# BWR Containment Venting

**Revision 1 dated** 10/29/2013



Prepared by NEI and the BWROG

## **Purpose**

Document the benefits and consequences of the proposed protective action to perform Anticipatory Venting of Boiling Water Reactor (BWR) containments during an extended loss of alternating current power (ELAP) event.

## **Discussion**

Anticipatory venting is a feature in the latest revision to the BWROG emergency procedure guidance (EPG/SAG Rev 3), which was developed based on lessons-learned from the March 2011 Fukushima Daiichi accident (see Attachment 1). A key feature of Revision 3 is to permit containment venting earlier than previously permitted. Early removal of energy from containment during an ELAP via the containment vents is the most effective action that can be taken to support the containment and core cooling safety function capabilities described in NEI 12-6 Table 3-1 for Mark 1 and Mark II (and some Mark III) containment designs.

Anticipatory venting provides margin to vessel and containment conditions that could result in core damage and containment rupture during the ELAP event.

## **Benefits**

Anticipatory venting of BWR containments during an ELAP event is a protective action that provides protection by:

- Limiting containment pressure
- Limiting containment temperature
- Limiting suppression pool temperature
- Providing time for implementation of the phase 2 and 3 core and containment cooling mitigating strategies by reducing the potential adverse impacts high temperature suppression pool water can have on the operation of Reactor Core Isolation Cooling (RCIC) (and High Pressure Coolant Injection (HPCI))
- Allowing portable pumps to inject water into the reactor at lower pressures.

These benefits serve to facilitate and enable timely implementation of strategies that can achieve the benefits listed above that protect the fuel cladding and containment integrity.

## **Containment Decay Heat Removal**

Decay heat would be safely transferred to the suppression pool through the safety relief valves and operation of steam-driven injection systems (RCIC and/or HPCI).

During design basis accidents shutdown decay heat is removed from the containment with low pressure electric driven emergency core cooling systems (pumps and heat exchangers in the residual heat removal system). During an ELAP, the pumps and valves necessary to remove decay heat do not have power, and therefore, these systems cannot perform their functions.

Possible containment heat removal strategies were investigated for the ELAP which are discussed below:

### Establishing RHR Heat Exchanger Flow

Establishing RHR heat Exchanger flow would require repowering an installed pump to circulate suppression pool water through the RHR heat exchanger and cooling the heat exchangers with a portable pump, making field connections to components or switchgear. In addition, based on the loss of normal access to the ultimate heat sink assumption in NEI 12-06, a cooling source would need to be established to perform the ultimate heat sink function.

This option requires a portable generator to power an installed pump to circulate suppression pool water and portable pumps with capacity in the range of 1,000 to 1,500 gpm. Modifications for the RHRSW connection and a pump to circulate suppression pool water would be required.

Portable Heat Removal System with Delayed Venting

A portable decay heat removal system could connect to RHR piping to remove decay heat.

Bringing in portable heat transfer equipment and pumping stations for decay heat removal would require reliable and redundant equipment to be deployed and connected to existing plant piping. This would involve human interaction to breach systems and connect temporary systems in a timely manner. Remote heat exchangers would be needed to circulate primary water from the suppression pool either back to the RPV or in a suppression pool cooling mode. Similar to the option above this would require new large capacity hookup locations and significant time and manpower.

Suppression Pool Feed and Bleed

This process would remove suppression pool water to outside of the containment and replace it with cooler water. For some plants with larger containments and external storage capacity, feed and bleed can be a viable method to control containment temperature and pressure. It could maintain the suppression pool cooler than other options. Portable make up pumps with 1,000 to 1,500 gpm capacity would be required. In addition, this strategy would result in large amounts of reactor coolant being pumped outside of the containment.

Anticipatory Containment Venting

Heat removal from containment is accomplished by venting steam from the suppression pool before containment conditions degrade to levels that challenge limits. Steam generation removes a large amount of energy per unit mass, (*i.e.*, the latent heat of vaporization is greater than that afforded by single-phase heat transfer). Therefore, no make-up water to the suppression pool is needed in the first ~24 hours following event initiation.

Additionally, containment venting from the suppression pool air space provides a controlled vent path (for exhausted/scrubbed reactor steam) and maintains operation of an installed injection system (RCIC).

Among the methods listed above, anticipatory containment venting provides the most effective strategy for maintaining functionality of containment and core cooling. As a result, anticipatory venting is appropriate for use to mitigate an ELAP event. For most BWRs, containment venting provides the best option for containment pressure control and heat removal. It uses installed equipment that most BWRs employ.

