# Attachment E

# Severe Accident Mitigation Alternatives Analysis

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# VERMONT YANKEE NUCLEAR POWER STATION

# ATTACHMENT E.1

# EVALUATION OF PSA MODEL

## E.1 EVALUATION OF PSA MODEL

The severe accident risk was estimated using the PSA model and a Level 3 model developed using the MACCS2 code. The RISKMAN code was used to develop the Vermont Yankee Nuclear Power Station (VYNPS) PSA Level 1 and Level 2 models. This section provides the description of VYNPS PSA Levels 1, 2, and 3 analyses, CDF uncertainty, IPEEE analyses, and PSA model peer review.

### E.1.1 PSA Model – Level 1 Analysis

The PSA model (Level 1 and Level 2) used for the SAMA analysis was the most recent internal events risk model for VYNPS (Revision VY04R1) [Reference E.1-1]. This current model is an updated version of the model used in the 1993 individual plant examination and reflects the VYNPS configuration and extended power uprate design changes as of September 2004. The VYNPS model adopts the large event tree/small fault tree approach and uses the support state methodology, embodied in the RISKMAN code, for quantifying core damage frequency.

The PSA model has been updated several times since the IPE due to the following.

- Equipment performance: as data collection progresses, estimated failure rates and system unavailability data change.

- Plant configuration changes: plant configuration changes are incorporated into the PSA model.

- Modeling changes: the PSA model is refined to incorporate the latest state of knowledge and recommendations from industry peer reviews.

The PSA model contains the major initiators leading to core damage with baseline core damage frequencies listed in Table E.1-2.

The current VYNPS PSA model was reviewed to identify those potential risk contributors that made a significant contribution to core damage frequency. CDF-based Risk Reduction Worth (RRW) rankings were reviewed down to 1.005. Events below this point would influence the CDF by less than 0.5% and are judged to be highly unlikely contributors for the identification of cost-beneficial enhancements. These top events, including system failures, operator actions, and initiating events, were reviewed to determine if additional SAMA actions may need to be considered.

Table E.1-3 provides a correlation between the Level 1 RRW risk significant terms (system failures, operator actions, and initiating events) down to 1.005 identified from the VYNPS PSA model and the SAMAs evaluated in Attachment E.2.

The uncertainty associated with core damage frequency was estimated using Monte Carlo techniques implemented in RISKMAN for the base case model VY04R1. The results are shown below.

**Table E.1-1**
**Core Damage Frequency Uncertainty**

| Confidence | CDF(/ry) |
|---|---|
| Mean value | 5.42E-6 |
| 5th percentile | 2.57E-6 |
| 50th percentile | 4.29E-6 |
| 95 th percentile | 1.06E-5 |

The values above reflect the uncertainties associated with the data distributions used in the analysis. The ratio of the 95th percentile to the mean is about 2. This uncertainty factor is included in the factor of 10 used to determine the **upper bound estimated benefit** described in Appendix E Section 4.21.5.4.

## Table E.1-2
## VYNPS PSA Model CDF Results by Major Initiators

| IE Type | IE Description | CDF (/RY) | Percentage of CDF |
|---|---|---|---|
| FLOOD | Internal flooding | 1.46 E-06 | 29.07% |
| TPCS | Transients without power conversion systems (PCS) | 8.21 E-07 | 16.31% |
| LOOP | Loss of offsite power | 7.24 E-07 | 14.39% |
| LOACBUS | Loss of AC bus 3 | 4.02 E-07 | 7.99% |
| LOACBUS | Loss of AC bus 4 | 3.54 E-07 | 7.03% |
| IORV | Inadvertently -opened relief valve | 2.72 E-07 | 5.41% |
| LODCBUS | Loss of DC bus 1 | 2.58 E-07 | 5.13% |
| LODCBUS | Loss of DC bus 2 | 2.47 E-07 | 4.92% |
| TRANS | Reactor trip | 1.40 E-07 | 2.79% |
| ATWS | Anticipated transient without scram | 1.40 E-07 | 2.79% |
| SORV | Stuck-open relief valve | 6.91 E-08 | 1.38% |
| TSW | Total loss of service water | 5.06 E-08 | 1.00% |
| LOCAOC | LOCA outside containment | 3.69 E-08 | 0.73% |
| SLOCA | Small LOCA | 2.12 E-08 | 0.42% |
| ISLOCA | Interfacing system LOCA | 1.63 E-08 | 0.32% |
| LLOCA | Large LOCA | 1.28 E-08 | 0.26% |
| MLOCA | Medium LOCA | 2.79 E-09 | 0.06% |
|  | **Total** | **5.03 E-06** | **100%** |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| HPCI | 1.4966 | This term represents random failure of the HPCI system. Phase I SAMAs to improve availability and reliability of the HPCI system that have already been implemented include raising backpressure trip setpoints and proceduralizing intermittent operation. Additional improvements were evaluated in Phase II SAMAs 049, 050, 051, 052, 053, and 054. |
| RCIC | 1.4223 | This term represents random failures of the RCIC system. Phase I SAMAs to improve availability and reliability of the RCIC system that have already been installed include raising backpressure trip setpoints and proceduralizing intermittent operation. Additional improvements were evaluated in Phase II SAMAs 049, 050, 051, 052, 053, and 054. |
| ECCS Low Pressure Interlock | 1.3472 | This term represents random failures of reactor low-pressure transmitters during transients with stuck open SRVs or LOCAs in which random failures prevent all low-pressure injection valves from opening. Phase II SAMAs 065 and 066 to reduce the risk due to failure of the ECCS low-pressure interlock were evaluated. |
| Depressurization (SRVs and ADS Logic) | 1.2724 | This term represents random failures of the SRVs to open for depressurization during transients and small LOCAs. Phase I SAMAs to enhance reliability of the SRVs that have already been implemented include adopting symptom based EOPs and SAGs, modifying ADS logic, and upgrading SRV pneumatic components. Additional improvements were evaluated in Phase II SAMAs 059 and 060. |
| Loss of Feedwater - initiating event | 1.1796 | This term represents the initiating event for loss of feedwater. Modifications to significantly reduce or eliminate the potential for loss of feedwater, such as installing a digital feedwater control system, providing a backup water supply and adding a third feedwater pump, have already been implemented. Many of the Phase II SAMAs (e.g., 035, 051, 052, 053, and 054) explored potential benefits for mitigation of this event. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Operator Action:<br>Operator fails to open SRVs for vessel depressurization during transients and small LOCA | 1.1110 | This term represents operator failure to manually open the SRVs for depressurization during transients and small LOCAs. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |
| Loss of Offsite Power - initiating event<br>PC – Plant Centered<br>GR – Grid Related | 1.0951-PC<br>1.0605-GR | This term represents the loss of offsite power initiating event. Industry efforts over the last twenty years have led to a significant reduction in plant scrams from all causes. Improvements related to enhancing offsite power availability or reliability and coping with plant SBO events were already implemented and evaluated during preliminary SAMA screening. Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system reliability or to cope with loss of offsite power and SBO events were evaluated. |
| Torus Vent via TVS-86 and Rupture Disk | 1.0948 | This term represents random failures of components in the containment vent path. A hardened pipe vent path was implemented as a result of the NRC Containment Performance Program to provide a redundant means for containment heat removal capability. Several Phase I SAMAs regarding the drywell spray system were already installed to provide containment decay heat removal capability by plant design. Therefore, no Phase II SAMAs were proposed to reduce random failure of containment vent path components. However, Phase II SAMA 063 to control containment venting within a narrow pressure band to prevent rapid depressurization during venting was evaluated. |
| Loss of 4.16KV Bus 3 - initiating event | 1.0869(IE) | This term represents loss of 4.16KV bus 3. Phase I SAMAs to improve 4.16KV bus crosstie capability and procedures to repair or replace failed 4.16KV breakers have already been implemented. Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system reliability or to cope with loss of offsite power and SBO events were evaluated. |

### Table E.1-3
### Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
### (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Emergency Diesel Generators (A & B) | 1.0810 | This term represents random failures of the emergency diesel generators, leading to an SBO event. Phase I SAMAs to improve reliability of the emergency diesel generators by creating a crosstie of EDG fuel oil supplies and a backup source for diesel cooling have already been installed. In addition, Phase II SAMAs 002, 003 and 032 to improve reliability of the EDGs were evaluated. |
| Loss of 4.16KV Bus 4 - initiating event | 1.0756 | This term represents loss of 4.16KV bus 4. Phase I SAMAs to improve 4.16KV bus crosstie capability and procedures to repair or replace failed 4.16KV breakers have already been installed. Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system reliability or to cope with loss of offsite power and SBO events were evaluated. |
| Operator Action:<br>Operator fails to initiate HPCI/RCIC during transients, medium and small LOCAs | 1.0685 | This term represents operator failure to initiate HPCI/RCIC to perform the core cooling function during transients, medium LOCAs, and small LOCAs when automatic initiation fails. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |
| Operator Action:<br>Operator fails to align firewater system and John Deere Diesel for alternate injection | 1.0660 | This term represents operator failure to align the John Deere diesel generator to provide electric power to 480VAC bus 9 during a loss of offsite power event. With bus 9 energized and supplying MCC8B and 9B, battery charging is maintained as well as power to RHR valves necessary for aligning the diesel fire pump for alternate RPV vessel injection. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |

### Table E.1-3
### Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
### (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Containment $N_2$ | 1.0553 | This term represents random failure of the containment nitrogen system for SRV operation during loss of offsite power. A Phase I SAMA, adding high-pressure nitrogen bottles as a backup to the normal nitrogen supply, has already been installed to improve reliability of the containment nitrogen system. Since failure of the SRVs has a larger risk reduction worth than failure of this support system, the benefit derived from Phase II SAMA 060, "improve SRV design," is greater than the benefit possible from improving the nitrogen supply system. Also, the cost of adding another nitrogen supply is judged comparable to the cost of modifying the SRVs. Therefore, no Phase II SAMAs were evaluated to further improve reliability of nitrogen supply to the SRVs. |
| Diesel Fire Pump and John Deere Diesel for Alternate Injection | 1.0584 | This term represents random failure of diesel fire pump P40-1A and John Deere diesel generator during the alignment of John Deere diesel generator to provide alternate RPV vessel injection during a loss of offsite power event. Phase I SAMAs to use the fire protection system as a backup source for containment spray and reactor vessel injection during loss of offsite power have already been installed to provide redundant capability for RPV injection and heat removal. Phase II SAMA 064 to provide a crosstie for fire protection from RHRSW system to RHR loop B to further improve injection capability was evaluated. |
| Inadvertent Opening of Relief Valve—initiating event | 1.0571 | This term represents the initiating event of inadvertent opening of a relief valve. Improvement of the SRV design and SRV reseat reliability, to reduce the probability and consequences of this initiating event, were evaluated in Phase II SAMAs 055 and 060. |
| Loss of Bus DC-1 and associated battery—initiating event | 1.0541(IE)<br>1.0264 | These terms represent the initiating event of a complete loss of the 125VDC bus DC-1 and random failures of battery A-1. Phase I SAMAs to improve alternate battery charging capability, replace existing batteries with more reliable ones, and DC bus crosstie capability have already been installed. Phase II SAMAs 028, 029, 030, and 033 for enhancing DC system availability and reliability were evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Loss of Bus DC-2 and associated battery - initiating event | 1.0517(IE)<br>1.0316 | These terms represent the initiating event of a complete loss of 125VDC bus DC-2 and random failures of battery B-1. Phase I SAMAs to improve alternate battery charging capability, replace existing batteries with more reliable ones and DC bus crosstie capability have already been installed. Phase II SAMAs 028, 029, 030, and 033 for enhancing DC system availability and reliability were evaluated. |
| Torus Cooling Mode of RHR & RHRSW | 1.0515 | This term represents random failure of the torus cooling mode of the RHR and RHRSW systems. Containment spray mode of RHR and fire protection system crosstie has already been implemented to provide redundant containment heat removal capability. In addition, Phase II SAMAs 004, 010 and 017 to improve the reliability of containment decay heat removal were evaluated. |
| Operator Action:<br>Operator fails to open SRVs for vessel depressurization during medium LOCA | 1.0408 | This term represents operator failure to manually open the SRVs to depressurize during a medium LOCA. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |
| Loss of Service Water - initiating event | 1.0102 | These terms represent random passive failures of the service water system and the initiating event of a complete loss of the service water system. Enhancement of the service water system was evaluated in Phase II SAMA 001. |
| Internal Flooding Initiator, SW pipe break in torus room, at El. 213' of the reactor building | 1.0397 | This term represents the initiating event of SW pipe break in torus room, at El. 213' of the reactor building. A Phase I SAMA, enhancement of "Loss of Service Water" procedure to contain a mitigation strategy for each break location, has already been implemented. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Operator Action:<br>Operator fails to recognize the need to vent the torus for pressure reduction | 1.0367 | This term represents operator failure to recognize the need to vent the torus for pressure reduction during loss of containment heat removal accident sequences. Phase II SAMA 063 to control containment venting within a narrow pressure band to prevent rapid containment depressurization during venting was evaluated. |
| Internal Flooding Initiator, SW pipe break in NE ECCS corner room of the reactor building | 1.0357 | This term represents the initiating event of SW pipe break in NE ECCS corner room of the reactor building. A Phase I SAMA to increase berm height to prevent flooding of the ECCS corner room has already been installed. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, SW pipe break in SE ECCS corner room of the reactor building | 1.0343 | This term represents the initiating event of SW pipe break in SE ECCS corner room of the reactor building. A Phase I SAMA modifying and sealing the hatch lift points and hatch edges has already been installed to ensure hatches are watertight. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, SW pipe break at El. 303’ of the reactor building | 1.0324 | This term represents the initiating event of SW pipe break at El. 303’ of the reactor building. A Phase I SAMA, adding chase berms at elevation 303’, has already been installed. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Bus 2 (supplied by SU XFMR) – 4.16KV | 1.0318 | This term represents the initiating event of a complete loss of offsite power from the 345 KV switchyard and 115 KV line. Phase I SAMAs to improve 4.16KV bus crosstie capability, procedures to repair or replace failed 4.16KV breakers and provide connection to an alternate source of offsite power have already been installed. Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system reliability or to cope with loss of offsite power and SBO events were evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| RPS | 1.0316 | This term represents random failure of the reactor protection system. Several Phase I SAMAs to minimize the risks associated with ATWS scenarios have already been installed. No Phase II SAMAs were evaluated to further improve reliability of RPS. However, Phase II SAMAs 057 and 058 to enhance the reliability of the standby liquid control system and improve ATWS capability to mitigate the consequences of this event were evaluated. |
| Transient with PCS available - initiating event | 1.0287 | This term represents the initiating event of a transient with PCS available. Industry efforts over the last twenty years have led to a significant reduction of plant scrams from all causes. Phase II SAMA 046 to improve MSIV design and mitigate the consequences of this event was evaluated. |
| Operator Action:<br>Operator fails to align a condensate transfer pump to inject via LPCI or core spray lines for alternate injection | 1.0282 | This term represents operator failure to align condensate transfer pump to inject via LPCI or core spray lines for alternate injection. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |
| Operator Action:<br>Operator fails to initiate alternate cooling mode from the cooling tower deep basin | 1.0257 | This term represents operator failure to align water from the west cooling tower deep basin to the suction of the RHRSW pumps to cool a number of loads normally cooled by the service water system. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject. |

### Table E.1-3
### Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
### (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Feedwater/Condensate | 1.0237 | This term represents random failure of the feedwater and condensate injection path. Phase I SAMAs creating connections of existing or alternate water sources to feedwater and condensate, and installing motor driven feed water pumps, have already been installed to increase the availability of injection subsequent to MSIV closure. Many of the Phase II SAMAs (e.g. 050, 051, 052, 053, and 054) explored potential benefits of enhancing the reliability of high pressure injection systems. |
| Internal Flooding Initiator, SW pipe break (north) affecting MCCs and ECCS in NE corner room of the reactor building | 1.0218 | This term represents the initiating event of SW pipe break in NE ECCS corner room of the reactor building. A Phase I SAMA, enhancement of "Loss of Service Water" procedure to contain a mitigation strategy for each break location, has already been implemented. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Bus 1 (supplied by SU XFMR) – 4.16KV | 1.0200 | This term represents the initiating event of a complete loss of offsite power from the 345 KV switchyard and 115 KV line. Phase I SAMAs to improve 4.16KV bus crosstie capability, procedures to repair or replace failed 4.16KV breakers and provide connection to an alternate source of offsite power have already been installed. Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system reliability or to cope with loss of offsite power and SBO events were evaluated. |
| Vernon Tie | 1.0153 | This term represents random failure of Vernon tie line circuit breakers to close and operator failure to close two breakers from the control room. Phase I SAMAs to provide an alternate source of offsite power, proceduralize steps in recovery of offsite power after SBO, and protect control cable of Vernon tiebreakers have already been installed. No Phase II SAMAs were evaluated to further improve reliability of the Vernon tie. However, Phase II SAMAs 028, 029, 030, 031, 033 and 036 for enhancing AC or DC system availability or reliability to cope with the loss of offsite power and SBO events were evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Internal Flooding Initiator, fire protection pipe break in upper RCIC room at El. 232' | 1.0177 | This term represents the initiating event of fire protection pipe break in torus room, at El. 232' of the reactor building. A Phase I SAMA, to provide a relief path to relieve water accumulation in the upper RCIC to lower RCIC area before floor failure, has already been implemented. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| ATWS with MSIV Closed - initiating event | 1.0155 | This term represents the ATWS initiating event. Several Phase I SAMAs to create a boron injection path through CRD, increase boron concentration, and provide RPT, ARI, and FW trip to minimize the risks associated with ATWS scenarios have already been installed. In addition, Phase II SAMAs 057 and 058 to enhance reliability of the standby liquid control system and improve ATWS capability to mitigate the consequences of this event were evaluated. |
| Internal flooding Initiator, SW pipe break in affecting instrument panels and 480V MCC, at El. 280' of the reactor building | 1.0144 | This term represents the initiating event of SW pipe break at El. 280' of the reactor building. A Phase I SAMA, enhancement of "Loss of Service Water" procedure to contain a mitigation strategy for each break location, has already been implemented. In addition, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Alternate Cooling | 1.0143 | This term represents random failure of alternate cooling from the west cooling tower deep basin to the suction of the RHRSW pumps. Phase II SAMA 064 to improve alternate cooling capability was evaluated. |
| Stuck Open SRVs – initiating event | 1.0139 | This term represents the initiating event of stuck open SRVs. Improvement of SRV reseat reliability and SRV design were evaluated in Phase II SAMAs 055 and 060. |
| Operator Action:<br>Operator fails to start a TBCCW pump | 1.0133 | This term represents operator failure to start TBCCW pump locally from the motor control panel and establish cooling to BOP components for RPV makeup and heat removal. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Internal Flooding Initiator, circulating water pipe break in turbine building | 1.0130 | This term represents the initiating event of circulating water pipe break in the turbine building. Phase I SAMAs to improve inspection of expansion joints on the main condenser and to change procedures to reduce the probability of a circulating water piping break have already been implemented. No Phase II SAMA was evaluated to further reduce this initiator. However, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Operator Action:<br>Operator fails to initiate SLC during an ATWS without main condenser | 1.0130 | This term represents operator failure to initiate SLC during an ATWS without main condenser. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject |
| Internal Flooding Initiator, SW pipe break in intake structure | 1.0119 | This term represents the initiating event of SW pipe break in the intake structure. Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Loss of PCS - initiating event | 1.0111 | This term represents the initiating event of a loss of PCS. Industry efforts over the last twenty years have led to a significant reduction of plant scrams from all causes. Phase II SAMA 046 to improve MSIV design and mitigate the consequences of this event was evaluated. |
| Operator Action:<br>Operator fails to initiate and control feedwater and condensate during transients and small LOCA and medium LOCAs | 1.0079 | This term represents operator failure to align feedwater and condensate injection to perform the core cooling function during transients, medium LOCAs and small LOCAs. Phase I SAMAs including improvements to plant procedures, and installation of instrumentation to enhance the likelihood of success of operator action in response to accident conditions, have already been implemented. No additional Phase II SAMAs were recommended for this subject |
| 24 VDC ECCS Bus B | 1.0079 | This term represents random failures of the 24VDC ECCS Bus B system. A Phase I SAMA, replacing the 24VDC batteries with 125VDC to 24VDC converters, has already been implemented. Phase II SAMA 047 to protect the power cabinet from internal flooding to further improve reliability of 24VDC ECCS buses was evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Internal Flooding Initiator, fire protection pipe break (northeast) cascading to torus room at El. 252' reactor building | 1.0078 | This term represents the initiating event of fire protection pipe break (northeast) cascading to torus room at El. 252' reactor building. Phase I SAMAs, fire protection system standpipe, was enhanced to reduce internal flooding risk contribution. No Phase II SAMA was evaluated to further reduce this initiator. However, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, SW pipe break affecting EDG-1A, EDG-1B, diesel room A, turbine building | 1.0073 | This term represents the initiating event of SW pipe break in diesel room A, turbine building. Phase II SAMA 047 to reduce the contribution of internal flooding was evaluated. |
| Internal flooding Initiator, auxiliary steam break affecting EDG-1A, turbine building | 1.0071 | This term represents the initiating event of auxiliary steam break in diesel room A, turbine building. Phase I SAMAs to improve doors in the turbine building have already been installed. No Phase II SAMA was evaluated to further reduce this initiator. However, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, auxiliary steam break affecting EDG-1B, turbine building | 1.0067 | This term represents the initiating event of auxiliary steam break in diesel room B, turbine building. Phase I SAMAs to improve doors in the turbine building have already been installed. No Phase II SAMA was evaluated to further reduce this initiator. However, Phase II SAMA 047 to reduce the CDF contribution of internal flooding was evaluated. |
| 24 VDC ECCS Bus A | 1.0065 | This term represents random failures of the 24VDC ECCS Bus A system. A Phase I SAMA, replacing the 24VDC batteries with 125VDC to 24VDC converters has already been installed. Phase II SAMA 047 to protect the power cabinet from internal flooding to further improve the reliability of 24VDC ECCS buses was evaluated. |
| Internal Flooding Initiator, SW pipe break in general areas of turbine building | 1.0059 | This term represents the initiating event of SW pipe break in general areas of the turbine building. Phase II SAMA 047 to reduce the contribution of internal flooding was evaluated. |

## Table E.1-3
## Correlation of Level 1 Risk Significant Terms to Evaluated SAMAs
## (Continued)

| Risk Significant Terms | RRW | Disposition |
|---|---|---|
| Internal Flooding Initiator, SW pipe break in HVAC room of turbine building | 1.0059 | This term represents the initiating event of SW pipe break in the HVAC room of the turbine building. Phase II SAMA 047 to reduce the contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, unisolable SW pipe break in torus room, at El. 213' reactor building | 1.0054 | This term represents the initiating event of unisolable SW pipe break in torus room, at El. 213' of the reactor building. A Phase I SAMA, enhancement of "Loss of Service Water" procedure to contain a mitigation strategy for each break location, has already been implemented. In addition, Phase II SAMA 047 to reduce the contribution of internal flooding was evaluated. |
| Internal Flooding Initiator, SW pipe break affecting EDG-1A, EDG-1B, diesel room B, turbine building | 1.0053 | This term represents the initiating event of SW pipe break in diesel room B, turbine building. Phase II SAMA 047 to reduce the contribution of internal flooding was evaluated. |

## E.1.2 PSA Model – Level 2 Analysis

### E.1.2.1 Containment Performance Analysis

The VYNPS Level 2 PSA model used for the SAMA analysis is the most recent internal events risk model which is an updated version of the model used in the Individual Plant Examination, [Reference E.1-2]. The Level 2 PSA model used for the SAMA analysis, Revision VY04R1, reflects the VYNPS configuration and extended power uprate design changes as of September 2004. Specifically, the VYNPS Level 2 model has been updated to incorporate insights from the independent peer review and the NEI Guidelines, NEI 00-02, on PRA peer review.

