation during or following venting through the HCVS. The approaches discussed below are not considered to be the only possible approaches to protecting the HCVS. Alternative design approaches are considered acceptable, provided that either detonation in the HCVS is prevented or the system is designed to withstand the possible detonation of Hydrogen or CO.

H.2 Design Systems to Prevent Detonation/Deflagration

Design of the HVCS may include features that prevent air/oxygen backflow into the discharge piping. Use of design features in sections of pipe susceptible to air intrusion from intermittent HCVS operation can also be used to minimize detonation/deflagration potential.

There are several possible approaches to be able to prevent air from entering the discharge piping:

> One approach is to use an isolation valve or other device (e.g., similar to a loop-seal device) at the discharge point of the vent. If an isolation system is used to prevent air back-flow, the system should account for the possible vacuum created by the cooling of steam in the susceptible piping sections once the HCVS isolation valves are closed. However, there are difficulties related to this option due to the operational burden for periodic system checks and replenishment of water required during vent operation.
>
> A water-based filter may also prevent air from entering the upstream piping entering the filter. The design should consider that the vacuum generated in the piping could result in sufficient air leakage that can result in a mixture that can detonate. However, difficulties associated with this are back pressure concerns, contamination of the medium and fouling as well as replenishment during vent operation.

Another possible approach to prevent detonation is to size the vent such that continuous venting occurs, once the vent is opened. This can also be accomplished through use of a flow-control valve restricting vent flow. This approach would be used if the containment would be expected to remain pressurized for an extended period (e.g., sustained operation) given a severe accident has occurred and no containment cooling is provided. The use of a continuous vent operation should include several high level features:

1) Procedural guidance should ensure the HCVS operation begins prior to the production of Hydrogen or CO. This will prevent any detonation when the initial venting occurs.
2) Spurious Closure of the HCVS isolation valves should be prevented through the use of designing valves using this guidance. Protection from automatic closure signals should be provided.
3) The design should include methods for purging the HCVS piping following completion of the containment venting. Use of portable bottles or similar is considered sufficient for this process. See discussion below for attributes important to the use of a purge system.
4) As with any containment atmosphere control/venting strategy, controls must be in place (administrative or otherwise) to prevent negative pressure inside containment drawing air/oxygen back into that volume.

The feasibility of a continuous vent path for all scenarios would need to be evaluated.

H.3 Vent Path Inerting

Use of a purge system in sections of pipe susceptible to air intrusion from intermittent HCVS operation can also be used to minimize detonation/ deflagration potential. Given the pressure and significant flow through the HCVS when the vent is initially opened, it is not expected that a detonation would occur in the HCVS line when the vent process begins. Detonation is a concern; however, once the vent line is closed, as air enters the piping following steam condensation or Hydrogen gas leaving the discharge. Therefore, purging of the line may be considered as a mitigation strategy immediately following the closure of the HVCS isolation valves.

Additionally, purge system operation should account for any piping elevation changes, where oxygen, Hydrogen or CO might accumulate at a high point in non-inerted piping in the HCVS.

Alternatively; the design may utilize an inert gas system which provides positive pressure in the vent pipe above atmospheric. Use of a continuously operating system should consider the elevation of the HCVS discharge to ensure positive flow through the system when containment vent is not occurring.

H.4 Design HCVS Piping for Detonation

Methods of designing the HCVS piping/components against flammable gas detonation/deflagration are discussed below. Susceptible portions of the piping should be determined based on where oxygen can be drawn into the piping/interfacing piping.

The evaluation of gas ignition is to document the capability of the HCVS piping to maintain integrity should deflagration or detonation occurs. Deformation of the pipe is acceptable given the integrity of the pipe is shown to be maintained.

The design of the HCVS is required to withstand the dynamic loading resulting from hydrogen deflagration/detonation. For design purposes, the HCVS is not required to consider assumed simultaneous loads that would not be present or occur during the venting of hydrogen (e.g. seismic loads).

The following provides a list of steps to be considered to ensure the HCVS is properly designed to tolerate a possible hydrogen deflagration/detonation:

1. Review the history/commitments of associated site equipment
    a. Research existing/similar piping system(s) for:
        1) ASME Code commitments.
        2) Seismic Classification.
        3) Current Service Level of like/similar equipment.
2. Establish classifications of new piping or piping to be modified
    a. New loading combinations for pipe in standby (with Containment Isolation Valves -CIV(s) closed
        1) Consider hydrogen detonation pressure loading (7878 kPa/1143 psia).
        2) If it is determined that a potential carbon monoxide detonation could occur, consider a detonation pressure loading of 9393 kPa (1362 psia) instead of the value for hydrogen cited in 2.a.i (See Note 1).
        3) Determine the additional loads (both dynamic and static) which should be considered the detonation load (if the option to design the vent to accommodate a detonation is chosen.) Note that, if a filter is used in the vent system, its ability to accommodate a potential hydrogen detonation should be a consideration.
    b. New loading combinations for pipe in operation
        1) Determine max pipe metal temperature.
        2) Determine max pressure based on "Order" sections 1.2.1 and 1.2.8.