Mark I BWRs have hardened containment vents installed per Generic Letter 89-16, which will be enhanced per EA-13-109. Operators are trained on the use of this equipment. The only portable equipment necessary for most BWRs is that required to maintain DC power and a compressed gas source to operate the vent valves. Plant procedures exist today to use this equipment in Mark I BWRs.

Lowering peak containment temperatures and pressures by discharging decay heat from the reactor through the suppression pool to the suppression pool vent provides margin for containment equipment and margin to containment design limits. Venting the suppression

chamber removes heat from the suppression pool and limits the rise in the suppression pool water temperature.

Most BWRs are equipped with a RCIC system which is driven by reactor steam and delivers coolant to the reactor. Suppression pool water cools the RCIC pump bearings. Venting ensures cooler suppression pool water for RCIC, prolonging RCIC operation. This provides time for plant personnel to take mitigating strategy actions to set up low pressure injection equipment in response to an ELAP. The low pressure equipment will be able to inject to the vessel and serve as a backup to RCIC should it subsequently fail.

**Anticipatory Containment Venting Procedure Guidance**

Venting the suppression pool is currently permitted in the EOPs based on earlier EPG/SAG revisions for beyond design basis events when containment pressure cannot be maintained below the Pressure Suppression Pressure (typically 20-30 psig) and before containment pressure reaches the Primary Containment Pressure Limit (typically near the design pressure of containment - for example - 56 psig for Mark I plants).

BWRs are in the process of implementing the latest BWROG guidance, BWROG EPG/SAG, Revision 3 in plant EOPs (See Attachment 2 for addition information on the process used to revise plant EOPs). Revision 3 adds an override to allow anticipatory venting from the suppression chamber:

> After containment pressure rises above the high drywell pressure scram set point (~2 psig) and,
>
> If pressure reduction is required to restore and maintain adequate core cooling or to reduce offsite dose.

The high drywell pressure scram setpoint was chosen as the earliest allowable pressure for initiation of anticipatory containment venting, because it has been an EOP action level since the earliest of guideline revisions. As such, there is no need to develop additional action points that may increase the complexity of the operating procedures. It also provides the operator with a great deal of flexibility to remove decay heat from the suppression pool for the widest possible range of conditions.

Once the suppression pool/containment is pressurized to 10–15 psig, there is sufficient differential pressure to effectively remove energy from the suppression pool via the containment vent.

Venting after pressure exceeds the 2 psig high pressure scram setpoint provides margin to prevent core damage and the irreversible and unpredictable rupture of the containment. Opening the vent earlier allows more energy to be removed from the containment. In contrast, delaying containment venting until containment pressure approaches the design pressure reduces the opportunity of removing energy from the containment, resulting in a more challenging event for the plant operators.

Anticipatory vent actions provided in EPG/SAG Revision 3 do not create a new operator action, but merely allow an existing approved action to be taken earlier for an event such as an ELAP. This change does not create a new concern with maintaining an inert containment since current EOP venting guidance similarly allows removal of some nitrogen from the drywell. The anticipatory containment venting strategy is performed prior to any core damage (i.e., before any significant hydrogen generation in the reactor), and by its very nature, significantly reduces the chance of core damage, and reduces the possibility or magnitude of any resultant hydrogen generation.

Hydrogen is a concern if oxygen is present in the containment. Mark I and Mark II containments are inerted with nitrogen to minimize oxygen in the containment. Venting containment will vent some of the nitrogen out of the containment and could allow oxygen to enter if the containment pressure becomes lower than atmospheric pressure during venting. Vents designed to remove one-percent-decay-heat provides operators a controllable means to lower containment pressure. The EPG/SAG Revision 3 anticipatory override only permits opening the containment vent above ~2 psig. Operators are trained to control parameters such that control values are not exceeded. As containment pressure is reduced below ~5 psig by venting, pressure changes will be very slow as the differential pressure is being reduced. Operators will stop venting before the containment pressure reaches ~2 psig. This will reduce the likelihood of containment pressure becoming lower than atmospheric pressure.

Containment sprays are another method to control containment pressure when AC sources are available. Power to these valves is not available during an ELAP. These valves could be procedurally opened when AC sources are restored. If this occurred, containment spray termination is procedurally required prior to the containment pressure reaching 0 psig to ensure no outside atmosphere flows into the containment. Initiation of containment spray is governed by the Drywell Spray Initiation Limit curve to ensure pressure is not reduced too rapidly. This curve conservatively assumes the most limiting gas configuration in the containment and the most limiting spray water temperature. If containment spray was interrupted by an ELAP, plant specific power restoration procedures will ensure pumps are not restarted with open valves to prevent water hammer issues.

