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Severe Accident Mitigation Alternatives (SAMA) Analysis

Guidance Document

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Nuclear Energy Institute

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NOTICE

EXECUTIVE SUMMARY

This document provides a template for completing the severe accident mitigation alternatives (SAMA) analysis in support of license renewal. Its purpose is to identify the information that should be included in the SAMA portion of a license renewal application environmental report to reduce the necessity for Nuclear Regulatory Commission (NRC) requests for additional information (RAIs). The method described relies upon NUREG/BR-0184 regulatory analysis techniques, is a result of experience gained through past SAMA analyses, and incorporates insights gained from review of NRC evaluations of SAMA analyses and associated RAIs.

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List of Acronyms

Acronym	Definition
AC	alternating current
AMSAC	ATWS mitigation system actuation circuitry
ATWS	anticipated transient without scram
BWR	boiling water reactor
CCW	component cooling water
CDF	core damage frequency
CRD	control rod drive
CST	condensate storage tank
CS	containment spray
DC	direct current
ECCS	emergency core cooling system
EDG	emergency diesel generator
EOP	emergency operating procedure
EPRI	Electric Power Research Institute
FIVE	fire-induced vulnerability evaluation
HPCI	high pressure coolant injection
HRA	human reliability analysis
HVAC	heating, ventilation, and air conditioning
IPE	individual plant examination
IPEEE	IPE – external events
ISLOCA	interfacing systems loss of coolant accident
LERF	large, early release frequency
LOCA	loss of coolant accident
LOOP	loss of off-site power

Acronym	Definition
LPCI	low pressure coolant injection
MACCS2	MELCOR accident consequence code system
MCC	motor control center
MSIV	main steam isolation valve
NPSH	net positive suction head
NRC	Nuclear Regulatory Commission
PSA	probabilistic safety assessment
PWR	pressurized water reactor
RAI	request for additional information
RCIC	reactor core isolation cooling
RHR	residual heat removal
RHRSW	residual heat removal service water
RPV	reactor pressure vessel
RWCU	reactor water cleanup
SAG	severe accident guidelines
SAMA	severe accident mitigation alternatives
SAMDA	severe accident mitigation design alternatives
SBO	station black-out
SLC	standby liquid control
SMA	seismic margins analysis
SRV	safety relief valve
SW	service water
TBCCW	turbine building closed cooling water
USI	unresolved safety issue

SEVERE ACCIDENT MITIGATION ALTERNATIVES (SAMA) ANALYSIS

GUIDANCE DOCUMENT

1 INTRODUCTION

This document provides a template for completing the severe accident mitigation alternatives (SAMA) analysis in support of license renewal. Its purpose is to identify the information that should be included in the SAMA portion of a license renewal application environmental report to reduce the necessity for Nuclear Regulatory Commission (NRC) requests for additional information (RAIs). The method described relies upon NUREG/BR-0184 regulatory analysis techniques, is a result of experience gained through past SAMA analyses, and incorporates insights gained from review of NRC evaluations of SAMA analyses and associated RAIs.

1.1 PURPOSE

The purpose of the analysis is to identify SAMA candidates that have the potential to reduce severe accident risk and to determine if implementation of each SAMA candidate is cost-beneficial.

1.2 REQUIREMENTS

- **10 CFR 51.53(c)(3)(ii)(L)**
- **The environmental report must contain a consideration of alternatives to mitigate severe accidents "...if the staff has not previously considered severe accident mitigation alternatives for the applicant's plant in an environmental impact statement or related supplement or in an environment assessment..."**
- **10 CFR 51, Subpart A, Appendix B, Table B-1, Issue 76**
- **"...The probability weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts from severe accidents are small for all plants. However, alternatives to mitigate severe accidents must be considered for all plants that have not considered such alternatives...."**

2 METHOD

The SAMA analysis consists of the following steps.

- **Determine Severe Accident Risk**

  Level 1 and 2 Probabilistic Safety Assessment (PSA) Model

  Use the plant-specific PSA model (Section 3.1 through Section 3.3) as input to a Level 3 PSA analysis. Incorporate external event contributions as described in Section 3.1.2.

  Level 3 PSA Analysis

  Use Level 1 and 2 PSA output and site-specific meteorology, demographic, land use, and emergency response data as input for a Level 3 PSA (Section 3.4). Estimate the severe accident risk i.e., off-site dose and economic impacts of a severe accident.

- **Determine Cost of Severe Accident Risk / Maximum Benefit** – Use NRC regulatory analysis techniques to estimate the cost of severe accident risk. Estimate the maximum benefit that a SAMA could achieve if it eliminated all risk i.e., the maximum benefit (Section 4).

- **SAMA Identification** – Identify potential SAMA candidates (that prevent core damage and that prevent significant releases from containment) from the PSA model, Individual Plant Examination (IPE) and IPE – External Events (IPEEE) recommendations, and industry documentation (Section 5). As has been demonstrated by past SAMA analyses, SAMA candidates are not likely to prove cost-beneficial if they only mitigate the consequences of events that present a low risk to the plant. Therefore, PSA importance analyses play a key role in the SAMA identification process.

- **Preliminary Screening (Phase I SAMA Analysis)** – Screen out SAMA candidates that are not applicable to the plant design, candidates that have already been implemented or whose benefits have been achieved at the plant using other means, and candidates whose roughly-estimated cost exceeds the maximum benefit. PSA insights may be used to screen SAMA candidates that do not address significant contributors to risk in this phase (Section 6).

- **Final Screening (Phase II SAMA Analysis)** – Estimate the benefit of severe accident risk reduction to each remaining SAMA candidate and compare to an implementation cost estimate to determine net cost-benefit (Section 7). In an implementation cost estimate, all costs associated with the SAMA should be considered including design, engineering, safety analysis, installation, and long-term maintenance, calibrations, training, etc. that will be required as a result of the change. As has been demonstrated by past SAMA analyses, cost-beneficial SAMAs are most likely limited to procedure changes and minimal hardware changes.

Sensitivity Analysis – Evaluate how changes in SAMA analysis assumptions and uncertainties would affect the cost-benefit analysis (Section 8).

- **Identify Conclusions** – Summarize results and identify conclusions (Section 9). List potentially cost-beneficial SAMA candidates.

The remainder of this document describes these steps in more detail and indicates associated information that should be included in the SAMA portion of the license renewal environmental report. Figure 1 provides a graphical representation of the SAMA analysis process.

3 SEVERE ACCIDENT RISK

Describe the PSA models used to calculate severe accident risk. Describe the Level 1 PSA model (internal and external), the Level 2 PSA model, PSA model review history, and the Level 3 PSA model, as shown in Section 3.1 through Section 3.4. Include results of the severe accident risk calculation as shown in Section 3.5.

