CONSIDERATION OF ADDITIONAL REQUIREMENTS FOR CONTAINMENT VENTING SYSTEMS FOR BWRs WITH MARK I AND MARK II CONTAINMENTS

ACRS Subcommittee Meeting

October 31, 2012

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Purpose

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- To discuss the staff's draft Commission paper and proposed recommendations on imposing new requirements related to containment venting systems for boiling water reactors with Mark I and Mark II containments

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Agenda

- Taskings
- Schedule update
- Discussion of draft SECY paper and proposed recommendation

Tasking (1)

- SRM on SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned"
  - The staff should quickly shift the issue of "Filtration of Containment Vents" from the "additional issues" category and merge it with the Tier 1 issue of hardened vents for Mark I and Mark II containments such that the analysis and interaction with stakeholders needed to inform a decision on whether filtered vents should be required can be performed concurrently with the development of the technical bases, acceptance criteria, and design expectations for reliable hardened vents

Tasking (2)

- SRM from August 7, 2012 Commission Meeting on status of actions taken in response to lessons learned from the Fukushima Dai-ichi accident
  - In the forthcoming notation vote paper on filtered vents, the staff should include a discussion of accident sequences where the filters are and are not beneficial

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Schedule

- Current Schedule
  - November 30 SECY Paper to Commission
  - November 20 SECY Paper to EDO
  - ACRS Interactions
    - November 1 Full Committee mtg
    - October 31 Subcommittee mtg
    - October 26 Draft Rev. 2 Commission Paper
    - October 19 Draft Rev. 1 Commission Paper
    - October Subcommittee mtg
    - September Subcommittee mtg
    - June Subcommittee mtg

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Draft Paper Outline

- SECY Main Paper and Enclosures
  1. Evaluation of Options
  2. Design and Regulatory History
  3. Foreign Experience
  4. BWR Mark I & II Containment Performance During Severe Accidents
  5. Technical Analyses (MELCOR/MACCS/PRA)
  6. Stakeholder Interactions
  7. Draft Orders

Main Paper

- Discuss issues associated with severe accident containment venting and relevance to Mark I and II containments
- Identify potential options
- Basis for staff's recommendation
- Discuss role of quantitative analysis and qualitative analysis
- Provide concise writeups referencing enclosures for details

Options Considered

1. No change (EA-12-050)
2. Severe accident capable vent
3. Filtered vent
4. Performance-based approach

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Proposed Recommendation

- Option 3 – Filtered Vent
  - The NRC staff finds that the combination of quantitative and qualitative factors best supports the installation of filtered venting systems at BWRs with Mark I and II containments

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Basis for Proposed Recommendation

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- Cost-justified substantial safety enhancement
  - Quantitative analysis
  - Qualitative analysis
    - Enhances defense-in-depth (containment vulnerabilities and severe accident uncertainties)
    - Filter provides a fission product retention capability independent of plant accident response

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Enclosure 1 Evaluation of Options

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- Summary of considerations in decision-making
- Consideration of adequate protection
- Decision on substantial safety enhancement
- Inclusion of qualitative arguments
- Presentation of results including sensitivity analysis

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Cost-Benefit Analysis

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Quantitative Cost/Benefit Analysis Per Plant				
	Severe Accident Capable		Filtered	
Total Costs ($k)	(2,027)[1]		(16,127)	
Core Damage Frequency	$2x10^{-5}$yr	$2x10^{-4}$/yr	$2x10^{-5}$/yr	$2x10^{-4}$/yr
Total Benefits ($k)	938	9,380	1,648	16,480
Net Value (Benefits – Costs)	(1,089)	+7,353	(14,479)	+353