Revision 3 does allow a larger venting window as compared to Revision 2. If venting was started per Revision 3 and plant AC power was restored after a brief ELAP (1 to 3 hours), venting would not be needed. If a “brief” ELAP did occur, containment integrity could be restored by closing either of the open containment venting valves.

Some BWRs take credit for containment pressure to ensure the ECCS low pressure pumps have at least the minimum required net positive suction head (NPSH). Venting containment will lower containment pressure. While the anticipatory containment venting strategy in EPG/SAG Revision 3 lowers containment pressure, it is permitted in an override statement only, “if pressure reduction is required to restore and maintain adequate core cooling or to reduce the total offsite dose.” If low pressure electric driven ECCS pumps are in operation, AC power is available; therefore there is no issue with core cooling. This override will therefore not be used if the low pressure electric driven ECCS pumps are available. For many postulated accidents (including Design Basis LOCAs), the low pressure motor driven ECCS pumps are available for RPV injection and suppression pool cooling. For such accidents, containment pressure may rise above 2 psig, but anticipatory venting would not be authorized since adequate core cooling is provided.

NPSH for RCIC will be addressed for each BWR relying on RCIC during an ELAP in responses to NRC Order 12-049.

EPGs are intended to prevent core damage. If core damage is not prevented, EPGs are exited and SAGs will be entered. Anticipatory venting the containment is not allowed by the SAGS. Operators would examine plant conditions and follow existing SAG venting guidance.

## Existing Venting Capability

From the previous discussion, it is clear that venting the containment is the most effective means for maintaining or restoring the key safety functions of core cooling and containment for Mark I and II (and some Mark III) containment designs for certain beyond design basis event conditions. Restoration of containment closure, i.e., closing the containment isolation vent

valves, is likewise important if the event escalates to core damage. The majority of plants use safety-related air/nitrogen operated containment isolation valves controlled by a solenoid valve. The solenoid valves are generally supplied power from station batteries and the gas pressure from installed or portable compressed gas bottles. Suppression chamber venting at most plants is initiated by opening two safety-related primary containment isolation valves. This provides redundant isolation capability for terminating the vent.

Currently, Mark II and III containments have venting capabilities using low pressure piping or ductwork (not hardened). Mark III containments have smaller vent piping and, therefore, more limited venting capabilities. Mark III containments have a larger containment volume that reduces the need for venting and combined with an external suppression pool cooling supply, allow a feed and bleed strategy to effectively remove heat from the containment.

Many Mark I and Mark II plants can remotely operate the containment isolation valves, but dependent on how Generic Letter 89-16 was implemented, these valves may not have electrical or pneumatic motive force to operate them under ELAP conditions. All Mark I and Mark II plants will have the capability to operate containment vent valves with a dedicated source of motive power after implementation of EA-13-109. Venting through non-hardened vents will remove decay heat from the containment, thus reducing the chance of core damage, but may complicate accident management in plant buildings.

There are no containment vents that automatically open. A deliberate action, e.g., key locked switches, is required to initiate containment venting.

**Evaluation of the Impact of Anticipatory Containment Venting**

This evaluation provides an assessment regarding the effects that containment venting directions in EPG/SAG Rev. 3 have on typical BWR dominant severe accidents compared with those in EPG Rev. 2. This new guidance allows the decision makers to vent containment earlier than would be directed when using Revision 2 of the EPG/SAGs.

The following qualitative assessment is presented to evaluate the risk effects associated with anticipatory venting. The potential impact of the containment venting strategy is assessed to understand if opening the containment vent earlier during pre-core damage sequences would have any of the following effects:

a. Increase core damage frequency (CDF)
b. Create “earlier” core damage sequences
c. Increase the potential for containment failure

The following apply to this evaluation of the risks associated with anticipatory venting include the following:

- Mark I and II BWRs are assumed to have a hard pipe containment vent from the suppression pool airspace for the purpose of this evaluation. This hard pipe vent path is assumed to be selected for the vent action.

  Note: Currently, Mark II plants do not have an installed hardened containment vent. This means that anticipatory venting would potentially be through ductwork. There have been analyses performed by the NRC [RMIEP – NUREG/CR-4832 [2]] that have assessed the effects of venting at high containment pressures near design pressure (approximately 45 psig) on a Mark II Reactor Building environment and the systems housed in the Reactor Building. These evaluations have indicated that most ECCS and RCIC equipment would survive the vent operations at the studied Mark II plant. However, other accident response activities will be complicated due to the

environmental challenges created by the vent activity.

