Enclosure 1

Evaluation of Options

Contents

1.0 Introduction

The purpose of this enclosure is to ~~synthesis~~describe the various technical and policy evaluations conducted by the NRC staff to support an integrated decision on the need for additional requirements for severe accident venting of boiling water reactors with Mark I and Mark II containments. Fundamental to this ~~synthesis~~evaluation is the regulatory analysis. This enclosure provides the results of ~~that synthesis~~the NRC staff's development and consideration of various factors and summarizes the basis for the staff's recommendations.

The NRC performs regulatory analyses as part of its process for evaluating the merits of imposing new requirements on its licensees. The methodology and standard assumptions are described in NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," and NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook." The methodology includes the consideration of various costs and benefits associated with a possible change in regulatory requirements as well as consideration of qualitative factors and arguments that are difficult to present in quantitative measures such as financial costs or averted radiation exposures.

Within the regulatory analysis, there are several key assumptions and factors that are important in evaluating the costs and benefits and representing them in a common term (dollars). Many of these factors were determined during the development of NUREG/BR-0184, which was published in 1997. The NRC staff was considering updating the regulatory analysis guidance prior to the Fukushima accident. The accident provided other potential insights into some of the assumptions in the NRC's approach to performing regulatory analyses. An example of a factor that is subject to change in updating the guidance includes the conversion factor of $2,000 per person-rem for averted radiation exposures (derived from a potentially dated value of a statistical life). The staff has performed a regulatory analysis of the proposed options (severe accident capable vents and filtered vents) using existing guidance. This analysis is summarized in Section 2 of this enclosure. To evaluate the possible sensitivity of the regulatory analysis to changes in the standard factors described in existing guidance, the staff is providing, in Section 3 of this enclosure, a summary of a regulatory analysis using revised values for selected assumptions and factors.

1.1 Identification of Options

As discussed in SECY-12-0025, the staff was to evaluate several possible options for revising the severe accident capabilities of boiling water reactors with Mark I and Mark II containments. The possible options evaluated include the following:

Base Case (Option 1 or Status Quo)

The base case used in the regulatory analysis is the current fleet of affected boiling water reactor plants (31 units located at 20 sites with an average remaining license term of 25 years) assuming, to the extent practical, the completion of the post-Fukushima Tier 1 items (e.g., implementation of mitigating strategies, reliable hardened containment vents, and integration of accident-related procedures). There are, however, significant uncertainties associated with the analyses and consequence evaluations associated with the base case. Examples of these include the following:

- The frequency and consequences of severe accident conditions (i.e., core damage, hydrogen generation, and containment challenge from high pressures); the experience at Fukushima; current U.S. plant designs and procedures; and planned enhancements to designs and procedures.

- The efficiency of the suppression pool and plant systems (e.g., containment sprays or systems to flood the drywell cavity) in capturing and removing fission products (i.e., providing a decontamination function) and thereby limiting the release of radioactive materials to the site environs.

Option 2: Installation of a severe accident capable venting system (without filter)

This alterative involves the upgrading or replacement of the reliable hardened vents required by EA-12-050 with a venting system designed and installed to remain functional during severe accident conditions (i.e., release of fission products, hydrogen, and high containment pressures and temperatures). This modification would be pursued to increase confidence in maintaining the containment function following core damage events. Although venting ~~of~~the containment during severe accident conditions could result in a significant release of radioactive materials, the act of venting could prevent gross containment failures that would hamper accident management (e.g., continuing efforts to cool core debris) and result in larger releases of radioactive material.

In addition to ensuring ~~a~~the containment venting system, its supporting equipment, and instrumentation was capable of functioning in severe accident conditions, reviews of plant shielding and other protections for personnel would be required for operation of the vents under harsh conditions. Similar requirements were included in NUREG-0737, "Clarification of TMI [Three Mile Island] Action Plan Requirements," as Action Item II.B.2, "Design Review of Plant Shielding and Environmental Qualification of Equipment for Spaces/Systems Which May be Used in Post-Accident Operations," and subsequently incorporated into the NRC's standard review plan for nuclear reactors (NUREG-0800). The TMI action item was imposed before the development of SAMGs and may not have been performed for some later activities related to responding to severe accidents.

An analysis of this option is provided in Section 2 using existing regulatory analysis guidance to determine if the benefits justify the approximate $2 million cost of plant modifications~~ is provided in Section 2.~~. A revised analysis to address concerns about the possible need to update or change the regulatory analysis guidance is provided in Section 3. The NRC staff notes that Option 2 could be pursued as part of an overall filtering strategy as is being proposed by the nuclear industry. The combination of a severe accident capable vent and a filtering strategy that uses various mechanisms to minimize the release of fission products differs from Option 4 (performance-based approach) in that a specific performance measure (e.g., a combined decontamination factor) would not be treated as a firm regulatory requirement.

A complicating factor in developing Option 2 for Mark II containments is the possibility that molten core material on the drywell floor of the Mark II containment may fail the downcomers or the drywell sump drain lines and result in suppression pool bypass. This issue is described in more detail in Enclosure 4. A bypass of the suppression pool would in turn negate the possible benefits of a severe accident capable venting system in terms of avoiding containment overpressure conditions and a scrubbed release through the suppression pool. The staff concludes that Option 2 for Mark II containments may need to include plant design changes to minimize the possibility of such a bypass event. For example, design features were incorporated into the Advanced Boiling Water Reactor (ABWR) to prevent core debris from entering the lower drywell sump and ablating concrete and breaching the embedded drywell liner. These design changes would likely result in higher costs for Mark II containments but the average of the plant costs (including Mark I and Mark II) is expected to remain close to the staff's estimate of $2 million.

If Option 2 is selected, the staff recommends that it be imposed by issuing an order or revising existing Order EA-12-50. A draft of a proposed order is provided in Enclosure 7 **[TO BE DEVELOPED IF THE STEERING COMMITTEE SUPPORTS OPTIONS 2 OR 3]**. The upgrading of the venting system to ensure its functionality during severe accident conditions would also be required for Option 3 (filtered venting) and Option 4 (performance-based approach) and would need to be addressed within the development and implementation of those options should they be selected.

Option 3: Installation of a filtered severe accident venting system

This option involves the installation of a filtered containment vent system that is intended to prevent the release of significant amounts of radioactive material following most severe accident scenarios at BWRs with Mark I and Mark II containments. The filtering system and connections to the containment wetwell and drywell would need to be capable of operation during conditions associated with significant core damage, including breaching of the reactor vessel. Similar to Option 2 (severe accident capable venting system), the approach significantly increases the chances of preventing gross containment failure and substantially supports accident management efforts to arrest further plant degradation and the release of radioactive materials. The inclusion of a filter minimizes the amount of radioactive material released to the environment during the venting of containments.

The assumed approach involves the installation of external filters similar to those installed at some foreign plants following the accidents at Three Mile Island and Chernobyl (see Enclosure 3). An analysis of this option using existing regulatory analysis guidance to determine if the benefits outweigh the approximate $15 million dollar cost of plant modifications is provided in Section 2. A revised analysis to address concerns about the possible need to update or change the regulatory analysis guidance is provided in Section 3. If Option 3 is selected, the staff recommends imposing the related requirements of Option 3 by issuing an order or a revision to Order EA--12-50. A draft of a proposed order is provided in Enclosure 7 **[TO BE DEVELOPED IF THE STEERING COMMITTEE SUPPORTS OPTIONS 2 OR 3]**..

Option 4: Performance-Based Approach

Another possible approach involves the establishment of performance criteria (e.g., defined decontamination factor or site-specific cost/benefit analysis) and allowing licensees to select and justify systems or combinations of systems such as suppression pools, containment sprays, or separate filters to accomplish the function and meet the performance criteria. For this option, the staff did not analyze a specific filtering system but instead drew on insights from the various sensitivity studies to define a possible performance-based approach. Section 4 of this Enclosure discusses potential performance-based approaches in more detail.

In keeping with previous experience on developing performance-based requirements, the staff envisions that this option would be pursued through the rulemaking process. The rulemaking process is usually used for performance-based approaches because they tend to involve extensive interactions with stakeholders and the development of detailed industry and regulatory guidance documents. It may be appropriate to proceed with Option 2 and the related order to ensure the venting systems currently being designed and implemented under EA-12-050 are made severe accident capable. This would support the subsequent rulemaking for a performance-based approach while possibly reducing the net costs for the changes to containment venting systems. The rulemaking process includes performing a regulatory analysis for the proposed requirements, which would be dependent on the chosen performance measure. For the purpose of this paper, the regulatory analysis for Option 4 is addressed in a more subjective discussion dealing with possible benefits, costs, and uncertainties.

This option may align with the industry proposal described in the letter dated October 5, 2012, from the Nuclear Energy Institute on “Containment Filtration Strategies for Mitigating Radiological Releases in Severe Accidents for BWR Mark I and Mark II Plants to Reduce the Risk of Land Contamination.”

1.2 Other Items

As ~~demonstrated by~~ mentioned in the above ~~discussions of the base case and the analyses~~discussion of the proposed options, the uncertainties associated with the assessment of these ~~issues~~approaches are important in attempting to reach a regulatory decision. In addition to ~~those discussions~~the quantitative evaluations in Sections 2 and 3, there are also a number of qualitative factors and policy issues that bear directly on the issue of requiring filtered vents. These qualitative factors and policy issues are discussed in Section 5 and include:

- Significant uncertainties in technical analyses
- Containment functions as part of defense in depth
- Hydrogen control
- Severe accident management
- Emergency planning
- ~~Safety culture~~
- Independence of barriers
- International practices
- Severe Accident Policy Statement
- ~~Societal factors~~
- Consistency between reactor technologies
- External events
- Multi-unit events

There are also several issues related to containment venting to consider beyond the options discussed above.

1.2.1 Vents in Areas other than Primary Containment

This ~~option~~issue involves the possible installation of vents in areas other than primary containment. An example is the installation of vents to prevent detonation of hydrogen within the reactor building as occurred at Fukushima. Given that this topic is associated with the control of hydrogen, its ultimate resolution will be via the Tier 3 item associated with NTTF Recommendation 6, "Hydrogen Control and Mitigation Inside Containment or in Other Buildings." However, there is a significant relationship between the control of hydrogen within the primary containment and other plant areas, and the decisions associated with severe accident capable or filtered containment venting. The outcomes from this paper will be considered in the staff's assessment and proposals for possible paths to resolve Recommendation 6. If Option 2 or 3 were pursued, the ~~staff believes the~~ resulting containment venting system could ~~potentially substantially resolve~~play a substantial role in resolving Recommendation 6 for Mark I and Mark II containments. The most likely remaining issues to be addressed for these containment designs would be an assessment of hydrogen release pathways from bypass events, and the performance of containment seals and penetrations if post-severe accident high pressure conditions were maintained in the containment. Resolution of the issue would be highly dependent upon ensuring a highly reliable engineered pathway for releasing the hydrogen from the containment, and ensuring that there was minimal differential pressure across containment seals and penetrations following venting operations. The staff notes that venting strategies involving maintaining containment pressure at elevated levels, or strategies involving containment vent cycling at elevated levels would continue to present the potential for hydrogen leakage from the primary containment to other buildings and may not be as beneficial in resolving NTTF Recommendation 6.

1.2.2 Drywell Flooding Capabilities

Various risk assessments performed by the NRC and industry for BWRs with Mark I or Mark II containments have concluded that the addition of water to the drywell has a significant benefit to controlling the release of radioactive materials for those severe accident scenarios involving fuel melting through the reactor vessel. The water added to the drywell provides cooling of the molten fuel, can arrest its progression, and prevent a loss of the drywell containment function (e.g., liner melt-through, containment over-pressurization failure, containment over-temperature failure). The importance of providing cooling water to protect the containment was a factor in establishing the mitigating strategies and capabilities associated with the possible loss of large areas of the plant due to explosions or fire (10 CFR 50.54(hh~~).~~)). Current capabilities are addressed in the NRC endorsed guidance ~~in~~document NEI-06-12, "B.5.b Phase 2 & 3 Submittal Guideline," and call for the addition of approximately 300 gallons per minute via a portable pump and flow paths into the drywell or reactor vessel. For the purpose of this assessment, the staff has incorporated this capability into its characterization of the status quo and has not proposed additional requirements within the proposed options for severe accident capable or filtered containment vents. This capability is very important to the success of Options 2, 3 or 4 for scenarios where the core melts through the reactor pressure vessel and could then lead to containment failure. The importance of this capability to any severe accident venting requirements may warrant a more specific requirement than is currently in place via 10 CFR ~~50.54(hh) and the related guidance.~~ 50.54(hh) and the related guidance. Because there are existing requirements and guidance related to this capability, the NRC staff has not included a similar requirement in the draft orders provided in Enclosure 7 for options 2 and 3. However, the longer-term rulemaking associated with the proposed options 2, 3 or 4 could consider the addition of more explicit requirements for the capability for core debris cooling during severe accident scenarios. An additional consideration is the degree to which core or drywell sprays are credited for providing a scrubbing or decontamination function for the radioactive materials within the drywell during a severe accident. The staff will, if necessary, address this issue as part of its implementation of the decisions reached on possible requirements for severe accident capable or filtered containment venting systems.