The VYNPS Level 2 model includes two types of considerations: (1) a deterministic analysis of the physical processes for a spectrum of severe accident progressions, and (2) a probabilistic analysis component in which the likelihood of the various outcomes are assessed. The deterministic analysis examines the response of the containment to the physical processes during a severe accident. This response is performed by

- utilization of the MAAP code [Reference E.1-3] to simulate severe accidents that have been identified as dominant contributors to core damage in the Level 1 analysis, and
- reference calculation of several hydrodynamic and heat transfer phenomena that occur during the progression of severe accidents. Examples include debris coolability, pressure spikes due to ex-vessel steam explosions, scoping calculation of direct containment heating, molten debris filling the pedestal sump and flowing over the drywell floor, containment bypass, deflagration and detonation of hydrogen, thrust forces at reactor vessel failure, liner melt-through, and thermal attack of containment penetrations.

The Level 2 analysis examined the dominant accident sequences and the resulting plant damage states (PDS) defined in Level 1. The Level 1 analysis involves the assessment of those scenarios that could lead to core damage. A list of the PDS and descriptions from the Level 2 analysis is presented in Table E.1-8.

A full Level 2 model was developed for the IPE and completed at the same time as the Level 1 model. The Level 2 model consists of a single containment event tree (CET) with functional nodes that represent phenomenological events and containment protection system status. The nodes were quantified using subordinate trees and logic rules. A list of the CET functional nodes and descriptions used for the Level 2 analysis is presented in Table E.1-4.

## Table E.1-4
## Notation and Definitions for Vermont Yankee CET Functional Nodes Description

| CET Node | CET Functional Node Description |
|---|---|
| Core cooling (CC) | This top event is used to determine which sequences from the front-line event tree need to be further evaluated in the CET. CC success means that no core damage has occurred. When CC succeeds, all other top events in the CET are bypassed. |
| Containment Intact (CI) | This top event identifies the status of the containment at the beginning of the CET. CI is set to success when containment heat removal succeeds in the front-line event tree. CI is set to failure when containment heat removal fails in the front-line event tree. |
| Isolated Containment (IS) | This top event represents containment isolation at the beginning of the CET. The success criterion is defined as no containment opening with an equivalent size of greater than 2 inches in diameter. The failure for containment isolation results in a release path to the reactor building or directly to the environment. |
| Vessel Depressurization (VD) | This top event identifies the status of the reactor pressure vessel (RPV) pressure. VD is set to success when RPV pressure is low. VD is set to failure when RPV pressure is high. |
| In-vessel Recovery (VR) | This top event accounts for the potential recovery of core cooling before RPV failure. VR success means that some core damage has occurred, but that the RPV is not breached. VR failure means that core debris has failed the RPV bottom head or penetration. |
| Inerted Containment (IN) | This top event accounts for the potential that the containment is not inerted (e.g., during a 24-hour Technical Specification LCO). |
| Combustible Gas Venting (GV) | This top event represents the potential for hydrogen burn given core damage has occurred and a de-inerted containment exists (i.e., IN=failure). |
| Drywell Integrity (DI) | This top event considers early, energetic drywell failures. DI success means that no significant drywell leakage develops as a result of the energetic phenomena, which can occur during or shortly after RPV failure. DI failure means that drywell failure occurs as a result of postulated energetic phenomena. |

## Table E.1-4
## Notation and Definitions for Vermont Yankee CET Functional Nodes Description (Continued)

| CET Node | CET Functional Node Description |
|---|---|
| Spray Drywell (SD) | This top event indicates whether the drywell could be sprayed with water before RPV failure occurs. SD success implies the presence of water on the drywell floor at the time of RPV failure, which decreases the likelihood of drywell shell melt-through by molten debris. |
| Shell Integrity (SI) | This top event considers the potential failure of the drywell shell due to core debris after RPV failure. SI failure implies that a large hole is opened in the drywell shell at the elevation where it contacts the concrete pedestal floor. |
| Containment Flooding (CF) | This top event accounts for the probable success/failure of containment flooding as performed by VYNPS EOPs/SAGs when RPV level cannot be restored and steam cooling is insufficient to cool the core. |
| Drywell Vent (DV) | Top event DV occurs only after CF success. CF success implies that water is being injected into the RPV and that the operator controls containment water level such that the core remains submerged. During this evolution, drywell pressure rises due to decay heat, combustible gas production, and decreasing gas space as containment water level rises. Therefore drywell pressure must be controlled (i.e., DV is success) to prevent containment overpressure failure. |
| Quench Debris (QD) | This top event considers the delivery of water to the drywell, via drywell sprays, or via injection to the RPV and drainage out an RPV breach onto the drywell floor. Success implies the availability of water and the formation of a coolable debris bed such that concrete attack is precluded. |
| Heat Removal (HR) | This top event considers use of the RHR system for containment heat removal after RPV breach. |
| Torus Vent (TV) | This top event occurs after HR fails. TV considers use of the hard-piped torus vent as an alternative to the RHR system for containment heat removal. Success for top event TV requires that a vent path be open from the torus airspace and that the operator uses this path to control containment pressure. |
| Suppression Pool Scrubbing (SP) | This top event considers the potential for a release to bypass the suppression pool. Failure of SP involves a release into the drywell, along with a stuck-open torus-to-drywell vacuum breaker. Without suppression pool scrubbing, the release from containment failures located in the wetwell airspace (or opening of the torus vent) will be much higher than it would be with suppression pool scrubbing. |

## Table E.1-4
## Notation and Definitions for Vermont Yankee CET Functional Nodes Description (Continued)

| CET Node | CET Functional Node Description |
|---|---|
| Limit Size of Failure (LS) | Top event LS is used to estimate the size of containment failures for event sequences where all means of containment heat removal have failed and containment failure is imminent. LS success means that the failure is limited to a small size. "Small" is defined as less than about 0.2 square feet in area. Small failures will prevent further pressurization of containment, but will not cause a rapid depressurization. LS failure means that a large failure occurs, which results in a rapid depressurization of containment. |
| Drywell (DR) | This top event assesses the potential for over-temperature or over-pressure failure of the drywell. DR success means that no significant leakage from the drywell occurs, which means that the failure is located in the torus. DR failure means that the drywell fails, and the resulting release is assumed to be through the drywell head. |
| Wetwell (WW) | This top event is used to partition the torus failures into those that occur in the torus airspace and those that occur in the wetwell below the waterline. WW success means that the failure occurs in the torus airspace, and that the wetwell water remains available for scrubbing. WW failure means that water drains from the wetwell. |
| Reactor Building (RB) | This top event is used to assess the ability of the reactor building to retain fission products released from containment. Success of top event RB is defined to be a reduction of the containment release magnitude by one "category". |

The Large Early Release Frequency (LERF) is an indicator of containment performance from the Level 2 results because the magnitude and timing of these releases provide the greatest potential for early health effects to the public. The frequency calculated is approximately 1.54E-6 per year. Figure E.1-1 and Figure E.1-2 summarize the Level 2 results.

LERF represents a modest fraction (thirty percent) of all release end states. Five types of accidents dominate the internal large early release: transients, accidents initiated by station blackout, loss-of-coolant accidents, interfacing system loss of coolant accidents, and anticipated transient without scram.

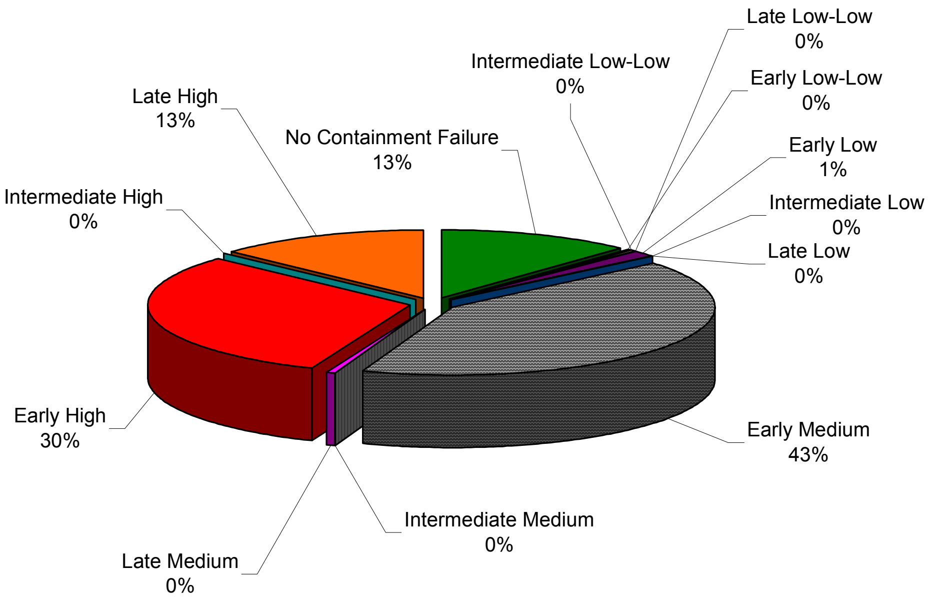

**Figure E.1-1**
**Vermont Yankee Radionuclide Release Category Summary**

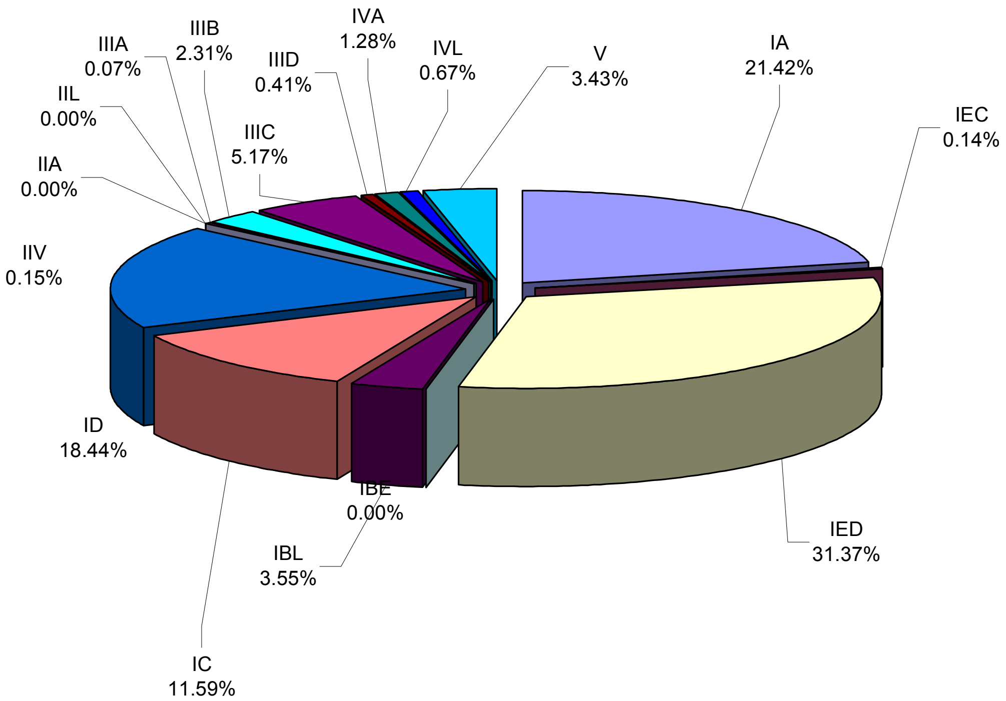

**Figure E.1-2**
**Vermont Yankee Plant Damage State Contribution to LERF**

### E.1.2.2 Radionuclide Analysis

#### E.1.2.2.1 Introduction

A major feature of a Level 2 analysis is the estimation of the source term for every possible outcome of the containment event tree (CET). The CET end points represent the outcomes of possible in-containment accident progression sequences. These end points represent complete severe accident sequences from initiating event to release of radionuclides to the environment. The Level 1 and plant system information is passed through to the CET evaluation in discrete plant damage states. An atmospheric source term may be associated with each of these CET sequences. Because of the large number of postulated accident scenarios considered, mechanistic calculations (i.e., MAAP calculations) are not performed for every end-state in the CET. Rather, accident sequences produced by the CET are grouped or "binned" into a limited number of release categories each of which represents all postulated accident scenarios that would produce a similar fission product source term.

The criteria used to characterize the release are the estimated magnitude of total release and the timing of the first significant release of radionuclides. The predicted source term associated with each release category, including both the timing and magnitude of the release, is determined using the results of MAAP calculations [Reference E.1-3].

#### E.1.2.2.2 Timing of Release

Timing completely governs the extent of radioactive decay of short-lived radioisotopes prior to an off-site release and, therefore, has a first-order influence on immediate health effects. Vermont Yankee characterizes the release timing relative to the time at which the release begins, measured from the time of accident initiation. Three timing categories are used:

early (0-6 hours),
intermediate (6-24 hours), and
late (>24 hours).

Based on MAAP calculations for a spectrum of severe accident sequences, Vermont Yankee expects that an Emergency Action Level (as defined by the Vermont Yankee Emergency Plan) will be reached within the first half hour after accident initiation. Reaching an Emergency Action Level initiates a formal decision-making process that is designed to provide public protective actions. Within 6 hours of accident initiation, the Level 2 analysis assumed that minimal off-site protective measures would be accomplished. After 24 hours, the Level 2 analysis assumed that off-site protective measures would be effective. Therefore, the definitions of the release timing categories are as follows.

- Early releases are CET end-states involving containment failure prior to or at vessel failure or after vessel failure and occurring within 0 to 6 hours measured from the time of accident initiation and for which minimal offsite protective measures would be accomplished.

- Intermediate releases are CET end-states involving containment failure prior to or at vessel failure or after vessel failure within 6 to 24 hours measured from the time of accident initiation, for which most of the offsite nuclear plant protective measures would be accomplished.

- Late releases are CET end-states involving containment failure greater than 24 hours from the time of accident initiation, for which offsite measures are fully effective.

#### E.1.2.2.3 Magnitude of Release

Source term results from previous risk studies suggest that categorization of release magnitude based on cesium iodide (CsI) release fractions alone are appropriate [References E.1-4, E.1-5]. The CsI release fraction indicates the fraction of in-vessel radionuclides escaping to the environment. (Noble gas release levels are non-informative since release of the total core inventory of noble gases is essentially complete given containment failure.) The source terms were grouped into five distinct radionuclide release categories or bins according to release magnitude.

(1) High (HI) - A radionuclide release of sufficient magnitude to have the potential to cause early fatalities. This implies a total integrated release of >10 percent of the initial core inventory of Cesium Iodide (CsI) [Reference E.1-6][1]

(2) Medium (MED) - A radionuclide release of sufficient magnitude to cause near-term health effects. This implies a total integrated release of between 1 and 10 percent of the initial core inventory of CsI [Reference E.1-6][2].

(3) Low (LO) - A radionuclide release with the potential for latent health effects. This implies a total integrated release of between 0.1 percent and 1 percent of the initial core inventory of CsI.

(4) Low-Low (LL) - A radionuclide release with undetectable or minor health effects over most of the population. This implies a total integrated release of between 0. 001 percent and 0.1 percent of the initial core inventory of CsI.

(5) Negligible (NCF) - A radionuclide release that is less than or equal to the containment design base leakage. This implies total integrated release of < 0.001 percent of the initial core inventory of CsI.

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[1] Once the CsI source term exceeds 0.1, the source term is large enough that doses above the early fatality threshold can sometimes occur within a population center a few miles from the site.

[2] The reference document indicates that for Cs release fractions of 1 to 10 percent, the number of latent fatalities is found to be at least 10% of the latent fatalities for the highest release.

The "total integrated release" as used in the above categories is defined as the integrated release within 36 hours after RPV failure. If no RPV failure occurs, then the "total integrated release" is defined as the integrated release within 36 hours after accident initiation.

#### E.1.2.2.4 Release Category Bin Assignments

Table E.1-5 summarizes the scheme used to bin sequences with respect to magnitude of release, based on the predicted cesium iodide release fraction and release timing.

The combination of release magnitude and timing produce thirteen distinct release categories for source terms. These are the representative release categories presented in Table E.1-6.

**Table E.1-5**
**Release Severity and Timing Classification Scheme Summary**

| **Release Severity** | | **Release Timing** | |
|---|---|---|---|
| **Classification Category** | **CsI % Release** | **Classification Category** | **Time of Initial Release from Accident Initiation** |
| High | Greater than 10 | Early (E) | Less than 6 hours |
| Medium | 1 to 10 | | |
| Low | 0.1 to 1 | Intermediate (I) | 6 to 24 hours |
| Low-Low | 0.001 to 0.1 | Late (L) | Greater than 24 hours |
| Negligible | Less than 0.001 | | |

**Table E.1-6**
**Vermont Yankee Release Categories**

| **Timing of Release** | **Magnitude of Release** | | | | |
|---|---|---|---|---|---|
| | Low | Low-Low | Medium | High | |
| Early | Early/Low | Early/LoLo | Early/Med | Early/High | NCF |
| Intermediate | Inter/Low | Inter /LoLo | Inter/Med | Inter/High | |
| Late | Late/Low | Late/LoLo | Late/Med | Late/High | |

### E.1.2.2.5 Mapping of Level 1 Results into the Various Release Categories

Plant Damage States (PDS) provide the interface between the Level 1 and Level 2 analyses (i.e. between core damage accident sequences and fission product release categories). In the plant damage state analysis, Level 1 results were grouped ("binned") according to plant characteristics that define the status of the reactor, containment, and core cooling systems at the time of core damage. This ensures that systems important to core damage in the Level 1 event trees and the dependencies between containment and other systems are handled consistently in the Level 2 analysis. A Plant Damage State therefore represents a grouping of Level 1 sequences that defines a unique set of initial conditions that are likely to yield a similar accident progression through the Level 2 Containment Event Trees and the attendant challenges to containment integrity.

From the perspective of the Level 2 assessment, PDS binning entails the transfer of specific information from the Level 1 to the Level 2 analyses.

- *Equipment failures in Level 1*. Equipment failures in support systems, accident prevention systems, and mitigation systems that have been noted in the Level 1 analysis are carried into the Level 2 analysis. In this latter analysis, the repair or recovery of failed equipment is not allowed unless an explicit evaluation, including a consideration of adverse environments where appropriate, has been performed as part of the Level 2 analysis.

- *Reactor pressure vessel (RPV) status*. The RPV pressure condition is explicitly transferred from the Level 1 analysis to the CET.

- *Containment status*. The containment status is explicitly transferred from the Level 1 analysis to the CET. This includes recognition of whether the containment is bypassed or is intact at the onset of core damage.

- *Accident sequence timing.* Differences in accident sequence timing are transferred with the Level 1 sequences. Timing affects such sequences as station blackout, internal flooding, and containment bypass (ISLOCA).

This transfer of information allows timing to be properly assessed in the Level 2 analysis.

Classifying core damage sequences by similar functional groupings can provide additional insights. A generalized core damage sequence functional classification scheme from NEI 91-04 [Reference E.1-7] is shown in Table E.1-7. The description of functional classes is presented here to introduce the terminology to be used in characterizing the basic types of challenges to containment.

In assessing the ability of the containment and other plant systems to prevent or mitigate radionuclide releases, it is desirable to further subdivide these generalized functional categories. In the second level binning process, the similar accident sequences grouped within each core damage functional class are further categorized into subclasses such that the potential for system recovery can be modeled. The interdependencies that exist between plant system operation and the core melt and radionuclide release phenomena are represented in the release frequencies through the binning process involving these subclasses. The binning process, which consolidates information from the systems' evaluation of accident sequences leading to core damage in preparation for transfer to the containment-source term evaluation, involves the identification of 17 classes and subclasses of accident sequence types. Table E.1-8 provides a description of the Vermont Yankee functional classes that are used to summarize the Level 1 results.

The plant damage state accident class designators and subclasses listed in Table E.1-9 represent the core damage end state categories from the Level 1 analysis that are grouped together as entry conditions for the Level 2 analysis. The Level 2 accident progression for each of the subclasses is then evaluated using a single containment event tree to determine the appropriate release category for each Level 2 sequence. Each end state associated with a Level 2 sequence is assigned to one of the release categories depicted in Table E.1-6. However, since not all the Level 2 sequences associated with each Level 1 core damage class may be assigned to the same release category, there is no direct link between a specific Level 1 core damage class and Level 2 release category. Rather, the sum of the Level 2 end state frequencies assigned to each release category determines the overall frequency of that release category. The release category frequency attributed to each Level 1 core damage class is determined by the binning rules described in the RISKMAN Level 2 model.

Based on the above binning methodology, the salient Level 2 results are summarized in Tables E.1-9 and E.1-10 respectively. Table E.1-9 summarizes the results of the CET quantification. This table identifies the total annual release frequency for each Level 2 release category. Table E.1-10 provides the release frequency for each Level 1/Level 2 end state combination.