- Containment vent is conservatively assumed to remain open after it is opened.
- The assumed failure to reclose the vent would limit the ability to use drywell sprays because of the restrictions on containment pressure to be above 0 or 2 psig (plant specific). This is due to both the low pressure of containment and the loss of non-condensables from containment making the containment more sensitive to DW spray initiation.
- No detailed quantification of accident sequences has been performed. The insights are based on qualitative assessments and reference to plant specific PRA scoping studies.
- Containment venting in the following accident evaluation is per EPG Rev. 3. This would not be implemented for those accident sequences with RHR available. Specifically, with RHR available, containment venting would not be procedurally allowed and would not necessarily be a primary mitigation step. Many postulated scenarios result in core damage despite the availability of suppression pool cooling, i.e., loss of injection is not being caused by degraded containment conditions. These scenarios may not challenge early containment venting.
- The accident scenarios that typically dominate BWR Mark I and II PRA results are examined.

Accident Evaluation

The following are concluded regarding implementation of anticipatory containment venting and the effect on CDF are as follows:

- Implementation of Rev. 3 EPG/SAGs is expected to decrease the overall CDF by extending the operability of RCIC and HPCI and low head injection sources to allow full mitigation or additional time for recovery (e.g., recovery of AC power). The principal influences of anticipatory venting to ensure adequate core cooling are discussed as follows:

  (a) Preserve turbine driven systems by avoiding high back pressure on the turbine system (i.e., RCIC) to enhance reliability.

  (b) Preserve turbine driven systems by limiting the suction temperature when the suppression pool is being used as the suction source.

  (c) Reduce the DW temperature to limit the impact on containment seals and SRV solenoids. SRVs may be required over the long term for low pressure injection.

  (d) Reduce containment pressure to both limit the challenge to the containment boundary and to limit the back pressure on low pressure injection systems (particularly low head injection systems) to ensure that adequate flow is available to maintain adequate core cooling.

The evaluation consists of the typical BWR accident sequences that compose the BWR risk profile. The typical BWR accident sequences have been defined in NEI 91-04 [1].

As noted above, the primary use of anticipatory venting guidance is considered to be in a Station Blackout (SBO), ELAP, or accidents that depend on turbine driven systems (e.g., RCIC operation) without suppression pool cooling; however, it can also be used to enhance the success of low head external injection sources that require the reactor pressure vessel (RPV) and containment to be at low pressure. These accidents (using NEI 91-04 [1] terminology) are primarily the following:

- Class IA: Loss of RPV makeup at high RPV pressure
- Class IB: Station-Blackout
- Class ID: Loss of RPV Makeup at Low RPV Pressure
- Class II: Loss of Containment Heat Removal

These accident classes are developed in NEI 91-04 and used at most BWR sites to categorize the types of severe accident sequences leading to core damage.

- Implementation of Rev. 3 EPG/SAGs would not increase CDF. In addition to the overall CDF, individual accident classes (i.e., different challenges) were also examined regarding the effect on CDF with the following insights:

  - Loss of RPV Makeup at High Reactor Pressure (Class IA)

    For these cases, the turbine driven systems are unavailable and the RPV cannot be successfully depressurized. Therefore, the EPG/SAG Rev. 3 override does not direct the use of anticipatory venting. See discussion under Class ID for cases with turbine driven systems available.

  - Loss of RPV Makeup Due to SBO or ELAP Conditions (Class IB)

    For these types of accidents, the largest benefit from the Rev. 3 EPG/SAG override is obtained. This override allows extended operation of turbine driven systems if they are available for all of the reasons cited above. Therefore, these types of accidents have the largest decrease in CDF.

    Generally, the anticipatory venting will extend the mitigation capability of HPCI and RCIC allowing additional time for AC recovery, or time to align portable injection systems, thereby decreasing CDF.

  - Loss of Containment Heat Removal (e.g., suppression pool cooling) (Class II)

    These types of accident sequences have adequate core cooling despite the loss of containment heat removal. For most of this spectrum of accidents, adequate core cooling is provided by low pressure motor driven systems. Therefore, no anticipatory venting is specified. There may be low frequency sequences that have no suppression pool cooling and no low pressure ECCS, but HPCI or RCIC is available. For these types of sequences, the condition similar to that discussed for ELAP and SBO sequences applies and anticipatory venting would result in extending the time period over which HPCI or RCIC operate and would enhance the ability for containment heat removal and pressure control.