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

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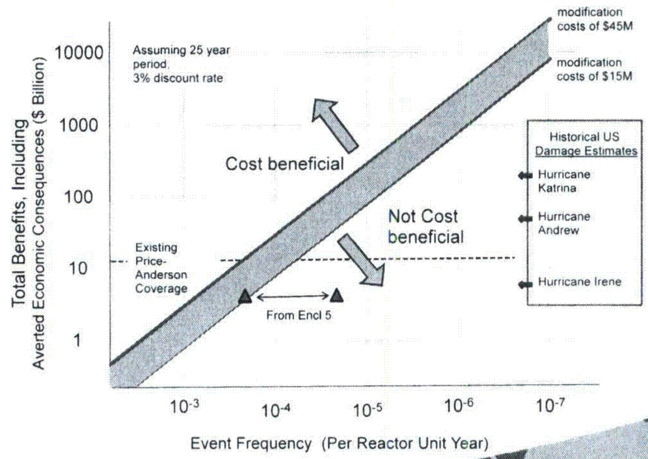
Break Even Cost/Benefit Considerations



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Qualitative Arguments

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- Providing defense in depth
- Addressing significant uncertainties
- International experience and practices
- Supporting severe accident management and response
- Improving Emergency Preparedness
- Hydrogen control
- Severe Accident Policy Statement
- Independence of barriers
- Consistency between reactor technologies
- External events
- Multi-unit events

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Enhances Defense-in-Depth

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- Containment is an essential element of defense-in-depth
- Addresses high conditional containment failure probability
- Filtering compensates for the loss of the containment barrier due to venting
- Filtering improves confidence to depressurize containment to address other severe accident challenges

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Uncertainties

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- Uncertainties in prevention and mitigation of severe accidents
  - Event frequency
  - Severe accident progression
  - Radiological consequences
  - Economic consequences

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International Practices

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- Extraordinary Meeting of Members of Convention on Nuclear Safety recommended “measures to ensure containment integrity, and filtration strategies and hydrogen management for the containment”
- Consistent with decisions of most European countries, Canada, Taiwan, and Japan

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Severe Accident Management Decision Making

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- Each option enhances the management of the accident by allowing operators to focus on recovery actions other than preventing gross containment failure
- Each proposed option provides some benefit but filtered systems are the simplest
- A performance-based approach could be integrated into other severe accident management activities and procedures

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Emergency Planning

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- The most benefit in terms of reducing the demands on emergency planning would be associated with Option 3 (filter) while the proposed change with the least benefit would be from Option 2 (unfiltered venting)

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Hydrogen

- Improves operator confidence in a "clean" release for hydrogen control
  - Allows early operator intervention to vent hydrogen and control containment pressure
  - Sustained lower pressure reduces leakage of hydrogen thru penetration seals
  - Decreased leakage reduces threat from hydrogen explosion to reactor building, spent fuel pool, and emergency responders

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Severe Accident Policy Statement

- 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 fits the current policy statement and its traditional application

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Independence of Barriers

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- 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

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Consistency Between Reactor Technologies

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- While the proposed improvements to venting systems for BWRs with Mark I and II containments address a known weakness in the severe accident performance for those plants, the pursuit of these improvements without resolving broader issues (e.g., NTTF Recommendation 1 and Severe Accident Policy Statement) introduces the possibility for inconsistent treatment of severe accident capabilities for the various reactor technologies

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External Events

- Beyond design basis external events such as the 2011 earthquake and tsunami will challenge normal and emergency power and cooling systems at a nuclear power plant
- There is a significant advantage to having installed equipment and/or strategies in place to address such events and conditions and thereby avoid the nuclear power plant compounding the consequences from the event

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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

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Enclosure 2
Design and Regulatory History

- Summarize the licensing and design considerations for Mark I and Mark II containments
- Why are Mark I and Mark II containments being discussed?
  - Ability of designs to withstand severe accident challenges
  - Defense in depth
  - Residual risk

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Enclosure 2
Design and Regulatory History

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- Mark I Containments
  - WASH-1400 & NUREG-1150 found that Mark I containments could be severely challenged if a severe accident occurred
  - Relatively small volume
    - Gas and steam buildup affect pressure more dramatically
  - BWR cores have ~3 times the quantity of zirconium as PWRs
    - Potential for hydrogen gas and containment pressurization

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Enclosure 2
Design and Regulatory History

- Mark II Containments
  - Similar to Mark I, the most challenging severe accident sequences are station blackout and anticipated transients without scram
  - Risk profile dominated by early failure with a release that bypasses the suppression pool
  - Hardened venting was considered not beneficial because of unacceptable offsite consequences without an external filter like MVSS
  - Staff did not recommend generic backfit of hardened vent, but recommended a comprehensive evaluation as part of the IPE program