For multi-unit sites, provide either separate results for each unit or results for a single unit with rationale for why the single analysis is representative or bounding for the other unit(s).

3.1 LEVEL 1 PSA MODEL

Level 1 PSA models determine CDF based on initiating event analysis, scenario development, system analyses, and human-factor evaluations.

3.1.1 INTERNAL EVENTS

3.1.1.1 Description of Level 1 Internal Events PSA Model

Identify and describe the Level 1 internal events PSA model used for the SAMA analysis, including the model freeze date. If different PSA versions are used for identifying SAMAs (Section 5.1) and for the benefit analysis (Section 7.1), the impact of using a later version should be described.

For example,

> *The Level 1 Internal Events PSA Model used for the SAMA analysis was the most recent internal events risk model (Revision xxx) that contains modeling of all plant changes implemented up to [date], uses failure and unavailability data to the same date, and resolves industry peer review comments on a previous revision of the model.*

Provide a breakdown of the internal events CDF by major contributors, initiators, or accident classes. Include contributions to core damage frequency from station blackout (single unit and dual unit) and anticipated transient without SCRAM events. Candidate SAMAs should concentrate on these events. Table 1 shows a typical accident class distribution.

Provide Level 1 internal events importance measures. This list may be combined with an evaluation of applicable SAMA candidates as shown in Table 9.

If applicable, identify changes to the Level 1 internal events PSA model made to accommodate the SAMA analysis.

3.1.1.2 Level 1 PSA Model Changes since IPE Submittal

Describe major changes to the Level 1 internal events PSA model since the IPE submittal and the impact these changes have had on CDF.

Discuss changes to the plant, such as power uprate or steam generator replacement that are planned or have occurred since the model freeze date. Indicate if the model used for the SAMA analysis addresses these changes. If the model used for the SAMA analysis does not address these changes, include a qualitative discussion of the impact of the changes on the SAMA analysis. If desired, sensitivity analyses may be performed to support the discussion (Section 8).

3.1.2 EXTERNAL EVENTS

The IPEEE identified the highest risk externally initiated accident sequences and potential means of reducing the risk posed by those sequences. Typically, the following external events were evaluated.

- Internal fires
- Seismic events
- Other external events such as high wind events, external flooding, transportation and nearby facility accidents

The type of information available for these initiators varies by the type of risk analysis performed for the IPEEE. For instance, a fire or seismic analysis performed using PSA modeling techniques produces quantitative results. However, due to differences in assumptions, model techniques, uncertainties (e.g., related to initiating event frequencies and human actions), care should be taken when comparing quantified external events with the results of the best-estimate internal events analysis. Furthermore, seismic margins analysis (SMA) does not produce a CDF (i.e., is a qualitative analysis) and is predicated on the ability to evaluate the seismic durability of equipment required to safely shut the plant down. The results of this kind of analysis do not directly lend themselves to the frequency-based SAMA analysis. Also, a fire analysis using the Electric Power Research Institute (EPRI) Fire-Induced Vulnerability Evaluation (FIVE) method produces fire zone CDF values that are conservatively high and not suitable for comparison with best-estimate internal events CDF values. As a result, each of the external event contributors must be considered in a manner suiting the type of risk analysis performed.

For each external event, summarize the risk analysis method and subsequent revisions as shown in Section 3.1.2.1 through Section 3.1.2.3. Discuss recommendations to reduce risk due to each external event, and indicate whether or not they have been implemented. Potential improvements from the IPEEE and improvements to address USI A-46 outliers that have not been implemented should be included in the list of Phase I SAMA candidates (Section 5.3). Describe the method used to quantitatively incorporate external event severe accident risk in the SAMA analysis, as shown in Section 3.1.2.4.

3.1.2.1 Internal Fires

3.1.2.1.1 Risk Analysis

Provide a brief discussion of the risk analysis method used for the IPEEE. Indicate if a fire PSA model was created, or if the EPRI FIVE method was used. If the EPRI FIVE method was used, identify first-pass assumptions and screening criteria (e.g., 1.0E-06) and discuss methods used to evaluate zones that did not screen on the first pass.

Indicate if the fire risk analysis has been updated since the IPEEE. If so, provide revised fire zone CDF values.

If the EPRI FIVE method was used, the results are conservative and not comparable to internal events core damage frequencies. If a fire PSA model was created, the results should be less conservative than if the FIVE method had been used, but caution must be exercised when making comparisons to best-estimate values. Discussion of specific conservatisms may be provided, as in the following examples.

Initiating Events:	*The frequency of fires and their severity are generally conservatively overestimated. A revised NRC fire events database indicates a trend toward lower frequency and less severe fires. This trend reflects improved housekeeping, reduction in transient fire hazards, and other improved fire protection steps at utilities.*
System Response:	*Fire protection measures such as sprinklers, CO_2, and fire brigades may be given minimal (conservative) credit in their ability to limit the spread of a fire.* *Cable routings are typically characterized conservatively because of lack of data regarding the routing of cables or lack of analytic modeling to represent the different routings. This leads to limited credit for balance of plant systems that are important in core damage mitigation.*
Sequences:	*Sequences may subsume a number of fire scenarios to reduce the analytical burden. Subsuming initiators and sequences is done to envelope those sequences included. This results in additional conservatism.*
Fire Modeling:	*Fire damage and fire spread are conservatively characterized. Fire modeling presents bounding approaches regarding the immediate effects of a fire and fire propagation (e.g., all components in a fire zone are failed by a fire in the zone, or all cables in a tray are failed for a cable tray fire).*
HRA:	*There is little industry experience with crew actions following fires. This has led to conservative characterization of crew actions in fire analyses. Because CDF is strongly correlated with crew actions, this conservatism has a profound effect on fire results.*
Level of Detail:	*Fire analyses may have a reduced level of detail in mitigation of the initiating event and subsequent system damage.*

Quality of Model: *The peer review process for fire analyses is less well developed than for internal events PSAs. For example, no industry process, such as NEI 00-02, exists for the structured peer review of a fire PSA.*

Recommended Improvements

Discuss existing fire prevention and mitigation features and recommended hardware or procedure changes (including those from the IPEEE and subsequent fire evaluations) to reduce risk in the dominant fire zones.

For example, the dominant fire zones may be monitored by a detection system that alarms in the control room, and they may be equipped with automatic suppression systems. Electrical cabinets in the zones may use rated cables that are difficult to ignite and slow to propagate. Radiant energy shields may be used to prevent a fire on one component from disabling redundant components. Also, hot work permit and transient combustible loading programs reduce possible ignition sources and the fire protection program maximizes the availability of fire protection equipment. If this discussion duplicates information provided to NRC for the IPEEE, reference to docketed correspondence may be substituted.