  - Loss of Makeup at Low RPV Pressure (Class ID)

For these types of accident challenges, the high pressure injection systems have generally been unavailable; therefore, the additional Rev. 3 guidance would have no impact relative to HPCI/RCIC operation. The residual Class ID sequences that have all ECCS failed would rely on alternate low pressure injection systems (e.g., RHRSW cross tie). For these low frequency sequences, earlier venting could be invoked to increase the potential for success of these low head systems to provide adequate core cooling. Successful implementation of earlier venting would decrease CDF.

In some other Class ID sequences, containment conditions may have forced RPV emergency depressurization thereby causing HPCI and RCIC to become ineffective. Other Rev. 3 EPG/SAG changes would combine with the anticipatory vent to preserve these injection systems for continued adequate core cooling under these low frequency sequences.

- <u>LOCA Events (Class III)</u>

  In general, these accident types result in depressurization of the RPV and defeat the turbine driven systems directly. Containment pressure may be elevated despite success of suppression pool cooling and prevent adequate injection from low head alternate injection systems. Anticipatory venting could be used to enhance the flow rate from low head, low pressure injection systems if that is all that is available. This would reduce the CDF for these very low frequency sequences or it would not be implemented. Otherwise, the override would not specify use of the vent.

- <u>Failure to Scram Sequences (Class IV e.g., ATWS)</u>

  These accident sequence challenges may result in rapid pool heatup and containment pressurization. The time difference associated with earlier containment venting (Rev. 3 EPG) and previous Rev. 2 EPG may not be significant based on higher power level possible for such ATWS sequences. Therefore, no significant difference in CDF is calculated for the worst case Class IV (ATWS) sequences. For less demanding events, the responses to Classes IA, ID, and II adequately reflect the CDF impact, i.e., CDF decreases slightly.

- <u>LOCA Outside Containment (Class V)</u>

  For these types of accidents, there is a significant release of high energy steam directly from the RPV to the Reactor Building. This depressurizes the RPV defeating the turbine driven systems and providing a pathway for containment heat removal without the need for venting. Therefore, there is no impact on CDF associated with the Rev. 3 EPG change to anticipatory venting.

  There may be postulated cases where the failure can be isolated. Under such “recovered” conditions, the types of sequences would be described by Classes IA, ID, and II as described above.

- Implementation of Rev. 3 EPG/SAGs for earlier containment venting would not increase the overall likelihood of earlier core damage.

  There is always the remote possibility that equipment failures or operator errors during earlier venting would lead to core damage. This may lead to the increase in frequency of earlier core damage, but only on specific low frequency scenarios. However, these postulated minor increases in earlier core damage due to equipment failures or operator errors occur at a substantially lower frequency than the CDF reduction achieved by the earlier venting action. The failure probability of turbine driven systems is generally found to be approximately 1E-02 based on data from NUREG/CR-6928 when assessed for extended operation. Under severely degraded plant conditions, this failure probability could rise to near 0.1. Anticipatory venting is expected to maintain the unavailability in the range of 0.01 to 0.1 for ELAP conditions for an extended time. Compared with this estimate for unavailability, effects of venting or related human errors may contribute only 1E-3 to 1E-4 to this unavailability. This represents approximately a 0.1% to 1% probability increase in the system unavailability. Therefore, this would not increase the overall frequency of earlier core damage.

The following conclusions regarding implementation of anticipatory containment venting on the frequency of uncontrollable containment venting is found by the review of BWR accident profiles. Containment venting can provide a potential pathway for the release from containment of steam and non-condensables prior to core damage or radionuclides following core damage; however, it can also prevent the catastrophic failure of containment. Characterizing the potential effects of a vent requires evaluation of both of these aspects of containment venting. Consistent with the assumption that the vent valve sticks open after its initial opening, an assessment is performed to examine the effects of this on the following:

- Uncontrolled containment vent
- Uncontrolled containment failure

Anticipatory venting and an assumed failure of the vent to reclose would lead to the condition of an uncontrolled vent release from the containment (e.g., steam and non-condesables). However, the open vent will preclude uncontrolled containment failure that may otherwise result from either steam generation or non-condensable gas generation. The following table shows the distinction in the effects of the anticipatory venting when the vent is assumed to fail in the open position.