**Table E.1-7**
**Level 1 Core Damage Functional Classes**

| Core Damage Functional Class | RPV Condition | Containment Condition |
|---|---|---|
| I | Loss of effective coolant inventory (includes high and low pressure inventory losses) | Intact |
| II | Loss of effective containment pressure control, e.g., heat removal | Breached or Intact |
| III | LOCA with loss of effective coolant inventory makeup | Intact |
| IV | Failure of effective reactivity control | Breached or Intact |
| V | LOCA outside containment | Breached (bypassed) |

## Table E.1-8
## Summary of Vermont Yankee Core Damage Accident Sequence Functional Classes

| Class | Sub-Class | Class Description | Point Estimate | % of Total CDF |
|---|---|---|---|---|
| I | A | Transient sequences with loss of all high- pressure injection and failure to depressurize. Core damage occurs with the reactor at high pressure. | 1.20E-06 | 23.98% |
| | BE | 'Early' SBO sequences. Core damage occurs due to early failure of HPCI and RCIC. | 3.19E-07 | 6.35% |
| | BL | 'Late' SBO. Core cooling is maintained by HPCI/RCIC until batteries deplete. | 8.39E-07 | 16.69% |
| | C | ATWS sequences where core damage is caused by loss of injection during level/power control. | 1.59E-08 | 0.32% |
| | D | Transient sequences with loss of all injection. Core damage occurs with the reactor at low-pressure. | 1.43E-06 | 28.46% |
| | EC | Transient sequences with delayed loss of dc power due to failure of battery chargers. | 0.00E+00 | 0.00% |
| | ED | 'Early' SBO sequences caused by failure of DC-1 and DC-2. | 5.52E-08 | 1.10% |
| II | A | Transient sequence with loss of all containment heat removal. Core damage is caused by containment failure. | 4.43E-07 | 8.81% |
| | L | Loss of containment heat removal with RPV breach but no initial core damage; core damage after containment failure. | 4.82E-08 | 0.96% |
| | V | Transient sequences where the main condenser and RHR fail, and the torus vent opens for containment pressure relief. Core damage occurs when ECCS systems fail NPSH, due to failure to reclose the vent. | 1.82E-07 | 3.63% |

## Table E.1-8
## Summary of Vermont Yankee Core Damage Accident Sequence Functional Classes (Continued)

| Class | Sub-Class | Class Description | Point Estimate | % of Total CDF |
|---|---|---|---|---|
| III | A | RPV ruptures due to failure of all over-pressure protection systems. | 4.36E-09 | 0.09% |
| | B | Small or Medium LOCA sequences for which the reactor cannot be depressurized prior to core damage occurring. | 1.35E-07 | 2.70% |
| | C | LOCA sequences with loss of injection. Core damage occurs with the reactor at low pressure. | 1.25E-07 | 2.49% |
| | D | LOCA sequences where core damage is caused by containment failure. Containment fails due to failure of vapor suppression (stuck-open vacuum breaker). | 6.35E-09 | 0.13% |
| IV | A | ATWS sequences where core damage is caused by containment failure. | 1.11E-07 | 2.20% |
| | L | ATWS sequences where core damage occurs due to overpressure failure of the Reactor Coolant System. | 5.26E-08 | 1.05% |
| V | - | Containment Bypass sequences. (Interfacing systems LOCA and LOCA outside of containment.) | 5.32E-08 | 1.06% |
| | | **Total** | **5.03E-06** | **1.00E+00** |

## Table E.1-9
## Vermont Yankee PSA Model 04 R1

| Release Category (Timing/Magnitude) | Release Frequency (Per year) |
|---|---|
| NCF | 6.06E-07 |
| L/LL | 0.0 |
| I/LL | 1.07E-08 |
| E/LL | 4.04E-09 |
| L/LO | 0.0 |
| I/LO | 0.0 |
| E/LO | 7.81E-08 |
| L/MED | 1.83E-08 |
| I/MED | 2.43E-09 |
| E/MED | 2.09E-06 |
| L/HI | 6.53E-07 |
| I/HI | 4.37E-09 |
| E/HI | 1.56E-06 |

<u>*Nomenclature*</u>

*Timing*

| | | |
|---|---|---|
| L | (Late) | - Greater than 24 hours |
| I | (Intermediate) | - 6 to 24 hours |
| E | (Early) | - Less than 6 hours |

*Magnitude*

| | | |
|---|---|---|
| NCF | (Little to no release) | - Less than 0.001% Cs Iodide |
| LL | (Low-Low) | - Less than 0.1% Cs Iodide |
| LO | (Low) | - 0.1 to 1% Cs Iodide |
| MED | (Medium) | - 1 to 10% Cs Iodide |
| HI | (High) | - Greater than 10% Cs Iodide |

## Table E.1-10
## Release Category Frequency Associated with Each Level 1 Core Damage Class
## Vermont Yankee PSA Model 04 R1

| Class | No Release | Early/ Lo-Lo | Inter/ Lo-Lo | Late/ Lo-Lo | Early/ Low | Inter/ Low | Late/ Low | Early/ Med | Inter/ Med | Late/ Med | Early/ High | Inter/ High | Late/ High | Total Release | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IA | 5.14E-7 | 3.22E-12 | 2.55E-9 | | | | | 3.48E-7 | 1.73E-10 | 1.11E-11 | 3.40E-7 | 6.57E-12 | 2.20E-10 | 6.91E-7 | 1.20E-6 |
| IEC | | | | | | | | | | | | | | | |
| IED | | | | | | | | 5.74E-11 | | | 5.51E-8 | | | 5.52E-8 | 5.52E-8 |
| IBE | | | | | | | | 1.39E-7 | | | 1.80E-7 | | | 3.19E-7 | 3.19E-7 |
| IBL | | | | | | | | 5.46E-7 | 2.16E-9 | | 2.86E-7 | 4.37E-9 | | 8.39E-7 | 8.39E-7 |
| IC | 9.69E-9 | | 2.19E-11 | | | | | 4.08E-9 | | | 2.15E-9 | | | 6.25E-9 | 1.59E-8 |
| ID | | 4.08E-11 | 7.94E-9 | | | | | 9.35E-7 | 7.39E-11 | 5.44E-12 | 4.87E-7 | | 1.54E-10 | 1.43E-6 | 1.43E-6 |
| IIA | | | | | | | | | | 1.65E-8 | | | 4.26E-7 | 4.43E-7 | 4.43E-7 |
| IIL | | | | | | | | | | 1.82E-9 | | | 4.64E-8 | 4.82E-8 | 4.82E-8 |
| IIV | | | | | | | | | | | 2.37E-9 | | 1.80E-7 | 1.82E-7 | 1.82E-7 |
| IIIA | 2.66E-9 | | 5.68E-12 | | | | | 5.96E-10 | 5.16E-13 | 1.11E-14 | 1.10E-9 | | 7.30E-13 | 1.70E-9 | 4.36E-9 |
| IIIB | 7.98E-8 | | 1.73E-10 | | | | | 1.97E-8 | 1.59E-11 | 1.20E-12 | 3.58E-8 | | 2.83E-11 | 5.57E-8 | 1.35E-7 |
| IIIC | | | 1.78E-11 | | | | | 4.51E-8 | 1.59E-12 | 5.42E-14 | 8.02E-8 | | 2.82E-12 | 1.25E-7 | 1.25E-7 |
| IIID | | | | | | | | | | | 6.35E-9 | | | 6.35E-9 | 6.35E-9 |
| IVA | | 3.11E-9 | | | 5.99E-8 | | | 2.78E-8 | | | 1.99E-8 | | | 1.11E-7 | 1.11E-7 |
| IVL | | 8.85E-10 | | | 1.82E-8 | | | 2.31E-8 | | | 1.04E-8 | | | 5.26E-8 | 5.26E-8 |
| V | | | | | | | | | | | 5.32E-8 | | | 5.32 E-8 | 5.32E-8 |
| **Column Total** | **6.06E-7** | **4.04E-9** | **1.07E-8** | **0.00E+0** | **7.81E-8** | **0.00E+0** | **0.00E+0** | **2.09E-6** | **2.43E-9** | **1.83E-8** | **1.56E-6** | **4.37E-9** | **6.53E-7** | **4.42E-6** | **5.03E-6** |
| Fraction | 12.07% | 0.08% | 0.21% | < 0.01% | 1.55% | < 0.01% | < 0.01% | 41.57% | 0.05% | 0.36% | 31.01% | 0.09% | 12.99% | 87.93% | 100.00% |

#### E.1.2.2.6 Release Magnitude Calculations

The MAAP computer code is used to assign both the radionuclide release magnitude and timing based on the accident progression characterization. Specifically, MAAP provides the following information:

- containment pressure and temperature versus time (time of containment failure is determined by comparing these values with the nominal containment capability);
- radionuclide release time and magnitude for a large number of radioisotopes; and
- release fractions for twelve radionuclide species.

## E.1.3 IPEEE Analysis

### E.1.3.1 Seismic Analysis

The seismic portion of the IPEEE program was completed in conjunction with the SQUG program. VYNPS performed a seismic margins assessment (SMA) following the guidance of NUREG-1407, *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*, June 1991, and EPRI NP-6041-SL, Revision 1, *A Methodology for Assessment of Nuclear Power Plant Seismic Margin*, August 1991. The SMA approach is a deterministic evaluation that does not calculate risk on a probabilistic basis. A number of plant improvements were identified in NUREG-1742 [Reference E.1-10]. These improvements were implemented, with the exception of a recommendation for upgrading the CST tank HCLPF value from 0.25g to 0.30g. However, the CST tank analysis has been reviewed and it was concluded that the tank shell stresses at the juncture with the chair rail support anchorage is the limiting feature in defining the HCLPF analysis results. Additional scoping investigation has been performed to define any modifications that can be implemented to raise the HCLPF value. No simple cost-effective enhancements have been identified that will significantly improve the HCLPF value of 0.25g. This value is significantly above the design SSE value of 0.14g. Therefore, no structural modifications to this tank will be implemented.

A number of plant improvements were identified in Tables 2.7 and 2.12 of NUREG-1742. These improvements have been implemented.

### E.1.3.2 Fire Analysis

The VYNPS internal fire risk model was performed in 1998 as part of the IPEEE submittal report [Reference E.1-8]. The VYNPS fire analysis was performed using EPRI's Fire Induced Vulnerability Evaluation (FIVE) methodology for qualitative and quantitative screening of fire areas and for fire analysis of areas that did not screen [Reference E.1-9]. The FIVE methodology is primarily a screening approach used to identify plant vulnerabilities due to fire initiating events.

Table E.1-11 presents the results of current VYNPS IPEEE fire analysis. (The values presented in Table E.1-11 are taken from NUREG-1742 [Reference E.1-10]. These values reflect the re-evaluation of the IPEEE fire CDF results [Reference E.1-8] to include response to NRC questions/issues regarding fire-modeling progression.) The significant fire scenarios involve fires occurring in the east and west switchgear rooms at elevation 248 feet, cable vault and cable vault battery room at elevation 262 feet, and control room at elevation 272 feet.

A number of plant improvements relative to Vermont Yankee were identified in Table 3.5 of NUREG-1742. These improvements were implemented.

### E.1.3.3 Other External Hazards

The Vermont Yankee IPEEE submittal [Reference E.1-8], in addition to the internal fires and seismic events, examined a number of other external hazards:

- high winds and tornadoes,
- external flooding, and
- ice, hazardous chemical transportation, and nearby facility incidents.

In consequence of the above external hazards evaluation, a number of HFO-related plant modifications have been implemented at Vermont Yankee, as identified in Table 4.1 of NUREG-1742 [Reference E.1-10].

No risks to the plant occasioned by high winds and tornadoes, external floods, ice, hazardous chemical transportation, and nearby facility incidents were identified that might lead to core damage with a predicted frequency in excess of $10^{-6}$/year. Therefore, these other external event hazards are not included in this attachment and are expected not to impact the conclusions of this SAMA evaluation.

## Table E.1-11
## Vermont Yankee Fire Updated Core Damage Frequency Results

| Building/ Area | Fire Compartment | Description | Initiator CDF (/yr) | Total Compartment CDF (/yr) |
|---|---|---|---|---|
| Reactor Building | RBNEC | Northeast ECCS Corner Room, El. 213' and 232' | 3.80E-09 | 3.80E-09 |
| | RBHP | HPCI Room, El. 213' | 9.00E-09 | 9.00E-09 |
| | RBRCL | Lower RCIC Corner Room, El. 213' at NW Corner | 6.70E-08 | 6.70E-08 |
| | RBRCU | Upper RCIC Corner Room, El. 232' at NW Corner | 4.50E-08 | 4.50E-08 |
| | RBSEC | Southeast ECCS Corner Room, El. 213' and 232' | 1.00E-08 | 1.00E-08 |
| | RBSWC1 | Southwest CRD Corner Room, El. 213' and 232' (treated as part of RB4) | See RB4 | See RB4 |
| | RB1 | Torus Room, El. 213', Zone RB1 (north) | 1.30E-07 | 1.30E-07 |
| | RB2 | Torus Room, El. 213', Zone RB2 (south) | 7.40E-07 | 7.40E-07 |
| | RB3 | Reactor Building, El. 252', Zone RB3 (north), self-ignited cable fire<br>Reactor Building, El. 252', Zone RB3 (north), in-situ MCC fire<br>Reactor Building, El. 252', Zone RB3 (north), transient lube oil spill<br>Reactor Building, El. 252', Zone RB3 (north), transient/in-situ Class A trash fire | | 5.10E-06 |
| | RB4 | Reactor Building, El. 252', Zone RB4 (south), self-ignited cable fire<br>Reactor Building, El. 252', Zone RB4 (south), CRD Repair Room fire<br>Reactor Building, El. 252', Zone RB4 (south), in-situ MCC fire<br>Reactor Building, El. 252', Zone RB4 (south), transient lube oil spill<br>Reactor Building, El. 252', Zone RB4 (south), transient/in-situ Class A trash fire | | 3.30E-06 |

## Table E.1-11
## Vermont Yankee Fire Updated Core Damage Frequency Results
## (Continued)

| Building/ Area | Fire Compartment | Description | Initiator CDF (/yr) | Total Compartment CDF (/yr) |
|---|---|---|---|---|
| Reactor Building | RBMG | Reactor Building, El. 280', Recirc. MG Set fire | 3.40E-07 | 3.40E-07 |
| | RB5 | Reactor Building, El. 280', Zone RB5 (north) | 7.30E-07 | 7.30E-07 |
| | RB6 | Reactor Building, El. 280', Zone RB6 (south) | 3.50E-07 | 3.50E-07 |
| | RB303 | Reactor Building, El. 303' | 4.90E-07 | 4.90E-07 |
| | RB318 | Reactor Building, El. 318' | 1.90E-08 | 1.90E-08 |
| | RB345 | Reactor Building, El. 345' | 1.50E-09 | 1.50E-09 |
| | RBSZ-S1 | Reactor Building, El. 252', Separation Zone Div. S1 trays | 6.50E-07 | 6.50E-07 |
| | RBSZ-S2 | Reactor Building, El. 252', Separation Zone Div. S2 trays | 6.50E-07 | 6.50E-07 |

## Table E.1-11
## Vermont Yankee Fire Updated Core Damage Frequency Results
## (Continued)

| Building/ Area | Fire Compartment | Description | Initiator CDF (/yr) | Total Compartment CDF (/yr) |
|---|---|---|---|---|
| Control Building | SGW | West Switchgear Room at El. 248', Bus 1/8 Fire | | 9.00E-06 |
| | | West Switchgear Room at El. 248', Bus 3 Fire | | |
| | | West Switchgear Room at El. 248', T-8 Transformer Fire | | |
| | SGE | East Switchgear Room at El. 248', Bus 2/9 Fire | | 7.00E-06 |
| | | East Switchgear Room at El. 248', Bus 4 Fire | | |
| | | West Switchgear Room at El. 248', T-9 Transformer Fire | | |
| | CV | Cable Vault, El. 262', Division S1 Panel Fire Affecting Division S2 Cable Trays | | 1.50E-05 |
| | | Cable Vault, El. 262', Division S2 Panel Fire Affecting Division S1 Cable Trays | | |
| | | Cable Vault, El. 262', Self-ignited Cable Fire | | |
| | | Cable Vault Battery Room, El. 262' | 3.20E-06 | 3.20E-06 |
| | | Control Room, El. 272' | 5.70E-06 | 5.70E-06 |
| Turbine Building | DGA | Emergency Diesel Generator Room A | 4.50E-07 | 4.50E-07 |
| | DGB | Emergency Diesel Generator Room B | 4.60E-07 | 4.60E-07 |
| | TURB | Turbine Building, All General Areas | 1.10E-06 | 1.10E-06 |
| | WMACH | Machine Shop and Stores Warehouse - South Turbine Building | See TURB | |
| Intake and Discharge Structure | INTCW | Circulating Water Pump Room Fire - Intake Structure | 1.60E-09 | 1.60E-09 |
| | INTSW | Service Water Pump Room Fire - Intake Structure | 3.10E-07 | 3.10E-07 |
| | DISCH | Discharge Structure Fire | 9.40E-10 | 9.40E-10 |

## Table E.1-11
## Vermont Yankee Fire Updated Core Damage Frequency Results
## (Continued)

| Building/ Area | Fire Compartment | Description | Initiator CDF (/yr) | Total Compartment CDF (/yr) |
|---|---|---|---|---|
| Radwaste | RADW | FRADW Radwaste Building Fire | See RWC | See RWC |
| | RWC | FRWC Radwaste Corridor Fire | 5.20E-08 | 5.20E-08 |
| Misc. Structures | AOG | Advanced Off Gas Building Fire | 1.40E-07 | 1.40E-07 |
| | DGOP | EDG Fuel Oil Storage Tank and Transfer Pump House Fire | 1.20E-08 | 1.20E-08 |
| | FOB | Office Building - North End of Turbine Building | See TURB | |
| | RHOUSE | Relay and Metering House - 345 kV Switchyard | 4.00E-07 | 4.00E-07 |
| | MTFRM | Main/Aux. Transformer Fire W/Propagation to Turbine Building | 6.80E-08 | 6.80E-08 |
| | STFRM | Startup Transformer Fire W/Propagation to Turbine Building | 2.80E-07 | 2.80E-07 |

### E.1.4 PSA Model Peer Review

In September 2000, the VYNPS PSA model was peer reviewed by the NEI/BWROG Peer Review Certification team. The peer review team published the final report in November 2000. The Peer Review Certification identified the following strengths and areas of improvements for the VYNPS PSA model:

- Containment Capability: The Vermont Yankee containment failure analysis represents a state of the art analysis of the containment strength and failure probability. The analysis was supported by a detailed plant specific analysis developed by Chicago Bridge and Iron. The documentation was detailed, traceable and available for review.

- Interfacing System LOCA: A realistic plant specific evaluation of the interfacing system LOCA frequency was prepared. The model was well documented and provided a systematic process identification and evaluation of potential containment bypass paths.

- Maintenance Unavailability and Failure Rate Analysis: The maintenance unavailability incorporated in the PRA was based on an excellent review and analysis of plant-specific data. Plant component failure date had also been recently evaluated at the time of the review.

- Tier 2 System Analysis Documentation: Vermont Yankee has maintained Tier 2 notebooks for the system analyses containing extensive background material. This information source proved useful to the reviewers and is a valuable resource for the PRA staff.

- System Dependencies: Although there was no single system dependency matrix, the system dependencies were clearly presented for each system in the system analysis notebook.

- Human Reliability Analysis: The Vermont Yankee PRA included a comprehensive treatment of human reliability. This included extensive incorporation of pre-initiator actions for post-initiators.

- Spatial Dependencies: Internal flooding and HVAC dependencies were systematically evaluated and documented. Plant-specific analyses supporting the models and modeling assumptions were provided.

- Level 2 Analysis: The Level 1/Level 2 interface, including the plant damage state and containment event tree end state definitions, was very detailed. The full spectrum of severe accident phenomena listed in the ASME PRA Draft Standard was considered in the Level 2 evaluation.

Maintenance and Update Process: VYNPS follows the standardized practice guidance for documentation of PSA model elements developed by Entergy Nuclear Northeast to maintain the PSA model.

### E.1.4.1 Recommended Areas of Improvement

The Peer Review Certification identified the following areas of improvement for the VYNPS PRA.

- PRA Guidance

  The lack of guidance documents was cited as a weakness for most of the technical elements examined as part of this review. In some areas (e.g., elements SY, HR, L2 and AS), the documentation has sufficient detail to provide a certain level of guidance. But the reviewers agreed that the development of guidance documents, if followed and maintained, can be an important element in maintaining the quality of the PRA.

  Resolution

  Entergy Nuclear Northeast has developed and utilized standardized practice guidance for documentation of PSA model elements, which will be used in planned future updates of the VYNPS PSA model.

- Dependence of Human Actions

  There did not seem to be any systematic check to insure that where multiple human actions are included in a scenario, the potential dependence between these actions had been considered. One significant scenario containing potential dependence between human actions (the third highest in core damage frequency) was identified by the reviewers (see Fact and Observation sheet QU-6). A sensitivity quantification (e.g., set all human actions to 0.1) is commonly performed as part of the PRA quantification process to confirm that the CDF frequency is not being understated by treating multiple human failure probabilities as independent events.

  Resolution

  Dependencies among human actions were examined and documented in "Vermont Yankee Dependent HEP Assessment." All of the dynamic operator actions modeled in the VYNPS PRA were included in this assessment. The approach used to judge the level of dependence among operator actions was based on dependency level categories and conditional probabilities developed in NUREG/CR-1278, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*. NUREG/CR-1278 identifies five levels of dependence: ZD (zero dependence), LD (low dependence), MD (moderate dependence), HD (high dependence), and CD (complete dependence). Based on NUREG/CR-1278, time, function, and spatial attributes were used to determine the level of dependence among operator actions within an accident sequence.

These attributes were used to develop qualitative criteria (rules) that were used to assign the level of dependence (CD, HD, MD, LD, ZD) among the operator actions. Quantitative values associated with the level of dependence were assigned and used in a quantitative sensitivity assessment.

These updated dependencies resulted in an increase in CDF of 0.61%, compared to the base model. Based on the 5E-07 threshold it can be concluded that this negligible change did not justify the need for a permanent model change.

- Independent Review Process

  There is little documentation of any independent review associated with most documents. A documented process calling for a review by a qualified, independent analyst should be added to the PRA maintenance procedure. This would improve the quality of the PRA.

  Resolution

  The PRA update procedure calls for the undertaking and documentation of an independent review of modeling changes and evaluations. This has been implemented for all PRA updates.

- Generic Initiating Event Data

  The generic sources of LOCA and loss of offsite power frequencies referenced in the PRA are outdated. More recent data is available in NUREG/CR-5750 (LOCAs) and NUREG/CR-5496 (LOSP) and should be incorporated during the next PRA update.

  Resolution

  Initiating event frequencies were reviewed and updated as documented in 2002 [Reference E.1-11] as well as in 2004 [Reference E.1-12].

- Success Criteria Traceability

  Documentation of the accident sequence model success criteria and their bases should be improved. There are notebooks containing some of the necessary documentation, although no clear roadmap is provided linking MAAP calculations and other supporting analyses to the accident sequence model.

  Resolution

  In 2002 the PSA success criteria were reviewed and documented, definitions clarified and references identified.

- System Modeling

  The system models were graded as capable of supporting risk significant evaluations, but the review team had difficulty reaching consensus on this grade as there were a number of areas identified that should be improved to make the models more flexible and easier to use for applications. The Vermont Yankee PRA uses a number of modeling simplifications that reduce the capabilities of the RISKMAN program to produce potentially insightful reports (e.g., basic event importance, system importance). For example, taking advantage of model symmetries reduces the number of split fractions that need to be quantified and simplifies the event tree input, but skews the basic event importance results (see F&O Sys-14). Also, there is an optional conditional split fraction replacement logic input that allows the software to associate the correct basic event importance (for a class of scenarios) that has not been developed in the Vermont Yankee model (see F&O Sys-13). These modeling simplifications had distinct advantages when PRA software and personal computers were less powerful but should be removed to take advantage of all the reporting features.

  Resolution

  Symmetric split fractions have been developed for all multi-train top events as part the 2004 EPU RISKMAN model (VY04R1).

- Common Cause Parameters

  Common cause failures are modeled extensively and appropriately in the PRA, but the data source for the common cause failure parameters is outdated. New data available through the NRC and INEEL need to be incorporated in the PRA as part of the next update. This is critical due to the importance of common cause failures with respect to CDF.

  Resolution

  As part of the PSA 2002 update, a review of the Common Cause Failure (CCF) parameters presented in NUREG-5497 was performed and the results compared with the values used in the VYNPS PSA model. It was concluded that the values utilized in the Vermont Yankee PSA model remain appropriate and there is not a strong basis for replacing our current common cause factors with those provided in NUREG-5497 at this time.