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[1] Note: Although Reference 2 cites carbon monoxide as an example of a "severe accident condition" combustible gas in the introduction paragraph of Attachment 2, that compound is not cited again in Requirement 1.2.11 as having the potential to deflagrate or detonate.

        3) Determine applicability of seismic loading.
        4) Determine the probability of occurrence and the ASME classification as suggested in the next section.

3. Establish configuration for new/modified pipe
    a. Configure piping to meet applicable requirements of the "Order."
4. Determine maximum stresses on vent piping
    a. Considerations
        1) Set load combination using detonation load as dominant for each stress category. For example:
            a) General membrane (pipe pressure retaining material shell).
            b) Local membrane.
            c) Bending.
        2) Consider worst case thrust load due to detonation, for example:
            a) Maximum pressure.
            b) Maximum temperature.
            c) Acoustic wave load for each pipe segment.
            d) Dynamic responses and bending moments.
        3) Design the pipe supports
            a) Evaluate the existing pipe supports (if applicable) and allowable loads.
            b) Perform stress analysis of the pipe to determine the support system so that all the stresses meet allowable limits.
            c) Perform support design and also determine whether the existing supports meet the design requirements.
        4) There are many pipe stress analysis codes available in the market and each utility may have their own standard. Individual sites are expected to use pipe stress analysis codes that comply with that station's design process.

H.4.1 Suggested Classification and Load Combination Approach based on Contemporary Guidance

This section provides a suggested Service Level classification and Load Combination for the particular case of detonation loading from a combustible gas detonation. Individual sites must determine the applicability of this approach with respect to their unique site requirements and piping design commitments.

Code Class - Document 10CFR50.55a recommends RG 1.26 (Reference 9) as offering guidance for Quality Groups which provide an indication for

ASME Code classifications. Per the cited regulatory guide (see Section 2.(d)), the piping associated with the HCVS downstream from the second containment isolation valve should be considered as Quality Group C based on the risk of ground level release due to vent integrity failure. This is considered analogous to ASME Code Class III. As such, ASME Section III, Subsection ND is used to provide guidance for the allowable stresses for this material. ND-3600 is used for piping design.

Service Level – NUREG-0661 (Reference 11) provides guidance for consideration of service “limits” in Section 4.3. Note that “limit” and “level” are considered to be interchangeable. Both Service Level C and Service Level D are cited under sub-sections 4.3.1.3 and 4.3.1.4 (respectively). Both of these service levels are considered to be associated with low-probability events. However, combining this reference with Reference 10, Service Level C is the only level which is cited as applicable to hydrogen detonations (see further information below relative to RG-1.57). As such, Service Level C is considered appropriate for this loading.

Load Combinations - In the “Background” Section of RG 1.57 (Reference 10), 10 CFR 50.44(b)(5)(v)(B) is cited as the basis for a statement saying that, “systems and components necessary to…maintain containment integrity will be capable of performing their functions during and after exposure to the environmental conditions created by the burning of hydrogen, including local detonations, unless such detonations can be shown to be unlikely to occur.” This statement specifically refers to Mark III containments as Mark I and Mark II containments require an inert atmosphere. However, in the venting case considered, the isolated vent systems in these models can no longer rely on the inerted containment effluent to prevent hydrogen detonations; therefore, these loads typically reserved for Mark III containments should be considered for this isolated extension of containment in this particular scenario. Such a scenario (conducive to a local detonation) can only be typified as a severe accident.

With respect to the SSE it is understood that (based on the example of Fukushima Dai-ichi) a SSE may well be the precursor to an accident which could evolve into a severe accident (including core damage and hydrogen generation). And aftershocks will likely occur after the initial earthquake. However these aftershocks (along with the earthquake itself) are typically not long duration events. They are more typically lower in magnitude, short and sporadic. As discussed in I.B.3(c) in Part C of RG 1.57, the Service Level C load combinations, all consider the SSE except for those combinations which deal with pressure from hydrogen generation or hydrogen burning. Considering the minimal opportunity for a hydrogen detonation to occur in a vent pipe, that pipe would not be expected to experience these 2 unlikely loading conditions simultaneously.