1.3 Justification for Imposing Requirements

In the development of new or revised regulatory requirements, the NRC uses regulatory analyses such as discussed in Sections ~~1~~2 and ~~2~~3 to help in the decision-making process, but the agency is not fully constrained by the quantitative cost/benefit calculations. There are two primary cases when the agency's deliberations might lead to an action even though the costs of that action might appear to outweigh the benefits. These two rationales involve either:

1) finding that one or more of the options discussed is needed to provide reasonable assurance of adequate protection of the public health and safety[1], or

2) finding that one or more of the options justify the associated costs as a result of the combination of the standard regulatory analysis and other qualitative factors.

Adequate Protection

The first case involves the specific exceptions included in 10 CFR 50.109, "Backfitting," to the need to perform cost/benefit analyses for some NRC actions imposing new requirements on licensees. The exceptions listed in paragraph a(4) of 10 CFR 50.109 are:

> (i) That a modification is necessary to bring a facility into compliance with a license or the rules or orders of the Commission, or into conformance with written commitments by the licensee; or
>
> (ii) That regulatory action is necessary to ensure that the facility provides adequate protection to the health and safety of the public and is in accord with the common defense and security; or
>
> (iii) That the regulatory action involves defining or redefining what level of protection to the public health and safety or common defense and security should be regarded as adequate.

In the case of the potential options being considered (Options 2, 3, or 4), exceptions (ii) or (iii) could be invoked if the Commission were to determine that such changes were needed to address the current or a revised standard for adequate protection. A discussion of the history and traditional use of the NRC invoking the standard of reasonable assurance of adequate protection is provided in SECY-12-0110, "Consideration of Economic Consequences Within the NRC's Regulatory Activities."

[1] In the case of a finding that an action is needed for adequate protection of public health and safety, the NRC is actually not allowed to consider costs in its decisions. So the process should be that a finding is made regarding adequate protection independent of costs instead of invoking the adequate protection provisions because the costs have been found to exceed the calculated benefits.

The NRC staff assessed the possible benefits associated with the options described in this paper for improving containment venting at BWRs with Mark I and II containments. The assessment and lessons learned from the Fukushima accident indicate that functions to delay core damage and containment failure in combination with protective actions taken to evacuate or shelter the public are able to minimize risks to the public health and safety. The NRC has traditionally reserved the use of the adequate protection standard to the protection of public health and safety and invoked it for design basis accidents, selected functions to prevent core damage (e.g., EA-12-050), and programs to ensure licensees have strategies or contingencies for severe accidents (e.g., emergency planning, EA-12-049, and 10 CFR 50.54(hh)). ~~A requirement for more specific severe accident design features to limit the release of radioactive materials beyond~~ The staff is therefore not convinced that ~~necessary to protect the public health and safety would not seem to~~ Options 2, 3, or 4 align with the traditional use of the adequate protection provision of the NRC's regulations. ~~The staff is therefore not recommending consideration of Options 2, 3, or 4 under the adequate protection standard. However~~ For this reason, the staff has proceeded with analyses of proposed venting modifications as possible cost-justified substantial safety improvements, although recognizing that the Commission is the ultimate determiner of whether any of the proposed options ~~can~~should be pursed to ensure reasonable ~~confidence~~assurance of adequate protection of public health and safety.

The NRC staff does not currently consider the potential economic consequences of an accident within its deliberations on adequate protection. A Commission decision to revise the agency's accounting of offsite land contamination (Option 3 in SECY-12-0110) could affect arguments related to finding whether or not the addition of a filtered vent system for BWRs with Mark I or II containments might be needed for a revised adequate protection standard or a separate equivalent standard for economic consequences. Even in the absence of Commission direction to revise the current focus on public health and safety in deliberations on adequate protection (or equivalent standard for economic consequences), the current assessment process for a regulatory analysis includes consideration of offsite costs and the topic is ~~addressed as an~~discussed within the additional qualitative ~~factor~~factors in Section 5 of this enclosure.

The evaluation of the proposed options provided later in this enclosure considers both quantitative and qualitative factors. An assessment using only those factors represented in quantifiable terms (i.e., dollars) would not fully support the deliberative process. However, the importance of the qualitative factors in judging the merits of the four options related to containment vents for BWR Mark I and II containments is itself indicative of possible issues with the NRC's current regulatory framework. The NTTF identified some of these same issues and considered them in its formulation of Recommendation 1, which included developing an improved framework for addressing beyond-design-basis events and revising the regulatory analysis guidelines to more effectively integrate safety goals and a defense-in-depth philosophy. It is possible that actions taken in response to Recommendation 1 or other initiatives will provide revised guidance on the balancing of risk insights and defense in depth such that one or more of the proposed options would more clearly be associated with a finding of reasonable assurance of adequate protection of public safety. In the mean time, the NRC staff has proceeded to an evaluation of the options as possible cost-justified safety enhancements.

Cost-Justified Safety Enhancements

Because requiring ~~the use of~~ severe-accident capable hardened vents and/or filtered vents does not appear to ~~be applicable to~~justify citing an exception under 10 CFR 50.109(a)(4), a two-part backfit analysis must be applied, as described in 10 CFR 50.109(a)(3). ~~The~~ Before proceeding to a comparison of costs and benefits, the first part of the test under (a)(3) is whether there is a "substantial increase in the overall protection of the public health and safety or the common defense and security derived from the backfit." NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," includes the following explanation (from Staff Requirements Memorandum "SECY-93-086—Backfit Considerations," dated June 30, 1993) regarding the need for plant backfits to provide a substantial increase in safety:

> The Commission has stated that "substantial" means important or significant in a large amount, extent, or degree. Applying such a standard, the Commission would not ordinarily expect that safety-applying improvements would be required as backfits that result in an insignificant or small benefit to the public health and safety, regardless of costs. On the other hand, the standard is not intended to be interpreted in a manner that would result in disapprovals of worthwhile safety or security improvements having costs that are justified in view of the increased protection that would be provided. This approach is flexible enough to allow for qualitative arguments that a given proposed rule would substantially increase safety. The approach is also flexible enough to allow for arguments that consistency with national and international standards, or the incorporation of widespread industry practices, contributes either directly or indirectly to a substantial increase in safety. Such arguments concerning consistency with other standards, or incorporation of industry practices, would have to rest on the particulars of a given proposed rule. The Commission also believes that this approach of "substantial increase" is consistent with the Agency's policy of encouraging voluntary initiatives.

NUREG/BR-0058 describes the use of the NRC safety goals as a means to evaluate whether a proposed backfit provides substantial safety improvements but also recognizes the limitations of this approach for modifications that do not change core damage estimates but provide improvements to containment performance. Specifically, the guidance states:

> The NRC recognizes that in certain instances, the screening criteria may not adequately address certain accident scenarios of unique safety or risk interest. An example is one in which certain challenges could lead to containment failure after the time period adopted in the safety goal screening criteria, yet early enough that the contribution of these challenges to total risk would be nonnegligible, particularly if the failure occurs before effective implementation of accident management measures. In these circumstances, the analyst should make the case that the screening criteria do not apply and the decision to pursue the issue should be subject to further management decision.
>
> Furthermore, note that the safety goal screening criteria described in these Guidelines do not address issues that deal only with containment performance. Consequently, issues that have no impact on core damage frequency (ΔCDF of zero) cannot be addressed with the safety goal screening criteria. However, because mitigative initiatives have been relatively few and infrequent compared with accident preventive initiatives, mitigative initiatives will be assessed on a

case-by-case basis with regard to the safety goals. Given the very few proposed regulatory initiatives that involve mitigation, this should have little overall impact from a practical perspective on the usefulness of the safety goal screening criteria.

The issue of whether the possible imposition of requirements for severe accident capable or filtered venting systems satisfy the "substantial safety improvement" standard was assessed by senior NRC managers on the Japan Lessons-Learned Steering Committee (SECY-11-0117). The managers decided that the possible modifications should proceed to the estimation and evaluation of values and impacts within the regulatory analysis process. These estimates and evaluations are provided in the following sections of this enclosure.

2.0 Evaluation of Options Using Existing Regulatory Analysis Guidance

The staff, with assistance from Sandia National Laboratory, performed analyses using MELCOR and MACCS2 computer simulations to characterize the expected plant response and offsite consequences for an extended loss of electrical power at a representative BWR with a Mark I containment design. The following key assumptions were used in the simplified regulatory analyses provided in this enclosure:

- Base Event Frequency for events for which the severe accident capable or filtered venting system would add significant value is assumed to be 2x10^{-5} per year. This value is taken from results from individual plant examinations, NRC Standardized Plant Analysis Risk (SPAR) models, and engineering judgment. This value is considered representative of the core damage frequency for the operating plants with Mark I and II containment designs.
- To address the uncertainties associated with event frequencies, the assessment is also performed assuming a core damage frequency of ~~3x10~~2x10^{-4} per year, which is a factor of 10 above the base event frequency[2].
- Assuming a lower value of CDF would reduce the calculated benefits in a similar fashion but in the opposite direction, thereby making the proposals less cost-effective. Since the reduction is proportional to the CDF assumption (i.e., reducing CDF by a factor of 10 reduces the calculated benefit by a factor of 10), the staff has not specifically included within the discussions or tables the sensitivity to lower CDFs.
- The specific assumptions regarding transients, equipment performance, and recovery actions are discussed in the technical analyses sections provided in Enclosure 5.

The base case and ~~above~~ sensitivity analyses are summarized below in terms of the various factors used in the regulatory analysis guidelines. A more complete assessment of uncertainties and sensitivities is provided in Enclosure 5c and in the regulatory analysis that is available in the Agencywide Documents Access and Management System (ADAMS) as Accession No. MLxxxxxxxxx.

[2] The range was selected to provide decisionmakers with information about sensitivities to certain assumptions and to address uncertainties, plant-to-plant variations, and the limited number of PRAs including external events. The NRC staff is not placing any particular importance on the upper value used except as a part of sensitivity studies provided for CDF and other parameters.

2.1 Public Health (Accident)

For the purpose of establishing the base case, those scenarios involving the potential for a significant release of radioactive material through a containment vent path are identified and evaluated in terms of consequences and estimated accident frequencies. In the case of BWRs with Mark I and II containment designs, this subset of severe accidents make up the majority of the sequences involving large releases (with the remainder involving failures of containment and releases through pathways other than through a controlled and possibly filtered pathway). Containment failures could for example occur as a result of severe accident conditions that involve high pressures in the containment (e.g., venting failures) or scenarios that involve a molten core breaching both the reactor vessel and drywell liner (e.g, lack of drywell spray).

The results from the simulations of an extended loss of electrical power transient are consistent with previous evaluations and the experience from the Fukushima Dai-ichi accident in terms of the viability of avoiding large exposures to the general public by the evacuation of populations near a nuclear power plant. The analysis assumes however that populations are instructed to return to their homes following an accident if projected dose rates fall below the defined criteria (e.g., 500 mrem/year). This longer term exposure of populations from the residual contamination of the countryside is controllable but is assumed in order to estimate a plausible balancing of public health and economic impacts. In this case, reducing public exposures by limiting the return of populations to affected areas would result in an increase in the economic consequences by preventing the use of homes and businesses.

For the status quo, a related scenario described in Enclosure 5 is Case 6 which includes failure of containment on overpressure and a long-term population dose of 310,000 Rem to the public within 50 miles of the site. As discussed in Enclosure 5, consideration of various possible sequences of events, with assumed probabilities, leads to an estimated 50-mile population dose risk of 10.2 Rem/reactor-year.