- Presentation and Interpretation of Results

  The presentation of PRA results should be expanded to assist in developing insights. Additional reports could be generated with the current model (e.g., initiator contribution to CDF), and the model should be requantified with the "save sequence cutoff" reduced to include a higher percentage of total CDF in the split fraction and top event importance reports. It is also suggested that the LERF results be requantified as part of the PRA update.

Resolution

The cutoff values for importance calculations have been reduced from the original IPE. LERF results are included in all major PSA model updates.

- Uncertainty Analysis

  No data uncertainty analysis has been performed for the current Vermont Yankee PRA. A documented analysis in this area may provide additional insights into the PRA results. It is again noted that the current structure of the model makes the uncertainty calculation engine of the RISKMAN PRA software ineffective. Many of the basic event failure rates loaded into the program are point estimates. The model simplifications identified in F&Os SY-13 (CSF replacement) and SY-14 (symmetry) also need to be addressed before the RISKMAN uncertainty engine can be used effectively.

  Resolution

  F&Os SY-13 and SY-14 were resolved and implemented in models VY00 and VY04, respectively. The uncertainty associated with the core damage frequency was estimated using Monte Carlo techniques implemented in RISKMAN for the base case model VY04R1. Results include mean, 5th, 50th, and 95th percentile values. These values reflect the uncertainties associated with the data distributions used in the analysis.

- Maintenance and Update Process

  The PRA update procedure was in a draft form at the time of the review. As mentioned under "PRA Strengths," it is the opinion of the review team that the Vermont Yankee PRA staff is headed in the right direction with this procedure. It is mentioned here to emphasize the importance of addressing the review comments and finalizing this procedure in the near future.

  Resolution

  The VYNPS PSA update procedure was completed and was utilized for the VY 2002 PRA update and subsequent updates. This procedure has since been replaced by Entergy fleet procedure ENN-DC-151, PSA Maintenance and Update.

### E.1.4.2 Major Changes since Original IPE Submittal

The following major changes have been incorporated in the Vermont Yankee PSA model since the original IPE submittal.

- Updated IE frequencies

  Initiating event frequencies were reviewed and updated as documented in 2002 [Reference E.1-11] as well as in 2004 [Reference E.1-12].

- Updated HEP values

  HEP values were updated to reflect EOP and SAMG revisions, plant modifications and extended power uprate.

- Revised flooding events modeling

  Significant changes were made to the modeling of flooding events to reflect enhancements to operating procedures and evaluation of component vulnerability to flooding.

- Main station battery chargers

  A plant upgrade was made to the main station battery chargers to provide 100% redundancy and improve reliability for the 125 VDC main station batteries and DC buses DC-1 and DC-2.

  This upgrade consisted of the following:

  - Adding a new 125 VDC charger, designated BC-1-1D, dedicated to 125 VDC bus DC-2. This charger will be identical to the existing chargers, except for some small electronics parts on circuit cards.

  - Dedication of the existing battery charger BC-1-1C, formerly called the ‘swing charger’, to 125 VDC bus DC-1.

  - All four battery chargers are modeled. If either, or both, aligned battery chargers fail, its corresponding backup charger is questioned. It is conservatively assumed that operator failure to align one backup charger will also guarantee failure to align the other backup charger.

  - Removal of the load shed feature from each of the 480 VAC feeder breakers to the three existing battery chargers. Consistent with this modification, there will be no load shed feature on the feeder breaker to the new battery charger. Removal of the load shed feature eliminates the need for plant operators to restore the battery chargers following a loss of normal power event. This results in the elimination of LNP specific split fractions for C1C2.

(The original IPE model took no credit for alignment of the swing charger (BC-1-1C) following failure of one of the two normally aligned battery chargers.)

- Revised modeling of the recirculation loop discharge valves MOVs 53A/53B for LPCI injection (1998)

  Depending on the postulated break size and location (particularly a large, suction side break), LPCI flow to the intact loop could bypass the core by flowing through the RPV lower plenum and out the break if the intact loop discharge valve is not closed. Thus, failure to close the intact recirculation loop discharge valve could be a LPCI subsystem failure mode for some events and is now considered in the model.

- Modification to OS rules to better reflect operating procedures

  Automatic isolation of non-essential SW loads was implemented to satisfy conservative design basis criteria. Based on our review, this modification has little effect on the "best estimate" IPE analysis which is not limited to design basis.

  Service water valves SW-20, SW-19A and SW-19B were modified to automatically close when SW header pressure (as measured in the ECCS corner rooms) decreases below 50 psig for greater than 27 seconds. Sustained low SW header pressure is indicative of a loss of normal power event (LNP) which causes all operating SW pumps to stop and only two SW pumps to automatically restart. When postulating conservative design basis assumptions of single active pump failure and no credit for operator action, only one operating pump may be subject to damage from run-out flow, and flow to critical components (EDGs) may be deficient. Automatic isolation of non-essential cooling loads will quickly increase the SW system flow resistance, limit pump run-out, and allow time for operators to manually start other pumps if needed. The original plant design required control room operators to manually isolate the non-essential loads if a loss of normal power (LNP) event occurred.

- Revised split fraction values

  The PRA models many multi-train systems as single top event. The original IPE often used the same split fraction to model a top event where one train was degraded or failed due to support system failures. This provided accurate CDF values but did not always accurately reflect the risk importance of specific components or trains. An update to the PRA model was performed to create train-specific split fractions for all top events.

- Updated generic failure rate data for selected components

  The failure rates of selected components for which generic failure rates were applied were updated to reflect more recent industry data. In the LPCI ISLOCA (Interfacing System LOCA) analysis, the probability for the LPCI check valve LCV-46A leakage failure was inadvertently doubled. The correct failure probability for LCV-46A is 7.45E-04/yr, (IPE Section 3.2.36) but the value used in the model was 1.48E-03/yr.

Using the correct check valve failure probability, the frequency of the LCPI ISLOCA initiating event was reduced by approximately 30%. The total annual ISLOCA frequency (for LPCI, CS, and SDC) changed from 2.29E-07/yr to 1.71E-07/yr, a reduction of 25%. There were no other model changes required to correct this error.

- ARI/RPT instrumentation

  New ARI/RPT instrumentation was installed to satisfy the ATWS rule equipment diversity requirements. The diverse equipment installed by this EDCR included new reactor level and reactor pressure transmitters, alarm relay modules and relays and modification of two existing water level transmitter loops. The intent of the design upgrade is to diversify the ATWS mitigation equipment (ARI/RPT) from reactor protection system (RPS) equipment so as to reduce the likelihood of common mode failures between both systems.

- Revised feedwater/condensate (FWCN) system

  The original feedwater/condensate model conservatively credited only the feedwater low flow valve as an injection path for power levels below 10 percent power, when in fact success could also be achieved through either of the main feedwater control valves. A modification was made to the FWCN model to credit either of the main feedwater regulation valves, in addition to the low flow valve, for power levels below 10 percent power.

- Modeled plant modification - 24VDC ECCS system

  The following modifications were made to the 24V DC ECCS system.

  - The 24V ECCS batteries were removed.

  - The 24V DC battery chargers were replaced with 24V DC converters.

- Modeled plant modification - containment $N_2$ system

  A seismically designed backup system has been installed consisting of two high-pressure $N_2$ cylinders regulated to feed the SRV accumulators when normal $N_2$ system pressure degrades. This modification was added to the $N_2$ systems model.

- Improved service water recovery model

  Changes were made to the AW top event fault tree to include an improved SW recovery model, in place of the estimated recovery factor that was being used. The recovery model reflects operator response to a variety of system failure modes. The SW recovery model was based upon the Vermont Yankee LOSW initiating event fault tree analysis.

- Updated RPS fault tree model

  The VYNPS 2004 PSA model update incorporated an update of the scram failure probabilities using NUREG/CR-5500, Vol.3, *Reliability Study: General Electric Reactor Protection System, 1984-1995*, May 1999. This report documents an analysis of the safety-related performance of the reactor protection system (RPS) at U.S. General Electric commercial reactors during the period 1984 through 1995. The General Electric RPS designs covered in the unavailability estimation included those with relay-based trip systems. The fault tree developed for this design assumed a BWR/4 plant, virtually identical to that used at VYNPS.

- Modeled effects associated with extended power uprate (EPU)

  The EPU caused three model changes.

  - Thermal hydraulic calculations using the MAAP computer code at the proposed increased power level indicated that the number of times an SRV would be expected to cycle open/closed would increase by approximately 15%. This increased cycling would increase the probability that an SRV would fail to re-close. Therefore, the stuck-open relief valve probabilities given a transient initiator for the individual SRVs was increased a similar amount.

  - VYNPS installed a spring safety valve (SSV) to provide additional overpressure capacity to satisfy ASME code requirements at the proposed increased power level. Top event fault trees SO (i.e., "Safety/Relief Valves Fail to Open") and PR (i.e., "Pressure Relief System - ATWS Mitigation") were revised to include the addition of this new valve.

  - Human error probabilities (HEPs) were revised because a higher power level results in reduced times available for some actions. To quantify the potential impact of this performance shaping factor change, thermal hydraulic calculations were used to re-quantify a number of the HEPs used in the Vermont Yankee PSA model.

## E.1.5 The MACCS2 Model – Level 3 Analysis

### E.1.5.1 Introduction

SAMA evaluation relies on Level 3 PRA results to measure the effects of potential plant modifications. A Level 3 PRA model using the MELCOR Accident Consequences Code System Version 2 (MACCS2) [Reference E.1-13] was created for VYNPS. This model, which requires detailed site-specific meteorological, population and economic data, estimates the consequences in terms of population dose and offsite economic cost. Risks in terms of population dose risk (PDR) and offsite economic cost risk (OECR) were also estimated in this analysis. Risk is defined as the product of consequence and frequency of an accidental release.

For postulated internal events, this analysis considers a base case and two sensitivity cases to account for variations in data and assumptions. The base case uses estimated time and speed for evacuation. Sensitivity case 1 is the base case with delayed evacuation. Sensitivity case 2 is the base case with lower evacuation speed.

PDR was estimated by summing over all releases the product of population dose and frequency for each accidental release. Similarly, OECR was estimated by summing over all releases the product of offsite economic cost and frequency for each accidental release. Offsite economic cost includes costs that could be incurred during the emergency response phase and costs that could be incurred through long-term protective actions.

### E.1.5.2 Input

The following sections describe the site-specific input parameters used to obtain the off-site dose and economic impacts for cost-benefit analyses.

#### E.1.5.2.1 Projected Total Population by Spatial Element

The total population within a 50-mile radius of VYNPS was estimated for the year 2032, the end of the proposed license renewal period, for each spatial element by combining transient (tourist) population data with total resident population projections obtained from Massachusetts, New Hampshire, New York, and Vermont. All projections were based on 2000 census data.

To determine the number of transient individuals, each state agency with authority over tourism was contacted (Table E.1-12). The four states provided different types of tourism data, and different methods were used to estimate transient populations.

## Table E.1-12
## State Tourism Offices

| State | Office | Data Year | Reporting Regions |
|---|---|---|---|
| Massachusetts | Massachusetts Office of Travel and Tourism | 2000 | Six geographic regions |
| New Hampshire | New Hampshire Division of Travel and Tourism Development | 2002 | Seven geographic regions |
| New York | New York State Department of Economic Development | 2002 | Entire state |
| Vermont | Vermont Department of Tourism and Marketing | 2001 | Twelve geographic regions |

Massachusetts tourism regions are based on towns. The appropriate data layer was downloaded from Massachusetts Geographic Information System (GIS) and reclassified to tourism regions. No GIS ready base map was available for the New Hampshire tourism regions. To assemble a map layer for New Hampshire, detailed locator maps were geo-referenced and tourism regions were digitized on-screen. Only state level data existed for New York and the state base map was used. Vermont tourism regions are based on Vermont Regional Planning Commission boundaries and the appropriate map layer was downloaded from Vermont Center for Geographic Information and reclassified to tourism regions.

To determine the resident projections, each state agency responsible for population projections was contacted (Table E.1-13). Because no reporting entity projected populations to the target year of 2032, least square regression approximation was used to project the resident population for all counties within a 50-mile radius of VYNPS.

The total county level population values were estimated by summing the projected resident and transient population with an assumption that the transient/resident population ratio remains constant through 2032.

**Table E.1-13**
**State Population Projection Offices**

| State | Office | Years Projections Based on | Final Year Projected |
|---|---|---|---|
| Massachusetts | Massachusetts Institute for Social and Economic Research | 1980-2000 | 2020 |
| New Hampshire | Office of State Planning | 1960-2000 | 2025 |
| New York | New York Statistical Information System | 1990-2000 | 2030 |
| Vermont | Department of Aging & Disabilities | 1990-2000 | 2020 |

The estimated 2032 total population was then interpolated to target areas (spatial elements) by weighting each variable by the area it covers. The distribution of projected 2032 total population within the 240 spatial elements is illustrated in Figure E.1-3.

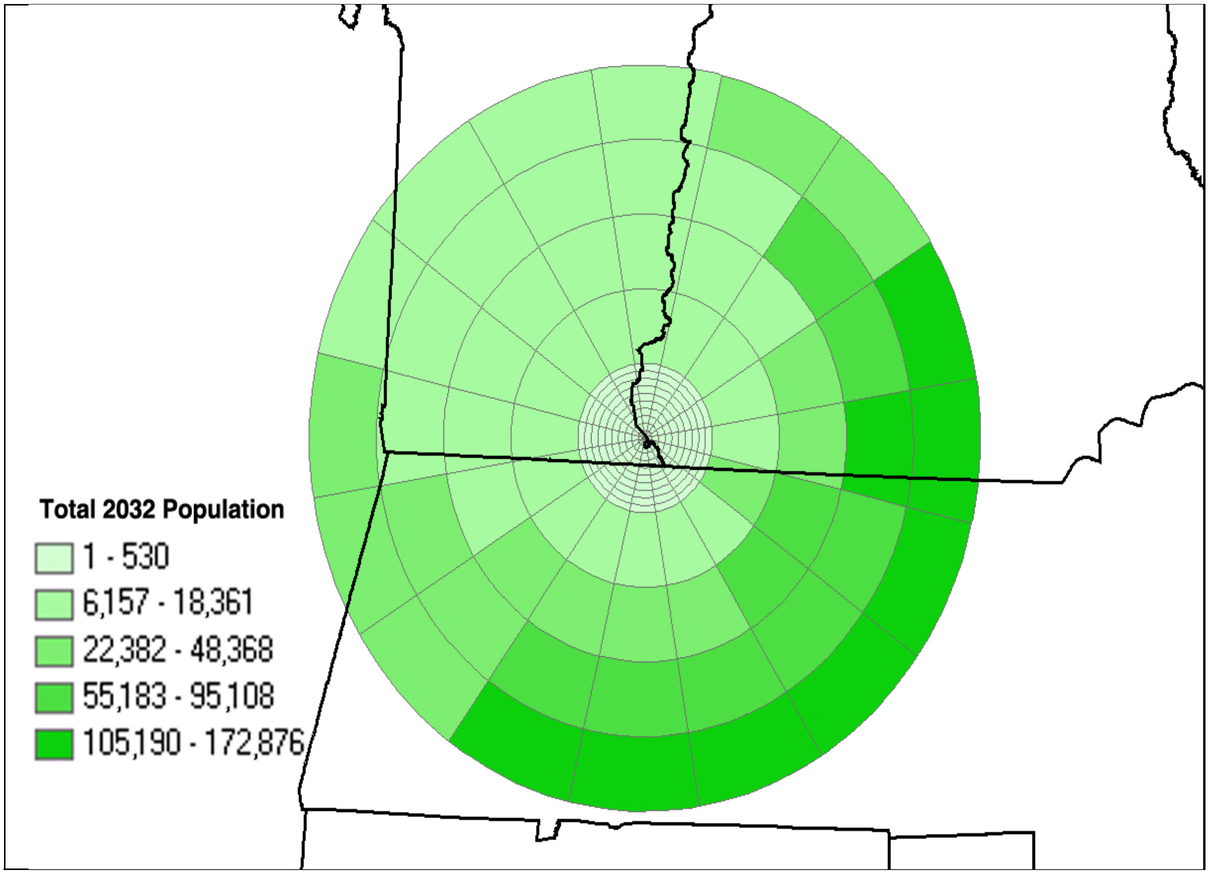

**Figure E.1-3**
**Projected 2032 Total Population within 50 Miles of VYNPS**

### E.1.5.2.2 Land Fraction

Census 2000 TIGER/Line Water Bodies data [Reference E.1-14] for the four states and seventeen counties within the 50-mile radius were used to calculate the extent of land and surface water coverage. The land fraction value for each spatial element equals 1 (area of spatial element in water / total area of spatial element). Calculated values ranged from 0.01 to 1.00. A value of 1.00 indicates the spatial element area is all land, with no significant surface water.

### E.1.5.2.3 Watershed Class

Watershed classes are defined as either land (Class 1) or water (Class 2). As noted in Section E.1.5.2.2, all spatial elements have non-zero land fraction values, showing that none of them are composed solely of surface water. Therefore, there is only one watershed type (Class 1 - land) in the 50-mile area around VYNPS, so all 240 spatial elements were assigned the watershed class value of 1.

### E.1.5.2.4 Regional Economic Data

County level economic data were obtained from the US Department of Agriculture. The Census of Agriculture is conducted every five years and data from 1997, 1992, and 1987 were used to extrapolate 2002 using least squares regression.

#### *Region Index*

Each spatial element was assigned to an economic region, defined in this report as a county. Where a spatial element is comprised of more than one county, it is assigned to the county that has the most area in that element.

#### *FRMFRC – Fraction of Land Devoted to Farming (Table E.1-14)*

*Approximate land area, proportion in farms (percent)* was downloaded directly from the Census of Agriculture CD-ROM for each county. Because1987 data was not available, only 1992 and 1997 data were used to extrapolate to 2002.

#### *ASFP – Total Annual Farm Sales (Table E.1-14)*

*Land in farms (acres)* was downloaded from the Census of Agriculture CD-ROM for each county and converted to hectares. *Market value of agricultural products sold ($1,000)* was downloaded from the CD-ROM for each county, multiplied by 1000, and divided by *Land in farms* (in hectares) to obtain ASFP (dollars/hectare).

#### *DPF – Fraction Of Farm Sales Resulting From Dairy Production (Table E.1-14)*

*Dairy products sold ($1,000)* was downloaded from the Census of Agriculture CD-ROM for each county and divided by *Market value of agricultural products sold ($1,000)*. In two cases (1997

Hampden County, Massachusetts, and 1992 Franklin County, Massachusetts), privacy issues precluded reporting values for *Dairy products sold ($1,000)*. In each of these instances, values were estimated by the following method: first, the total reported value of *Dairy products sold* for the state of Massachusetts was downloaded ($59,773,000 in 1997 and $60,430,000 in 1992); second, the values of *Dairy products sold* for all Massachusetts reporting counties in that year were summed ($57,597,000 in 1997 and $60,305,000 in 1992); third, the difference ($2,176,000 in 1997 and $125,000 in 1992) was distributed to all counties not reporting based on the proportion of reported dairy farms in each county.

*VFRM – Farmland Property Value (Table E.1-14)*

*Estimated market value of land and buildings: average per acre (dollars)* was downloaded directly from the Census of Agriculture CD-ROM for each county and converted to dollars/ hectare.

## Table E.1-14
## Regional Economic Data for Counties within 50 Miles of VYNPS

| County | FRMFRC | | | ASFP (dollars/hectare) | | | | DPF | | | | VFRM (dollars/hectare) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 1997 | 2002 | 1987 | 1992 | 1997 | 2002 | 1987 | 1992 | 1997 | 2002 | 1987 | 1992 | 1997 | 2002 |
| *Massachusetts* | | | | | | | | | | | | | | | |
| Berkshire | 10% | 11% | **12%** | 613 | 728 | 815 | **921** | 52% | 54% | 46% | **45%** | 4,964 | 8,216 | 7,784 | **9,808** |
| Franklin | 17% | 17% | **17%** | 733 | 996 | 1,339 | **1,628** | 45% | 41% | 30% | **24%** | 5,165 | 6,427 | 5,632 | **6,208** |
| Hampden | 10% | 10% | **10%** | 1,007 | 1,249 | 1,922 | **2,308** | 21% | 19% | 12% | **8%** | 7,213 | 8,093 | 11,409 | **13,101** |
| Hampshire | 16% | 15% | **14%** | 1,054 | 1,146 | 1,685 | **1,926** | 34% | 29% | 20% | **14%** | 6,427 | 9,516 | 9,536 | **11,602** |
| Middlesex | 6% | 6% | **6%** | 3,183 | 3,512 | 4,631 | **5,224** | 6% | 6% | 4% | **3%** | 12,256 | 18,896 | 24,122 | **30,291** |
| Worcester | 12% | 11% | **10%** | 996 | 1,068 | 1,385 | **1,538** | 30% | 29% | 22% | **19%** | 9,294 | 8,933 | 10,467 | **10,738** |
| *New Hampshire* | | | | | | | | | | | | | | | |
| Cheshire | 8% | 9% | **10%** | 1,211 | 1,342 | 1,634 | **1,818** | 29% | 29% | 24% | **22%** | 6,494 | 6,247 | 5,520 | **5,113** |
| Hillsborough | 7% | 7% | **7%** | 875 | 939 | 1,069 | **1,155** | 29% | 29% | 20% | **17%** | 8,967 | 10,885 | 8,582 | **9,093** |
| Merrimack | 8% | 11% | **14%** | 569 | 936 | 1,139 | **1,452** | 37% | 38% | 24% | **19%** | 4,947 | 5,827 | 5,837 | **6,426** |
| Sullivan | 11% | 14% | **17%** | 529 | 822 | 948 | **1,186** | 67% | 45% | 32% | **13%** | 4,008 | 4,287 | 4,940 | **5,343** |
| *New York* | | | | | | | | | | | | | | | |
| Columbia | 28% | 28% | **28%** | 1,027 | 1,228 | 1,563 | **1,809** | 41% | 39% | 37% | **35%** | 6,541 | 7,085 | 6,390 | **6,521** |
| Rensselaer | 22% | 24% | **26%** | 613 | 702 | 717 | **781** | 63% | 58% | 57% | **53%** | 3,252 | 3,815 | 4,480 | **5,077** |
| Washington | 39% | 37% | **35%** | 751 | 975 | 983 | **1,134** | 79% | 72% | 74% | **70%** | 2,486 | 2,936 | 3,049 | **3,387** |

## Table E.1-14
## Regional Economic Data for Counties within 50 Miles of VYNPS
## (Continued)

| County | FRMFRC | | | ASFP (dollars/hectare) | | | | DPF | | | | VFRM (dollars/hectare) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1992** | **1997** | **2002** | **1987** | **1992** | **1997** | **2002** | **1987** | **1992** | **1997** | **2002** | **1987** | **1992** | **1997** | **2002** |
| *Vermont* | | | | | | | | | | | | | | | |
| Bennington | 8% | 8% | **8%** | 502 | 490 | 617 | **652** | 62% | 65% | 59% | **59%** | 3,205 | 4,221 | 4,529 | **5,309** |
| Rutland | 22% | 21% | **20%** | 464 | 509 | 557 | **603** | 79% | 77% | 74% | **71%** | 2,921 | 3,314 | 3,158 | **3,368** |
| Windham | 9% | 9% | **9%** | 622 | 791 | 1,075 | **1,282** | 61% | 56% | 46% | **40%** | 4,218 | 4,917 | 5,379 | **6,000** |
| Windsor | 14% | 15% | **16%** | 344 | 358 | 544 | **615** | 68% | 58% | 36% | **21%** | 4,008 | 4,485 | 5,184 | **5,735** |

Values in bold extrapolated using least squares regression.