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Enclosure 2
Design and Regulatory History

- Mark I Containments
  - Containment Performance Improvement Program
    - Determine what actions, if any, should be taken to reduce the vulnerability to severe accidents
    - Staff recommended
      - Improve hardened vent
      - Improve RPV depressurization system
      - Provide alternate water supply to RPV and drywell sprays
      - Improve emergency procedures and training
    - Commission approved hardened vent
    - Other recommendations evaluated as part of IPE program

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Enclosure 3
Foreign Experience

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- Status of filtered vents and regulatory basis in other countries
- Identify basis for pursuing filtered vents
- Identify any operational experience or adverse systems interactions

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Enclosure 3
Foreign Experience

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- Staff visited Sweden, Switzerland, and Canada
- Insights from visits and public meetings consistent with previous findings
  - 1988 CSNI Report 156, Specialists' Meeting on Filtered Containment Venting Systems
- Together, FCVS and containment flooding scrub fission products from core debris and remove decay heat

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Enclosure 3
Foreign Experience

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- Technical Bases Summary
  - Manage severe accident overpressure challenges
  - Defense-in-depth to address uncertainties associated with severe accidents
  - Significantly reduce offsite release
- After Barsebäck filter was installed, subsequent filter costs considered low to modest

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Enclosure 3
Foreign Experience

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- Quantitative Bases Summary
  - Release performance goal
  - Risk informed
    - Level 1 frequencies low but not sufficient
    - After the decision, ensure equipment performance is acceptable generically and on plant-specific basis
      - Acceptable not judged quantitatively – "significantly reduce", "almost eliminate", etc.
      - Factored into emergency planning

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Enclosure 3
Foreign Experience

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FCVS Status at Non-U.S. BWR Facilities

FCVS Status	GE Mark I	GE Mark II	ABB Mark II	GE Mark III	Other	ABWR	Totals	
FCVS Operational	1	0	6	1	5	0	**13**	30%
Committed	6	7	0	5	4	3	**25**	57%
Considering	1	0	0	1	0	0	**2**	5%
No FCVS	2	2	0	0	0	0	**4**	9%
Non-U.S. Totals	**10**	**9**	**6**	**7**	**9**	**3**	**44**	

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Enclosure 4
Mark I & II Severe Accident Performance

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- Containment Spray Systems
- Containment Flooding
- Containment Venting
- Decontamination by Drywell Spray
- Decontamination by the Wetwell
- Mark I Containments
- Mark II Containments
- Decontamination by External Engineered Filter Systems
- EPRI Evaluation of Severe Accident Venting Strategies for Mitigation of Radiological Releases
- Passive Containment Vent Actuation Capability
- Early Venting

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Enclosure 4
Mark I & II Severe Accident Performance

- EOPs, SAMGs, and EDMGs describe multiple containment vent pathways and use of portable pumps for reactor and drywell injection with focus on preventing core damage

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Enclosure 4
Mark I & II Severe Accident Performance

- DW Sprays for Decontamination
  - Spray headers designed for DBA purposes (pressure control and heat removal) with flow rates of 1,000's GPM
  - Portable pumps with flow rates in low 100's GPM which is good for cavity flooding and not as effective for decontamination

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Enclosure 4
Mark I & II Severe Accident Performance

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- Suppression Pool for Decontamination
  - SRV discharge via T-quencher in bottom of subcooled suppression pool
  - Downcomer pipes which discharge higher in the suppression pool at or near saturation temperatures

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Decontamination Factors

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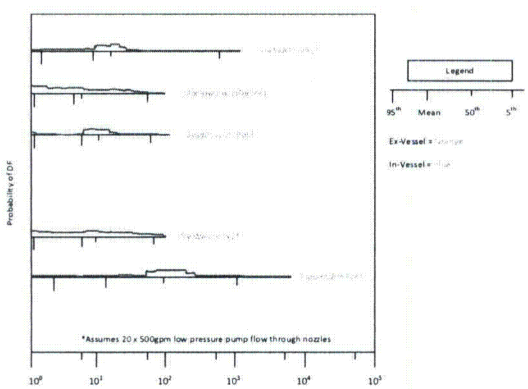