2.1.1 Option 2 – Severe Accident Capable Vents

To estimate the potential benefits of requiring a severe accident capable venting system, the staff used the simulations and risk estimates from Enclosure 5. The estimated population dose risk for a severe accident capable vent is 5.9 Rem/reactor-year or a net benefit of 4.3 Rem/reactor-year~~.~~ when compared to the base case. Using the existing guidance for NRC regulatory analyses, the estimated dose savings are converted to dollars using the equation:

[(Estimated Accident Frequency) x (Change in Population Dose)] x ($2,000/person-rem) x
[1- exp (-(discount rate) x (remaining reactor life)]/(discount rate)

Where: 4.3 Rem/reactor-year reflects the frequency and change in estimated dose
Conversion Factor of $2,000 per Rem
Discount rates are assumed to be 3 percent[3]
Remaining reactor life assumed to be 25 years.

[3] A complete regulatory analysis is available in the Agencywide Documents Access and Management System (ADAMS) as Accession No. MLxxxxxxxxx and includes an alternate assessment using a 7% discount rate. The 3% discount rate provides a higher calculated benefit and is used for the remainder of this enclosure.

Using the above assumptions, the benefits of the severe accident capable vent in terms of avoiding doses to the population are estimated to be $150,000 per reactor unit.

The above estimated benefits are proportional to the estimated accident frequency and the related uncertainties. If, for example, the estimated frequency related to a severe accident were raised to 32x10^{-4}/reactor year, the associated benefits would increase to $2.251.50 million per unit.

2.1.2 Option 3 – Filtered Vents

The installation of a filtering system with expected performance requirements would significantly reduce the release and subsequent exposure of the population. For the sake of this evaluation, the values associated with Modification 6 from Enclosure 5 are used. These estimates include a risk evaluation estimate for population dose of 2.0 Rem per reactor-year or a projected reduction of 8.2 Rem per reactor-year when compared to the base case. Using the equation given above, the reduction in projected dose risks translates into a net benefit of $290,000 per reactor unit.

The above estimated benefits would increase to $ 4.352.90 million per unit if the estimated accident frequency and were raised to 32x10^{-4}/reactor year.

The uncertainties associated with expected decontamination factors for suppression pools and sprays were assessed by performing additional simulations with the MELCOR and MACCS2 computer codecodes. Sensitivity studies related to various scenarios and decontamination factors are provided in Enclosure 5. A very conservative estimate with limited credit for scrubbing by the suppression pool or sprays and venting from the drywell resulted in a reduction in dose for a filtered vent path of nearly 4 million Rem for a population within 50 miles. TheThat value would, in turn, translate, using the above equation and core damage frequency of 2x10^{-5} per year, into a calculated benefit of $2.8 million per unit in current dollars.

2.2 Occupational Health (Accident)

Accidents involving significant core damage will result in an increase in occupational exposures at the plant. A range of estimated occupational exposures were taken from NUREG/BR-0184 to simulate the possible effects of severe accident capable and filtered venting systems. A containment failure due to overpressure or liner melt-through was assumed to result in the highest estimate of immediate occupational dose from the regulatory analysis handbook, which is 14,000 person-rem. The conditions associated with severe accident capable vents were assumed to reduce the associated occupational exposure to 3,300 person-rem. Finally, the filtered release was assumed to result in the lowest immediate occupational exposure of 1,000 person-rem, which is approximately the occupational dose received from the Three Mile Island accident. The risk assessment provided in Enclosure 5 considered the possible end states and their likelihood for the various possible modifications and provided dose risk for the immediate accident period. The following total occupational dose risks are derived from combining the immediate occupational doses and the longer term (cleanup) doses from NUREG/BR-0184.

- Status Quo — 0.88 person-rem/reactor-year
- Severe accident capable (Mod 2) — 0.56 person-rem/reactor-year

- Filtered vent (Mod 6) 0.33 person-rem/reactor-year

Using the same equations and assumptions ($2,000 per person-rem and CDF of 2x10^{-5} per year) as used above for consideration of public doses results in an estimated benefit of $11,000 per unit for severe accident capable vents and $19,000 per unit for filtered vents. Increasing the estimated frequency of core damage to 3E2x10^{-4} per year would result in an increase of estimated benefit for the severe accident capable vents to $165110,000 per unit and to $285190,000 per unit for filtered vents.

Another potential impact in terms of evaluating filtered vents would be the number of workers added to participate in offsite cleanup activities following a major release. However, decisions related to cleanup activities for the nearby countryside could consider and assess the expected dose to workers versus the economic impact of not recovering the affected areas. The potential dose-related costs for the cleanup of contaminated offsite areas are accounted for in the assessment of potential effects on offsite property.

2.3 Offsite Property

The U.S. has an existing structure for nuclear power plants that involves measures to prevent, contain, and mitigate releases of radioactive materials and, if necessary, to compensate individuals for the potential damages to health, property, or income. For the purpose of this discussion, prevention and containment relate to attempts to arrest a nuclear accident and maintain the radioactive material within the plant (including confining materials within containment or within a filter). Mitigation relates to limiting the impact on public health through protective actions such as sheltering or evacuation. Provisions for compensation are addressed by the Price-Anderson Act and related NRC regulations. Compensation for nuclear accidents is not usually addressed within regulatory analyses since it involves the source and flow of funds but does not influence the actual amount of damages caused by a potential nuclear accident. It is worth noting however that the funding from the current insurance pools that is available to address a major nuclear accident in the U.S. is approximately $12 billion.

The results from the computer simulations include estimates for the amount of land area that could be contaminated following the modeled scenarios as well as an estimate of total economic costs (assuming loss of use of property, businesses, etc.). The results from the analyses for one of the cases (Case 6 with containment failure on overpressure) used in the risk assessments described in Enclosure 5 is a land contamination area of 34 km^2 and an economic consequence of $847 million. Consideration of various possible sequences of events, with assumed probabilities, leads to an estimated offsite cost risk of $630,000 per reactor-year.

2.3.1 Option 2 – Severe Accident Capable Vents

Using the same assumptions and cases discussed above for population doses, the estimated difference in the offsite cost risk for Modification 2 (assumed passive vent from wetwell) is $19,767 per reactor-year. Using the existing guidance and assumptions for NRC regulatory analyses, the estimated difference in economic consequences in current dollars (i.e., the benefit of the severe accident capable vent) is $348,000 per reactor unit. Assuming an event frequency of 32x10^{-4} per year would increase the calculated benefit to $5.223.48 million per unit.

2.3.2 Option 3 – Filtered Vents

The installation of a filtering system with expected performance requirements would significantly reduce the estimated affected land area and related economic consequences. The filtered venting system in this assessment uses the offsite cost risk reductions from Enclosure 5 for Modification 6 (assumed passive vent from wetwell with filter), which were estimated to be $34,166 per reactor-year. Using the established assumptions and conversions, the avoided economic consequences translates in current dollars to a benefit of $600,000 per reactor unit. As with the other factors, this result is directly correlated to estimated accident frequencies and ~~would increase~~ increases to $~~9~~6.0 million per unit if a frequency of ~~3~~2$\times10^{-4}$ per year ~~was~~is assumed. Additional discussions regarding the uncertainties and other issues associated with estimating economic consequences are provided in Section 3.

2.4 Onsite Property

A severe accident at a nuclear power plant is assumed to result in the loss of the affected unit in terms of the future electrical output and early decommissioning (complicated by the post-accident conditions). The installation of a filter within the containment vent path would not likely change the total loss of the unit experiencing significant fuel damage. However, a filter could limit contamination of nearby units and the associated increase in onsite property damage, including loss of generation from the co-located units. The radiation exposure for site cleanup ~~were~~was addressed under the factor related to occupational health. Other cleanup costs are addressed using guidance from NUREG/BR-0184 and the estimates of risk factors provided in Enclosure 5.

The onsite property costs are used to address the possible loss of electrical generation resulting from an accident. For the purpose of this evaluation, the radioactive releases from either the base case or Option 2 are assumed to result in the permanent closure of not only the unit with the damaged core but also units located on the same site. In accordance with existing practices, the impact of these shutdowns is modeled as the replacement costs for a 10-year period (after which alternate energy supplies would become available). The filtered venting case is assumed to result in the loss of the co-located units for one year. Of the 31 BWR units with Mark I or II containments, 8 are single unit sites, 16 could impact one other operating unit, and 7 could impact 2 other operating units. Based on these site combinations, consideration of the loss of co-located facilities on a generic basis for Mark I and II units is addressed by multiplying the loss of electrical generation by a factor of 1.75.

2.4.1 Option 2 – Severe Accident Capable Vents

The estimated difference in the onsite cost risk for Modification 2 (assumed passive vent from wetwell) is $15,185 per reactor-year. Using the existing guidance and assumptions for NRC regulatory analyses, the estimated difference in onsite costs in current dollars (i.e., the benefit of the severe accident capable vent) is $268,000 per reactor unit. Assuming an event frequency of ~~3~~2$\times10^{-4}$ per year would increase the calculated benefit to $~~4.0~~2.68 million per unit.

The cost from the loss of electrical generation from co-located facilities was estimated assuming an average value of $9.9 million per reactor-year. Using the generic factor of 1.75 and a period of 10 years for needed power replacement results in an undiscounted consequence estimate of $173.25 million. Considering the likelihood of such events results in a value of $3,500 for an event frequency of 2x10^{-5} per year and of $5235,000 for the value of 32x10^{-4} per year. However, since this loss is the same as for the base case, it is not used directly but is instead used to estimate a savings for the following filtered vent option.

2.4.2 Option 3 – Filtered Vents

The estimated difference in the onsite cost risk for Modification 6 (assumed passive vent from wetwell with filter) is $24,485 per reactor-year which translates into an estimated difference in onsite costs in current dollars (i.e., the benefit of the filtered vent) of $430,000 per reactor unit. Assuming an event frequency of 32x10^{-4} per year would increase the calculated benefit to $6.54.3 million per unit.

The cost from the loss of electrical generation from co-located facilities was estimated assuming an average value of $9.9 million per reactor-year. Using the generic factor of 1.75 and a period of 1 year for needed power replacement for the undamaged unit results in an undiscounted consequence estimate of $17.325106.425 million. Considering the likelihood of such events results in a value of $3502,100 for an event frequency of 2x10^{-5} per year and of $5,20021,000 for the value of 3-2 x- 10^{-4}per^{4} per year. This can be represented as a savings of $3,1501,400 for the 2x10^{-5} per year frequency and $46,80014,000 for an assumed event frequency of 32x10^{-4} per year.

2.5 Industry Implementation

The base case involves implementing current requirements (e.g., EA-12-049 and 12-050) and therefore does not involve additional costs. The implementation costs for providing a severe accident capable reliable hardened vent could vary significantly between plants based on equipment configurations and plans regarding the implementation of EA-12-50. An assumed cost for this evaluation is $2 million per unit, which is based primarily on judgment and gross estimates of time and materials for many of the plants that would need to perform modifications. As discussed in Enclosure 4, the costs for severe accident capable vents for Mark II containment designs will likely be higher than for Mark I units. The higher cost reflects the likely need to modify containments to prevent a molten core from causing a bypass of the suppression pool due to failure of drain lines below the reactor vessel. Given that avoiding bypass of the wetwell is needed to make the severe accident capable vents a viable option for the Mark II design, protection of the downcomers and drain lines are included in the cost of this option for Mark II containments. The implementation costs for the filtered venting system are estimated based on discussions with foreign plants, vendors, and other stakeholders. The estimated costs used in this assessment are $15 million per unit.[4]

2.6 Industry Operation

The base case involves implementing current requirements (e.g., EA-12-049 and 12-050) and therefore does not involve additional costs. The upgrading of venting systems to be compatible with severe accident conditions is not expected to add significantly to the operating costs of a

[4] Some stakeholders have noted that an estimate of $15 million seems low and that the price could be factors of 2 or 3 higher. The costs could be expected to be significantly above $15 million if the system wasis designed and installed as safety-related equipment or needed to be protected from beyond design basis external events.

nuclear power plant and is therefore not estimated for this evaluation. The operating costs for maintaining the filtered venting system, including training, are estimated based on discussions with foreign plants, vendors, and other stakeholders. The estimated costs used in this assessment are $60,000 per unit per year in current dollars for a present value of $1.1 million (3% discount rate and 25 year license term).

2.7 NRC Implementation

The base case involves implementing current requirements (e.g., EA-12-049 and 12-050) and therefore does not involve additional costs. The implementation costs for development of regulations for a severe accident capable or filtered vent and subsequent reviews and inspections are estimated to involve a total NRC cost of $830,000 or approximately $27,000 per unit.