*VNFRM – Non-Farm Property Value*

To determine VNFRM, each state agency with authority over taxation was contacted (Table E.1-15) and a 2002 equalized valuation for each county was obtained. Within each state, equalized fair market values were used to account for inherent variation in locally derived assessment levels. However, no equalization across states was performed. Additionally, while New York has a state agency responsible for property taxation (Office of Real Property Services) this agency only reported *equalization rates*, not assessed market value. Each New York county individually holds assessed market values, thus equalized market values for New York counties were calculated by multiplying the assessed market value by the equalization rate which was obtained from the New York Office of Real Property Services. Equalization rates were 99.72 for Columbia County, 41.45 for Rensselaer County, and 85.95 for Washington County. *Farmland market values* were downloaded directly from the Census of Agriculture CD-ROM for each county and extrapolated to 2002 using least squares regression on data from 1997, 1992, and 1987. VNFRM (Table E.1-16) is the equalized value minus farmland market value, divided by the population.

**Table E.1-15**
**State and County Offices Contacted for Property Tax Information**

| State | Office |
|---|---|
| Massachusetts | Department of Revenue - Division of Local Services |
| New Hampshire | Department of Revenue Administration |
| New York | Office of Real Property Services |
| Columbia | Columbia County Real Property Tax Service Agency |
| Rensselaer | Rensselaer County Bureau of Tax |
| Washington | Washington County Real Property Services |
| Vermont | Department of Taxes - Division of Property Valuation and Review |

## Table E.1-16
## 2002 Non-Farm Property Value (VNFRM) for the VYNPS 50-Mile Area

| County | Equalization Value (dollars) | Farmland Market Value (dollars) | Population | VNFRM (dollars/ person) |
|---|---|---|---|---|
| *Massachusetts* | | | | |
| Berkshire | 10,128,705,700 | 259,731,000 | 125,984 | 78,335 |
| Franklin | 5,324,642,100 | 143,333,000 | 72,630 | 71,338 |
| Hampden | 22,241,884,700 | 177,993,000 | 454,321 | 48,565 |
| Hampshire | 8,719,157,400 | 54,931,000 | 158,108 | 54,167 |
| Middlesex | 177,029,532,800 | 319,118,000 | 1,467,201 | 120,440 |
| Worcester | 49,986,317,100 | 339,680,000 | 798,563 | 62,170 |
| *New Hampshire* | | | | |
| Cheshire | 4,751,674,409 | 113,754,000 | 75,025 | 61,818 |
| Hillsborough | 31,402,845,100 | 152,054,000 | 392,844 | 79,550 |
| Merrimack | 10,951,143,111 | 165,530,000 | 140,122 | 76,973 |
| Sullivan | 2,833,432,669 | 115,613,000 | 41,075 | 66,167 |
| *New York* | | | | |
| Columbia | 5,019,609,652 | 291,141,000 | 63,345 | 74,646 |
| Rensselaer | 5,959,712,490 | 239,393,000 | 152,219 | 37,580 |
| Washington | 3,141,437,197 | 227,897,000 | 61,640 | 47,267 |
| *Vermont* | | | | |
| Bennington | 3,375,796,622 | 48,967,000 | 37,124 | 89,614 |
| Rutland | 4,201,027,749 | 142,922,000 | 63,617 | 63,790 |
| Windham | 4,229,687,483 | 102,626,000 | 44,578 | 92,581 |
| Windsor | 5,275,153,879 | 196,634,000 | 57,731 | 87,969 |

*VALWF - Value of Farm Wealth*

MACCS2 requires only an average value of farm wealth (dollars/hectare) for the 50-mile radius area. This value is *Estimated market value of land and buildings ($1000)* plus *Estimated market value all machinery and equipment ($1000)* divided by *Land in Farms (acres)* converted to hectares (all values from Census of Agriculture CD-ROM extrapolated to 2002) and weighted by the area each county has in the VYNPS 50-mile radius area VALWF is $9,550.39/hectare.

*FRFIM - Fraction of Farm Wealth due to Improvements*

MACCS2 requires an average fraction of farm wealth due to improvements (roads, buildings, ponds, etc.). Census of Agriculture *Estimated market value of land and buildings ($1000)* could not be used because the value of land and buildings could not be separated. Thus the MACCS2 default value of 0.25 was assumed.

*VALWNF- Value of Non-Farm Wealth*

MACCS2 input requires an average value of non-farm wealth. This value is VNFRM for each county (Table E.1-16), weighted by the area of each county in the VYNPS 50-mile radius. VALWNF is $72,098.28/person.

*FRNFIM - Fraction of Non-Farm Wealth due to Improvements*

MACCS2 requires an average value of the fraction of non-farm wealth due to improvements. The MACCS2 default value of 0.8 was assumed.

### E.1.5.2.5 Agriculture Data

MACCS2 requires input regarding crop types, growing season, and average fraction of farmland devoted to each crop type. Average values for the 50-mile radius area are used instead of specific values for each of the 240 spatial elements.

MACCS2 uses the seven crop categories listed in Table E.1-17.

## Table E.1-17
## Crop Categories

| Pasture | Stored Forage | Grain | Legumes and Nuts | Leafy Green Vegetables | Roots and Tubers | Other Food |
|---|---|---|---|---|---|---|
| Various grasses | Alfalfa | Wheat | Soybeans | Lettuce | Potatoes | Apples |
| | Clover | Oats | Peanuts | Cabbage | Carrots | Grapes |
| | Sorghum | Barley | Snap beans | Broccoli | Beets | Oranges |
| | | Corn (incl. sweet corn) | Dried beans | Spinach | Sugar | Grapefruit |
| | | Sorghum | Peas | Celery | Onion | Lemon |
| | | | Nuts | Cauliflower | | Tomatoes |
| | | | | Greens | | Cucumbers |
| | | | | | | Peppers |

The number of acres used for each crop category was obtained from the Census of Agriculture CD-ROM for each county. These values were divided by *Land in farms (acres)* to determine the fraction of farmland devoted to each crop category. Summing the fraction of farmland devoted to each of the seven crop categories does not necessarily add up to one because significant farmland acres are devoted to woodlands, idle cropland, cropland used for cover crops (not harvested and not pasture), cropland on which crops failed, cropland in summer fallow, and farmland in houses, ponds, and roads. Each crop category was extrapolated to 2002 using least squares regression from 1997, 1992, and 1987 data (Table E.1-18) and weighted by the area of each county in the VYNPS 50-mile radius. The final weighted average fraction of farmland devoted to each crop is shown in Table E.1-18.

The recommended MACCS2 growing season dates were assumed [Reference E.1-15].

## Table E.1-18
## Average Fraction (Percent) of Farmland Devoted to Each Crop Type

| County | Pasture | Stored Forage | Grain | Legumes and Nuts | Leafy Green Vegetables | Roots and Tubers | Other Food |
|---|---|---|---|---|---|---|---|
| *Massachusetts* | | | | | | | |
| Berkshire | 19.0 | 33.5 | 3.6 | 0.0 | 0.0 | 0.0 | 1.1 |
| Franklin | 20.0 | 25.6 | 1.2 | 0.0 | 0.2 | 1.3 | 4.3 |
| Hampden | 15.0 | 23.3 | 1.6 | 0.1 | 0.1 | 0.0 | 4.3 |
| Hampshire | 13.1 | 27.5 | 6.4 | 0.4 | 0.3 | 4.9 | 6.2 |
| Middlesex | 10.9 | 25.1 | 4.2 | 0.2 | 0.5 | 0.3 | 7.0 |
| Worcester | 15.4 | 27.7 | 1.0 | 0.1 | 0.0 | 0.0 | 4.0 |
| *New Hampshire* | | | | | | | |
| Cheshire | 12.7 | 16.8 | 0.5 | 0.0 | 0.0 | 0.0 | 3.9 |
| Hillsborough | 17.2 | 27.4 | 1.3 | 0.1 | 0.1 | 0.1 | 7.1 |
| Merrimack | 4.4 | 22.6 | 0.5 | 0.0 | 0.0 | 0.0 | 2.3 |
| Sullivan | 11.0 | 22.1 | 1.0 | 0.0 | 0.0 | 0.0 | 3.9 |
| *New York* | | | | | | | |
| Columbia | 16.0 | 44.4 | 12.1 | 1.7 | 0.1 | 0.1 | 3.3 |
| Rensselaer | 16.0 | 36.2 | 15.6 | 0.3 | 0.0 | 0.0 | 0.8 |
| Washington | 18.6 | 48.3 | 5.1 | 0.4 | 0.0 | 0.2 | 1.2 |
| *Vermont* | | | | | | | |
| Bennington | 12.9 | 32.7 | 0.3 | 0.0 | 0.0 | 0.0 | 5.7 |
| Rutland | 20.1 | 34.2 | 0.4 | 0.0 | 0.0 | 0.0 | 2.9 |
| Windham | 20.4 | 27.6 | 0.1 | 0.0 | 0.2 | 0.1 | 8.7 |
| Windsor | 18.2 | 23.9 | 0.1 | 0.0 | 0.0 | 0.0 | 6.6 |
| Weighted Average | 15.3 | 29.3 | 3.2 | 0.2 | 0.1 | 0.4 | 4.3 |

### E.1.5.2.6 Meteorological Data

The MACCS2 model requires meteorological data for wind speed, wind direction, atmospheric stability, accumulated precipitation, and atmospheric mixing heights. The required data were obtained from the VYNPS site meteorological monitoring system and regional National Weather Service stations.

Site specific meteorological data included 8,760 consecutive hourly values of wind speed, wind direction, and delta temperature recorded at the VYNPS meteorological tower in 2002. The VYNPS meteorological monitoring system meets the technical requirements of Regulatory Guide 1.23. The meteorological data were provided in Microsoft Excel format in twelve monthly data files [Reference E.1-16].

Processing of VYNPS site meteorological data to conform to the MACCS2 input specifications was made using Microsoft Excel spreadsheets. Data processing was performed as follows.

#### *Date and Time*

The VYNPS data format of mm/dd/yyyy was converted to "day of the year" format. Values ranged from 1 (January 1, 2002) through 365 (December 31, 2002). Hours were converted from 0 to 23 daily to 1 to 24, by adding 1 to every hour in the raw VYNPS data file.

#### *Wind Direction*

The VYNPS raw data for wind direction was expressed as degrees "from". MACCS2 requires the data in terms of downwind sector values of 1 to 16 (N to NNW). This conversion was accomplished in Excel by using a lookup table to assign the mirrored directional bin (each 22.5 degrees wide) to the raw wind direction data. For example, a raw data wind direction value of 180 degrees (from), was converted to a sector value of 1 indicating the downwind direction was in sector 1 (north). The lower (35 feet above ground level) wind direction data was used for the MACCS2 input.

#### *Wind Speed*

The VYNPS raw data for wind speed was in miles per hour. MACCS2 requires the data in terms of tenths of a meter per second. The conversion of wind speed from miles per hour to tenths of a meter per second was accomplished by Excel in two steps. The first step applied a conversion factor of 0.4470392 to the data in miles per hour to obtain meters per second. The second step multiplied the result of the first step by a factor of 10. The VYNPS lower (35 feet above ground level) wind speed was used for MACCS2 input.

#### *Atmospheric Stability Class*

Atmospheric stability is usually given in terms of a Pasquill Stability Class index based on the adiabatic lapse rate, or rate of change of temperature with altitude. This value is normally negative unless there is a temperature inversion—when temperature increases with altitude.

The Pasquill Stability Class index is alphabetic (letters A through G) where each letter denotes a specific lapse rate range. MACCS2 input requires the conversion of Pasquill Stability Class to numerical values 1 through 7. Table E.1-19 shows the relationship between lapse rates, atmospheric stability, Pasquill classes, and MACCS2 input values.

The VYNPS meteorological raw data files include values of upper and lower delta temperature. The upper delta temperature value is the difference between the temperature recorded at the 33-foot and 295-foot levels; the lower delta temperature value is the difference between the 33-foot and 198-foot levels. The lower delta temperature values were used to calculate MACCS2 input hourly stability class values.

An Excel spreadsheet was used to first calculate the lapse rate (degrees C/100 meters) by changing the hourly VYNPS lower delta temperature values from degrees Fahrenheit to degrees Celsius, then dividing by the change in elevation converted from feet to 100 meters, and finally determining the MACCS2 input value according to the ranges shown in Table E.1-19.

**Table E.1-19**
**Stability Class Categories**

| Lapse Rate (degrees C/100 meters) | Atmospheric Stability Description | Pasquill Stability Class | MACCS2 Input Value |
|---|---|---|---|
| <-1.9 | Extremely unstable | A | 1 |
| -1.9 to -1.7 | Moderately unstable | B | 2 |
| -1.7 to -1.5 | Slightly unstable | C | 3 |
| -1.5 to -0.5 | Neutral | D | 4 |
| -0.5 to 1.5 | Slightly stable | E | 5 |
| 1.5 to 4.0 | Moderately stable | F | 6 |
| >4.0 | Extremely stable | G | 7 |

### *Accumulated Precipitation*

The VYNPS raw meteorological data files provided hourly precipitation values in the format x.xx inches. These values were converted to the MACCS2 input format by multiplying each value by 100 to provide precipitation in hundredths of an inch.

### *Regional Mixing Height Data*

One of the most important parameters to characterize the dispersion potential of the atmosphere is the mixing height. Mixing height is defined as the height of the atmosphere above ground level within which a released contaminant will become mixed (from turbulence) within approximately one hour. Mixing height values are computed using readily available ground-level and upper-air data from the National Weather Service.

MACCS2 requires morning and afternoon mixing height values, in hundreds of meters, for each season of the year. Daily mixing height values (for morning and afternoon) for the vicinity of VYNPS in 2002 were obtained from the National Climatic Data Center (NCDC) [Reference E.1-17].

The morning values were calculated by NCDC using the lowest surface temperature which occurred from 0200 to 0600 hours each day. The afternoon values were calculated in a similar way, except the maximum surface temperature which occurred from 1200 to 1600 hours was used.

The NCDC daily values for morning and afternoon mixing heights were averaged for each month, then monthly values were averaged into seasonal values. Each season was defined as a 3-month period starting with the winter season of January, February, and March.

Calculated seasonal mixing height values were rounded to the nearest hundred and divided by 100 to express values in hundreds of meters. Mixing height values for 2002 are shown in Table E.1-20.

**Table E.1-20**
**Morning and Afternoon Mixing Height Values in 2002**

| Season | Morning Mixing Height (m) | MCCS2 Input Value (100 m) | Afternoon Mixing Height (m) | MCCS2 Input Value (100 m) |
|---|---|---|---|---|
| Winter | 679 | 7 | 954 | 10 |
| Spring | 502 | 5 | 1504 | 15 |
| Summer | 368 | 4 | 1423 | 14 |
| Fall | 640 | 6 | 752 | 8 |

### E.1.5.2.7 Emergency Response Assumptions

#### *Emergency Planning Zone Description*

VYNPS is located in southeast Windham County, Vermont, on the west bank of the Connecticut River immediately upstream of the Vernon Hydroelectric Station. The topography of the area is gently rolling terrain and low hills along the Connecticut River valley. The land use is a mixture of industrial, commercial, and diversified agricultural production.

The VYNPS area is served by limited access highways such as Interstate 91, and secondary traffic roads such as Route 5, Route 9, Route 10, Route 30, Route 63, Route 78, and Route 119. There is non-commercial boat traffic on the Connecticut River. The New England Central Railroad has access through the Emergency Planning Zone (EPZ).

The VYNPS Emergency Planning Zone is composed of a 10-mile radius area (Figure E.1-4) divided into 16 compass bearing sectors and 1-mile radii.

#### *Evacuation Delay Time*

A detailed analysis of evacuation scenarios in EPZ was addressed in the VYNPS Evacuation Time Estimate Study [Reference E.1-18]. This analysis addressed the range and variation of public reaction to the evacuation notification process. The time between the issuance of an evacuation notification and the beginning of the public evacuation is referred to as either "delay time" or "public response time." Public response time has three components:

- receive warning - the time period between the activation of the prompt public notification system and the receipt by the public of the message to evacuate;
- travel home - the time period required for the public to drive from work or shopping, etc., to home; and
- prepare home for evacuation - the time period required to gather essential belongings and prepare home for absence.

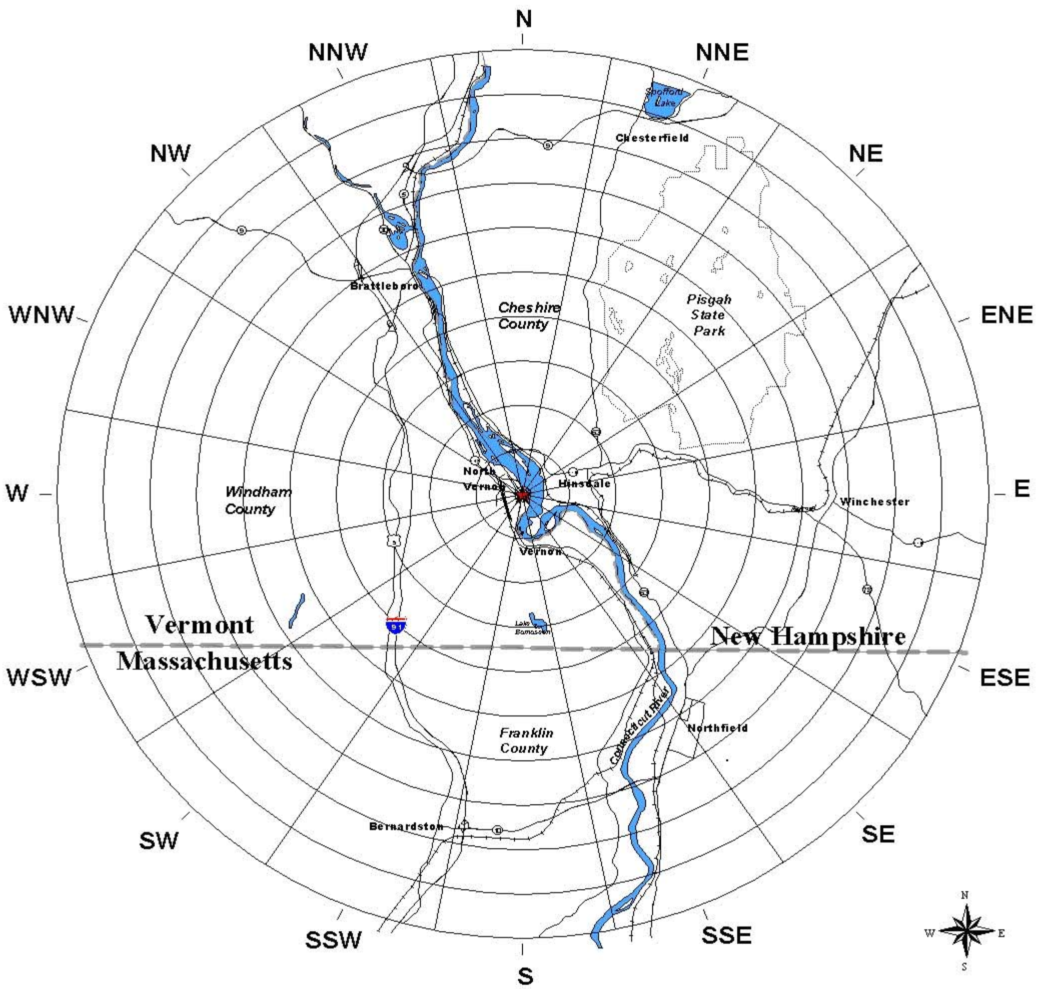

**Figure E.1-4**
**VYNPS 10-Mile EPZ**

The VYNPS evacuation time estimate study addressed numerous scenarios including time of day, normal and adverse weather conditions, resident and transient populations, special facilities (schools, hospitals, etc.), and other factors. Public response time estimates are summarized in Table E.1-21. These values indicate that within the 10-mile EPZ the general public would be prepared to begin an evacuation within a minimum of 0 minutes to a maximum of 2 hours and 35 minutes from activation of the evacuation notification process. The maximum response time estimate is based on the worse case scenario which would occur during the day under adverse (winter) weather conditions. The average of response time values of 1 hour and 20 minutes was used in the analysis.

**Table E.1-21**
**Public Evacuation Response Time Estimates**

| | **Range of Response Times (Minutes)** |
|---|---|
| 1. Receive warning | |
| -General population | 0-15 |
| -Special locations | 0-45 |
| 2. Travel home | |
| -Normal weather | 0-30 |
| -Adverse weather | 0-50 |
| 3. Prepare home for evacuation | 0-60 |

*Evacuation Speed*

The VYNPS evacuation time estimate study estimated that the general public within the full EPZ could be evacuated within 2 to 3 hours after the delay time. The longest times were required for evacuation scenarios occurring during the day under winter adverse weather conditions.

The VYNPS evacuation time estimate study did not report estimates of specific evacuation speeds for the various scenarios. Therefore, speed was estimated using the following assumptions:

- the distance traveled by the general public from evacuated sites near VYNPS would be 10 miles, and
- total evacuation time for the general public within the 0-10 mile radius zone would range from 2 to 3 hours.

A conservative estimate of evacuation speed, therefore, ranges from 5.0 miles/hour (2.2 meters/sec) to 3.33 miles/hour (1.5 meters/sec). The average evacuation speed of approximately 4 miles/hr (1.8 meters/sec) was used in the analysis.

### E.1.5.2.8 Core Inventory

The estimated VYNPS core inventory (Table E.1-22) used in the MACCS2 input is based on an extended power uprate level of 1912 MWt, which is 20 percent higher than the rated power of 1593 MWt. The information in Table E.1-22 is derived from NUREG/CR-4551 [Reference E.1-15] for a power level of 1912 MWt.