Potential improvements to reduce risk in the dominant fire zones (including those from the internal fire portion of the IPEEE and subsequent fire evaluations) should be included in the list of Phase I SAMA candidates (Section 5.3).

3.1.2.2 Seismic Events

3.1.2.2.1 Risk Analysis

Provide a brief discussion of the risk analysis method used for the IPEEE. Indicate if a seismic PSA model was created, or if the EPRI SMA method was used.

Indicate if the seismic risk analysis has been updated since the IPEEE. If so, provide revised results.

If a seismic PSA model was created, discuss whether the seismic CDF value is conservative or best-estimate. Discussion of specific conservatisms may be provided as in the examples for internal fires.

Recommended Improvements

Discuss enhancements (including those recommended in the IPEEE) to ensure equipment on the safe shutdown list is capable of withstanding a review level earthquake. Discuss USI A-46 resolution and whether all identified outliers have been addressed. If this discussion duplicates information provided to NRC for the IPEEE, reference to docketed correspondence may be substituted.

Potential improvements to minimize seismic risk (including those from the seismic events portion of the IPEEE, subsequent seismic evaluations, and improvements to address unresolved USI A-46 outliers) should be included in the list of Phase I SAMA candidates (Section 5.3).

3.1.2.3 Other External Events

3.1.2.3.1 Risk Analysis

Provide a brief discussion of the risk analysis method used for the IPEEE and indicate if the analysis has been updated since the IPEEE. If so, provide revised results.

Discussion of specific conservatisms may be provided as in the examples for internal fires.

Recommended Improvements

Describe existing prevention and mitigation features and recommended hardware or procedure changes from the IPEEE to reduce risk from external events caused by high winds, external flooding and transportation accidents, as applicable. If this discussion duplicates information provided to NRC for the IPEEE, reference to docketed correspondence may be substituted.

Potential improvements to reduce risk from other external events (including those from the other events portion of the IPEEE) should be included in the list of Phase I SAMA candidates (Section 5.3).

3.1.2.4 External Event Severe Accident Risk

Discuss the method used to address external event risk. As discussed previously, the preferred method is dependent on the risk analysis methods available for the plant. IPEEE reports typically concluded that the risk from other external events (i.e., not fire and seismic events) is less than 1E-06/rx-yr. Therefore, these events are typically not the dominant contributors to external event risk and quantitative analysis of these events is not practical. Thus, the various combinations of internal fire and seismic risk analysis are discussed below.

FIVE and SMA Methods

The SMA method does not provide a quantitative result, but resolution of outliers assures that the seismic risk is low and further cost-beneficial seismic improvements are not expected. Therefore, the FIVE results may be used as a measure of total external events risk.

Estimate the degree of conservatism for the external events risk. Since a FIVE method fire analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower fire CDF. NRC staff has accepted that a more realistic fire CDF may be a factor of three less than the screening value obtained from a FIVE analysis (Reference 1). Technical justification should be provided for selection of a reduction factor.

Reduce the fire CDF by an appropriate factor and compare to the internal events CDF to estimate an external events multiplier.

For example,

> *Assume that the total of the unscreened fire zone CDFs from the FIVE analysis is 2.7E-05/rx-yr. Also, assume that the internal event CDF is 8E-06/rx-yr.*
>
> *Given a factor of three reduction, the resulting fire CDF would be about 9E-06/rx-year, which is the same order of magnitude as the internal events CDF. This would justify use of an external events multiplier of two.*

Use the external events multiplier on the maximum benefit (Section 4.5) and on the upper bound estimated benefits for individual SAMA candidates during the Phase II screening (Section 7).

<u>Fire PSA and SMA Method</u>

The SMA method does not provide a quantitative result, but resolution of outliers assures that the seismic risk is low and further cost-beneficial seismic improvements are not expected. Therefore, the fire PSA results may be used as a measure of total external events risk.

Estimate the degree of conservatism for the external events risk. If the fire PSA analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower fire CDF. Technical justification should be provided supporting determination of a reduction factor to obtain a more realistic fire CDF.

Use the reduction factor on the baseline fire PSA results and compare to the internal events CDF to obtain an external events multiplier as described for the FIVE method. Use the external events multiplier on the maximum benefit (Section 4.5) and on the upper bound estimated benefits for individual SAMA candidates during the Phase II screening (Section 7).

<u>FIVE Method and Seismic PSA</u>

Since the FIVE method and seismic PSA provide quantitative results, the results may be combined to represent the total external events risk.

Estimate the degree of conservatism for the external events risk. Since a FIVE method fire analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower fire CDF. NRC staff has accepted that a more realistic fire CDF may be a factor of three less than the screening value obtained from a FIVE analysis (Reference 1). Also, if the seismic PSA analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower seismic CDF. Technical justification should be provided supporting determination of reduction factors to obtain more realistic fire and seismic CDF.values

Reduce the fire and seismic CDF values by their factors, combine to obtain a total external events CDF, and compare to the internal events CDF to estimate an external events multiplier.

For example,

> *Assume that the total of the unscreened fire zone CDFs from the FIVE analysis is 2.7E-05/rx-yr. Assume that the seismic PSA resulted in a CDF of 3E-6/rx-yr; which was estimated to be a factor of four higher than a best-estimate of seismic CDF. Also, assume that the internal event CDF is 8E-06/rx-yr.*
>
> *Given a factor of three reduction, the resulting fire CDF would be about 9E-06/rx-year.*
>
> *Given a factor of four reduction, the resulting seismic CDF would be about 8E-7/rx-yr.*
>
> *Thus, the total external events risk would be 9.8E-6, which is the same order of magnitude as the internal events CDF. This would justify use of an external events multiplier of two.*

Use the external events multiplier on the maximum benefit (Section 4.5) and on the upper bound estimated benefits for individual SAMA candidates during the Phase II screening (Section 7).

<u>Fire PSA and Seismic PSA</u>

Since fire PSA and seismic PSA provide quantitative results, the results may be combined to represent the total external events risk.

Estimate the degree of conservatism for the external events risk. If the fire PSA analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower fire CDF. Technical justification should be provided supporting determination of a reduction factor to obtain a more realistic fire CDF. Also, if the seismic PSA analysis contains numerous conservatisms, as discussed previously, a more realistic assessment could result in a substantially lower seismic CDF. Technical justification should be provided supporting determination of a reduction factor to obtain a more realistic seismic CDF.

Reduce the fire and seismic CDF values by their factors, combine to obtain a total external events CDF, and compare to the internal events CDF to estimate an external events multiplier (as in the above example). Use the external events multiplier on the maximum benefit (Section 4.5) and on the upper bound estimated benefits for individual SAMA candidates during the Phase II screening (Section 7).