Implementation of Rev. 3 EPG/SAGs is expected to have the following effects on dominant accident sequences as defined in Reference 1.

| Accident Sequence Type | | Will changing from Rev 2 to Rev 3 Increase Uncontrolled Containment Vent[1] Frequency | Will changing from Rev 2 to Rev 3 Lower the Uncontrolled Containment Failure Frequency |
|---|---|---|---|
| Class | Definition | | |
| IA | Loss of inventory makeup in which the reactor pressure remains high | Yes | Yes |
| IB[2] | A station blackout and loss of coolant inventory makeup | Yes | Yes |
| ID | Loss of coolant inventory makeup in which reactor pressure has been successfully reduced below 200 psi | Yes | Yes |
| II | Loss of containment heat removal with the RPV initially intact; core damage induced post containment challenge | Yes | Yes |
| III | Accident sequences initiated or resulting in medium or large LOCAs for which the reactor is at low pressure and no effective injection is available | Yes | Yes |
| IV | Accident sequences involving failure of adequate shutdown reactivity | Yes | Yes |

(1) The following definitions are used in this discussion:

- Uncontrolled Containment Vent results from the assumed stuck open vent. The uncontrolled containment vent releases the contents of the containment. Before core damage this would consist of steam and non-condensables. This vent path presents the opportunity for eventual re-closure and for the selection of the release location, e.g., via the suppression pool scrubbed pathway.
- Uncontrolled Containment Failure is a structural failure of the containment boundary. The assessment of venting is that it represents a controllable pathway for containment pressure control and radionuclide release. The assumption of a stuck open containment vent does not alter this conclusion. The pathway is still selected and the pathway can eventually be reclosed. It has prevented a structural failure of containment.

(2) The predominant use of the vent would be in Class IB accident sequences (ELAP). For the other sequences, there would only be a very small percentage of the class of

accidents (very small frequency) that would involve an anticipatory vent. For the very small incremental set of sequences the effects of the anticipatory vent are identified.

The use of the anticipatory containment venting in Rev 3 of the EPG/SAGs and the assumption of the vent remains open results in an increase in the uncontrolled containment vent cases. However, anticipatory venting in Rev 3 would reduce the probability of uncontrolled containment failure by reducing the challenges to containment, including reducing the core melt progression challenges.

**NRC Guidance on Venting**

Both Generic Letter 89-16 and NRC Order EA-13-109 recognize the effectiveness of venting for BWRs. All BWRs have some venting capabilities. Mark I BWRs added hardened vents in the 1990s in accordance with Generic Letter 89-16, Installation of a Hardened Suppression Pool Vent, September 1, 1989 which states:

> *"...implementation of reliable venting capability and procedures can reduce the likelihood of core melt from accident sequences involving loss of long-term decay heat removal by about a factor of 10. Reliable venting capability is also beneficial, depending on plant design and capabilities, in reducing the likelihood of core melt from other accident initiators, for example, station blackout and anticipated transients without scram. As a mitigation measure, a reliable suppression pool vent provides assurance of pressure relief through a path with significant scrubbing of fission products and can result in lower releases even for containment failure modes not associated with pressurization (i.e., liner melt through).*
>
> *Finally, a reliable hardened suppression pool vent allows for consideration of coordinated accident management strategies by providing design capability consistent with safety objectives. For the aforementioned reasons, the staff concludes that a plant modification is highly desirable and a prudent engineering solution of issues surrounding complex and uncertain phenomena."*

Recently, NRC Order EA-13-109 was issued requiring Mark I and Mark II BWRs to install a reliable hardened containment vent system (HCVS) capable of operation during severe accidents. This order requires improvements in the Mark I and II BWR vents to make them more reliable, hardened and severe accident capable.

SECY-12-0157, Consideration of Additional Requirements for Containment Venting Systems for Boiling Water Reactors with Mark I and Mark II Containments, November 26, 2012 stated:

> *"In approving venting for the BWRs with Mark I and Mark II containments, the staff noted its basic concern that: venting even if it results in some radiological consequences should only be undertaken as an extreme means to prevent core melt or as a last resort measure to prevent the irreversible and unpredictable rupture of the containment which could otherwise lead to a large release."*

Containment venting is recognized as an effective means to prevent core melt and to prevent a containment rupture during a beyond design basis event.

**Conclusion**

Anticipatory venting the suppression chamber allows removal of the latent heat of vaporization from the water in the suppression pool. Anticipatory venting requires minimal support systems for most BWRs and is readily available. Anticipatory venting of containment is an effective means to remove heat from the containment for most BWRs.

Learning lessons from operating experiences is a key tool for continued safe reactor operation.

One of the key lessons learned from the events at Fukushima Daiichi is that earlier venting could have provided more time for operator actions to prevent core damage and ensure containment integrity.