## Table E.1-22
## VYNPS Core Inventory (Becquerels)

| Nuclide | Inventory | Nuclide | Inventory |
|---|---|---|---|
| Co-58 | 1.08E+16 | Te-131m | 2.70E+17 |
| Co-60 | 1.29E+16 | Te-132 | 2.64E+18 |
| Kr-85 | 1.77E+16 | I-131 | 1.83E+18 |
| Kr-85m | 6.44E+17 | I-132 | 2.68E+18 |
| Kr-87 | 1.17E+18 | I-133 | 3.83E+18 |
| Kr-88 | 1.58E+18 | I-134 | 4.19E+18 |
| Rb-86 | 9.92E+14 | I-135 | 3.61E+18 |
| Sr-89 | 1.96E+18 | Xe-133 | 3.84E+18 |
| Sr-90 | 1.39E+17 | Xe-135 | 9.12E+17 |
| Sr-91 | 2.55E+18 | Cs-134 | 2.99E+17 |
| Sr-92 | 2.66E+18 | Cs-136 | 8.02E+16 |
| Y-90 | 1.49E+17 | Cs-137 | 1.79E+17 |
| Y-91 | 2.40E+18 | Ba-139 | 3.53E+18 |
| Y-92 | 2.67E+18 | Ba-140 | 3.49E+18 |
| Y-93 | 3.04E+18 | La-140 | 3.56E+18 |
| Zr-95 | 3.15E+18 | La-141 | 3.28E+18 |
| Zr-97 | 3.25E+18 | La-142 | 3.16E+18 |
| Nb-95 | 2.98E+18 | Ce-141 | 3.16E+18 |
| Mo-99 | 3.44E+18 | Ce-143 | 3.08E+18 |
| Tc-99m | 2.97E+18 | Ce-144 | 2.05E+18 |
| Ru-103 | 2.61E+18 | Pr-143 | 3.02E+18 |
| Ru-105 | 1.74E+18 | Nd-147 | 1.35E+18 |
| Ru-106 | 7.09E+17 | Np-239 | 4.02E+19 |
| Rh-105 | 1.30E+18 | Pu-238 | 2.79E+15 |
| Sb-127 | 1.64E+17 | Pu-239 | 7.08E+14 |
| Sb-129 | 5.71E+17 | Pu-240 | 8.87E+14 |
| Te-127 | 1.59E+17 | Pu-241 | 1.53E+17 |
| Te-127m | 2.14E+16 | Am-241 | 1.55E+14 |
| Te-129 | 5.35E+17 | Cm-242 | 4.10E+16 |
| Te-129m | 1.41E+17 | Cm-244 | 2.21E+15 |

#### E.1.5.2.9 Source Terms

Twelve release categories corresponding to internal event sequences were identified and entered as part of the MACCS2 input. The details of the source terms for postulated internal events are available in on-site documentation. A linear release rate was assumed between the time the release started and the time the release ended.

### E.1.5.3 Results

Risk estimates for one base case and two sensitivity cases were analyzed with MACCS2. The base case assumes an 80-minute delay and 1.8 meters/sec speed for evacuation. Sensitivity case 1 is the base case with delayed evacuation of 2 hours. Sensitivity case 2 is the base case with lower evacuation speed of 1 meter/sec.

Table E.1-23 shows estimated base case mean risk values for each release mode for postulated internal events. The estimated mean values of population dose risk (PDR) and offsite economic cost risk (OECR) for VYNPS are 9.16 person-rem/yr and $21,000/yr, respectively.

**Table E.1-23**
**Base Case Mean PDR and OECR Values for Postulated Internal Events**

| Release Mode | Frequency (/yr) | Population Dose (person-sv)* | Offsite Economic Cost ($) | Population Dose Risk (PDR) (person-rem/yr) | Offsite Economic Cost Risk (OECR) ($/yr) |
|---|---|---|---|---|---|
| NCF | 6.06E-07 | 1.30E+01 | 1.89E+06 | 7.88E-04** | 1.15E+00 |
| E/ HI | 1.50E-06 | 2.73E+04 | 6.20E+09 | 4.10E+00 | 9.30E+03 |
| E/MED | 2.10E-06 | 1.47E+04 | 3.39E+09 | 3.09E+00 | 7.12E+03 |
| E/ LO | 7.81E-08 | 2.11E+03 | 8.36E+07 | 1.65E-02 | 6.53E+00 |
| E/ LL | 3.99E-09 | 6.18E+02 | 1.02E+07 | 2.47E-04 | 4.07E-02 |
| V | 5.32E-08 | 2.96E+04 | 5.60E+09 | 1.57E-01 | 2.98E+02 |
| I/HI | 4.37E-09 | 3.53E+04 | 8.40E+09 | 1.54E-02 | 3.67E+01 |
| I/MED | 2.43E-09 | 1.02E+04 | 1.29E+09 | 2.48E-03 | 3.13E+00 |
| I/LO | 1.07E-08 | 2.71E+03 | 1.12E+08 | 2.90E-03 | 1.20E+00 |
| I/LL | 0.00E+00 | 2.80E+02 | 3.52E+06 | 0.00E+00 | 0.00E+00 |
| L/HI | 6.53E-07 | 2.69E+04 | 6.37E+09 | 1.76E+00 | 4.16E+03 |
| L/MED | 1.83E-08 | 1.13E+04 | 1.77E+09 | 2.07E-02 | 3.24E+01 |
| | | | **Totals** | **9.16E+00** | **2.10E+04** |

* 1 sv = 100 rem

** 7.88E-04 (person-rem/yr) = 6.06E-07 (/yr) x 1.30E+01 (person-sv) x 100 (rem/sv)

Results of sensitivity analyses indicate that a delayed evacuation or a lower evacuation speed would not have significant effects on the offsite consequences or risks determined in this study. Table E.1-24 summarizes offsite consequences in terms of population dose (person-sv) and offsite economic cost ($) for the base case and the sensitivity cases. Comparison of the consequences indicates that the maximal deviation is less than 4% between the base case population dose and the Sensitivity Case 2 population dose for the Early, Low-Low Magnitude release mode (E/LL).

**Table E.1-24**
**Summary of Offsite Consequence Results for Postulated Internal Events**

| | Population Dose (person-sv) | | | Offsite Economic Cost ($) | | |
|---|---|---|---|---|---|---|
| **Release Mode** | **Base Case** | **2 –hr Delayed Evacuation** | **Lower Speed of Evacuation** | **Base Case** | **2 –hr Delayed Evacuation** | **Lower Speed of Evacuation** |
| NCF | 1.30E+01 | 1.30E+01 | 1.31E+01 | 1.89E+06 | 1.89E+06 | 1.89E+06 |
| E/ HI | 2.73E+04 | 2.75E+04 | 2.78E+04 | 6.20E+09 | 6.20E+09 | 6.20E+09 |
| E/MED | 1.47E+04 | 1.48E+04 | 1.48E+04 | 3.39E+09 | 3.39E+09 | 3.39E+09 |
| E/ LO | 2.11E+03 | 2.12E+03 | 2.13E+03 | 8.36E+07 | 8.36E+07 | 8.36E+07 |
| E/ LL | 6.18E+02 | 6.28E+02 | 6.39E+02 | 1.02E+07 | 1.02E+07 | 1.02E+07 |
| V | 2.96E+04 | 3.02E+04 | 3.03E+04 | 5.60E+09 | 5.60E+09 | 5.60E+09 |
| I/HI | 3.53E+04 | 3.53E+04 | 3.54E+04 | 8.40E+09 | 8.40E+09 | 8.40E+09 |
| I/MED | 1.02E+04 | 1.02E+04 | 1.02E+04 | 1.29E+09 | 1.29E+09 | 1.29E+09 |
| I/LO | 2.71E+03 | 2.71E+03 | 2.71E+03 | 1.12E+08 | 1.12E+08 | 1.12E+08 |
| I/LL | 2.80E+02 | 2.81E+02 | 2.81E+02 | 3.52E+06 | 3.52E+06 | 3.52E+06 |
| L/HI | 2.69E+04 | 2.69E+04 | 2.69E+04 | 6.37E+09 | 6.37E+09 | 6.37E+09 |
| L/MED | 1.13E+04 | 1.13E+04 | 1.13E+04 | 1.77E+09 | 1.77E+09 | 1.77E+09 |

### E.1.6 References

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# VERMONT YANKEE NUCLEAR POWER STATION

# ATTACHMENT E.2

# SAMA CANDIDATES SCREENING AND EVALUATION

## E.2 EVALUATION OF SAMA CANDIDATES

This section describes the generation of the initial list of potential SAMA candidates, screening methods, and the analysis of the remaining SAMA candidates.

### E.2.1 SAMA List Compilation

A list of SAMA candidates was developed by reviewing industry documents and considering plant-specific enhancements not identified in published industry documents. Since VYNPS is a conventional GE nuclear power reactor, considerable attention was paid to the SAMA candidates from SAMA analyses for other GE plants. Industry documents reviewed include the following.

- Hatch SAMA Analysis (Reference E.2-1)
- Calvert Cliffs Nuclear Power Plant SAMA Analysis (Reference E.2-2)
- GE ABWR SAMDA Analysis (Reference E.2-3)
- Peach Bottom SAMA Analysis (Reference E.2-4)
- Quad Cities SAMA Analysis (Reference E.2-5)
- Dresden SAMA Analysis (Reference E.2-6)
- Arkansas Nuclear One Unit 2 SAMA Evaluation (Reference E.2-7)

The above documents represent a compilation of most SAMA candidates developed from the industry documents. These sources of other industry documents include the following.

- Limerick SAMDA cost estimate report (Reference E.2-8)
- NUREG-1437 description of Limerick SAMDA (Reference E.2-9)
- NUREG-1437 description of Comanche Peak SAMDA (Reference E.2-10)
- Watts Bar SAMDA submittal (Reference E.2-11)
- TVA response to NRC's RAI on the Watts Bar SAMDA submittal (Reference E.2-12)
- Westinghouse AP600 SAMDA (Reference E.2-13)
- NUREG-0498, Watts Bar Final Environmental Statement, Supplement 1, Section 7 (Reference E.2-14)
- NUREG-1560, Volume 2, NRC Perspectives on the IPE Program (Reference E.2-15)
- NUREG/CR-5474, Assessment of Candidate Accident Management Strategies (Reference E.2-16)

In addition to SAMA candidates from review of industry documents, additional SAMA candidates were obtained from plant-specific sources, such as the VYNPS individual plant examination (Reference E.2-17) and individual plant evaluation of external events (Reference E.2-18). In both the IPE and IPEEE, several enhancements related to severe accident insights were recommended and implemented.

The current VYNPS PSA model was also used to identify plant-specific modifications for inclusion in the comprehensive list of SAMA candidates. The risk significant terms from the PSA model were reviewed for similar failure modes and effects that could be addressed through a potential enhancement to the plant. The correlation between SAMAs and the risk significant terms are listed in Table E.1-3.

The comprehensive list, available in on-site documentation, contained a total of 302 Phase I SAMA candidates.

### E.2.2 Qualitative Screening of SAMA Candidates (Phase I)

The purpose of the preliminary SAMA screening was to eliminate from further consideration enhancements that were not viable for implementation at VYNPS. Potential SAMA candidates were screened out if they modified features not applicable to VYNPS, if they had already been implemented at VYNPS, or if they were similar in nature and could be combined with another SAMA candidate to develop a more comprehensive or plant-specific SAMA candidate. During this process, 57 of the Phase I SAMA candidates were screened out because they were not applicable to VYNPS, 4 of the Phase I SAMA candidates were screened out because they were similar in nature and could be combined with another SAMA candidate, and 175 of the Phase I SAMA candidates were screened out because they had already been implemented at VYNPS, leaving 66 SAMA candidates for further analysis. The final screening process involved identifying and eliminating those items whose implementation cost would exceed their benefit as described below. Table E.2-1 provides a description of each of the 66 Phase II SAMA candidates.

### E.2.3 Final Screening and Cost-Benefit Evaluation of SAMA Candidates (Phase II)

A cost/benefit analysis was performed on each of the remaining SAMA candidates. If the implementation cost of a SAMA candidate was determined to be greater than the potential benefit (i.e., there was a negative net value), the SAMA candidate was considered not to be cost beneficial and was not retained as a potential enhancement.

The expected cost of implementation of each SAMA was established from existing estimates of similar modifications. Most of the cost estimates were developed from similar modifications considered in previously performed SAMA and SAMDA analyses. In particular, these cost-estimates were derived from the following major sources.

- GE ABWR SAMDA Analysis (Reference E.2-3)
- Peach Bottom SAMA Analysis (Reference E.2-4)
- Quad Cities SAMA Analysis (Reference E.2-5)

- Dresden SAMA Analysis (Reference E.2-6)
- ANO-2 SAMA Analysis (Reference E.2-7)

The cost estimates did not include the cost of replacement power during extended outages required to implement the modifications, nor did they include contingency costs associated with unforeseen implementation obstacles. Estimates based on modifications that were implemented or estimated in the past were presented in terms of dollar values at the time of implementation (or estimation) and were not adjusted to present-day dollars. In addition, several implementation costs were originally developed for SAMDA analyses (i.e., during the design phase of the plant), and therefore do not capture the additional costs associated with performing design modifications to existing plants (i.e., reduced efficiency, minimizing dose, disposal of contaminated material, etc.). Therefore, the cost estimates were conservative.

The benefit of implementing a SAMA candidate was estimated in terms of averted consequences. The benefit was estimated by calculating the arithmetic difference between the total estimated costs associated with the four impact areas for the baseline plant design and the total estimated impact area costs for the enhanced plant design (following implementation of the SAMA candidate).

Values for avoided public and occupational health risk were converted to a monetary equivalent (dollars) via application of the NUREG/BR-0184 (Reference E.2-19) conversion factor of $2,000 per person-rem and discounted to present value. Values for avoided off-site economic costs were also discounted to present value.

As this analysis focuses on establishing the economic viability of potential plant enhancement when compared to attainable benefit, often detailed cost estimates were not required to make informed decisions regarding the economic viability of a particular modification. Several of the SAMA candidates were clearly in excess of the attainable benefit estimated from a particular analysis case.

For less clear cases, engineering judgment on the cost associated with procedural changes, engineering analysis, testing, training and hardware modification was applied to determine if a more detailed cost estimate was necessary to formulate a conclusion regarding the economic viability of a particular SAMA. Based on a review of previous submittals' SAMA evaluations and an evaluation of expected implementation costs at VY, the following estimated costs for each potential element of the proposed SAMA implementation are used.

:

| Type of Change | Estimated Cost Range |
|---|---|
| Procedural only | $25K-$50K |
| Procedural change with engineering required | $50K-$200K |
| Procedural change with engineering and testing/training required | $200K-$300K |
| Hardware modification | $100K to >$1000K |

In most cases, more detailed cost estimates were not required, particularly if the SAMA called for the implementation of a hardware modification. Nonetheless, the cost of each unscreened SAMA candidate was conceptually estimated to the point where conclusions regarding the economic viability of the proposed modification could be adequately gauged. The cost-benefit comparison and disposition of each of the 66 Phase II SAMA candidates is presented in Table E.2-1.

Bounding evaluations (or analysis cases) were performed to address specific SAMA candidates or groups of similar SAMA candidates. These analysis cases overestimated the benefit and thus were conservative calculations. For example, one SAMA candidate suggested installing a digital large break LOCA protection system. The bounding calculation estimated the benefit of this improvement by total elimination of risk due to large break LOCA (see analysis in Phase II SAMA 62 of Table E.2-1). This calculation obviously overestimated the benefit, but if the inflated benefit indicated that the SAMA candidate was not cost-beneficial then the purpose of the analysis was satisfied.

A description of the analysis cases used in the evaluation follows.

### *Additional Service Water Pump*

This analysis case was used to evaluate the change in plant risk from installing an additional service water pump. An additional service water pump reduces the impact of common cause pump failures on failure of the service water system. A bounding analysis was performed by setting the CDF contribution due to loss of service water to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $120,000. This analysis case was used to model the benefit of Phase II SAMA 1.

### *Redundant Train to EDG Building HVAC*

This analysis case was used to evaluate the change in plant risk from providing a redundant train to the existing EDG building ventilation system. Enhancements of the HVAC system increase the availability of components dependent upon room cooling. A bounding analysis was performed by setting both emergency diesel generator failure probabilities to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $470,000. This analysis case was used to model the benefit of Phase II SAMA 2.

*Improvements Related to Diagnosis of EDG Building HVAC*

This analysis case was used to evaluate the change in plant risk from providing a high temperature alarm, or redundant louver and thermostat, for the EDG building ventilation system to improve diagnosis of EDG building HVAC system failures. A bounding analysis was performed by reducing the failure probability of both EDGs to continue to run by a factor of three in the level 1 PSA model, which resulted in an upper bound benefit of approximately $160,000. This analysis case was used to model the benefit of Phase II SAMA 3.

*Decay Heat Removal Capability*

This analysis case was used to evaluate the change in plant risk from installing an additional decay heat removal system. Enhancements of decay heat removal capability decrease the probability of loss of containment heat removal. A bounding analysis was performed by setting the events for loss of the torus cooling mode of the RHR and RHRSW systems to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $530,000. This analysis case was used to model the benefit of Phase II SAMAs 4, 12, and 17.

*Filtered Vent*

This analysis case was used to evaluate the change in plant risk from installing a filtered containment vent to provide fission product scrubbing. A bounding analysis was performed by binning all successful torus venting sequences into the Low-Low release category. Reducing the releases from the vent path resulted in an upper bound benefit of approximately $2,000. This analysis case was used to model the benefit of Phase II SAMAs 5, and 22.

*Containment Vent for ATWS Decay Heat Removal*

This analysis case was used to evaluate the change in plant risk from installing a containment vent to provide alternate decay heat removal capability during an ATWS event. A bounding analysis was performed by setting the events for loss of the torus cooling mode of the RHR and RHRSW systems during ATWS sequences to zero in the level 1 PSA model, which resulted in no benefit. This analysis case was used to model the benefit of Phase II SAMAs 6, and 56.

*Molten Core Debris Removal*

This analysis case was used to estimate the change in plant risk from providing a molten core debris cooling mechanism, thereby preventing a melt-through of the base mat. A bounding analysis was performed by setting containment failure due to core-concrete interaction (not including liner failure) to zero in the level 2 PSA model, which resulted in an upper bound benefit of approximately $640,000. This analysis case was used to model the benefit of Phase II SAMAs 7, 8, 11, 14,15, 25 and 26.

*Drywell Head Flooding*

This analysis case was used to evaluate the change in plant risk from providing a modification to flood the drywell head such that if high drywell temperature occurred, the drywell head seal would not fail. A bounding analysis was performed by setting the probability of drywell head failure to zero in the level 2 PSA model, which resulted in an upper bound benefit of approximately $20,000. This analysis case was used to model the benefit of Phase II SAMAs 9 and 23.

*Reactor Building Effectiveness*

This analysis case was used to evaluate the change in plant risk by mitigating fission product release from the reactor building. Reactor building effectiveness was conservatively modeled by binning all releases in the reactor building into the Low-Low release category. This resulted in an upper bound benefit of approximately $1,410,000. This analysis case was used to model the benefit of Phase II SAMAs 10, 16, and 24.

*Strengthen Containment*

This analysis case was used to evaluate the change in plant risk from strengthening containment to reduce the probability of containment over-pressurization failure. A bounding analysis was performed by setting the CDF contribution due to ATWS and loss of the torus cooling mode of the RHR and RHRSW systems to zero in the level 1 PSA model and setting all energetic containment failure modes (DCH, steam explosions, late over-pressurization) to zero in the level 2 PSA model. This resulted in an upper bound benefit of approximately $530,000. This analysis case was used to model the benefit of Phase II SAMAs 13, 18, 19, and 27.

*Vacuum Breakers*

This analysis case was used to evaluate the change in plant risk from improving the reliability of vacuum breakers to reseat following a successful opening and eliminate suppression pool scrubbing failures from the containment analysis. A bounding analysis was performed by setting the vacuum breaker failure probability to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $40,000. This analysis case was used to model the benefit of Phase II SAMA 20.

*Temperature Margin for Seals*

This analysis case was used to evaluate the change in plant risk from increasing the temperature margin for seals to reduce the potential for containment failure under adverse conditions. A bounding analysis was performed by setting containment failure due to high temperature drywell seal failure to zero in the level 2 PSA model, which resulted in an upper bound benefit of approximately $20,000. This analysis case was used to model the benefit of Phase II SAMA 21.

*DC Power*

This analysis case was used to evaluate the change in plant risk from plant modifications that would increase the availability of Class 1E DC power (e.g., increasing battery capacity or using fuel cells). It was assumed that battery life could be extended from 4 hours to 24 hours to simulate additional battery capacity. This enhancement would extend HPCI and RCIC operability and allow more credit for AC power recovery. A bounding analysis was performed by changing the time available to recover offsite power before HPCI and RCIC are lost from 4 hours to 24 hours during station blackout scenarios in the level 1 PSA model. This resulted in an upper bound benefit of approximately $160,000. This analysis case was used to model the benefit of Phase II SAMAs 28, 29, 33, 40 and 41.

*Improve DC System*

This analysis case was used to evaluate the change in plant risk from improving injection capability by auto-transfer of AC bus control power to a standby DC power source upon loss of the normal DC source. A bounding analysis was performed by setting the loss of DC bus 1 initiator to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $290,000. This analysis case was used to model the benefit of Phase II SAMA 30.

*Dedicated DC Power and Additional Batteries and Divisions*

This analysis case was used to evaluate the change in plant risk from plant modifications that would enhance the availability and reliability of Class 1E DC power (e.g., providing a dedicated DC power supply, additional batteries, or additional divisions). A bounding analysis was performed by setting the loss of DC bus 1 initiator, and one division of DC power, to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $480,000. This analysis case was used to model the benefit of Phase II SAMAs 38 and 39.

*Turbine Generator*

This analysis case was used to evaluate the change in plant risk from plant modifications that would improve onsite AC power availability and reliability (e.g., installing a gas turbine generator, steam driven generator, or gas turbine). A bounding analysis was performed by setting failure of the Vernon tie to zero in level 1 PSA model, which resulted in an upper bound benefit of approximately $460,000. This analysis case was used to model the benefit of Phase II SAMAs 31, 34, 35, 36 and 37.

*Bypass Diesel Generator Trips*

This analysis case was used to evaluate the change in plant risk from changing emergency procedures to bypass EDG protective trips, or changing the trip set points, to enable continued EDG operation beyond the current trip point. A bounding analysis was performed by reducing the failure probability of both EDGs to run by a factor of three in level 1 PSA model, which resulted in an upper bound benefit of approximately $160,000. This analysis case was used to model the benefit of Phase II SAMAs 32.

*Locate RHR Inside Containment*

This analysis case was used to evaluate the change in plant risk from moving the RHR system inside containment to prevent an RHR system ISLOCA event outside containment. A bounding analysis was performed by binning the ISLOCA sequences adding into the same end states as medium LOCA sequences, which resulted in an upper bound benefit of approximately $70,000. This analysis case was used to model the benefit of Phase II SAMA 42.

*ISLOCA*

This analysis case was used to evaluate the change in plant risk from reducing the probability of an ISLOCA by increasing the frequency of valve leak testing. A bounding analysis was performed by setting the ISLOCA initiator to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $50,000. This analysis case was used to model the benefit of Phase II SAMA 43.

*ISLOCA Release*

This analysis case was used to evaluate the change in plant risk from plant modifications that would ensure all ISLOCA releases are scrubbed. A bounding analysis was performed by binning the ISLOCA sequences to the Low-Low release category, which resulted in an upper bound benefit of approximately $50,000. This analysis case was used to model the benefit of Phase II SAMA 44.

*Containment Isolation Valve Position Indication*

This analysis case was used to evaluate the change in plant risk from installing redundant and diverse limit switches on each containment isolation valve to reduce the failure frequency of containment isolation valves and ISLOCA. A bounding analysis was performed by setting the ISLOCA initiator to zero in the level 1 PSA model and making all containment isolation valve fault trees successful in the level 2 PSA model, which resulted in an upper bound benefit of approximately $70,000. This analysis case was used to model the benefit of Phase II SAMA 45.

*MSIV Design*

This analysis case was used to evaluate the change in plant risk from improving MSIV design to decrease the likelihood of containment bypass scenarios. A bounding analysis was performed by setting the main steam line LOCA outside containment to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $4,000. This analysis case was used to model the benefit of Phase II SAMA 46.