3.2 LEVEL 2 PSA MODEL

Level 2 PSA models determine release frequency, severity, and timing based on Level 1 PSA, containment performance, and accident progression analyses.

3.2.1 DESCRIPTION OF LEVEL 2 PSA MODEL

Identify and describe the Level 2 PSA model used for the SAMA analysis, including the model freeze date.

For example,

> *The Level 2 PSA model used for the SAMA analysis was the most recent model (Revision xxx) that contains modeling of all plant changes implemented up to [date], uses failure and unavailability data to the same date and resolves industry peer review comments on a previous revision of the model.*

Provide a description of the release severity and timing scheme. This may be in paragraph form or like the example shown in Table 2.

Provide a table or matrix describing the mapping of Level 1 accident sequences into Level 2 release categories and a description of the representative release sequences.

Provide the release category frequencies and fission product release characteristics (release fractions, timing, and energy). If the sum of release frequencies does not equal the total CDF, an explanation should be provided. Table 3 displays sample release category frequencies and release fractions.

Provide Level 2 importance measures. These measures should not only be based on consideration of large early release frequency contributors, but should consider other release categories that are major contributors to population dose. This list may be combined with an evaluation of applicable SAMA candidates as shown in Table 9.

If applicable, identify changes to the Level 2 PSA model made to accommodate the SAMA analysis.

3.2.2 LEVEL 2 PSA MODEL CHANGES SINCE IPE SUBMITTAL

Describe changes to major modeling assumptions, containment event tree structure, accident progression / source term calculations, or binning of endstates in the Level 2 PSA model since the IPE submittal and the impact these changes have had on large, early release frequency (LERF).

Discuss changes to the plant, such as power uprate or steam generator replacement that are planned or have occurred since the model freeze date. Indicate if the model used for the SAMA analysis addresses these changes. If the model used for the SAMA analysis does not address these changes, include a qualitative discussion of the impact of the changes on the SAMA analysis. If desired, sensitivity analyses may be performed to support the discussion (Section 8).

3.3 MODEL REVIEW SUMMARY

Provide a brief description of in-house and peer reviews of the Level 1 and 2 PSA models that have been performed since the IPE. For example,

> *The model has been updated several times since completion of the IPE to maintain it consistent with the as-built plant, to incorporate improved thermal hydraulic results, and to incorporate PSA improvements. The updates have involved a cooperative effort including both licensee personnel and PSA consultant support. In each of the updates, an independent review of revisions to the PSA model is performed. The PSA model and results have been maintained as plant calculations or engineering reports. As part of each major update, in order to ensure adequacy of the updated model, an expert panel reviews the PSA model results. The panel is typically composed of experienced personnel from various plant organizations, including Operations, System Engineering, Design Engineering, Safety Analysis, and PSA.*
>
> *An Owner's Group peer review of the model was conducted in [date]. The results of this review are described below.*
>
> *In addition, Nuclear Regulatory Commission (NRC) Staff reviewed results of the prior version of the model as part of the benchmarking of the Significance Determination Program Notebook. The Staff and its contractors conducted the review at the site during [date]. The Staff further reviewed the model, primarily the human reliability analysis and fire risk analysis, as part of its review of the risk impact of extended power uprate. This review included a site visit in [date].*

Provide a brief description of the overall findings of the owner's group peer review. Discuss significant findings or observations and indicate if resolution was included in the model used for the SAMA analysis. If the model used for the SAMA analysis does not address significant findings or observations, include at least a qualitative discussion of the impact of the findings or observations on the SAMA analysis. Sensitivity analyses may be performed to support the discussion (Section 8).

3.4 LEVEL 3 PSA MODEL

Level 3 PSA models determine off-site dose and economic impacts of severe accidents based on Level 1 PSA results, Level 2 PSA results, atmospheric transport, mitigating actions, dose accumulation, early and latent health effects, and economic analyses.

Provide a description of the Level 3 analysis method and input data. In many SAMA analyses, the MELCOR Accident Consequence Code System (MACCS2) (Reference 2) is used to calculate the off-site consequences of a severe accident. Some SAMA analyses have used previous Level 3 analyses such as those included in NUREG/CR-4551. Description of the method may be no more than a reference to the document describing the method. However, the various input parameters and associated assumptions must still be described.

The following sections describe input data if MACCS2 (Reference 2) is the analysis tool. If another code is used, similar description of the input parameters must be documented.

3.4.1 POPULATION DISTRIBUTION

Provide a predicted population within a 50-mile radius of the site. The predicted population distribution may be obtained by extrapolating publicly available census data. Transient population included in the site emergency plan should be added to the census data before extrapolation. Explain why the population distribution used in the analysis is appropriate and justify the method used for population extrapolation. Typically, with increasing population, the predicted population is estimated for a year within the second half of the period of extended operation. Extrapolation to a later date, and therefore a larger population, adds conservatism to the analysis. Of course, if a population reduction is projected, extrapolation to an earlier date would be more reasonable.

The population distribution should be by location in a grid consisting of sixteen directional sectors, the first of which is centered on due north, the second on 22.5 degrees east of north, and so on. The direction sectors should be divided into a number of radial intervals extending out to at least 50 miles. A sample population distribution is provided in Table 4.

3.4.2 ECONOMIC DATA

Provide economic data from publicly available information (e.g., from the U.S. Census Bureau, U.S. Department of Agriculture, or state tax office) on a region-wide basis. Economic data should be expressed in today's dollars (dollars for the year in which the SAMA analysis is being performed), not extrapolated to the end of the period of extended operation. Economic data from a past census can be converted to today's dollars using the ratio of current to past consumer price indices.

Describe the values and bases for the following economic estimates.

- Cost of evacuation
- Cost for temporary relocation (food, lodging, lost income)
- Cost of decontaminating land and buildings

- Lost return on investments from properties that are temporarily interdicted to allow contamination to be decreased by decay of nuclides
- Cost of repairing temporarily interdicted property
- Value of crops destroyed or not grown because they were contaminated by direct deposition or would be contaminated by root uptake
- Value of farmland and of individual, public, and non-farm commercial property that is condemned

Sample MACCS2 economic data is provided in Table 5.

3.4.3 NUCLIDE RELEASE

Provide a discussion of the source of core inventory values and a list of those values. Table 6 shows sample core inventory values. The actual list of radioisotopes may differ from the list in Table 6.

MACCS2 default core inventory values are for a reference plant with a power level of 3,412 megawatts-thermal. Since actual core inventory is usually fuel vendor proprietary information, plant-specific core inventory values may be obtained by scaling the MACCS2 default values by the ratio of power level to reference plant power level. Additional adjustment of the core inventory values may be necessary to account for differences between fuel cycles expected during the period of extended operation and the fuel cycle upon which the MACCS2 default core inventory values are based.