Anticipatory containment venting in accordance with EPG/SAG Rev 3 will protect the containment function. The new EOP revisions, developed from EPG/SAG Rev 3, will not increase the core damage frequency. Using the capabilities of existing designs and the limitations imposed by EA-12-049 regarding availability of the ultimate heat sink, the most appropriate strategy for promptly removing heat from the containment is anticipatory venting.

**References:**

1. Severe Accident Issue Closure Guidelines, NEI 91-04, Rev. 1, December 1994.
2. Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP), NUREG/CR-4832, Sandia National Laboratory, July 1992.

**Attachments:**

1. Discussion of Events at Fukushima Daiichi
2. Plant EOP Procedure Change Process for Implementing BWROG EPG/SAG Revisions

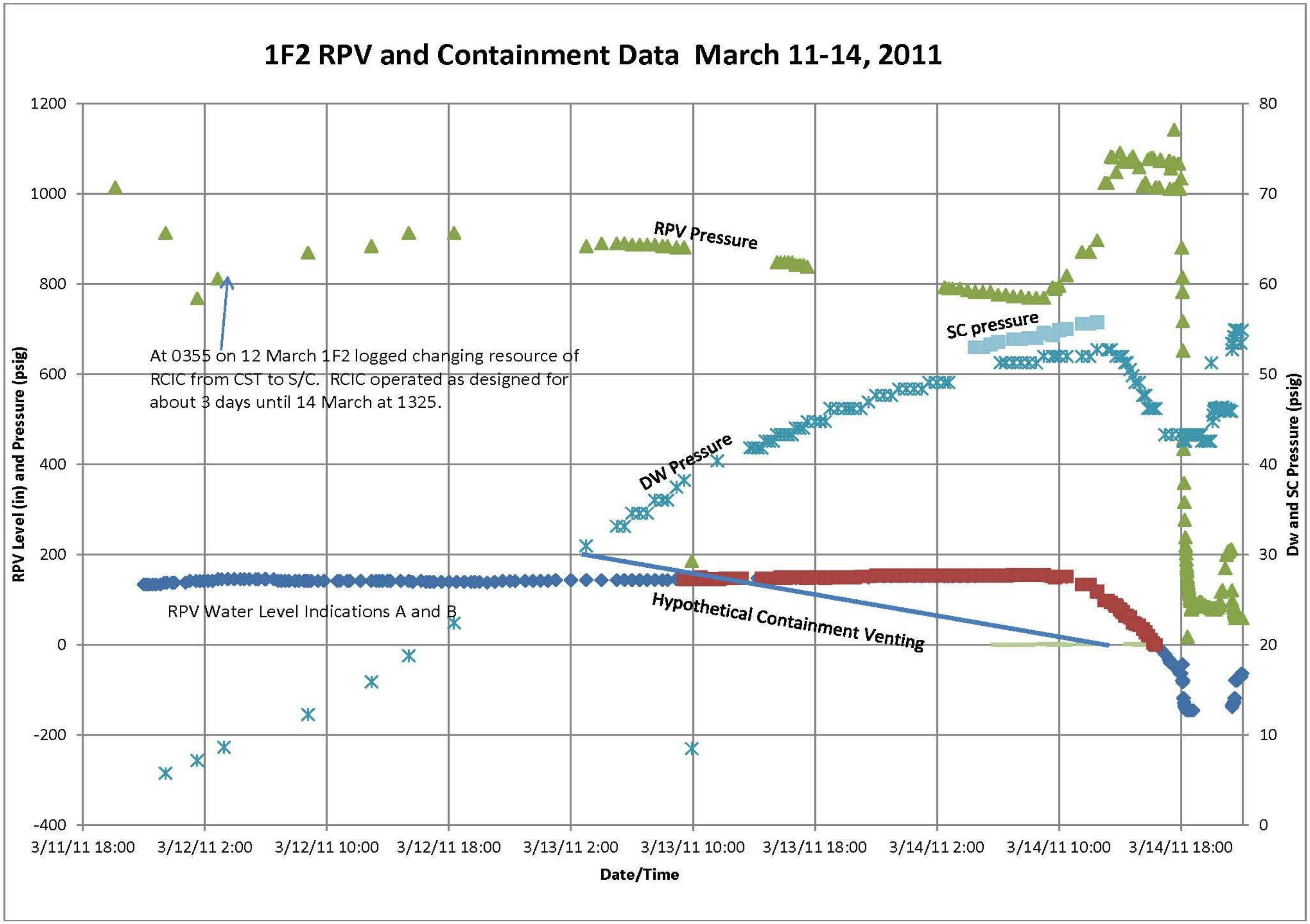
## Attachment 1 Discussion of Events at Fukushima Daiichi

The following graph demonstrates the basis for anticipatory containment venting.