### *Shield Electrical System from Water Spray*

This analysis case was used to evaluate the change in plant risk from installing a barrier to shield electrical equipment from water spray induced by internal flooding. For this case, setting the CDF contribution due to water spray on electrical equipment to zero in the level 1 PSA model constituted a bounding analysis. Elimination of core damage from internal flooding sequences by installing a shield on electrical equipment resulted in an upper bound benefit of approximately $260,000. This analysis case was used to model the benefit of Phase II SAMA 47.

### *Diesel to CST Makeup Pumps*

This analysis case was used to evaluate the change in plant risk from installing an independent diesel for the CST makeup pumps to allow continued operation of the high pressure injection system during an SBO event. As currently modeled, if CST water level is low, swapping HPCI/ RCIC suction from the CST to the torus allows continued HPCI/RCIC injection. Therefore, a bounding analysis was performed by setting the probability of the operator failing to switchover from CST to torus to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $20,000. This analysis case was used to model the benefit of Phase II SAMA 48.

### *High Pressure Injection System*

This analysis case was used to evaluate the change in plant risk from plant modifications that would increase the availability of high pressure injection (e.g., installing an independent AC powered high pressure injection system, passive high pressure injection system, or an additional high pressure injection system). A bounding analysis was performed by setting the CDF contribution due to unavailability of the HPCI system to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $1.56 million. This analysis case was used to model the benefit of Phase II SAMAs 49, 50, 51, 53 and 54.

### *Improve the Reliability of High Pressure Injection System*

This analysis case was used to evaluate the change in plant risk from plant modifications that would increase the reliability of the high pressure injection system. A bounding analysis was performed by reducing the HPCI system failure probability by a factor of three in the level 1 PSA model, which resulted in an upper bound benefit of approximately $1.05 million. This analysis case was used to model the benefit of Phase II SAMAs 52.

### *SRV Reseat*

This analysis case was used to evaluate the change in plant risk from improving the reliability of SRVs reseating. A bounding analysis was performed by setting the stuck open SRVs initiator to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $90,000. This analysis case was used to model the benefit of Phase II SAMA 55.

*ATWS*

This analysis case was used to evaluate the change in plant risk from improving ATWS coping capability. For this case, setting the CDF contribution due to ATWS events to zero in the level 1 PSA model constituted a bounding analysis. Elimination of all core damage due to ATWS resulted in an upper bound benefit of approximately $110,000. This analysis case was used to model the benefit of Phase II SAMA 57.

*Diversity of Explosive Valves*

This analysis case was used to evaluate the change in plant risk from providing an alternate means of opening a pathway to the RPV for standby liquid control (SLC) system injection, thereby improving success probability for reactor shutdown. A bounding analysis was performed by setting common cause failure of SLC explosive valves to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $4,000. This analysis case was used to model the benefit of Phase II SAMA 58.

*Reliability of SRVs*

This analysis case was used to evaluate the change in plant risk from installing additional signals to automatically open the SRVs. This improvement would reduce the likelihood of SRVs failing to open, thereby reducing the consequences of medium LOCAs. A bounding analysis was performed by setting the probability of SRVs failing to open to zero during medium LOCA sequences in the level 1 PSA model, which resulted in an upper bound benefit of approximately $120,000. This analysis case was used to model the benefit of Phase II SAMA 59.

*Improve SRV Design*

This analysis case was used to evaluate the change in plant risk from improving the SRV design to increase the reliability of opening, thus increasing the likelihood that accident sequences could be mitigated using low pressure injection systems. A bounding analysis was performed by setting the probability of SRVs failing to open during RPV depressurization to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $780,000. This analysis case was used to model the benefit of Phase II SAMA 60.

*Self-Cooled ECCS Pump Seals*

This analysis case was used to evaluate the change in plant risk from providing self-cooled ECCS pump seals to eliminate dependence on the component cooling water system. A bounding analysis was performed by setting the CDF contribution from sequences involving RHR pump failures to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $40,000. This analysis case was used to model the benefit of Phase II SAMA 61.

### *Large Break LOCA*

This analysis case was used to evaluate the change in plant risk from installing a digital large break LOCA (LBLOCA) protection system. A bounding analysis was performed by setting the LBLOCA initiator to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $40,000. This analysis case was used to model the benefit of Phase II SAMA 62.

### *Controlled Containment Venting*

This analysis case was used to evaluate the change in plant risk from changing the design of the containment vent valve and venting procedure to establish a narrow pressure control band. This would prevent rapid containment depressurization when venting, thus avoiding adverse impact on the ability of the low pressure ECCS injection systems to take suction from the torus. A bounding analysis was performed by reducing the probability of the operator failing to recognize the need to vent the torus by a factor of three in the level 1 PSA model, which resulted in an upper bound benefit of approximately $180,000. This analysis case was used to model the benefit of Phase II SAMA 63.

### *Cross-Tie of RHRSW System to RHR Loop B*

This analysis case was used to evaluate the change in plant risk from installing a crosstie from the RHRSW system to RHR loop B for alternate injection to the vessel. A bounding analysis was performed by setting the probability of the RHRSW loop A crosstie valves failing to open to zero in the level 1 PSA model, which resulted in an upper bound benefit of approximately $4,000. This analysis case was used to model the benefit of Phase II SAMA 64.

### *ECCS Low Pressure Interlock - Procedure Change*

This analysis case was used to evaluate the change in plant risk from changing the procedure to allow the operator to defeat the ECCS low pressure interlock circuitry that inhibits opening the RHR low pressure injection and core spray injection valves following sensor or logic failure. A bounding analysis was performed by setting the CDF contribution due to sensor failure, low pressure permissive logic failure, and miscalibration to zero in the level 1 PSA model. This resulted in an upper bound benefit of approximately $1.43 million. This analysis case was used to model the benefit of Phase II SAMA 65.

### *ECCS Low Pressure Interlock - Hardware Modification*

This analysis case was used to evaluate the change in plant risk from installing a bypass switch to allow operators to bypass the ECCS low pressure interlock circuitry that inhibits opening of the RHR low pressure injection and core spray injection valves following sensor or logic failure. A bounding analysis was performed by setting the CDF contribution due to sensor failure, low pressure permissive logic failure, and miscalibration to zero in the level 1 PSA model. This resulted in an upper bound benefit of approximately $1.43 million. This analysis case was used to model the benefit of Phase II SAMA 66.

## E.2.4 Sensitivity Analyses

Two sensitivity analyses were conducted to gauge the impact of assumptions upon the analysis. The benefits estimated for each of these sensitivities are presented in Table E.2-2.

A description of each sensitivity case follows.

*Sensitivity Case 1: Years Remaining until End of Plant Life*

The purpose of this sensitivity case was to investigate the sensitivity of assuming a 28-year period for remaining plant life (i.e., eight years on the original plant license plus the 20-year license renewal period). The 20-year licensing renewal period was used in the base case. The resultant monetary equivalent was calculated using 28 years remaining until end of facility life to investigate the impact on each analysis case. Changing this assumption does not cause any additional SAMAs to be cost-beneficial.

*Sensitivity Case 2: Conservative Discount Rate*

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the discount rate. The discount rate of 7.0% used in the base case analyses is conservative relative to corporate practices. Nonetheless, a lower discount rate of 3.0% was assumed in this case. Changing this assumption caused SAMAs 49, 50, 51, 53 and 54 to appear cost-beneficial because implementation costs were estimated to be > $2,000,000 and the benefit of these SAMAs with a 3% discount rate is $2,080,000. However, these SAMAs involve installation of entirely new systems. The implementation costs were only estimated to the point that the base-case SAMAs were shown not to be cost-beneficial and the averted cost estimates are conservative. A rigorous estimate of costs and benefits, with a 3% discount rate, would show that these SAMAs are not cost-beneficial. Therefore, this sensitivity case does not cause any additional SAMAs to be cost-beneficial.

## E.2.5 References

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E.2-3 General Electric Nuclear Energy, Technical Support Document for the ABWR, 25A5680, Revision 1, January 18, 1995.

E.2-4 Appendix E—Environmental Report, Appendix G, Severe Accident Mitigation Alternatives Submittal Related to Licensing Renewal for the Peach Bottom Nuclear Power Plant Units 2 and 3, July 2001.

E.2-5 Appendix F, Severe Accident Mitigation Alternatives Analysis Submittal Related to Licensing Renewal for the Quad Cities Nuclear Power Plant Units 1 and 2, January 2003.

E.2-6 Appendix F, Severe Accident Mitigation Alternatives Analysis Submittal Related to Licensing Renewal for the Dresden Nuclear Power Plant Units 2 and 3, January 2003.

E.2-7 Appendix E—Attachment E, Severe Accident Mitigation Alternatives Submittal Related to Licensing Renewal for the Arkansas Nuclear One - Unit 2, October 2003.

E.2-8 Cost Estimate for Severe Accident Mitigation Design Alternatives, Limerick Generating Station for Philadelphia Electric Company, Bechtel Power Corporation, June 22, 1989.

E.2-9 NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants*, Volume 1, 5.35, Listing of SAMDAs considered for the Limerick Generating Station, U.S. Nuclear Regulatory Commission, May 1996.

E.2-10 NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants*, Volume 1, 5.36, Listing of SAMDAs considered for the Comanche Peak Steam Electric Station, U.S. Nuclear Regulatory Commission, May 1996.

E.2-11 Museler, W. J. (Tennessee Valley Authority) to NRC Document Control Desk, "Watts Bar Nuclear Plant (WBN) Units 1 and 2—Severe Accident Mitigation Design Alternatives (SAMDAs)," letter dated October 7, 1994.

E.2-12 Nunn, D. E. (Tennessee Valley Authority) to NRC Document Control Desk, "Watts Bar Nuclear Plant (WBN) Units 1 and 2 - Severe Accident Mitigation Design Alternatives (SAMDA) - Response to Request for Additional Information (RAI) - (TAC Nos. M77222 and M77223)," letter dated October 7, 1994.

E.2-13 Liparulo, N. J. (Westinghouse Electric Corporation) to NRC Document Control Desk, "Submittal of Material Pertinent to the AP600 Design Certification Review," letter dated December 15, 1992.

E.2-14 NUREG 0498, *Final Environmental Statement Related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2*, Supplement No. 1, U.S. Nuclear Regulatory Commission, April 1995.

E.2-15 NUREG-1560, *Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance*, Volume 2, U.S. Nuclear Regulatory Commission, December 1997.

E.2-16 NUREG/CR-5474, *Assessment of Candidate Accident Management Strategies*, U.S. Nuclear Regulatory Commission, March 1990.

E.2-17 Vermont Yankee Nuclear Power Station, Individual Plant Examination (IPE) Report, December 1993.

E.2-18 Vermont Yankee Nuclear Power Station, Individual Plant Examination of External Events (IPEEE) Report, June 1998.

E.2-19 NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook*, U.S. Nuclear Regulatory Commission, January 1997.

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements Related to RCP Seal LOCAs (Loss of CCW or SW)* | | | | | | | | |
| 001 | 8.a. Add a service water pump. | SAMA would reduce the impact of common cause failures on failure of the SW system. | 1.79% | 2.40% | $12,000 | $120,000 | $5,900,000 | Not cost effective |
| | **Basis for Conclusion**: The CDF contribution due to loss of service water was eliminated to conservatively assess the potential benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $5.9 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| *Improvements Related to Heating, Ventilation, and Air Conditioning* | | | | | | | | |
| 002 | Provide a redundant train of EDG room ventilation. | SAMA would increase the availability of components dependent on room cooling. | 7.36% | 9.28% | $47,000 | $470,000 | >$1,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from EDG failures was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $1 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 003 | Add a diesel building high temperature alarm, or redundant louver and thermostat. | SAMA would improve diagnosis of a loss of diesel building HVAC. | 2.39% | 3.06% | $16,000 | $160,000 | >$250,000 | Not cost effective |
| | **Basis for Conclusion:** The probability of EDG run failures was reduced by a factor of three to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $250,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| *Improvements Related to Accident Mitigation Containment Phenomena* | | | | | | | | |
| 004 | Install an independent method of suppression pool cooling. | SAMA would decrease the probability of loss of containment heat removal. | 7.36% | 10.59% | $53,000 | $530,000 | $5,800,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from loss of the torus cooling mode of RHR and RHRSW was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $5.8 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 005 | Install a filtered containment vent to provide fission product scrubbing.<br>Option 1: Gravel Bed Filter<br>Option 2: Multiple Venturi Scrubber | SAMA would provide an alternate decay heat removal method for non-ATWS events, with fission product scrubbing. | 0.00% | 0.11% | $200 | $2,000 | $3,000,000 | Not cost effective |
| | **Basis for Conclusion:** Successful torus venting sequences were binned into the Low-Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be $3 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 006 | Install a containment vent large enough to remove ATWS decay heat. | Assuming that injection is available, this SAMA would provide alternate decay heat removal in an ATWS event. | 0.00% | 0.00% | $0 | $0 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from loss of the torus cooling mode of RHR and RHRSW in ATWS event sequences was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 007 | Create a large concrete crucible with heat removal potential under the base mat to contain molten core debris. | SAMA would ensure that molten core debris escaping from the vessel would be contained within the crucible. The water cooling mechanism would cool the molten core, preventing a melt-through of the base mat. | 0.00% | 14.41% | $64,000 | $640,000 | >$100 million | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at ANO-2 was estimated to be $100 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 008 | Create a water-cooled rubble bed on the pedestal. | SAMA would contain molten core debris dropping on to the pedestal and would allow the debris to be cooled. | 0.00% | 14.41% | $64,000 | $640,000 | $19,000,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at ANO-2 was estimated to be $19 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 009 | Provide modification for flooding the drywell head. | SAMA would provide intentional flooding of the upper drywell head such that if high drywell temperatures occurred, the drywell head seal would not fail. | 0.00% | 0.30% | $2,000 | $20,000 | >$1,000,000 | Not cost effective |
| | **Basis for Conclusion:** Drywell head failures due to high temperature were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $1 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 010 | Enhance fire protection system and standby gas treatment system hardware and procedures. | SAMA would improve fission product scrubbing in severe accidents. | 0.00% | 33.00% | $141,000 | $1,410,000 | >$2,500,000 | Not cost effective |
| | **Basis for Conclusion:** Releases into the reactor building were binned into the Low-Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

<table>
<tr><th>Phase II SAMA ID</th><th>SAMA</th><th>Result of Potential Enhancement</th><th>CDF Reduction</th><th>Off-Site Dose Reduction</th><th>Estimated Benefit</th><th>Upper Bound Estimated Benefit</th><th>Estimated Cost</th><th>Conclusion</th></tr>
<tr><td rowspan="2">011</td><td>Create a core melt source reduction system.</td><td>SAMA would provide cooling and containment of molten core debris. Refractory material would be placed underneath the reactor vessel such that a molten core falling on the material would melt and combine with the material. Subsequent spreading and heat removal from the vitrified compound would be facilitated, and concrete attack would not occur.</td><td>0.00%</td><td>14.41%</td><td>$64,000</td><td>$640,000</td><td>>$5,000,000</td><td>Not cost effective</td></tr>
<tr><td colspan="8"><b>Basis for Conclusion:</b> Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS.</td></tr>
</table>

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 012 | Install a passive containment spray system. | SAMA would decrease the probability of loss of containment heat removal. | 7.36% | 10.59% | $53,000 | $530,000 | $5,800,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from loss of the torus cooling mode of RHR and RHRSW was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $5.8 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 013 | Strengthen primary and secondary containment. | SAMA would reduce the probability of containment over-pressurization failure. | 7.36% | 10.59% | $53,000 | $530,000 | $12,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contributions due to ATWS and loss of containment heat removal were eliminated. In addition, all energetic containment failure modes (DCH, steam explosion, late over-pressurization) were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities and ABWR was estimated to be $12 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 014 | Increase the depth of the concrete base mat or use an alternative concrete material to ensure melt-through does not occur. | SAMA would prevent base mat melt-through. | 0.00% | 14.41% | $64,000 | $640,000 | >$5,000,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 015 | Provide a reactor vessel exterior cooling system. | SAMA would provide the potential to cool a molten core before it causes vessel failure, if the lower head could be submerged in water. | 0.00% | 14.41% | $64,000 | $640,000 | $2,500,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $2.5 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

### Table E.2-1
### Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 016 | Construct a building connected to primary containment that is maintained at a vacuum. | SAMA would provide a method to depressurize containment and reduce fission product release. | 0.00% | 33.00% | $141,000 | $1,410,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** Releases into the reactor building were binned into the Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2 million at Peach Bottom. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 017 | 2.g. Add dedicated suppression pool cooling. | SAMA would decrease the probability of loss of containment heat removal. | 7.36% | 10.59% | $53,000 | $530,000 | $5,800,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from loss of the torus cooling mode of RHR and RHRSW was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $5.8 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 018 | 3.a. Create a larger volume in containment. | SAMA increases time before containment failure and increases time for recovery. | 7.36% | 10.59% | $53,000 | $530,000 | $8,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contributions due to ATWS and loss of containment heat removal were eliminated. In addition, all energetic containment failure modes (DCH, steam explosion, late over-pressurization) were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $8 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 019 | 3.b. Increase containment pressure capability (sufficient pressure to withstand severe accidents). | SAMA minimizes likelihood of large releases. | 7.36% | 10.59% | $53,000 | $530,000 | $12,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contributions due to ATWS and loss of containment heat removal were eliminated. In addition, all energetic containment failure modes (DCH, steam explosion, late over-pressurization) were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities and ABWR was estimated to be $12 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 020 | 3.c. Install improved vacuum breakers (redundant valves in each line). | This SAMA addresses the reliability of a vacuum breaker to reseat following a successful opening. | 0.20% | 0.66% | $4,000 | $40,000 | >$1,000,000 | Not cost effective |
| | **Basis for Conclusion:** Vacuum breaker failures and suppression pool scrubbing failures were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $1 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 021 | 3.d. Increase the temperature margin for seals. | This SAMA would reduce the potential for containment failure under adverse conditions. | 0.00% | 0.30% | $2,000 | $20,000 | $12,000,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to high temperature drywell seal failure was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities and ABWR were estimated to be 12 million and was judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA was not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 022 | 5.b/c. Install a filtered vent | SAMA would provide an alternate decay heat removal method for non-ATWS events, with fission product scrubbing. | 0.00% | 0.11% | $200 | $2,000 | $3,000,000 | Not cost effective |
|  | **Basis for Conclusion:** Successful torus venting sequences were binned into the Low-Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be $3 million. Therefore, this SAMA is not cost effective for VYNPS. |  |  |  |  |  |  |  |
| 023 | 7.a. Provide a method of drywell head flooding. | SAMA would provide intentional flooding of the upper drywell head such that if high drywell temperatures occurred, the drywell head seal would not fall. | 0.00% | 0.30% | $2,000 | $20,000 | >$1,000,000 | Not cost effective |
|  | **Basis for Conclusion:** Drywell head failures due to high temperature were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $1 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. |  |  |  |  |  |  |  |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 024 | 13.a. Use alternate method of reactor building spray. | This SAMA provides the capability to use firewater sprays in the reactor building to mitigate release of fission products into the reactor building following an accident. | 0.00% | 33.00% | $141,000 | $1,410,000 | >$2,500,000 | Not cost effective |
| | **Basis for Conclusion:** Releases into the reactor building were binned into the Low-Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 025 | 14.a. Provide a means of flooding the rubble bed. | SAMA would allow the debris to be cooled. | 0.00% | 14.41% | $64,000 | $640,000 | $2,500,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $2.5 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 026 | 14.b. Install a reactor cavity flooding system. | SAMA would enhance debris coolability, reduce core concrete interaction, and provide fission product scrubbing. | 0.00% | 14.41% | $64,000 | $640,000 | $8,750,000 | Not cost effective |
| | **Basis for Conclusion:** Containment failure due to core-concrete interactions (not including liner failures) was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at ANO-2 was estimated to be $8.75 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 027 | Add ribbing to the containment shell. | This SAMA would reduce the chance of buckling of containment under reverse pressure loading. | 0.00% | 10.59% | $53,000 | $530,000 | $12,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contributions due to ATWS and loss of containment heat removal were eliminated. In addition, all energetic containment failure modes (DCH, steam explosion, late over-pressurization) were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities and ABWR was estimated to be $12 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements Related to Enhanced AC/DC Power Reliability/Availability* | | | | | | | | |
| 028 | Provide additional DC battery capacity. | SAMA would ensure longer battery capability during an SBO, which would extend HPCI/RCIC operability and allow more time for AC power recovery. | 2.98% | 2.95% | $16,000 | $160,000 | $500,000 | Not cost effective |
| | **Basis for Conclusion:** The time available to recover offsite power before HPCI and RCIC are lost was changed from 4 hours to 24 hours during station blackout scenarios to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $500,000 by engineering judgment. Therefore, this SAMA was not cost effective for VYNPS. | | | | | | | |
| 029 | Use fuel cells instead of lead-acid batteries. | SAMA would extend DC power availability in an SBO, which would extend HPCI/RCIC operability and allow more time for AC power recovery. | 2.98% | 2.95% | $16,000 | $160,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The time available to recover offsite power before HPCI and RCIC are lost was changed from 4 hours to 24 hours during station blackout scenarios to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 030 | Provide auto-transfer of AC bus control power to a standby DC power source upon loss of the normal DC source. | SAMA would increase reliability of AC power and injection capability. | 5.17% | 5.79% | $29,000 | $290,000 | >500,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to loss of DC bus 1 was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $500,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 031 | Install a gas turbine generator. | SAMA would improve onsite AC power reliability by providing a redundant and diverse emergency power system. The use of gas fuel for a turbine generator would provide diversity plus additional redundancy. | 7.55% | 8.95% | $46,000 | $460,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the Vernon Tie was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 032 | Change procedure to bypass diesel generator trips, or change trip set-points. | SAMA would allow EDGs to operate longer. | 2.39% | 3.06% | $16,000 | $160,000 | >$250,000 | Not cost effective |
| | **Basis for Conclusion:** The probability of the EDGs failing to run was reduced by a factor of three to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $250,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 033 | 2.i. Provide 16 hour station blackout injection. | SAMA includes improved capability to cope with longer station blackout scenarios. | 2.98% | 2.95% | $16,000 | $160,000 | $500,000 | Not cost effective |
| | **Basis for Conclusion:** The time available to recover offsite power before HPCI and RCIC are lost was changed from 4 hours to 24 hours during station blackout scenarios to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $500,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 034 | 9.a. Install a steam driven turbine generator. | This SAMA would provide a steam driven turbine generator that uses reactor steam and exhausts to the suppression pool. If large enough, it could provide power to additional equipment. | 7.55% | 8.95% | $46,000 | $460,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the Vernon Tie was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 035 | 9.b. Provide an alternate pump power source. | This SAMA would provide a small, dedicated power source such as a dedicated diesel or gas turbine for the feedwater or condensate pumps so that they do not rely on offsite power. | 7.55% | 8.95% | $46,000 | $460,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the Vernon Tie was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 036 | 9.h. Install a gas turbine. | SAMA would improve onsite AC power reliability by providing a redundant and diverse emergency power system. | 7.55% | 8.95% | $46,000 | $460,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the Vernon Tie was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 037 | 9.i. Install a dedicated RHR (bunkered) power supply. | This SAMA would improve the reliability of the RHR System by enhancing the AC power supply system. | 7.55% | 8.95% | $46,000 | $460,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the Vernon Tie was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 038 | 10.a. Add a dedicated DC power supply. | This SAMA addresses the use of a diverse DC power system such as an additional battery or fuel cell for the purpose of providing motive power to certain components (e.g., RCIC). | 7.95% | 9.40% | $48,000 | $480,000 | $3,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to loss of DC bus 1, and one division of DC power (battery and bus), were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $3 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 039 | 10.b. Install additional batteries or divisions. | This SAMA addresses the use of a diverse DC power system such as an additional battery or fuel cell for the purpose of providing motive power to certain components (e.g., RCIC). | 7.95% | 9.40% | $48,000 | $480,000 | $3,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to loss of DC bus 1, and one division of DC power (battery and bus), were eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be $3 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 040 | 10.c. Install fuel cells. | SAMA would extend DC power availability in an SBO, which would extend HPCI/RCIC operability and allow more time for AC power recovery. | 2.98% | 2.95% | $16,000 | $160,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The time available to recover offsite power before HPCI and RCIC are lost was changed from 4 hours to 24 hours during station blackout scenarios to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 041 | 10.e. Extended station blackout provisions. | SAMA would extend DC power availability in an SBO, which would extend HPCI/RCIC operability and allow more time for AC power recovery. | 2.98% | 2.95% | $16,000 | $160,000 | $500,000 | Not cost effective |
| | **Basis for Conclusion:** The time available to recover offsite power before HPCI and RCIC are lost was changed from 4 hours to 24 hours during station blackout scenarios to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $500,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements in Identifying and Mitigating Containment Bypass* | | | | | | | | |
| 042 | Locate residual heat removal (RHR) inside containment. | SAMA would prevent intersystem LOCA (ISLOCA) outside containment. | 0.87% | 1.31% | $7,000 | $70,000 | >$500,000 | Not cost effective |
| | **Basis for Conclusion:** ISLOCA accident sequences were binned into the same end states as medium LOCA accident sequences to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Quad Cities was estimated to be greater than $0.5 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 043 | Increase frequency of valve leak testing. | SAMA could reduce ISLOCA frequency. | 0.83% | 1.20% | $5,000 | $50,000 | $100,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to ISLOCA was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $0.10 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 044 | Ensure all ISLOCA releases are scrubbed. | SAMA would scrub all ISLOCA releases. One example is to plug drains in the break area so that the break point would cover with water. | 0.00% | 1.20% | $5,000 | $50,000 | >$2,500,000 | Not cost effective |
| | **Basis for Conclusion:** ISLOCA sequences were binned into the Low-Low release category to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 045 | Add redundant and diverse limit switches to each containment isolation valve. | SAMA could reduce the frequency of containment isolation failure and ISLOCAs through enhanced isolation valve position indication. | 0.80% | 1.42% | $7,000 | $70,000 | >$1,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to ISLOCA was eliminated and containment isolation was made successful in the level 2 model to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at ANO-2 was estimated to be greater than $1 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 046 | 8.e. Improve MSIV design. | This SAMA would decrease the likelihood of containment bypass scenarios. | 0.20% | 0.11% | $400 | $4,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to a main steam line LOCA outside containment was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements in Reducing Internal Flooding Frequency* | | | | | | | | |
| 047 | Shield injection system electrical equipment from potential water spray. | This SAMA would reduce risk associated with internal flooding. Train A of the ECCS power cabinet, which provides power to one train of low-pressure sensors, would be impacted by flooding initiators. These low-pressure sensors provide a permissive signal, which allows the core spray and LPCI injection valves to open for RPV injection. | 4.77% | 4.91% | $26,000 | $260,000 | $250,000 | Retain |
| | **Basis for Conclusion:** Eliminated the CDF contribution due to internal flooding initiators that could impact injection system electrical equipment to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $250,000 by engineering judgment. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements Related to Feedwater/Feed and Bleed Reliability/Availability* | | | | | | | | |
| 048 | Install an independent diesel for the condensate storage tank makeup pumps. | SAMA would allow continued inventory in CST during a SBO. | 0.20% | 0.20% | $2,000 | $20,000 | $135,000 | Not cost effective |
| | **Basis for Conclusion:** As currently modeled, if CST water level is low, swapping HPCI/RCIC suction from the CST to the torus allows continued HPCI/RCIC injection. Therefore, operator failure to switchover from CST to torus was eliminated to conservatively assess the benefit of this SAMA on CDF. The cost of implementing this SAMA was estimated to be $135,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| *Improvements Related to Core Cooling System* | | | | | | | | |
| 049 | Provide an additional high pressure injection pump with independent diesel. | SAMA would reduce frequency of core melt from small LOCA and SBO sequences. | 33.40% | 28.71% | $156,000 | $1,560,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