Also provide a description of the characteristics associated with the release (i.e., elevation of release, thermal content of release). Use of a release height equal to half the height of the containment is acceptable, because it provides adequate dispersion of the plume to the surrounding area. Table 7 shows example release characteristics.

3.4.4 EMERGENCY RESPONSE

Discuss emergency response and evacuation parameter assumptions.

Provide an evacuation start time delay and a radial evacuation speed based on site-specific information. Since population dose is highly dependent on radial evacuation speed, and uncertainties may be introduced during derivation of a single evacuation speed from emergency plan information, sensitivity analyses should be documented to show that the radial evacuation speed used in the SAMA analysis is reasonable (Section 8.4).

Best-estimate values for groundshine and cloudshine shielding factors are acceptable (e.g., Grand Gulf values found in Table 3.28 of Reference 3).

MACCS2 default values are acceptable for other parameter inputs, such as inhalation and skin protection factors, acute and chronic exposure effects, and long-term protective data.

3.4.5 METEOROLOGICAL DATA

Describe the meteorological data used in the analysis, including wind speed, wind direction, stability class, seasonal mixing heights, and precipitation. Indicate the sources of the data (e.g., site meteorological tower, National Climatic Data Center).

Also indicate the span of the data. Examples include, "*a full year (2003) of consecutive hourly values,*" or "*an average of five years (1995-2003) of consecutive hourly values.*"

Explain why the data set and data period are representative and typical.

For example,

> *Annual meteorology data sets from 1998 through 2000 were investigated for use in MACCS2. The 1998 data set was found to result in the largest doses and was subsequently used to create the one-year sequential hourly data set used in MACCS2. The conditional dose from each of the other years was within 10 percent of the chosen year.*

If data is not from the plant meteorological tower, discuss why the data is acceptable.

3.5 SEVERE ACCIDENT RISK RESULTS

Provide the mean annual off-site dose and economic impact due to a severe accident for each of the release categories analyzed. Report results for all release categories, including those with normal containment leakage (intact containment). Provide total off-site dose and total economic impact, which are the baseline risk measures from which the maximum benefit is calculated (Section 4). Table 8 provides a sample summary of severe accident risk results.

4 COST OF SEVERE ACCIDENT RISK / MAXIMUM BENEFIT

Using the baseline risk measures from Section 3.5, calculate severe accident impacts in four areas: off-site exposure cost, off-site economic cost, on-site exposure cost, and on-site economic cost (Section 4.1 through Section 4.4). The following descriptions of the severe accident impact calculations are based on the NRC-accepted methods found in NUREG/BR-0184 (Reference 4).

Calculation of severe accident impacts involves an analysis period term, t_f, which can be defined as either the period of extended operation (20 years), or the years remaining until the end of facility life (from the time of the SAMA analysis to the end of the period of extended operation) (25 years or more). The value typically used for this term is the period of extended operation (20 years). Since this is a license renewal application, if the analysis determines that an aging-related SAMA is potentially cost-beneficial, the plant is under no obligation to implement the SAMA immediately. Thus, the plant will commit to implementing the SAMA by the beginning of the period of extended operation. Therefore, the benefits of the SAMA are only assured for 20 years. However, NRC has asked several plants to perform a sensitivity analysis using the period from the time of the SAMA analysis to the end of the period of extended operation to determine if SAMAs are potentially cost-beneficial if performed immediately. This sensitivity analysis should be performed to provide the information wanted by the regulator (Section 8.6).

Alternatively, the analysis could use the period from the time of the SAMA analysis to the end of the period of extended operation (25 years or more), and a sensitivity analysis would not be needed. This method adds conservatism to the analysis.

Calculation of severe accident impacts also involves a real discount rate, r, which is typically assumed to be 7% (0.07/year) as recommended in NUREG/BR-0184. A value of 7% is conservative because cost estimates are usually performed by utilities using values between 11 and 15%. Use of both a 7% and 3% real discount rate in regulatory analysis is specified in Office of Management Budget (OMB) guidance (Reference 5) and in NUREG/BR-0058 (Reference 6). The two discount rates represent the difference in whether a decision to undertake a project requiring investment is viewed as displacing either private investment or private consumption. A rate of 7% should be used as a baseline for regulatory analyses and represents an estimate of the average before-tax rate of return on an average investment in the private sector in recent years. A rate of 3% should also be used and represents an estimate of the "consumption rate of interest," i.e., the real, after-tax rate of return on widely available savings instruments or investment opportunities. To address this concern, perform a sensitivity analysis using a 3% real discount rate (Section 8.5).

Combine the severe accident impacts with the external events multiplier to estimate the total cost of severe accident risk. Since this is the maximum benefit that a SAMA could achieve if it eliminated all risk, it is the maximum benefit (Section 4.5).

4.1 OFF-SITE EXPOSURE COST

Convert the baseline off-site dose to dollars using the conversion factor of $2,000 per person-rem, and discount to present value using the following equation.

W_{pha} = $C * Z_{pha}$

Where:

W_{pha} = off-site exposure cost ($)
C = $[1-\exp(-rt_f)]/r$ (years)
t_f = analysis period (years) (see Section 4)
r = real discount rate (7% = 0.07/year) (see Section 4)
Z_{pha} = value of public health (accident) risk per year before discounting ($/year)

Z_{pha} = $2,000/person-rem * mean annual off-site dose impact due to a severe accident from Section 3.5

For example,

Assume the baseline off-site dose from Section 3.5 is 9 person-rem/year.

Then, Z_{pha} *= 9 person-rem/year * $2,000/person-rem = $18,000/year.*

Assume a 20-year analysis period and a 7% real discount rate.

Then, C is approximately 10.76 years.

*Therefore, off-site exposure cost is 10.76 years * $18,000/year = $193,680.*

4.2 OFF-SITE ECONOMIC COST

Discount the off-site economic cost to present value using the same equation as in Section 4.1, with

Z_{pha} = mean annual economic impact due to a severe accident from Section 3.5.

For example,

Assume the baseline off-site economic impact from Section 3.5 is $21,000/year, then Z_{pha} *= $21,000/year.*

Assume the same analysis period and real discount rate.

*Then, off-site economic cost = 10.76 years * $21,000/year = $225,960.*

4.3 ON-SITE EXPOSURE COST

The values for on-site (occupational) exposure consist of "immediate dose" and "long-term dose." The best estimate value provided in NUREG/BR-0184 for immediate occupational dose is 3,300 person-rem/event, and long-term occupational dose is 20,000 person-rem (over a ten-year clean-up period). The following equations are used to calculate monetary equivalents.