This graph shows the parameters recorded at Fukushima Daiichi Unit 2 (Mark I) during the approximately three days of RCIC operation following the start of the event. At approximately 03:55 on March12, 2011, RCIC suction was swapped from the Condensate Storage Tank (CST) to the suppression pool. At that time, drywell pressure was 9 psig which would indicate a saturation temperature of about 240°F.

If the containment vent could have been opened at 04:00 on March12, 2011, and had it been sufficiently designed, it could have limited temperatures in the suppression pool to 240°F. The temperature of 240°F and rising could impact the functionality of RCIC because the suction source is used to cool the RCIC bearings, which could ultimately fail at elevated temperature conditions. The containment vents installed on U.S. Mark I containments in response to NRC GL 89-16 all have a capacity of 1% or greater at the Primary Containment Pressure Limit. With a 1% capacity, opening the vent when containment pressure reaches 10-15 psig will limit the rise in containment pressure, thus providing operators with more time to perform mitigating actions such as lining up portable injection sources.

For the event at Fukushima unit 1F2 (based on the typical decay heat levels and a 1% venting capacity), it is estimated that pressure would have peaked at approximately 29 psig and then slowly lowered to approximately 20 psig by the time RCIC was lost on the third day. Had a LOCA or breach of the RPV by core debris occurred at the time of the loss of RCIC with containment pressure at 54 psig, the containment would not be expected to survive the pressure transient due to the loss of the pressure suppression capability. Had it occurred with containment pressure at 20 psig, it is likely that containment would survive either transient, since pressure suppression capability would have existed at the time.


1F2 RPV and Containment Data March 11-14, 2011
RPV Level (in) and Pressure (psig)
Dw and SC Pressure (psig)
Date/Time
1200
1000
800
600
400
200
0
-200
-400
80
70
60
50
40
30
20
10
0
3/11/11 18:00
3/12/11 2:00
3/12/11 10:00
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3/13/11 2:00
3/13/11 10:00
3/13/11 18:00
3/14/11 2:00
3/14/11 10:00
3/14/11 18:00
RPV Pressure
SC pressure
DW Pressure
At 0355 on 12 March 1F2 logged changing resource of RCIC from CST to S/C. RCIC operated as designed for about 3 days until 14 March at 1325.
RPV Water Level Indications A and B
Hypothetical Containment Venting

**Attachment 2**

**Plant EOP Procedure Change Process for Implementing**

**BWROG EPG/SAG Revisions**

Revisions to plant Emergency Operating Procedures (EOPs) are governed by a defined process that meets the requirements of NUREG-0899, "Guidelines for the Preparation of Emergency Operating Procedures," and lessons learned in NUREG-1358, “Lessons Learned from the Special Inspection Program for Emergency Operating Procedures” and its supplement. It is a robust procedure process. The change from Emergency Procedure Guideline/Severe Accident Guideline (EPG/SAG) Revision 2 to EPG/SAG Revision 3 will require the responsible implementing team to develop the Plant Specific Technical Guideline (PSTG) from the generic guideline. This is accomplished by substituting plant specific values for the generic values, calculating plant specific curves and action limits, substituting plant specific nomenclature for generic nomenclature, adding technical steps not required by generic guidelines but required for plant specific bases, and deleting EPG/SAG steps which do not apply to that plant.

The PSTG is then transformed into the plant specific flow charts and text based support procedures using a plant specific writer’s guide. These flowcharts and support procedures are verified using a team with skill sets in BWROG EPG/SAGs, plant operations, Human factors, operator training, and plant-specific writers guide. Checklists are provided to ensure that the changes to the flowcharts and support procedures are technically correct.

Once the flowcharts and text based support procedures are verified, they are validated using one of three methods: simulator method (preferred) walkthrough method, or table-top method.

The validation team consists of appropriate subset of following disciplines: Operations, Engineering and Training. If necessary, other expertise may be recruited. Simulator scenarios are established to evaluate the changes. The purpose of validation of the flowcharts and support procedures is to ensure they are usable by the operators.

Verification and validation is documented. After any comments are resolved, the flowcharts and appendices are reviewed and approved by the plant procedure change program. Changes require a 10CFR50.59 review also to ensure the changes do not introduce an unreviewed safety question.

Operators are trained on the new revisions before the revisions are implemented.