### Table E.2-1
### Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

<table>
<tr><th>Phase II SAMA ID</th><th>SAMA</th><th>Result of Potential Enhancement</th><th>CDF Reduction</th><th>Off-Site Dose Reduction</th><th>Estimated Benefit</th><th>Upper Bound Estimated Benefit</th><th>Estimated Cost</th><th>Conclusion</th></tr>
<tr><td rowspan="2">050</td><td>Install independent AC high pressure injection system.</td><td>SAMA would allow makeup and feed and bleed capabilities during an SBO.</td><td>33.40%</td><td>28.71%</td><td>$156,000</td><td>$1,560,000</td><td>>$2,000,000</td><td>Not cost effective</td></tr>
<tr><td colspan="8"><b>Basis for Conclusion:</b> The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS.</td></tr>
<tr><td rowspan="2">051</td><td>2.a. Install a passive high pressure system.</td><td>SAMA would improve prevention of core melt sequences by providing additional high pressure capability to remove decay heat through an isolation condenser type system.</td><td>33.40%</td><td>28.71%</td><td>$156,000</td><td>$1,560,000</td><td>>$2,000,000</td><td>Not cost effective</td></tr>
<tr><td colspan="8"><b>Basis for Conclusion:</b> The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2 million at Peach Bottom. Therefore, this SAMA is not cost effective for VYNPS.</td></tr>
</table>

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 052 | 2.d. Improved high pressure systems | SAMA will improve prevention of core melt sequences by improving reliability of high pressure capability to remove decay heat. | 22.47% | 19.4% | $105,000 | $1,050,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** Assumed the CDF contribution from reducing the HPCI system failure probability by a factor of 3 was estimated to bound the potential impact of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million and is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA was not cost effective for VYNPS. | | | | | | | |
| 053 | 2.e. Install an additional active high pressure system. | SAMA will improve reliability of high-pressure decay heat removal by adding an additional system. | 33.40% | 28.71% | $156,000 | $1,560,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 054 | 8.c. Add a diverse injection system. | SAMA will improve prevention of core melt sequences by providing additional injection capabilities. | 33.40% | 28.71% | $156,000 | $1,560,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| *Improvements Related to ATWS Mitigation* | | | | | | | | |
| 055 | Increase safety relief valve (SRV) reseat reliability. | SAMA addresses the risk associated with dilution of boron caused by the failure of the SRVs to reseat after standby liquid control (SLC) injection. | 1.39% | 1.64% | $9,000 | $90,000 | $2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to stuck open relief valves was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $2 million at Peach Bottom. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 056 | 11.a. Install an ATWS sized vent. | This SAMA would provide the ability to remove reactor heat from ATWS events. | 0.00% | 0.00% | $0 | $0 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from loss of the torus cooling mode of RHR and RHRSW in ATWS event sequences was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing of this SAMA at Peach Bottom was estimated to be greater than $2 million. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 057 | 11.b. Improve ATWS coping capability. | This SAMA includes items which reduce the contribution of ATWS to core damage and release frequencies. | 2.78% | 1.75% | $11,000 | $110,000 | >$500,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from ATWS sequences was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $0.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 058 | Diversify explosive valve operation. | An alternate means of opening a pathway to the RPV for SLC system injection would improve the success probability for reactor shutdown. | 0.20% | 0.11% | $400 | $4,000 | >$200,000 | Not cost effective |
| | **Basis for Conclusion:** Common cause failure of SLC explosive valves was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $0.2 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| *Other Improvements* | | | | | | | | |
| 059 | Increase the reliability of safety relief valves by adding signals to open them automatically. | SAMA reduces the consequences of medium break LOCAs. | 3.98% | 1.75% | $12,000 | $120,000 | >$1,500,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from operator failure to open SRVs for vessel depressurization during medium LOCAs was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $1.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 060 | 8.e. Improve SRV design. | This SAMA would improve SRV reliability thus increasing the likelihood that sequences could be mitigated using low-pressure heat removal. | 21.47% | 13.43% | $78,000 | $780,000 | >$2,000,000 | Not cost effective |
| | **Basis for Conclusion:** The probability of SRV failure to open for vessel depressurization was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $2 million at Peach Bottom. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 061 | Provide self-cooled ECCS pump seals. | SAMA would eliminate ECCS dependency on the component cooling water system. | 0.60% | 0.66% | $4,000 | $40,000 | >$200,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from sequences involving RHR pump failures was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $0.2 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 062 | Provide digital large break LOCA protection. | Upgrade plant instrumentation and logic to improve the capability to identify symptoms/precursors of a large break LOCA (a leak before break). | 0.40% | 0.55% | $4,000 | $40,000 | >$100,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution due to large break LOCA was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $100,000 by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |
| 063 | Control containment venting within a narrow band of pressure. | This SAMA would establish a narrow pressure control band. This would prevent rapid containment depressurization when venting, thus avoiding adverse impact on the ability of the low pressure ECCS injection systems to take suction from the torus. | 2.39% | 3.50% | $18,000 | $180,000 | $250,000 | Not cost effective |
| | **Basis for Conclusion:** The probability of the operator failing to recognize the need to vent the torus was reduced by a factor of 3 to conservatively assess the benefit of this SAMA on CDF. The cost of implementing this SAMA was estimated to be $0.25 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

### Table E.2-1
### Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| *Improvements Related to Internal Event Model (IPE, IPE Update, EPU) Insights* | | | | | | | | |
| 064 | Provide a crosstie from the RHRSW system to RHR loop B. | This SAMA would improve injection capabilities. | 0.20% | 0.11% | $400 | $4,000 | >$500,000 | Not cost effective |
| | **Basis for Conclusion:** The CDF contribution from failure of firewater crosstie to RHRSW loop A was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be greater than $0.5 million by engineering judgment. Therefore, this SAMA is not cost effective for VYNPS. | | | | | | | |

## Table E.2-1
## Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 065 | Improve operator action: Defeat low reactor pressure interlocks to open LPCI or core spray injection valves during transients with stuck open SRVs or LOCAs in which random failures prevent all low pressure injection valves from opening. | This SAMA would reduce the core damage frequency contribution from transients with stuck open SRVs and from LOCAs. Core spray and LPCI injection valves require a low pressure permissive signal from the same two sensors to open the valves for RPV injection. | 25.84% | 27.51% | $143,000 | $1,430,000 | $50,000 | Retain |
| | **Basis for Conclusion:** The probability of the ECCS low pressure permissives failing was eliminated to conservatively assess the benefit of this SAMA on CDF. The cost of implementing this SAMA was estimated to be $50,000 by engineering judgment. | | | | | | | |

### Table E.2-1
### Summary of Phase II SAMA Candidates Considered in Cost-Benefit Evaluation (Continued)

| Phase II SAMA ID | SAMA | Result of Potential Enhancement | CDF Reduction | Off-Site Dose Reduction | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 066 | Install a bypass switch to bypass the low reactor pressure interlocks of LPCI or core spray injection valves. | This SAMA would reduce the core damage frequency contribution from transients with stuck open SRVs and from LOCAs. Core spray and LPCI injection valves require a low pressure permissive signal from the same two sensors to open the valves for RPV injection. | 25.84% | 27.51% | $143,000 | $1,430,000 | $1,000,000 | Retain |
| | **Basis for Conclusion:** The probability of the ECCS low pressure permissives failing was eliminated to conservatively assess the benefit of this SAMA on CDF. The cost of implementing this SAMA at Dresden was estimated to be $1 million. | | | | | | | |

## Table E.2-2
## Sensitivity Analysis Results

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 1 | 8.a. Add a service water pump | $12,000 | $120,000 | $5,900,000 | $14,000 | $140,000 | $16,000 | $160,000 |
| 2 | Provide a redundant train/ means of EDG Room ventilation | $47,000 | $470,000 | $1,000,000 | $56,000 | $560,000 | $64,000 | $640,000 |
| 3 | Add a diesel building high temperature alarm, or redundant louver and thermostat | $16,000 | $160,000 | >$250,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 4 | Install an independent method of suppression pool cooling | $53,000 | $530,000 | $5,800,000 | $62,000 | $620,000 | $72,000 | $720,000 |
| 5 | Install a filtered containment vent to provide fission product scrubbing.<br>Option 1: Gravel Bed Filter<br>Option 2: Multiple Venturi Scrubber | $200 | $2,000 | $3,000,000 | $200 | $2,000 | $300 | $3,000 |
| 6 | Install a containment vent large enough to remove ATWS decay heat | $0 | $0 | >$2,000,000 | $0 | $0 | $0 | $0 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 7 | Create a large concrete crucible with heat removal potential under the basemat to contain molten core debris | $64,000 | $640,000 | >$100 million | $73,000 | $730,000 | $89,000 | $890,000 |
| 8 | Create a water-cooled rubble bed on the pedestal | $64,000 | $640,000 | $19,000,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 9 | Provide modification for flooding the drywell head | $2,000 | $20,000 | >$1,000,000 | $2,000 | $20,000 | $2,000 | $20,000 |
| 10 | Enhance fire protection system and/or standby gas treatment system hardware and procedures | $141,000 | $1,410,000 | >$2,500,000 | $161,000 | $1,610,000 | $198,000 | $1,980,000 |
| 11 | Create a core melt source reduction system | $64,000 | $640,000 | >$5,000,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 12 | Install a passive containment spray system | $53,000 | $530,000 | $5,800,000 | $62,000 | $620,000 | $72,000 | $720,000 |
| 13 | Strengthen primary and secondary containment | $53,000 | $530,000 | $12,000,000 | $62,000 | $620,000 | $72,000 | $720,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 14 | Increase the depth of the concrete basemat or use an alternative concrete material to ensure melt-through does not occur | $64,000 | $640,000 | >$5,000,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 15 | Provide a reactor vessel exterior cooling system | $64,000 | $640,000 | $2,500,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 16 | Construct a building to be connected to primary/ secondary containment that is maintained at a vacuum | $141,000 | $1,410,000 | >$2,000,000 | $161,000 | $1,610,000 | $198,000 | $1,980,000 |
| 17 | 2.g. Add a dedicated suppression pool cooling | $53,000 | $530,000 | $5,800,000 | $62,000 | $620,000 | $72,000 | $720,000 |
| 18 | 3.a. Create a larger volume in containment | $53,000 | $530,000 | $8,000,000 | $62,000 | $620,000 | $72,000 | $720,000 |
| 19 | 3.b. Increased containment pressure capability (sufficient pressure to withstand severe accidents) | $53,000 | $530,000 | $12,000,000 | $62,000 | $620,000 | $72,000 | $720,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 20 | 3.c. Improved vacuum breakers (redundant valves in each line) | $4,000 | $40,000 | >$1,000,000 | $4,000 | $40,000 | $5,000 | $50,000 |
| 21 | 3.d. Increased temperature margin for seals | $2,000 | $20,000 | $12,000,000 | $2,000 | $20,000 | $2,000 | $20,000 |
| 22 | 5.b/c. Install a filtered vent | $200 | $2,000 | $3,000,000 | $200 | $2,000 | $300 | $3,000 |
| 23 | 7.a. Provide a method of drywell head flooding | $2,000 | $20,000 | >$1,000,000 | $2,000 | $20,000 | $2,000 | $20,000 |
| 24 | 13.a.Use alternate method of reactor building spray. | $141,000 | $1,410,000 | >$2,500,000 | $161,000 | $1,610,000 | $198,000 | $1,980,000 |
| 25 | 14.a. Provide a means of flooding the rubble bed | $64,000 | $640,000 | $2,500,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 26 | 14.b. Install a reactor cavity flooding system | $64,000 | $640,000 | $8,750,000 | $73,000 | $730,000 | $89,000 | $890,000 |
| 27 | Add ribbing to the containment shell | $53,000 | $530,000 | $12,000,000 | $62,000 | $620,000 | $72,000 | $720,000 |
| 28 | Provide additional DC battery capacity | $16,000 | $160,000 | $500,000 | $19,000 | $190,000 | $22,000 | $220,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 29 | Use fuel cells instead of lead-acid batteries | $16,000 | $160,000 | >$2,000,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 30 | Provide auto-transfer of AC bus control power to a standby DC power source upon loss of the normal DC source. | $29,000 | $290,000 | >$500,000 | $35,000 | $350,000 | $40,000 | $400,000 |
| 31 | Install a gas turbine generator | $46,000 | $460,000 | >$2,000,000 | $54,000 | $540,000 | $62,000 | $620,000 |
| 32 | Change procedure to bypass diesel generator trips, or change trip set-points | $16,000 | $160,000 | >$250,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 33 | 2.i. Provide 16 hour station blackout injection | $16,000 | $160,000 | $500,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 34 | 9.a. Install a steam driven turbine generator | $46,000 | $460,000 | >$2,000,000 | $54,000 | $540,000 | $62,000 | $620,000 |
| 35 | 9.b. Provide an alternate pump power source | $46,000 | $460,000 | >$2,000,000 | $54,000 | $540,000 | $62,000 | $620,000 |
| 36 | 9.h. Install a gas turbine | $46,000 | $460,000 | >$2,000,000 | $54,000 | $540,000 | $62,000 | $620,000 |
| 37 | 9.i. Install a dedicated RHR (bunkered) power supply | $46,000 | $460,000 | >$2,000,000 | $54,000 | $540,000 | $62,000 | $620,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 38 | 10.a. Add a dedicated DC power supply | $48,000 | $480,000 | $3,000,000 | $56,000 | $560,000 | $65,000 | $650,000 |
| 39 | 10.b. Install additional batteries or divisions | $48,000 | $480,000 | $3,000,000 | $56,000 | $560,000 | $65,000 | $650,000 |
| 40 | 10.c. Install Fuel Cells | $16,000 | $160,000 | >$2,000,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 41 | 10.e. Extended station blackout provisions | $16,000 | $160,000 | $500,000 | $19,000 | $190,000 | $22,000 | $220,000 |
| 42 | Locate residual heat removal (RHR) inside of containment | $7,000 | $70,000 | >$500,000 | $8,000 | $80,000 | $9,000 | $90,000 |
| 43 | Increase frequency of valve leak testing | $5,000 | $50,000 | >$100,000 | $6,000 | $60,000 | $7,000 | $70,000 |
| 44 | Ensure all ISLOCA releases are scrubbed | $5,000 | $50,000 | >$2,500,000 | $5,000 | $50,000 | $6,000 | $60,000 |
| 45 | Add redundant and diverse limit switches to each containment isolation valve | $7,000 | $70,000 | >$1,000,000 | $8,000 | $80,000 | $9,000 | $90,000 |
| 46 | 8.e. Improved MSIV design | $400 | $4,000 | >$2,000,000 | $500 | $5,000 | $500 | $5,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 47 | Shield injection system electrical equipment from potential water spray | $26,000 | $260,000 | $250,000 | $31,000 | $310,000 | $35,000 | $350,000 |
| 48 | Install an independent diesel for the condensate storage tank makeup pumps | $2,000 | $20,000 | $135,000 | $2,000 | $20,000 | $2,000 | $20,000 |
| 49 | Provide an additional high pressure injection pump with independent diesel | $156,000 | $1,560,000 | >$2,000,000 | $185,000 | $1,850,000 | $208,000 | $2,080,000 |
| 50 | Install independent AC high pressure injection system | $156,000 | $1,560,000 | >$2,000,000 | $185,000 | $1,850,000 | $208,000 | $2,080,000 |
| 51 | 2.a. Install a passive high pressure system | $156,000 | $1,560,000 | >$2,000,000 | $185,000 | $1,850,000 | $208,000 | $2,080,000 |
| 52 | 2.d. Improved high pressure systems | $105,000 | $1,050,000 | >$2,000,000 | $125,000 | $1,250,000 | $141,000 | $1,410,000 |
| 53 | 2.e. Install an additional active high pressure system | $156,000 | $1,560,000 | >$2,000,000 | $185,000 | $1,850,000 | $208,000 | $2,080,000 |
| 54 | 8.c. Add a diverse injection system | $156,000 | $1,560,000 | >$2,000,000 | $185,000 | $1,850,000 | $208,000 | $2,080,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 55 | Increase the safety relief valve (SRV) reseat reliability | $9,000 | $90,000 | $2,000,000 | $10,000 | $100,000 | $12,000 | $120,000 |
| 56 | 11.a. Install an ATWS sized vent | $0 | $0 | >$200,000 | $0 | $0 | $0 | $0 |
| 57 | 11.b. Improved ATWS coping capability | $11,000 | $110,000 | >$500,000 | $13,000 | $130,000 | $14,000 | $140,000 |
| 58 | Diversify the explosive valve operation | $400 | $4,000 | >$200,000 | $500 | $5,000 | $500 | $5,000 |
| 59 | Increase the reliability of safety relief valves by adding signals to open them automatically | $12,000 | $120,000 | >$1,500,000 | $14,000 | $140,000 | $15,000 | $150,000 |
| 60 | 8.e. Improved SRV design | $78,000 | $780,000 | >$2,000,000 | $94,000 | $940,000 | $103,000 | $1,030,000 |
| 61 | Provide self-cooled ECCS pump seals | $4,000 | $40,000 | >$200,000 | $5,000 | $50,000 | $5,000 | $50,000 |
| 62 | Provide digital large break LOCA protection | $4,000 | $40,000 | >$100,000 | $4,000 | $40,000 | $5,000 | $50,000 |

## Table E.2-2
## Sensitivity Analysis Results (Continued)

| Phase II SAMA ID | SAMA | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Cost | Estimated Benefit | Upper Bound Estimated Benefit | Estimated Benefit | Upper Bound Estimated Benefit |
|---|---|---|---|---|---|---|---|---|
| | | Base Line | Base Line | | Sensitivity Case 1 | Sensitivity Case 1 | Sensitivity Case 2 | Sensitivity Case 2 |
| 63 | Control containment venting within a narrow band of pressure | $18,000 | $180,000 | $250,000 | $21,000 | $210,000 | $24,000 | $240,000 |
| 64 | Provide a crosstie from the RHRSW system to RHR loop B. | $400 | $4,000 | >$500,000 | $500 | $5,000 | $500 | $5,000 |
| 65 | Improve operator action: Defeat the low reactor pressure interlocks to open LPCI or core spray injection valves during the transients with stuck open SRVs or LOCAs in which random failures prevent all low pressure injection valves from opening | $143,000 | $1,430,000 | $50,000 | $168,000 | $1,680,000 | $192,000 | $1,920,000 |
| 66 | Install a bypass switch to bypass the low reactor pressure interlocks of LPCI or core spray injection valves | $143,000 | $1,430,000 | $1,000,000 | $168,000 | $1,680,000 | $192,000 | $1,920,000 |

# Attachment F

## Ecological Studies of the Connecticut River (2004)