Immediate Dose

$$W_{IO} = R * F * D_{IO} * C$$

Where:

W_{IO}	=	immediate on-site exposure cost ($)
R	=	monetary equivalent of unit dose ($/person-rem)
F	=	Level 1 internal events core damage frequency (events/year)
D_{IO}	=	immediate on-site (occupational) dose (person-rem/event)
C	=	$[1-\exp(-rt_f)]/r$ (years)
r	=	real discount rate (7% = 0.07/year) (see Section 4)
t_f	=	analysis period (years) (see Section 4)

For example,

Using the following values from above,

R	=	*$2,000/person-rem*
r	=	*0.07/year*
D_{IO}	=	*3,300 person-rem/event*
T_f	=	*20 years*

And assuming the Level 1 internal events core damage frequency,

F = *1E-6 events/year*

Then, the immediate on-site exposure cost is:

W_{IO} = *$2,000/person-rem * 1E-6 events/year * 3,300 person-rem/event * 10.76 years*

= *$71*

Long-Term Dose

$$W_{LTO} = R * F * D_{LTO} * C * \{[1 - \exp(-rm)]/rm\}$$

Where:

W_{LTO}	=	long-term on-site exposure cost ($)
R	=	monetary equivalent of unit dose ($/person-rem)
F	=	Level 1 internal events core damage frequency (events/year)
D_{LTO}	=	long-term on-site (occupational) dose (person-rem/event)
C	=	$[1-\exp(-rt_f)]/r$ (years)

r	=	real discount rate (7% = 0.07/year) (see Section 4)
t_f	=	analysis period (years) (see Section 4)
m	=	years over which long-term doses accrue

For example,

Using the following values from above,

R	=	*$2,000/person-rem*
r	=	*0.07/year*
D_{LTO}	=	*20,000 person-rem/event*
m	=	*10 years*
t_f	=	*20 years*
F	=	*1E-6 events/year*

Then, the long-term exposure cost is:

W_{LTO} = *$2,000/person-rem * 1E-6 events/year * 20,000 person-rem/event * 10.76 years * {[1 -exp(-0.07*10)]/0.07*10}*

= *$310*

<u>Total On-site Exposure</u> - Combining immediate and long-term on-site exposure costs results in a total on-site exposure cost, W_O, of

$$W_O = W_{IO} + W_{LTO}$$

For the example,

W_O = *($71 + $310) = $381*

4.4 ON-SITE ECONOMIC COST

On-site economic cost includes cleanup and decontamination cost, and either replacement power cost or repair and refurbishment cost.

<u>Cleanup and Decontamination</u>

Integrate the net present value of the total cost of clean-up and decontamination of a power reactor facility subsequent to a severe accident over the analysis period. The total cost of cleanup and decontamination of a power reactor facility subsequent to a severe accident is estimated in NUREG/BR-0184 to be $1.5E+9.

Calculate the present value of this cost as follows.

$$PV_{CD} = [C_{CD}/m] * \{[1 - \exp(-rm)]/r\}$$

Where:

PV_{CD}	=	net present value of a single event ($)
C_{CD}	=	total cost of cleanup and decontamination effort ($)
m	=	cleanup period (years)
r	=	real discount rate (7% = 0.07/year) (see Section 4)

For example,

Using the following values from above,

C_{CD}	=	*$1.5E+9*
m	=	*10 years*
r	=	*0.07/year*

*Then, PV_{CD} = $1.5E+9 / 10 years * {[1 -exp(-0.07*10)]/0.07/year} = $1.08E+9*

Integrate this cost over the analysis period as follows.

$$U_{CD} = PV_{CD} * C$$

Where:

U_{CD}	=	total cost of cleanup and decontamination over the analysis period ($-years)
PV_{CD}	=	net present value of a single event ($)
C	=	$[1-\exp(-rt_f)]/r$
r	=	real discount rate (7% = 0.07/year) (see Section 4)
t_f	=	analysis period (years) (see Section 4)

For example,

Using the following values from above,

PV_{CD}	=	*$1.08E+9*
r	=	*0.07/year*
t_f	=	*20 years*

Then, the cleanup and decontamination cost is,

*U_{CD} = $1.08E+9 * 10.76 years = 1.16E+10 $-years*

Replacement Power Cost

Determine the net present value of replacement power for a single event, PV_{RP}, using the following equation.

$$PV_{RP} = [B/r] * [1 - \exp(-rt_f)]^2$$

Where:

PV_{RP} = net present value of replacement power for a single event, ($)
r = real discount rate (7% = 0.07/year) (see Section 4)
t_f = analysis period (years) (see Section 4)
B = a constant representing a string of replacement power costs that occur over the lifetime of a reactor after an event (for a 910MWe "generic" reactor, NUREG/BR-0184 uses a value of $1.2E+8) ($/yr)

For example,

Assuming a 1023 MWe plant, and scaling B for power level,

B = 1.2E+8$/yr * 1023/910 = 1.35E+8$/yr

Using the following values from above,

r = *0.07/year*
t_f = *20 years*

Then, $PV_{RP} = [1.35E{+}8\$/yr/.07/yr] * [1 - \exp(-.07*20)]^2 = \$1.09E{+}9$

Sum the single-event costs over the entire analysis period, using the following equation.

$$U_{RP} = [PV_{RP}/r] * [1 - \exp(-rt_f)]^2$$

Where:

U_{RP} = net present value of replacement power over life of facility ($-year)
r = real discount rate (7% = 0.07/year) (see Section 4)
t_f = analysis period (years) (see Section 4)

For example,

Using the following values from above,

PV_{RP} = *$1.09E+9*
r = *0.07/year*
t_f = *20 years*

Then, the replacement power cost is,

$$U_{RP} = [\$1.09E{+}9/0.07/year] * [1 - \exp(-0.07*20)]^2 = 8.84E{+}9 \text{ \$-years}$$

Repair and Refurbishment Cost

Repair and refurbishment costs may be estimated in accordance with NUREG/BR-0184 as 20% of the cost of replacement power previously discussed. Assuming that replacement power will be required for the remaining life of the plant results in higher benefit estimates and is, therefore, more conservative than assuming the plant will be repaired.

Thus, repair and refurbishment costs need not be estimated.

Total On-Site Economic Cost

Calculate total on-site economic costs by summing cleanup/decontamination costs and replacement power costs, and multiplying this value by the internal events CDF.

For example,

Using the values from above and assuming an internal events CDF of 1E-6/year,

*Total onsite economic cost = (1.16E+10 $-years + 8.84E+9 $-years) * 1E-6/year = $20,440.*

4.5 TOTAL COST OF SEVERE ACCIDENT RISK / MAXIMUM BENEFIT

Calculate the severe accident impact by summing the off-site exposure cost, off-site economic cost, on-site exposure cost, and on-site economic cost.