Longer term NRC operating costs are not expected to change as a result of the possible addition of these requirements and not included in this evaluation.

2.8 Summary

The results of the evaluation of the costs and benefits of a dedicatedsevere accident capable and filtered vent system using the existing regulatory analysis guidelines are summarized below.

Costs ( ) and Benefits of Severe Accident Capable and Filtered Vent System $ K Per Unit				
	Severe Accident Capable		Filtered	
Factor	Best Estimate Frequency of 2x10^{-5} per year	Accident Frequency of 3x102x10^{-4} per year	Best Estimate Frequency of 2x10^{-5} per year	Accident Frequency of 3x102x10^{-4} per year
Public Health	150	2,2501,500	290	4,3502,900
Occupational Health	11	165110	19	285190
Offsite Property	348	5,2203,480	600	96,000
Onsite Property	268	4,0002,680	430	6,5004,300
Industry Implementation	(2,000)	(2,000)	(15,000)	(15,000)
Industry Operation	n/a	n/a	(1,100)	(1,100)
NRC Implementation	(27)	(27)	(27)	(27)
TOTAL	(1,250)	+9,6085,743	(14,778)	+4,008(2,737)

3.0 Evaluation of Options Including Possible Changes to Regulatory Analysis Guidance

The base case and related sensitivities for the evaluation were discussed in the previous section and much of that information is used for the revised analysis in this section; which focuses on possible updates or changes to the regulatory analysis guidance or assumptions related to the costs and benefits of a severe accident capable or filtered venting system for BWRs with Mark I or II containment designs. There are several possible changes that would impact the evaluation of the severe accident capable or filtered vent options. In general, the consequence analyses from Section 2 are carried forward to this assessment and revised factors are used to represent those consequences in terms of the cost/benefit calculations.

3.1 Public Health (Accident)

Section 2 described the evaluation of the base case and options in terms of possible exposures to the populations within 50 miles of a plant undergoing a severe accident for which the installation of severe accident capable or filtered vents could reduce the offsite consequences. A discussion of sensitivities to accident frequency and retention of fission products by suppression pools and sprays is provided in Enclosure 5. The other major factor in the assessment of possible public health benefits is the value used to convert population dose (Rem) into dollars based on various health studies and the valuation of impacts on life and health. The NRC staff is currently assessing a possible revision of the $2,000 per person-rem conversion factor, including a revision of the factor to $4,000 per person-rem.

The sensitivity of this assessment of the costs and benefits of installing a severe accident capable or filtered venting system for BWRs with Mark I or II containments is directly proportional to the assumed conversion factor. A doubling of the factor, to $4,000 per person-rem, would double the previously calculated benefits of the severe accident capable vent to $300,000 per unit while the benefit of a filtered system would be increased to $580,000 per unit. An increase in assumed accident frequency to 32x10^{-4} per year would then increase the benefits to $4.53.0 million and $5.8.7 million per unit respectively for the severe accident capable and filtered venting systems. The estimated benefit of the filter for the case where possible retention of fission products within the suppression pool is largely neglected via venting from the drywell would increase to $5.6 million dollars per unit. Revisions of the assumptions to decrease the frequency or the release of radioactive materials would likewise decrease the calculated benefits of the proposed filtered venting system.

3.2 Occupational Health (Accident)

As above, an increase in the dollars per person-rem conversion factor would double the estimates provided in Section 2. The estimated benefits would be $22,000 per unit for a severe accident capable vent and event frequency of 2x102x10^{-5} per year and $330220,000 for an estimated event frequency of 32x10^{-4} per year. Likewise the estimated benefits of a filtered vent system would increase to $38,000 and $570380,000 per unit respectively for the frequencies of 2x10^{-5} per- year and 3x102x10^{-4} per year.

3.3 Offsite Property

Estimates of the long-term economic consequences of the Fukushima Dai-ichi accident are continuing to evolve and may ultimately be used to update NRC guidance for performing regulatory analyses. Current estimates for the area surrounding Fukushima range from tens to hundreds of billions of dollars. As discussed in SECY-12-0110, "Consideration of Economic Consequences within the Nuclear Regulatory Commission's Regulatory Framework," the NRC staff is evaluating possible updates to the computer codes and models used to assess offsite property damages.

The fact that there continues to be a fairly wide range of estimates for the actual economic impact of previous events such Hurricane Katrina, which struck the southern U.S. in 2005, highlights the difficulty in predicting potential impacts for future disasters, including potential nuclear reactor accidents. Several journals provide estimates of around $125 billion, including the loss of oil production and refining, for economic impacts of Hurricane Katrina. Other major disasters, such as Hurricane Andrew in 1995 and Hurricane Irene in 2011, have been estimated to have caused around $45 billion in economic losses. A conservative simulation using MACCS2 was discussed in Enclosure 5 to address uncertainties in the performance of the suppression pool and sprays in limiting the release of radioactive materials. The simulation calculated total economic costs at $33 billion for that conservative representation of a large release from the modeled BWR.[5] In terms of a typical regulatory analysis, an estimated offsite cost of $33 billion translates (assuming an event frequency of $2\text{x}10^{-5}$ per year) into a net benefit of $11.6 million per unit. Given the ongoing efforts to assess and update capabilities to estimate economic consequences, the staff is not providing additional sensitivities here regarding the estimation of offsite property damage. This issue will be discussed again in qualitative terms in Section 5.

3.4 Onsite Property

As mentioned in Section 2, a severe accident at a nuclear power plant is assumed to result in the loss of the affected unit in terms of the future electrical output and early decommissioning (complicated by the post-accident conditions) for both the base case and the proposed options. The installation of a filter within the containment vent path could, however, limit contamination of nearby units and the associated increase in onsite property damage, including loss of generation from the co-located unit. The potential impacts could range from a temporary loss of the unaffected unit to its permanent closure due to economic, technical, or societal factors. The regulatory analysis includes sensitivities to a range of electrical energy costs but these were not found to dramatically affect the assessment. The results from Section 2 were as follows:

[5] Note that under the provisions of the Price-Anderson Act, damages that exceed the available insurance pools (currently at approximately $12 billion) would require actions on the part of the U.S. government to increase nuclear utility liability and/or contribute to the compensation funds.

Modification	Unit Cost	
	2x10^{-5}/yr Event Frequency	~~3x10~~2x10^{-4}/yr Event ~~Freqency~~Frequency
Severe Accident Capable	$268,000	$4.~~0~~2.68 million
Filter	$430,000	$~~6.5~~4.3 million

Although the replacement energy costs for the affected and co-located units do not appear to significantly affect the results of the regulatory analysis, the Fukushima accident also led to the shutdown of other nuclear units located away from the direct effects of the accident. Such shutdowns might result from new regulatory reviews or requirements, caution on the part of plant operators, or other societal factors. The possibility of such shutdowns and the resulting increase in replacement power is addressed as a sensitivity case in the regulatory analysis and ~~would~~could increase the calculated benefits from the installation of a filtering system~~ by $104,000~~. Early shutdown of a large number of units would also entail costs from decommissioning and disturbance of broader energy markets.

3.5 Industry Implementation

As discussed in Section 2, the costs of industry implementation are estimated to be $2 million for severe accident capable vents and $15 million for a filtered venting system. While there is considerable uncertainty with these estimates, the handling of industry implementation costs is not likely to be a significant issue within the updating of the regulatory analysis guidance and no additional discussion of sensitivities is provided here.

3.6 Industry Operation

The industry operating costs for maintaining the filtered venting system were estimated in Section 2 to be $60,000 per unit per year in current dollars for a present value of $~~893,000~~1.1 million (3% discount rate and ~~20~~25 year license term). As with the industry implementation costs, there are uncertainties associated with NRC estimates of industry operating costs but it is not likely to be identified as a significant issue when updating the regulatory analysis guidance. Therefore no additional discussion of sensitivities is provided here.

3.7 NRC Implementation

As discussed for the previous two factors, NRC implementation costs for development of regulations have uncertainties but this element of the regulatory analysis is not likely to be a major issue for updating the regulatory analysis guidance. The NRC implementation costs are estimated to ~~involve~~ be approximately $27,000 per unit.

3.8 Summary

The results of the evaluation of the costs and benefits of a dedicatedsevere accident capable and filtered vent system using possible revision of the existing regulatory analysis guidelines are summarized below:

Costs ( ) and Benefits of Modified Vent System ($ K) Per Unit						
Factor	Best Estimate (from Section 1)		Revised to Address Sensitivity to Changes to Regulatory Analysis Assumptions			
	Severe Accident Capable	Filtered	Severe Accident Capable(1) (at 2x10^{-5}yr)	(at 3x102x10^{-4}/yr)	Filtered (at 2x10^{-5}/yr)	(at 3x102x10^{-4}/yr)
Public Health	150	290	300	4,5003,000	580	8,7005,800
Occupational Health	11	19	22	330220	38	570380
Offsite Property	348	600	348	5,2203,480	600*	96,000
Onsite Property	268	430	268	4,0202,680	430	6,5004,300
Industry Implementation	(2,000)	(15,000)	(2,000)		(15,000)**	
Industry Operation	n/a	(1,100)	n/a		(1,100)	
NRC Implementation	(27)	(27)	(27)		(27)	
TOTAL	(1,250)	(14,778)	(1,089)*	+12,043 7,353	(14,479)	+8,6433 53

(1) As discussed in Enclosures 4, the costs for severe accident capable vents for Mark II containment designs will likely be higher than for Mark I units. The higher cost reflects the likely need to modify containments to prevent a molten core from causing a bypass of the suppression pool due to failure of drain lines below the reactor vessel. Avoidance of a wetwell bypass is needed to make the severe accident capable vents a viable option for the Mark II design.

* Uncertainties in estimating consequences is addressed further as a qualitative factor in Section 5. As previously mentioned, a largely unmitigated release leads to offsite property damage on the order of $33 billion, which in turn translates into a benefit for filtered vents of approximately $11.6 million per unit.

** Note that some stakeholders have stated that the price of a filtered vent system could range from $30 – 45 million

* Uncertainties in estimating consequences is addressed further as a qualitative

~~factor in Section 5. As previously mentioned, a largely unmitigated release leads to offsite property damage on the order of $33 billion, which in turn translates into a benefit for filtered vents of approximately $11.6 million per unit.~~

~~** Note that some stakeholders have stated that the price of a filtered vent system could range from $30 – 45 million~~

4.0 Performance-Based Approach (Filtration Strategy)

As previously noted in Sections 2 and 3, there are significant uncertainties associated with some of the key parameters used in the regulatory analyses. These include the frequency of the scenarios that would benefit from severe accident capable or filtered vents, the efficiency of various systems in limiting the release of radioactive materials, and the economic consequences of a severe accident that results in the contamination of environs near a reactor facility. An issue related to uncertainties is the plant-to-plant variations that limit the effectiveness of generic assessments and generic solutions. The various BWRs with Mark I and II containments have many similarities but also differences in design features, system capabilities and vulnerabilities, risk contributors, number of co-located units, and geographic locations. Such differences between plants has given rise to the possible benefits of developing a performance-based approach, which would require each licensee to evaluate the needed performance of the containment venting function and implement appropriate design and procedure changes to satisfy the performance requirement.

Consideration of a performance-based approach is also consistent with the instructions from the Commission in its Staff Requirements Memoradum (SRM) for SECY-11-0124, “Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report,” dated October 18, 2011. In that SRM, the Commission stated:

> As the staff evaluates Fukushima lessons-learned and proposes modifications to NRC’s regulatory framework, the Commission encourages the staff to craft recommendations that continue to realize the strengths of a performance-based system as a guiding principle. In order to be effective, approaches should be flexible and able to accommodate a diverse range of circumstances and conditions. In consideration of events beyond the design basis, a regulatory approach founded on performance-based requirements will foster development of the most effective and efficient, site-specific mitigation strategies, similar to how the agency approached the approval of licensee response strategies for the “loss of large area” event under its B.5.b program.

A performance-based regulatory approach is one that establishes performance and results as the primary basis for regulatory decisionmaking, and incorporates the following attributes:

1) measurable (or calculable) parameters (i.e., direct measurement of the physical parameter of interest or of related parameters that can be used to calculate the parameter of interest) exist to monitor system, including facility and licensee, performance,

2) objective criteria to assess performance are established based on risk insights, deterministic analyses, and/or performance history,

3) licensees have flexibility to determine how to meet the established performance criteria in ways that will encourage and reward improved outcomes, and

4) a framework exists in which the failure to meet a performance criterion, while undesirable, will not in and of itself constitute or result in an immediate safety concern.