FIGURE 1: Uncertainty Distributions for Cesium Decontamination Factors (DFs)
Mark I Containment – Peach Bottom

Source: "Assessment of In-Containment Aerosol Removal Mechanisms," BNL Technical Report L-1535, 1992

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Enclosure 4
Mark I & II Severe Accident Performance

- EPRI Investigation of Strategies for Mitigating Radiological Releases in Severe Accidents
  - Employs a portable pump to flood drywell cavity and maintain suppression pool subcooling
  - Controls containment pressure near design value for holdup, settling, plate-out, spray effect, and high velocity discharge into suppression pool
  - Cycles containment vent valves to maintain containment pressure band (substantial reliance on instrumentation, valves/actuators, and operator actions)
  - Swap-over from WW to DW vent after 20 hours as containment floods up

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Enclosure 5a
MELCOR

- Based on SOARCA MELCOR modeling
- Accident sequences
  - Informed by SOARCA and Fukushima
  - Long-term SBO (base case 16 hr RCIC)
- Mitigation actions
  - B.5.b and/or FLEX provide core spray or drywell spray (300 gpm)
  - Containment venting
- Sensitivity analysis
  - Spray flow rate and timing, wetwell versus drywell venting, and RCIC duration

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Insights from MELCOR Calculations

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- Water on the drywell floor is needed to prevent liner melt-through
  - Also scrubs fission products and reduces drywell temperature
- Venting prevents over-pressurization failure
  - Wetwell venting is preferable to drywell venting
- Need combination of venting and drywell flooding
  - More reduction in fission product release
  - Maintain reactor building integrity

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Enclosure 5b MACCS2

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- Offsite population doses, including doses to off-site decontamination workers
- Individual latent cancer fatality risk and prompt fatality risk
- Land contamination
- For different thresholds of Cs-137 concentration in soil (Ci/km2)
- Economic costs

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Insights from MACCS2 Calculations

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- The health effect of interest is latent cancer fatality risk, which is controlled in part by the habitability (return) criterion
  - Essentially no prompt fatality risk
- In terms of long-term radiation, the most important isotope is Cs-137, and most of the doses are from ground shine
- There is a non-linear relationship between decontamination factor and both land contamination area, health effects, and economic consequences

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Enclosure 5c PRA

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- Conditional containment failure probability
- Insights from Severe Accident Mitigation Alternatives (SAMA) Analyses
- Technical approach
- Results
- Uncertainties

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Enclosure 5c
PRA

- To estimate the risk reduction resulting from installation of a severe accident containment vent for use in regulatory analysis
  - 50-mile population dose (Δperson-rem/ry)
  - 50-mile offsite cost (Δ$/ry)
  - Onsite worker dose risk (Δperson-rem/ry)
  - Onsite cost risk (Δ$/ry)
  - Land contamination (Δconditional contaminated land area)

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Enclosure 6
Stakeholder Interactions

- Numerous public meetings
- Stakeholder input and presentations
  - Filter vendors
  - Public interest groups
  - Regulated industry

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Enclosure 7
Draft Orders

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- Considerations
  - Assessing proposed implementation date
  - Provide high level technical requirements
  - Detailed guidance document to be developed with consideration of stakeholder input

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Previous ACRS Questions

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- Uncertainties on particle removal capabilities
  - Discussed in Enclosures 4 and 5a
  - Particle removal efficiency is dependent upon various parameters including particle size
  - Submicron particles are difficult to remove
  - Uncertainty in particle size distribution given an accident

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Previous ACRS Questions

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- Impact of noble gases on site operations
  - Elevated release with stable meteorological conditions have a relatively low impact
  - Elevated release with unstable meteorological conditions (i.e., plume washdown to site) would have greater impact
    - Shielded locations should limit doses to regulatory limits

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Conclusions

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- The NRC staff finds that the combination of quantitative and qualitative factors best supports the installation of filtered venting systems at BWRs with Mark I and II containments (Option 3)

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