For the example, the sum of the baseline costs is as follows.

Off-site exposure cost	=	*$193,680*
Off-site economic cost	=	*$225,960*
On-site exposure cost	=	*$381*
On-site economic cost	=	*$20,440*
Severe accident impact	=	*$440,461*

Combine the severe accident impact with the external events multiplier (Section 3.1.2.4) to calculate the total cost of severe accident risk. Since this is the maximum benefit that a SAMA could achieve if it eliminated all risk, it is the maximum benefit.

For example,

If the external events multiplier in Section 3.1.2.4 is two,

*Maximum benefit = $440,461 * 2 = $880,922*

The maximum benefit is used in the Phase I screening process (Section 6) to eliminate SAMAs that are not cost-beneficial. If the estimated cost of implementing a SAMA exceeds this value, it is excluded from further analysis.

5 SAMA IDENTIFICATION

Develop a list of SAMA candidates by reviewing the major contributors to CDF and population dose based on the plant-specific risk assessment and the standard BWR or PWR list of enhancements (Table 13 or 14). The following sections provide a more detailed description of the identification process and the necessary documentation.

5.1 PSA IMPORTANCE

Identify plant-specific SAMA candidates by reviewing dominant risk contributors (to both CDF and population dose) in the Level 1 and Level 2 PSA models. Describe how dominant risk contributors, including dominant sequences, equipment failures, and operator actions identified through importance analyses, were used to identify plant-specific SAMA candidates. This should include a review of dominant sequences or cutsets for failures that could be addressed through an enhancement to the plant. It should also include a similar review of dominant equipment and human failures based on importance measures. Past SAMA analyses have shown that SAMA candidates are not likely to prove cost-beneficial if they only mitigate the consequences of events that present a low risk to the plant.

The definition of "dominant sequences or cutsets" is open to interpretation. The SAMA portion of the license renewal environmental report should indicate how the dominant sequences were defined and the rationale for the cutoff value. For example, *"The top 100 Level 1 cutsets, representing 62% of the total CDF, were reviewed. Individual cutsets below this point have little influence on CDF and are therefore not likely contributors for identification of cost beneficial enhancements."*

Similarly, the definition of dominant equipment and human failures is open to interpretation. The SAMA portion of the license renewal environmental report should indicate how the dominant failures were defined and the rationale for the cutoff value. For example, *"Failures with risk reduction worth > 1.005 were identified as the most important failures. Events below this point influence CDF by less than 0.5% and are therefore not likely contributors for identification of cost beneficial enhancements."*

Provide a list of equipment failures and human actions that have the greatest potential for reducing risk based on importance analysis. For each dominant contributor describe relevant Phase I SAMAs and list the Phase II SAMA(s) that address that contributor. SAMAs may be hardware changes, procedure changes, or enhancements to programs, including training and surveillance programs. Hardware changes should not be limited to permanent changes involving addition of new, safety-grade equipment, but should also include lower cost alternatives, such as temporary connections using commercial grade equipment (e.g., portable generators and temporary cross-ties). Previous SAMA analyses for similar plants are a prime source for identifying potential low-cost alternatives to address similar risk contributors. If a SAMA was not evaluated for a dominant risk contributor, justify why SAMAs to further reduce the contributor would not be cost-beneficial.

A sample partial PSA importance review is provided in Table 9.

5.2 PLANT IPE

Plant IPE submittals included a list of risk-based insights and potential plant improvements. Identify if potential improvements have not been implemented.

Include potential improvements that have not been implemented in the list of Phase I SAMA candidates.

5.3 PLANT IPEEE

Potential improvements to reduce the risk in dominant fire zones and to reduce seismic risk and risk from other external events (including those from the IPEEE, subsequent fire and seismic evaluations, and improvements to address USI A-46 outliers) should be included in the list of Phase I SAMA candidates.

5.4 INDUSTRY SAMA CANDIDATES

Include the generic BWR or PWR enhancements (Table 13 or 14) in the list of Phase I SAMA candidates.

5.5 LIST OF PHASE I SAMA CANDIDATES

The combined list of potential improvements from Section 5.1 through Section 5.4 is the list of Phase I SAMA candidates. Maintain this comprehensive list of SAMA candidates, with the source of each candidate indicated, in on-site documentation. Due to its size and limited value to NRC reviewers, this list need not be included in the SAMA portion of the license renewal environmental report.

A sample partial list of Phase I SAMA candidates is presented in Table 10. The last two columns in this table are part of the Phase I analysis and are discussed in Section 6.

6 PHASE I ANALYSIS

Perform a preliminary screening of SAMA candidates to eliminate SAMAs from further consideration. This step is taken to limit the number of SAMAs for which detailed analysis in Phase II is necessary. Describe the screening criteria used in the Phase I analysis. The following are examples of screening criteria that may be applied.

- Not Applicable: If a SAMA candidate does not apply to the plant design, it is not retained. For example, installation of accumulators for turbine-driven feedwater pump flow control valves would not require further analysis at a plant with motor operated turbine-driven feedwater pump flow control valves.

- Already Implemented: If a SAMA candidate has already been implemented at the plant, it is not retained. For example, installation of motor generator set trip breakers in the control room to reduce the frequency of core damage due to an ATWS would not require further analysis at a plant with a control room actuated diverse scram system.

- Combined: If a SAMA candidate is similar in nature and can be combined with another SAMA candidate to develop a more comprehensive or plant-specific SAMA candidate, only the combined SAMA candidate is retained. For example, addition of an independent reactor coolant pump seal injection system and use of an existing hydro test pump for reactor coolant pump seal injection provide similar risk-reduction benefits. If the lower-cost alternative is not cost-beneficial, the higher-cost alternative also will not be cost-beneficial. Therefore, the higher-cost alternative would not require further analysis.

- Excessive Implementation Cost: If a SAMA requires extensive changes that will obviously exceed the maximum benefit (Section 4.5), even without an implementation cost estimate, it is not retained. For example, the cost of installing an additional, buried off-site power source would exceed the maximum benefit from Section 4.5 and would not require further analysis. Consideration should be given to lower cost alternatives, such as temporary connections using commercial grade equipment (e.g., portable generators and temporary cross-ties), procedure enhancements, and training enhancements that could offer much of the potential risk reduction at a fraction of the cost of safety-related modifications.

- Very Low Benefit: If a SAMA from an industry document is related to a non-risk significant system for which change in reliability is known to have negligible impact on the risk profile, it is not retained. For example, if the instrument air system is not a risk-significant system at the plant, and failure of the air compressors is not on the PSA importance list (Section 5.1), the plant risk profile would be unchanged if the air compressors were made perfectly reliable. Therefore, an improvement to replace the current air compressors with a more reliable model would not require further analysis.