There are several approaches that could be developed where measurable or calculable parameters could be established to define physical and procedural requirements that could be used to monitor licensee performance in limiting the possible releases from severe accident scenarios involving the venting of Mark I and Mark II containments.

The NRC has traditionally approached the development of performance-based regulations using the rulemaking process to accommodate the needed interactions with stakeholders and the appropriate development of performance standards. Simpler measures to be described below might be effectively imposed by issuance of orders, but measures for which additional research is needed or involve other policy issues (e.g., broader societal measures) would more likely be pursued through the rulemaking process. The staff would include in any proposed rulemaking for this option an assessment of costs and benefits related to the performance-based approach.

In a letter dated October 5, 2012, the Nuclear Energy Institute (NEI) proposed that licensees for each plant with Mark I or Mark II containments develop a “filtering strategy” that could include use of existing systems and, if deemed appropriate, additional equipment such as filters. The performance-based option and the NEI proposal would seem to require, at a minimum, that the venting system be capable of operations under severe accident conditions (Option 2). The establishment of a performance measure could, for some plants, result in the installation of a filtering system (Option 3) if it is determined that such a system is needed to meet the performance measure with the needed level of confidence.

Performance Measures

The most straightforward approach to defining a performance measure would be to define a parameter such as a required decontamination factor (DF) for the available combination of plant systems such as core or drywell sprays, the suppression pool, the reactor building, and if necessary an installed filtering system. A traditional NRC approach would be to define a source term (defined radionuclides and chemical forms) and require licensees to analyze the effectiveness of the various systems and ensure plant capabilities satisfied the acceptance criteria (including adding a filter if necessary). The NRC could prescribe analyses methods and/or review the analyses performed for the various plants and their specific configurations. Requirements placed on the analyses could include validation against tests, experiments, and operating histories. This type of approach would likely not specifically account for plant specific risk profiles but instead establish specific accident conditions to analyze. Defining a specific collective DF would also be consistent with the traditional NRC practice for design basis accidents of defining regulatory limits in terms of radiation dose to a representative individual (or contamination per unit area) at a specified distance from the release. However, for severe accident conditions, the NRC has more recently required the development of strategies or contingencies and not established specific requirements for individual structures, systems, or components (e.g., the aircraft impact assessment rule in 10 CFR 50.150 and the loss of large area requirements defined in 10 CFR 50.54(hh)). Development of a filtering strategy without defining a specific performance measure was discussed as a possible approach under Option 2.

The consideration of risk contributors and importance measures could be included in the establishment of the performance measure to address significant plant differences. The performance goal could be established for event frequencies above an established criteria or the event frequency and DF could be considered together in a more complicated consideration of limiting the exposure to a representative individual (or contamination per unit area). This type of an approach recognizes and tries to address the differences in plant designs and related differences in the importance of various accident sequences to core damage and containment failure. The following figure from NUREG-1560 presents the range in accident sequence contributions for various accident scenarios for BWR 3/4 plants.

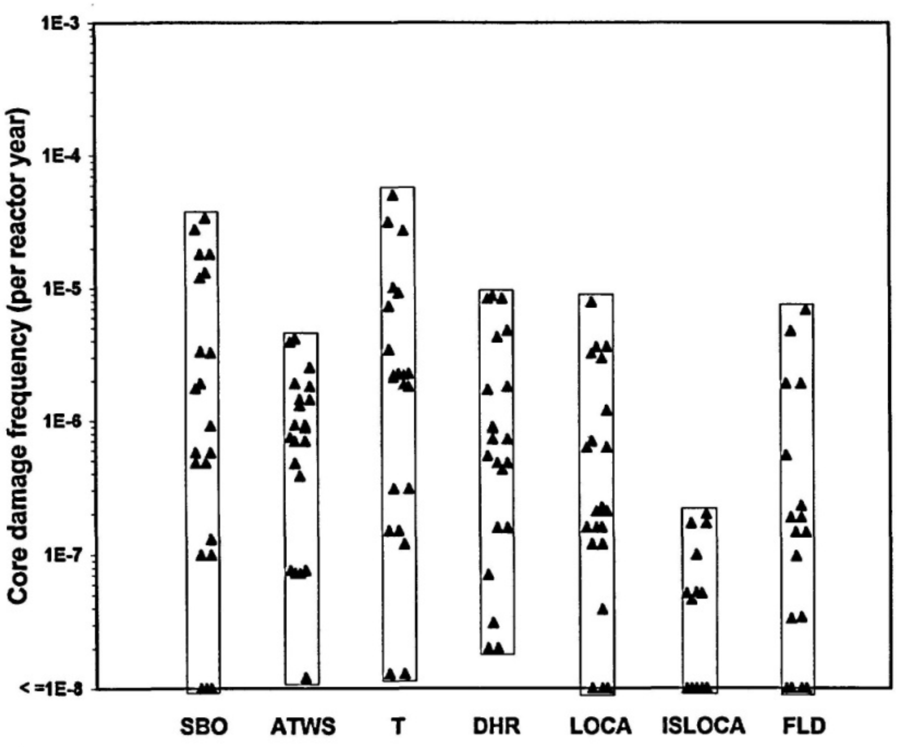


Figure 3.6 Reported IPE accident sequence CDFs for BWR 3/4 plants with RCIC.

NUREG-1560, "Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance"

SBO – Station Blackout	T – Other Transients
ATWS – Anticipated Transients Without Scram	LOCA – Loss of Coolant Accidents
DHR – Transients with Loss of Decay Heat Removal	ISLOCA – Interfacing System LOCA
FLD – Internal Flood Initiators	

A third alternative for a performance based approach consists of including additional~~ societal~~ measures into the determination of the required performance of the collective systems to limit the release of radioactive materials. An example would be to define as low as reasonably achievable requirements similar to that described in NUREG-2150, "A Proposed Risk Management Regulatory Framework," and current assessments of severe accident mitigation alternatives (SAMA). This approach would not only account for design differences but also factors such as the differences in potential economic consequences due to plant location. Such an approach would differ from the traditional calculation of doses to a representative individual, which tends to make requirements largely independent of location. Hypothetically, under this approach a plant might need to install additional measures to contain radioactive materials compared to a very similar plant because it is located in a more economically developed location. It should be noted that the second and third alternatives would likely require licensees to have and maintain plant specific PRAs and therefore these approaches may have a relationship to activities such as the resolution of NTTF Recommendation 1 on possible changes to the NRC's regulatory framework (including possibly requiring licensees to have and maintain a plant specific PRA).

As previously mentioned, the NRC staff envisions that the performance-based option would be pursued via the rulemaking process. Interactions with stakeholders during the development of the proposed and final rulemaking would help inform the regulatory analysis that would be performed for such a rulemaking. Given the rulemaking would involve developing specific performance measures and subsequent analysis of the resultant costs and benefits, the NRC staff has not specifically addressed the performance-based option within the regulatory analyses described in Sections 2 and 3 of this enclosure. However, it is the case that any approach for using the containment venting systems during severe accident conditions would require modifications to existing systems (or planned systems to satisfy Order EA-12-050) to ensure they were capable of operation following core damage and related conditions. Option 2 would therefore appear to set the minimum costs and related benefits for the performance-based approach. Additional costs for the performance-based approach ~~could~~will likely include additional studies and possibly scaled testing and/or experiments to demonstrate the ability of sprays, pools, and filters to contain radioactive materials~~. Given that the industry has proposed a performance-based approach to allow plant specific assessments, it would appear that they consider the performance-based approach to be less expensive than the installation of filters at all BWRs with Mark I and II containments. The staff expects therefore,~~ through the implementation of a predictable and repeatable strategy as suggested by the recent Electric Power Research Institute (EPRI) study. The staff expects that the costs and related benefits of the performance-based approach lies between Options 2 and 3, both of which might be ~~considered ~~found to be cost justified safety enhancements upon consideration of uncertainties and qualitative factors.

While the costs of Option 4 ~~would~~could be comparable to Options 2 or 3, the completion schedule for the activity would likely be ~~significantly~~at least several years longer. All of the uncertainties mentioned throughout this paper will complicate any measures to define, review, and implement a system that meets the selected performance measure with the desired level of confidence. ~~The development of an approach and specific performance measure could therefore take a couple of years. The rulemaking process would then add a couple more and finally the implementation of the rule could add even more. The period from issuance of the requirement to final implementation of EA-12-050 for reliable hardened vents for Mark I and II containments is expected to take about 5 years. Realistically, the development of technical positions, rulemaking, and implementation of Option 4 could easily take twice that amount of~~

~~time. The staff notes that consideration of filtered vents is a Tier 1 issue, wherein the Commission established through the SRM for SECY-11-0124 a proposed completion date of all items by 2016.~~In a letter dated October 5, 2012, NEI noted that to determine if the EPRI approach was, indeed, feasible and without unintended consequences considerable time would be required:

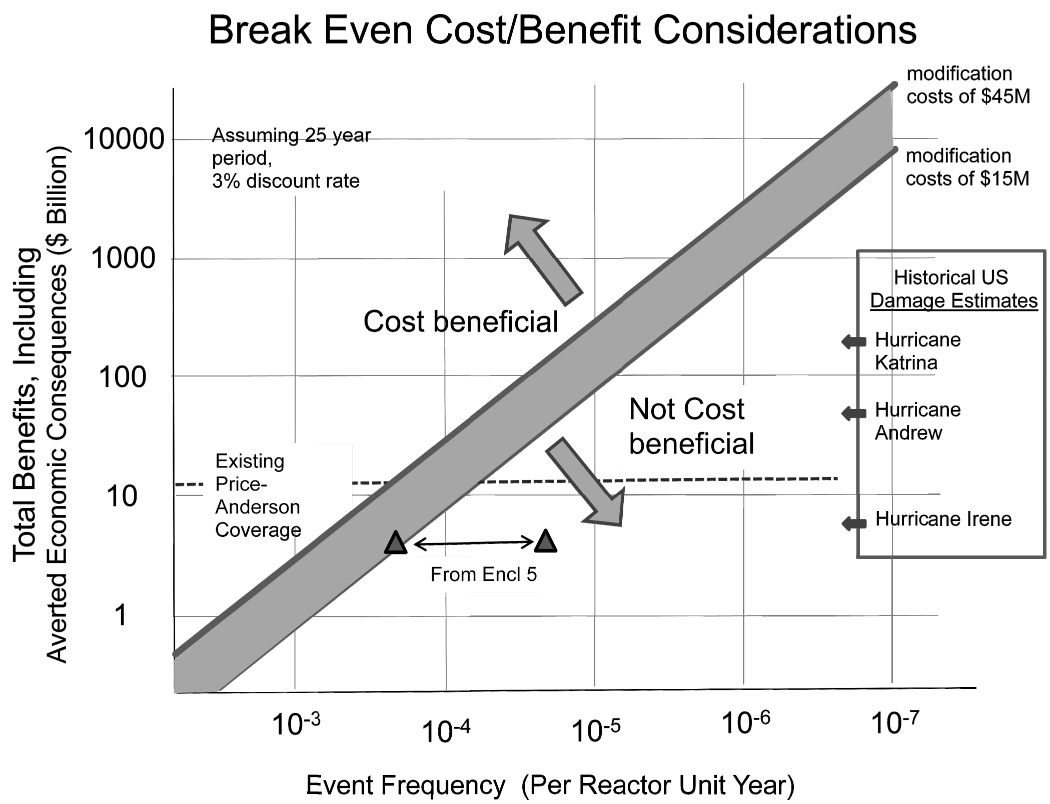
> "Applying the findings of the EPRI study to individual plants will take significant effort and time. At a minimum, each plant (or class of plants) will have to perform a specific evaluation based on the EPRI methodology to determine the appropriate strategy to implement. This would require, prior to initiation of the study, alignment with NRC on the filtering strategy performance-basis, development of a regulatory vehicle, implementation guidance, design basis assumptions, severe hazard considerations, accident scenario requirements, etc. Experience suggests that this will involve numerous meetings among NRC staff, industry and other stakeholders over at least 24 months.
>
> Following development of the performance-basis, etc., a significant amount of time is required to perform the required analysis, engineering, design, development, procurement, plant walk-downs, installation, testing, training, and so on."