With the SSE not considered in the loading combination, the remaining loading combination to be considered for combustible gas detonation load (based on Reference 10 guidance) is as follows:

$$D + Pg_2 + T_0 + R_0$$

Or - Dead load+Detonation Pressure load+Thermal load+Pipe Reaction load

Where:

D = Dead loads
Pg_2 = Pressure resulting from uncontrolled hydrogen burning (this is considered as detonation pressure).
T_0 = Most critical thermal loads (assumed to be effluent temperature).
R_0 = Pipe reaction load (assumed to be thrust loading from detonation)
P_0 = Any external pressure loading based on variations in ambient pressure (outside of vent piping)

Note that peak temperature (due to detonation) will lag behind the detonation pressure load such that T_0 would be minimal. Pipe reaction load will be determined by pipe designers.

H.4.2. Methodology

The loading being considered (hydrogen detonation) is considered as a Service Level C (Emergency) condition. As such the allowable stress allowance provided in ND-3654.1 may be utilized. Section 4.3 of NUREG-0661, Service Level C is characterized as applicable to design basis type events. As the precursor to such a detonation (release of hydrogen during a severe accident) would be characterized as a well beyond design basis accident that deteriorates into a severe accident with core damage, and the aforementioned required conditions for an actual detonation to occur are so remote, Service Level D allowable stresses may be considered appropriate for this scenario. However, it is understood that the intent of the Level D limit is to withstand a single occurrence. It is expected that the vent be capable of withstanding multiple hydrogen detonations; therefore, Service Level D alone would not provide the margin required to ensure system functionality.

The purpose of this evaluation is not to consider the vent system function, only that the occurrence of hydrogen detonations (as stated in this document) will not cause a failure of the pipe’s pressure retaining capability. System function and component survivability to perform that function will be addressed in the final design detailed analysis for the system.

H.4.2.1 Bases for Loading due to Detonation

In order to address the Reference 2, Requirement 1.2.11 statement that the system shall be designed to withstand dynamic loading resulting from hydrogen deflagration and detonation, a simplified evaluation can be performed using standard methods.

H.4.2.2 Detonation Pressure Considered for Carbon Monoxide

Once CO is a part of the vented gas, deflagration/detonation (of CO) will occur much the same as it would for hydrogen as outlined above.

H.5 Discussion

Based on the conclusions/positions stated above, the potential scenario of concern would be one in which steam collapses in an HCVS after fuel damage (and after the venting off of the majority of the original nitrogen loading) and draws outside air back into the vent system. This is the only scenario with reasonable potential to cause the formation of a deflagrable mixture. As such, it is the scenario to be considered in an evaluation of a potential hydrogen deflagration and the worst case damage which could occur.

With typical calculated pressure loadings using methods above, many standard grades and thicknesses of the commonly used SA-106 pipe could accommodate the stresses from such a loading condition. Stress calculations utilizing contemporary ASME Section III formulae show that such a loading can be accommodated by standard SA-106 Gr A 12” pipe prior to any corrosion considerations. Since this pipe will be isolated normally and not subject to typical flow conditions, corrosion can be considered negligible. However, due to the dynamic loading induced on a typical piping system (with bends and elbows) by such a pressure spike, the actual stresses experienced for any given vent system will be dependent on the piping system configuration and support structures.

H.6 References

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H.6.3. C-J Detonation Studies in Hydrogen-Chlorine, Carbon Disulfide-Oxygen and Carbon Monoxide-Hydrogen-Oxygen-Nitrogen Mixtures, Christiane M. Guirao, et al, McGill University, July 1972.

H.6.4. “Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants,” International Atomic Energy Agency, Vienna, 2011.

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H.6.7. “Combustion of BWR-Typical Radiolytic Gas Mixtures,” Final Report for the International Radiolytic Gas Combustion Project, VGB-Contract SA “AT” 13/04, December, 2007.

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H.6.10. Regulatory Guide 1.57, “Design Limits and Loading Combinations for metal Primary Reactor Containment System Components,” Revision 2.

H.6.11. NUREG-0661, “Safety Evaluation Report, Mark I Containment, Long-Term Program,” March 1980.

H.6.12. Comparison of critical conditions for DDT in regular and irregular cellular detonation systems; M.S. Kuznetsov et al, May 2000.

H.6.13. NRC Inspection Manual, Temporary Instruction 2515/121, (as associated with) Verification of Mark I Hardened Vent Modifications (GL 89-16), 5/24/94.

H.6.14. JLD-ISG-2012-02, Compliance with Order EA-12-050, Reliable Hardened Containment Vents, Interim Staff Guidance, Revision 0, September 29, 2012.

H.6.15. NEDO-33572, Revision 3, Licensing Topical Report, ESBWR ICS and PCCS Condenser Combustible Gas Mitigation and Structural Evaluation, September 2010.