The significance of the longer implementation period for Option 4 is dependent upon one's characterization of the safety issue being addressed. For those people that consider containment venting improvements to be an important enhancement or possibly even needed for reasonable assurance of adequate protection of public safety, a delay of several years would be a significant negative for this option. However, for those that view possible improvements to severe accident features as worthwhile but not necessarily urgent safety enhancements, the longer schedule can be viewed in the context of providing an opportunity to coordinate the venting issue with other improvement efforts and development of policies applicable to all reactor technologies.

5.0 Other Factors and Policy Issues

The regulatory analyses provided in Sections 2 and 3 of this enclosure assessed the possible imposition of requirements for venting systems for Mark I and Mark II containments, and whether such requirements meet the standard to be cost effective substantial safety improvements. The assessments were performed using the process described in established guidance and considered where possible uncertainties in the assumptions and possible changes to the guidance being considered at the time of this assessment. The analyses considered severe accident capable vents and filtered venting systems. Another option for a performance-based approach was discussed in Section 4 and likely falls between the other options in terms of expected costs and benefits.

A regulatory analysis using existing guidance, including standard assumptions, would not appear to justify the imposition of additional requirements on the venting systems for BWR Mark I and Mark II containments. However, sensitivity studies and analyses using values of event frequency and accident consequence in the upper range of the uncertainty bands result in the ~~potential~~calculated benefits potentially justifying the likely costs of improved venting systems. The existing guidance in NUREG/BR-0058 discusses the possible consideration of qualitative factors instead of~~,~~ or as a supplement to the quantitative analyses such as presented in Sections~~-~~ 2 and 3 of this enclosure and in more detail in the complete regulatory analysis. In this case, the NRC staff is considering various qualitative factors to supplement the previous discussions. A way to consider the combination of quantitative and qualitative factors is to envision the break-even values for when a particular modification would be justified in terms of limiting consequences for events of certain frequencies. In this case, plant modification costs were assumed for the filtered vent ($15 - $45 million) with other data associated with the BWRs with Mark I and II containments and resulted in the following break-even figure:



As shown above, the "best estimate" valuation (event frequency of 2 x10^{-5}/yr) is outside the break-even region while assuming an event frequency of ~~3x10~~2x10^{-4}/yr would appear to strengthen the argument for making the filtered vents on the basis of it being a cost ~~justification~~justified safety enhancement. ~~Other~~The various qualitative factors discussed in the following sections can likewise be viewed as either affecting the frequency of challenges to containment integrity or affecting the release of a large amount of radioactive material from the plant (which results in economic consequences) and thereby moving one toward or away from the break-even region shown in the figure.

A discussion of several significant qualitative factors is provided below.

5.1 Uncertainties

As discussed above, there ~~remains~~are significant uncertainties in estimating the frequency of events for which a severe accident capable or filtered venting system would be a useful severe accident design feature. The results of the regulatory analyses are sensitive to the event frequency and as shown above, a frequency assumption of ~~3x10~~2x10^{-4} per year is sufficient to make the filtered vent marginally cost effective. There are also significant uncertainties in the calculation of event consequences in terms of the dispersion of radioactive material into the site environs. This is due in part to significant uncertainties regarding the degree to which radioactive materials would be retained within the plant as a result of systems such as sprays and suppression pools. Estimating economic consequences given a large release also includes large uncertainties ~~as it is difficult~~related to ~~model~~modeling the many different aspects of local economies and their impact on the larger economy. An example of this is the supply chain disruptions that followed the tsunami in Japan or the flooding in Thailand. Just as an increase in event frequency by approximately an order of magnitude was sufficient to change the results of the cost/benefit analyses, so would an increase in consequences by an order of magnitude appear to change the balance between costs and benefits.

Summary – Uncertainties

Significant uncertainties exist in the estimation of event frequencies and consequences. This factor provides support for taking additional action. The benefits from the proposed changes, in terms of reducing the consequences from severe accidents, would be greatest for Option 3 (filter) while the least would be from Option 2 (unfiltered venting).

Option 1	
Option 2	⬆
Option 3	⬆⬆⬆
Option 4	⬆⬆

5.2 Defense in Depth

A key principal of NRC's regulation and oversight of nuclear power plants has historically been and continues to be "defense in depth." An aspect of defense in depth has traditionally been to have multiple barriers to the release of radioactive materials and equipment and personnel to (1) prevent accidents from occurring or progressing, (2) ~~containing~~contain radioactive materials if released from the fuel, and (3) ~~mitigating~~mitigate the possible release through protective actions such as evacuation. The containment systems at nuclear power plants play a key role in helping confine fission products within the plant if an accident progresses to a point where significant core damage has occurred. Containment designs also help to control accidents by absorbing the energy released from the reactor coolant system, holding water for long term core cooling, and protecting systems from external hazards. Given the key role of containment performance as an essential element of defense in depth, concerns regarding the performance of Mark I and II containments during severe accident conditions have been a topic of discussion for many years.

The logic underlying this set of basic goals is that each level of defense represents a threshold where failure to accomplish the prior goal introduces a significantly greater potential for consequences as well as a greater uncertainty in the phenomenology, in accident progression, and therefore, the ability to control the outcome of an event.

Prevention

The first goal, prevention of severe accidents, is chosen in recognition of the fact that there is little threat to public health and safety in the absence of core damage, while there is a significant increase in potential for major consequences once fission products are released from the fuel and cladding. In addition, much larger phenomenological uncertainties are introduced under severe accident conditions than when the core is undamaged and is in a fixed geometry. Finally, considerable uncertainty in the availability and functionality of core cooling equipment is also indicated, since major failures must have already occurred in order to arrive at a severe accident condition.

Containment

Containment of fission products on site in the event of a severe accident is the second defense in depth goal. This is a critical threshold because containment of fission products on site results in minimal impact to public health and the environment, while failure to contain the radioactive material leads to the potential for very large health, environmental and socio-economic consequences. Furthermore, once a large release has occurred, the ability to ~~control~~influence outcomes is limited by uncontrollable factors such as weather and public response. Thus, the containment goal is intended to provide a reliable backstop against uncertainties in the prevention of severe accidents, and to protect against the uncertainties associated with uncontrollable releases and the potentially large and varied consequences.

The event at TMI showed the importance of a reliable containment design - the second element of the defense in depth strategy. Despite extensive core damage, the containment was successful and limited fission product release to insignificant levels. The passive attributes of the containment building (i.e., the large volume and inherent strength) were critical for preventing the release despite the hydrogen detonation that ensued. At TMI, the containment barrier provided sufficient time for event diagnoses and recovery from operator errors that occurred earlier in the event. However, it should be noted that the accident at TMI was not complicated by an extended loss of electrical power and heat removal systems as was the case at Fukushima.

Mitigation of Release (Emergency Preparedness)

Emergency planning and response is the final defense in depth element. This element provides protection against uncertainties in containment performance under severe accident conditions. Evacuation and sheltering protect against acute doses. Relocation protects against long term health effects in the event of containment failure. This element does not, however, protect against environmental or socio-economic consequences.

The containment failures at Fukushima showed the importance of emergency planning (third element of defense in depth) for protection against acute doses. Evacuation, sheltering and relocation were very effective in limiting doses to the public. The Fukushima event also confirmed that, when containment fails in a severe accident, the consequences (economic, social and long term health) are large, difficult to estimate, and depend upon critical, but uncontrollable factors such as weather and subsequent public reaction. The wind pattern that blew predominantly out to sea during parts of the Fukushima accident was very important in limiting land contamination in Japan with its attendant consequences.

In considering additional requirements for venting systems for BWRs with Mark I or II containments, the deliberations will ultimately need to determine whether those additional protections are reasonable in light of the costs and the benefits, including the desire for effective defense in depth for dominant severe accident sequences. A process to consider in deliberating on the containment improvement options is to generally follow the progression of accidents and determine at what point does the combination of event probability and consequence, with consideration of related uncertainties, warrant regulatory controls. For BWRs, estimates of low core melt frequencies have, in part, justified the NRC's previous acceptance of the estimated high conditional failure probability of the Mark I and II containments. The containments did fail during the accident at Fukushima Dai-ichi facility much as predicted for those plant conditions. Another insight from the Fukushima accident was that the failure of containments not only resulted in a large release of radioactive material but also greatly complicated the attempts of plant operators to arrest the worsening conditions. An example is the loss of the reactor buildings (secondary containments) as a result of hydrogen explosions, which resulted from difficulties in venting to maintain pressures and hydrogen levels within the containment structures.

Summary – Defense in Depth

The relatively high likelihood of a failure of Mark I and II containments following a core melt accident calls into question the level of defense in depth being provided by this intended barrier to the release of radioactive material. Improving the chances that the containment venting function is available under severe accident conditions reduces the chances of failure and uncontrolled releases. Providing filters in the venting system significantly reduces the release of radioactive materials for the dominant core melt scenarios.

Option 1	
Option 2	⬆
Option 3	⬆⬆⬆
Option 4	⬆⬆

5.3 Hydrogen Control

In addition to providing a means of pressure control, severe accident capable or filtered venting systems could also remove hydrogen from the containment spaces and lesson the likelihood of hydrogen detonations in the containment structures or the reactor building. The primary consideration of improving the control of hydrogen during a severe accident is associated with the Tier 3 item related to NTTF Recommendation 6, "Hydrogen Control and Mitigation Inside Containment or in Other Buildings". However, the successful venting of containments during severe accidents could help address the potential problems of the buildup of hydrogen in primary and secondary containment systems. Selection of any of the venting options proposed in this paper will therefore influence and potentially help resolve hydrogen control issues for Mark I and II containments.

The potential benefits of venting hydrogen for BWRs with Mark I or II containments were evident during the accident at Fukushima. Hydrogen generated by various mechanisms associated with severe accidents made its way to the reactor buildings and resulted in the dramatic explosions associated with that event. Those explosions in turn increased the amount of radioactive materials escaping from the facility, complicated operators efforts to respond to the event, and increased concerns about the integrity of spent fuel pools. The location of the spent fuel pools within the BWR reactor buildings is another feature that makes the venting function and control of hydrogen especially important for these reactor designs. Proper venting of hydrogen would alleviate concerns associated with hydrogen burns within the reactor building impacting the integrity of the spent fuel pool.

Summary – Hydrogen Control

The experience at Fukushima Dai-ichi demonstrated the importance of effective control of hydrogen generated during severe accidents. The possible containment venting systems discussed in this paper (Options 2, 3 or 4) could provide a means of improving the control of hydrogen.

Option 1

Option 2

Option 3

Option 4

5.4 Severe Accident Management

The experiences at Fukushima demonstrated that responding to, and arresting the accident were more complicated by the problems associated with venting containment, and by the subsequent failure of containment. The failure of containments by overpressure conditions will create harsh environments in the reactor building and other plant locations. The elevated temperatures and radiation levels can in turn impede operators in their attempts to restore installed equipment or put into service temporary equipment such as that required by NRC Order EA-12-049. Severe accident capable vents would not only include equipment that could remain functional and support venting operations during severe accident conditions but would also address shielding and equipment operation to ensure personnel could execute needed tasks during a severe accident. Some severe accident capable venting designs include the use of passive features such as rupture disks to provide additional confidence that the system would operate and prevent failure of containment structures due to overpressure conditions.

The filtered vent designs would provide the same improvements to the plant to prevent containment failures and thereby help control conditions within the reactor building and other site areas. The filtered system could provide an additional advantage in that decision-makers could be more confident (or at least less stressed) about ordering the venting operation knowing that the filter would contain the vast majority of radioactive materials. From an accident management perspective, this increased confidence in the venting operation would enable measures to restore installed equipment, connect temporary equipment, or otherwise take measures to arrest the accident.

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5.5 Emergency Planning

The installation of severe accident capable or filtered venting systems can add to existing emergency planning margins (e.g., effective evacuation periods) by controlling the releases of radioactive materials as compared to containment failure by over-pressurization. The filtered vent system provides additional advantages by dramatically reducing the amount of radioactive materials released via containment venting during severe accident conditions. This could in turn allow different protective action recommendations that would reduce the number of evacuees and thereby reduce the stress and risks associated with such emergency measures. In addition to the effects on immediate protective measures to protect public health and safety, the filtered vent option reduces or eliminates concerns regarding the return of populations following a possible release of radioactive materials and the long term exposures associated with contamination of the countryside by the failure of containment or the release from an unfiltered venting operation. The issue of long-lasting effects from a release also relates to other qualitative factors such as societal considerations and uncertainties in estimating economic consequences.

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5.6 Safety Culture

Root cause investigations for core melt accidents (Rogovin report for TMI, IAEA report on Chernobyl, and Japanese review of Fukushima) concluded that a contributing factor for each event was that a safety culture or "mindset" existed in both the regulatory authorities and the industry that serious accidents were highly unlikely to happen. These findings are important because they identify factors which are difficult to treat quantitatively in risk assessment (safety culture, organizational effectiveness, human performance) and they add uncertainty to the probability of accidents and the ability of licensees to respond to accidents should they occur. This factor is especially relevant to the filtered vent option which could provide an additional level of protection with passive features to address many severe accident scenarios for BWRs with Mark I or II containments. This additional protection would be available for the remaining life of the units, which could include periods of varying licensee performance and differing levels or attention to or complacency about safety culture.

5.7 Independence of Barriers

The events at Fukushima highlighted the interdependence between the performance of core cooling functions and the pressure suppression containment designs used for BWRs with Mark I or Mark II containment designs. This dependent relationship between what is generally thought of as individual barriers to the release of radioactive materials has been noted in various severe accident studies and during the operating history of BWRs with Mark I or Mark II containments (see Enclosure 2). Although the primary fission product barriers are usually discussed as being largely independent from each other, the NRC has previously recognized and accepted some dependencies such as for the crediting of containment accident pressure for supplying net positive suction head for pumps in the emergency core cooling system. In its SRM for SECY-11-0014, "Use of Containment Accident Pressure in Analyzing Emergency Core Cooling System and Containment Heat Removal System Pump Performance in Postulated Accidents," the Commission directed the NRC staff to continue to use existing guidance in the standard review plan which states:

> Defense in depth is preserved (for example, system redundancy, diversity, and independence are maintained commensurate with the expected frequency and consequence of challenges to the system; defenses against potential common cause failures are maintained and the introduction of new common cause failure mechanisms is assessed; and defenses against human errors are maintained).

Although the above discussion relatedrelate to design basis functions, previous (pre-Fukushima) evaluations performed by the NRC also found that the expected frequency and consequences of severe accidents involving potential releases through established vent pathways for BWRs did not warrant additional severe accident design features (see SECY-89-017 and related SRM). The Commission could, however, find that the Fukushima accident has changed our understanding of severe accident frequencies and consequences such that measures are needed to address this issue and compensate for the lack of independence between the core cooling and containment functions. The installation of a filtered vent would be a plausible approach to improving the defense in depth attributes for BWRs with Mark I or Mark II containments. In their efforts to address lessons learned from Fukushima, the industry to date has emphasized additional measures for preventing core damage (e.g., making available portable pumps for injection into the core or drywell) versus the installation of an additional barrier (filters) on a dedicated vent pathway from containment.

A focus on preventing or arresting the progression of core damage is also consistent with the NRC Order EA-12-050 which requires modifications to ensure BWRs with Mark I and II containments have a reliable hardened vent to control containment pressure. EA-12-050 was issued with a finding that the action was needed for adequate protection and the following explanation was included in the order:

> The events at Fukushima Dai-ichi highlight the possibility that extreme natural phenomena could challenge the prevention, mitigation and emergency preparedness defense-in-depth layers. At Fukushima, limitations in time and unpredictable conditions associated with the accident significantly challenged attempts by the responders to preclude core damage and containment failure. In particular, the operators were unable to successfully operate the containment venting system. The inability to reduce containment pressure inhibited efforts to cool the reactor core. If additional backup or alternate sources of power had been available to operate the containment venting system remotely, or if certain valves had been more accessible for manual operation, the operators at Fukushima may have been able to depressurize the containment earlier. This, in turn, could have allowed operators to implement strategies using low-pressure water sources that may have limited or prevented damage to the reactor core. Thus, the events at Fukushima demonstrate that reliable hardened vents at BWR facilities with Mark I and Mark II containment designs are important to maintain core and containment cooling.

Summary – Independence of Barriers

Whereas it may not be necessary or practical to ensure the complete independence of each barrier to the release of radiation, it is desirable to minimize dependencies and address the high conditional failure probability of Mark I and Mark II containments following a compromise of the preceding barriers (fuel and coolant system). The filtered system would provide the most independence while the unfiltered vent could result in large releases in the attempts to reduce containment overpressure conditions.

Option 1

Option 2 ↑

Option 3 ↑↑↑

Option 4 ↑↑

5.~~8~~7 International Practices

A description of the staff's collection and assessment of information from various countries related to decisions on filtered venting systems is provided in Enclosure 3. As discussed in that enclosure, the majority of countries with BWRs using Mark I and Mark II containment designs have or are planning to modify the designs to include filtered containment venting systems. In addition, some countries are requiring filtered venting systems on other reactor containment designs. As previously mentioned, in the discussions on determining whether a proposed change meets the standard of a substantial increase in safety, the Commission stated:

> …The approach is also flexible enough to allow for arguments that consistency with national and international standards, or the incorporation of widespread industry practices, contributes either directly or indirectly to a substantial increase in safety. Such arguments concerning consistency with other standards, or incorporation of industry practices, would have to rest on the particulars of a given proposed rule…

Although there is not a particular international standard that calls specifically for filtered vents for Mark I and Mark II containments, the requirement is consistent with general standards and guides that call for improving the ability of containments to contain radioactive materials during severe accident conditions. Such a requirement would also place the U.S. among the majority of countries that have required filtered venting systems, and maintain its stature as a leader in nuclear safety. Another significant benefit from the international experience is that various filtering systems have been developed and installed. This lessens concerns that requiring filtered vents would necessitate research and development programs to design and test a new technology.

However, it should be noted that many countries that have decided to pursue filtered venting systems have done so in conjunction with the development of the defense in depth system described in guidance from ~~IAEA and WENRA.~~the International Atomic Energy Agency (IAEA) and Western European Nuclear Regulators' Association (WENRA). This defense in depth logic includes a specific level for dealing with severe accidents and minimizing the need to displace populations near nuclear power plants. The logic is shown below along with the corresponding regulatory structure in the U.S.

International System of Defense in Depth		Corresponding US Considerations	
1	Normal Operations	Normal Operations	
2	Anticipated Operational Occurrences	Anticipated Operational Occurrences	
3	Design Basis Accidents	Design Basis Accidents	Risk Informed Licensing
	Design Extension Events	Beyond Design Basis Events (Design Extension considered under Recommendation 1)	Reactor Oversight Process
4	Severe Accident	Safety Goal Policy Statement **Severe Accident Policy Statement** - **Operating Plants** - New Reactors	
5	Emergency Planning	Emergency Planning	

As shown above, the regulatory systems are similar in most areas but do differ in the treatment of beyond design basis and severe accidents. The Severe Accident Policy Statement is discussed as a separate qualitative factor in the following section.

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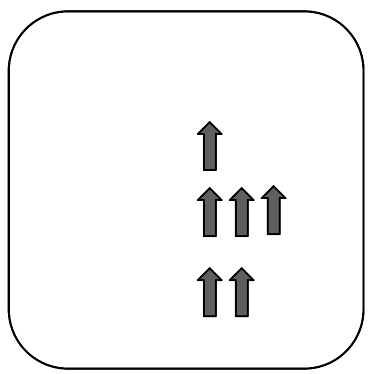

5.~~9~~8 Severe Accident Policy Statement

Following the 1979 accident at TMI, the U.S. and international nuclear safety community recognized that severe accidents needed further attention. The NRC evaluated, generically, the capability of existing plants to tolerate a severe accident. The NRC found that the design-basis approach contained significant safety margins for the analyzed events. These margins permitted operating plants to accommodate a large spectrum of severe accidents. Based on this information, the Commission, in the Severe Accident Policy Statement, "Policy Statement on Severe Accidents Regarding Future Designs and Existing Plants," (50 FR 32138, August 8, 1985), concluded that existing plants posed no undue risk to public health and safety, and that no basis existed for immediate action on generic rulemaking or other regulatory changes affecting these plants because of the risk posed by a severe accident. To address this issue for operating plants in the long term, the NRC issued SECY-88-147, "Integration Plan for Closure of Severe Accident Issues," in May 1988. This document identified the following necessary elements for closure of severe accidents:

- Performance of an individual plant examination
- Assessment of generic containment performance improvements (CPIs)
- Improved plant operations
- A severe accident research program
- An external events program
- An accident management program

Each of these programs and the conclusions reached has been discussed elsewhere in this paper. That portion of the Policy Statement that deals with operating plants states:

In light of the above principles and conclusions, the Commission's policy for operating reactors includes the following guidance:

- *Operating nuclear power plants require no further regulatory action to deal with severe accident issues unless significant new safety information arises to question whether there is adequate assurance of no undue risk to public health and safety.*
- *In the latter event, a careful assessment shall be made of the severe accident vulnerability posed by the issue and whether this vulnerability is plant or site specific or of generic importance.*
- *The most cost-effective options for reducing this vulnerability shall be identified and a decision shall be reached consistent with the cost-effectiveness criteria of the Commission's backfit policy as to which option or set of options (if any) are justifiable and required to be implemented.*
- *In those instances where the technical issue goes beyond current regulatory requirements, generic rulemaking will be the preferred solution. In other cases, the issue should be disposed of through the conventional practice of issuing ~~Bulletings~~Bulletins and Orders or Generic Letters where modifications are justified through backfit policy, or through plant-specific decision making along the lines of the Integrated Safety Assessment Program (ISAP) conception.*
- *Recognizing that plant-specific PRAs have yielded valuable insight to unique plant vulnerabilities to severe accidents leading to low-cost modifications, licensees of each operating reactor will be expected to perform a limited-scope, accident safety analysis designed to discover instances (i.e., outliers) of particular vulnerability to core melt or to unusually poor containment performance, given core-melt accidents. These plant-specific studies will serve to verify that conclusions developed from intensive severe accident safety analyses of reference or surrogate plants can be applied to each of the individual operating plants. During the next two years, the Commission will formulate a systematic approach, including the development of guidelines and procedural criteria, with an expectation that such an approach will be implemented by licensees of the remaining operating reactors not yet systematically analyzed in an equivalent or superior manner.*

For advanced nuclear power plants, including both the evolutionary and passive designs, the NRC concluded that vendors should address severe accidents during the design stage. Designers can take full advantage of the insights gained from such input as probabilistic safety assessments, operating experience, severe accident research, and accident analysis by designing features to reduce the likelihood that severe accidents will occur and, in the unlikely occurrence of a severe accident, to mitigate the consequences of such an accident. Incorporating insights and design features during the design phase is much more cost effective than modifying existing plants.

Summary – Severe Accident Policy Statement

Although the Severe Accident Policy Statement specifies that severe accident design features could be imposed on operating reactors using the established backfit process, the importance of the qualitative factors suggests a need to revisit portions of the current regulatory framework (including the Severe Accident Policy Statement). The status quo option best fits the current policy statement and its traditional application.

Option 1

Option 2

Option 3

Option 4

~~5.10 Societal Factors~~

~~The NRC's regulatory analysis includes consideration of offsite economic consequences as part of the cost/benefit assessment. However, in addition to the modeled economic factors and the related uncertainties, there are other societal factors that have been observed following the accident at Fukushima. A major factor is the public's reaction to the evacuation and long-term displacement of a large number of people and the rendering of a large land area as unusable for a significant period of time. Another factor is the public's acceptance of nuclear power as a reasonable source of electrical power. Although consideration of some of these societal factors goes beyond the normal jurisdiction of the NRC and involves broader national policies, it is nevertheless the fact that a major release from a nuclear power plant would likely be viewed as a major failure of the nuclear industry and the NRC.~~

~~5.11~~5.9 Consistency between Reactor Technologies

A comparison between a Mark I containment and a PWR containment of the conditional containment failure probability given various core damage events was provided in NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants." The figure below from NUREG-1150 shows that the conditional failure probability for Mark I containments is relatively high (approximately 0.75 for the plant evaluated in that study).

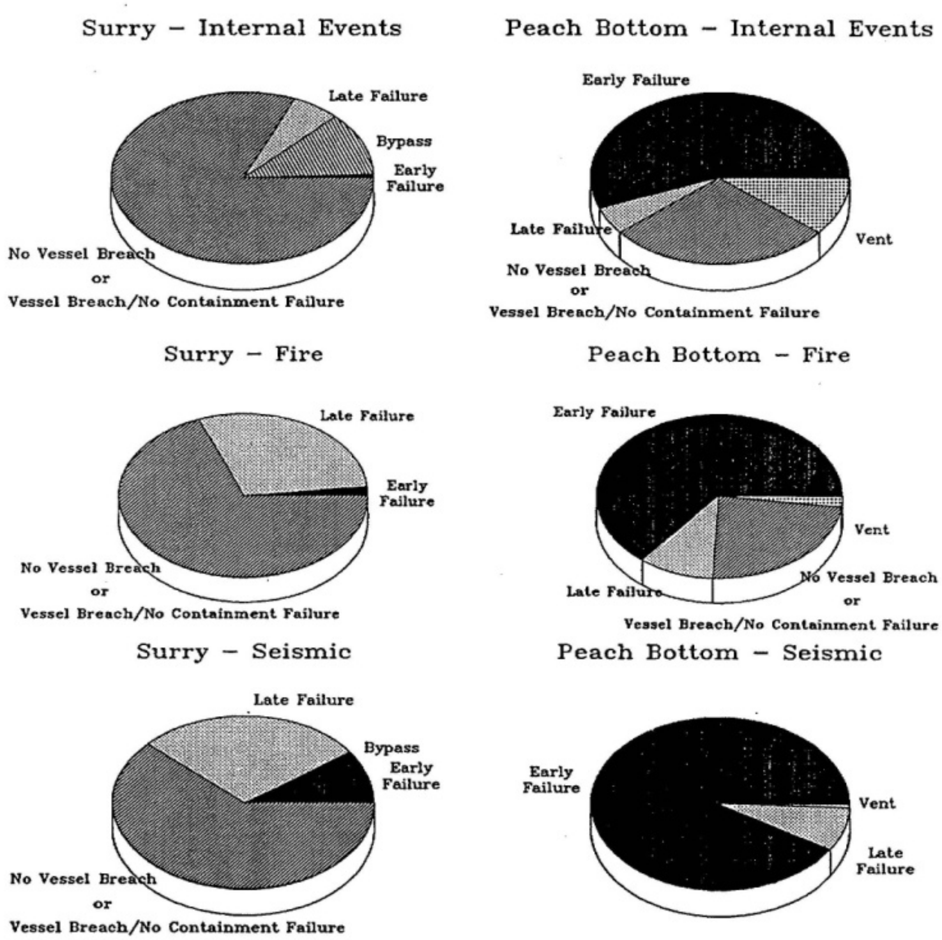

Figure 9.5 Relative probability of containment failure modes (internal and external events, Surry and Peach Bottom).

However, as pointed out in NUREG-1150 and NUREG-1560 and shown in the following figures, when combined with estimated frequencies of core damage events, the risk of large releases from BWRs with Mark I and Mark II containments is comparable to other plant designs. A lower core damage frequency is estimated due to a more diverse set of plant equipment able to add water to the reactor core under most plant conditions. The weighting of the defense in depth approaches to emphasize minimizing core damage can result in similar overall risk profiles for large releases. However, many of these core-cooling systems would be rendered unavailable for events such as an extended station blackout as occurred at Fukushima Dai-ichi. Thus given a core damage event, the higher conditional failure probability of containment failure means that a release is more likely.

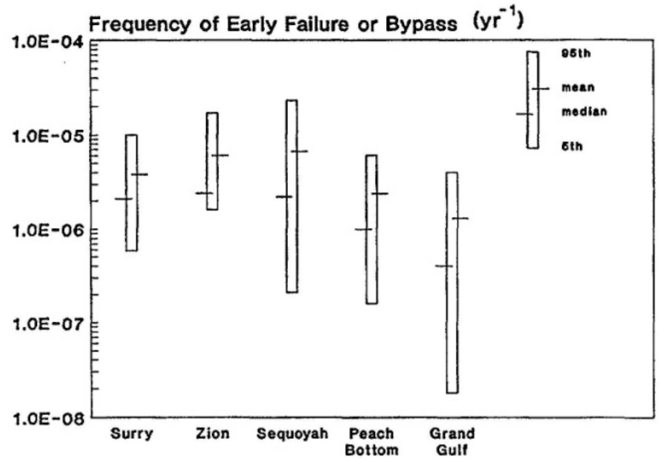

Figure 9.3 Frequency of early containment failure or bypass (all plants).

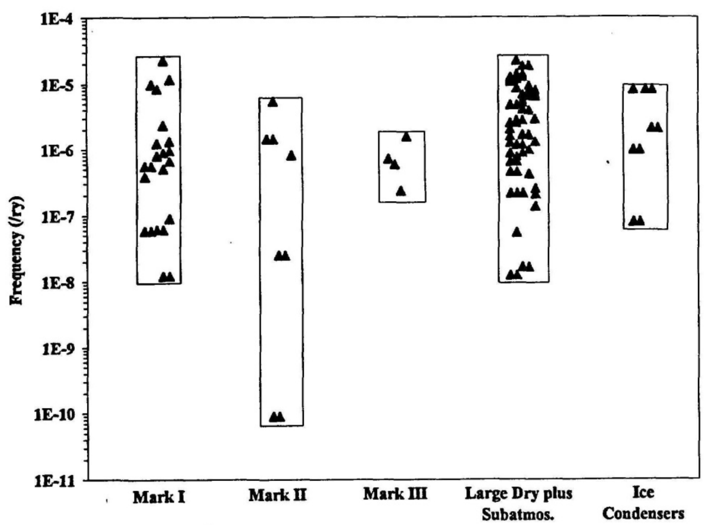

Figure E.3 Frequencies of significant early release (by containment type) as reported in the IPEs.

NUREG-1560, "Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance" ies

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5.~~12~~10 External Events

The technology comparison above may not fully address the influence of external events and the fact that such hazards could be the major contributors to the risk profiles for operating nuclear power plants. The estimated core damage frequencies for BWRs from internal events are lower than that for PWRs in part because of the multiple systems available to add water to the reactor core. However, events such as an extended loss of electrical power renders some of these systems unavailable and potentially reduces the BWR advantage for such events, which are likely caused by a major external event (e.g., a beyond-design-basis seismic or flooding event). Provided the enhanced venting systems, either severe accident capable or filtered, are able to survive the external event and remain available for use if the accident progresses to involve significant core damage, then the system could be a major part of the accident response. As mentioned under the severe accident management factor, the availability of a reliable venting system during severe accident conditions could help prevent conditions degrading further and enable responders to continue efforts to cool the molten core. The venting system thereby compliments the ability of the portable equipment to help arrest an event even if previous efforts had failed to prevent core damage.

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5.~~13~~11 Multi-Unit Events

The quantitative evaluations performed in Sections 2 and 3 did not consider potential scenarios involving accidents at more than one unit at a multiple unit site. The tsunami that flooded the Fukushima site initiated a series of events that resulted in core damage accidents at three of the six units sharing the site. The most likely cause of multi-unit accidents is a major external event such as that which occurred at Fukushima and discussed above. Although the frequencies of such events might be estimated for particular sites, the uncertainties are relatively large given the limited recorded histories and limited knowledge of hazards such as large seismic or flooding events. In addition, the possibility of core damage events at multiple units has the potential for larger releases and increased economic damage. By improving severe accident management functions and, especially in the case of the filtered vent, reducing the releases from each unit, the enhanced venting systems could help address concerns about concurrent core damage events at multiple units.

Summary – Multi-unit Events

A concern highlighted by the Fukushima accident is conditions or events (e.g., external hazards) which challenge multiple units at a nuclear facility. There is a significant advantage to having installed equipment and/or strategies in place to address such multi-unit events.

Option 1	
Option 2	↑
Option 3	↑↑
Option 4	↑↑

6.0 Summary

In light of the quantitative and qualitative considerations discussed above, it is clear that a decision on which option to pursue for venting of BWR Mark I and Mark II containments includes some subjective judgments. In fact, a plausible case can be made for any of the above options, either proceeding with currently imposed improvements (Option 1), the severe accident capable vents (Option 2), the installation of a filtered system (Option 3), or the development of a performance-based approach (Option 4). The following are some of the more significant positive and negative attributes (i.e., pros and cons) for each of the options.

Option 1: Continue with the implementation of Order EA-12-050 for reliable hardened vents to reduce the likelihood of core damage and failure of BWR Mark I and Mark II containments and take no additional action to improve their ability to operate under severe accident conditions or to require the installation of a filtered vent system.

Pros:

- Consistent with Severe Accident Policy Statement that no additional measures are needed for operating reactors
- No additional costs to industry and NRC
- Consistent with quantitative cost benefit analysis findings using current framework and assumptions
- Consistent with findings from SAMA analyses

Cons:

- Maintains defense in depth “imbalance” between prevention of core damage and mitigation (i.e., while measures have been taken to reduce chances of core melt, high conditional failure probability remains for containment if core melt does occur)
- Of the four options, results in highest doses and highest economic consequences in the unlikely event of a severe accident
- Inconsistent with international practices that emphasize reliable containment as a critical function

Option 2: Severe accident capable vents: Upgrade or replace the reliable hardened vents required by EA-12-050 with a containment venting system designed and installed to remain functional during severe accident conditions

Pros:

- Supports severe accident management by improving hydrogen control, pressure control (supports low pressure injection) and minimizing radiation releases to reactor building
- Reduces doses to emergency workers (relative to an uncontrolled containment failure)
- Consistent with industry approach in EPRI study (without performance measure)
- Involves limited changes to existing Order EA-12-050, related guidance, and implementation schedules

Cons:

- Uncertainty of decontamination factor is large and highly dependent upon the specifics and timing of the accident scenario
- Could involve significant release of radioactive materials when venting operations performed during severe accident conditions
- Does not resolve issues regarding use of drywell path for venting
- Not supported by quantitative cost benefit analysis using current framework and assumptions
- Could be viewed as inconsistent with both NRC’s Severe Accident Policy Statement and with International practices

Option 3: Filtered Vents: Design and install a filtered containment venting system that is intended to prevent the release of significant amounts of radioactive material following the dominant severe accident scenarios at BWRs with Mark I and Mark II containments

Pros:

- Supports severe accident management by improving hydrogen control, pressure control (supports low pressure injection) and minimizing radiation releases to reactor building
- Reduces doses to emergency workers (relative to an uncontrolled containment failure) without increasing offsite releases
- Ensures high decontamination factors that are independent of specifics of the accident sequence (excluding containment bypass sequences)
- Confidence in decontamination factor supports use of system from both wetwell and drywell
- Improves defense in depth balance between prevention and mitigation (i.e., addition of filter directly addresses containment performance issues)
- More consistent with international approach to containment reliability

Cons:

- Not supported by quantitative cost benefit analysis using current framework and assumptions (highest cost of proposed options)
- Could be viewed as inconsistent with NRC's Severe Accident Policy Statement

Option 4: Performance-Based Approach: Establish performance criteria and require licensees to justify operator actions and systems, or combinations of systems, such as suppression pools, containment sprays, and separate filters to accomplish the function and meet the performance criteria

Pros:

- Consistent with Commission Policy to encourage use of performance based requirements
- Possible to integrate with NRC's resolution of other regulatory policy issues and development of revised guidance on defense in depth and industry's evaluation of strategies and technologies
- Improves defense in depth balance between prevention and mitigation

Cons:

- Requires development of performance standards and acceptable methods for demonstration of compliance (difficult task given high uncertainties, limited testing, and nature of severe accident conditions)
- Would likely extend the resolution of this issue by several years
- Large uncertainties in both NRC and industry costs and schedules

Conclusion

The evaluation of the quantitative factors described in Sections 2 and 3 does not clearly show that either the severe accident capable or filtered venting systems meet the criteria for being cost-justified safety enhancements. ~~Revising~~However, revising assumptions related to event frequencies or event consequences to address the significant uncertainties in modeling severe accident scenarios could lead one to conclude that the proposed options are at least marginally cost-effective. ~~However~~In addition, the majority of the qualitative factors discussed ~~above~~in Section 5 support pursuing an improved venting system for BWRs with Mark I or Mark II containments to address specific design concerns (e.g., high conditional failure probability for containment failure given core melt); to support severe accident management functions by preventing releases of radioactive materials, hydrogen, and steam into the reactor building or other locations on the site; to minimize the contamination of the site environs; and to reduce the reliance on emergency planning for protection of public safety. ~~While a reasonable case can be made for any of the above options, either proceeding with the currently imposed improvements (Option 1), the severe accident capable vents (Option 2), or the development of a performance-based approach (Option 4), the~~The NRC staff finds that the combination of quantitative and qualitative factors (e.g., providing improved defense in depth) best supports the installation of filtered venting systems at BWRs with Mark I and II containments.