Provide a description of the screening process and its results, in sufficient detail that a reader can understand how the initial set of Phase I SAMAs was reduced to the more limited set of Phase II SAMAs (e.g., an accounting of the SAMAs eliminated by each criterion.)

Table 10 provides sample Phase I dispositions for individual SAMA candidates. Those SAMAs that require detailed cost-benefit analysis are retained for Phase II analysis (Section 7).

7 PHASE II SAMA ANALYSIS

Perform a cost-benefit analysis on each of the remaining SAMA candidates.

The benefit is the difference in the baseline cost of severe accident risk (maximum benefit from Section 4.5) and the cost of severe accident risk with the SAMA implemented (Section 7.1). The cost is the estimated cost to implement the SAMA (Section 7.2). If the estimated cost of implementation exceeds the benefit of implementation, the SAMA is not cost-beneficial.

For multi-unit sites, assure that the benefits and implementation costs are provided on a consistent basis, e.g., all benefit and all cost estimates are on a per-site basis. If benefit and cost estimates are provided on a per-unit basis, the impact (and efficiencies) associated with implementation of the SAMA at multiple units should be reflected in the estimated implementation costs.

7.1 SAMA BENEFIT

7.1.1 SEVERE ACCIDENT RISK WITH SAMA IMPLEMENTED

Perform bounding analyses to determine the change in risk following implementation of SAMA candidates or groups of similar SAMA candidates.

For each analysis case, alter the Level 1 internal events or Level 2 PSA model to conservatively consider implementation of the SAMA candidate(s). Then, calculate the severe accident risk measures using the same procedure used for the baseline case described in Section 3.

For SAMAs specifically related to external events, estimate the approximate benefits through use of the external events PRA, if available, or bounding-type analysis, (e.g., estimating the benefit of completely or partially eliminating the external event risk).

Describe the changes made to the PSA models for each analysis case.

For example,

LBLOCA

This analysis case was used to evaluate the change in plant risk profile that would be achieved if a digital large break LOCA protection system was installed. Although the proposed change would not completely eliminate the potential for a large break LOCA, a bounding benefit was estimated by removing the large break LOCA initiating event. This analysis case was used to model the benefit of SAMA 7.

DCPWR

This analysis case was used to evaluate plant modifications that would increase the availability of Class 1E DC power (e.g., increased battery capacity or the installation of a diesel-powered generator that would effectively increase battery capacity). Although the proposed SAMAs would not completely eliminate the potential failure, a bounding benefit was estimated by removing the battery discharge events and battery failure events. This analysis case was used to model the benefit of SAMAs 4, 5, 10, 12, and 24.

7.1.2 COST OF SEVERE ACCIDENT RISK WITH SAMA IMPLEMENTED

Using the risk measures from Section 7.1.1, calculate severe accident impacts in four areas: off-site exposure cost, off-site economic cost, on-site exposure cost, and on-site economic cost using the same procedure used for the baseline case described in Section 4.

As in Section 4.5, sum the severe accident impacts and combine with the external events multiplier (Section 3.1.2.4) to estimate the total cost of severe accident risk with the SAMA implemented. Use of the external events multiplier is inappropriate for some SAMAs. For example, SAMAs specifically related to external events that would not impact internal events (e.g., enhanced fire detections) and SAMAs related to specific internal event initiators (e.g., guard pipes for main steam line break events). Provide a discussion of SAMAs on which the external events multiplier was not applied.

7.1.3 SAMA BENEFIT

Subtract the total cost of severe accident risk with the SAMA implemented from the baseline cost of severe accident risk (maximum benefit from Section 4.5) to obtain the benefit.

List the estimated benefit for each SAMA candidate.

Table 11 provides a sample portion of a Phase II SAMA candidate list with estimated benefits listed.

7.2 COST OF SAMA IMPLEMENTATION

Perform a cost estimate for each of the Phase II SAMA candidates. Describe the cost estimating process and list the cost estimate for each SAMA candidate.

As SAMA analysis focuses on establishing the economic viability of potential plant enhancement when compared to attainable benefit, often detailed cost estimates are not required to make informed decisions regarding the economic viability of a particular modification. SAMA implementation costs may be clearly in excess of the attainable benefit estimated from a particular analysis case. For less clear cases, engineering judgment may be applied to determine if a more detailed cost estimate is necessary to formulate a conclusion regarding the economic viability of a particular SAMA. Nonetheless, the cost of each SAMA candidate should be conceptually estimated to the point where economic viability of the proposed modification can be adequately gauged.

For hardware modifications, the cost of implementation may be established from existing estimates of similar modifications from previously performed SAMA and SAMDA analyses. Costs associated with implementation of a SAMA including procurement, installation, long-term maintenance, surveillance, calibration, and training should be considered.

Discuss conservatisms in the cost estimates. For example, cost estimates may not include the cost of replacement power during extended outages required to implement the modifications. They also may not include contingency costs associated with unforeseen implementation obstacles. Estimates based on modifications that were implemented or estimated in the past may be presented in terms of dollar values at the time of implementation (or estimation), and not adjusted to present-day dollars. In addition, implementation costs originally developed for SAMDA analyses (i.e., during the design phase of the plant) 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.).

Table 11 provides a sample portion of a Phase II SAMA candidate list with cost estimates.

8 SENSITIVITY ANALYSES

Evaluate how changes in SAMA analysis assumptions would affect the cost-benefit analysis. Perform the following sensitivity analyses, as applicable.

Table 12 contains sample sensitivity analysis results.

8.1 PLANT MODIFICATIONS

Major changes to the plant, such as power uprate or steam generator replacement, may be planned or may have occurred since the model freeze date, as described in Section 3.1 and Section 3.2. If the Level 1 or Level 2 PSA model used for the SAMA analysis does not address a major plant change, a sensitivity analysis may be performed to support discussion of the impact of the change on the SAMA analysis results.

In this sensitivity analysis, modify the PSA model (or its results) to simulate incorporation of the plant modification and perform the Phase II analysis with the revised severe accident risk results. Sufficient margin exists in the maximum benefit estimation that the Phase I screening should not have to be repeated in the sensitivity analysis.

Discuss the plant modification and how its effects were simulated in the PSA model. Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis. If SAMAs appear cost-beneficial in the sensitivity results, discussion of conservatisms in the analysis, (e.g., conservatisms in cost estimates discussed in Section 7.2), and their impact on the results may be appropriate.

8.2 UNCERTAINTY

A discussion of CDF uncertainty, and conservatisms in the SAMA analysis that off-set uncertainty, should be included. For example, use of conservative risk modeling to represent a particular plant change may be used to offset uncertainty in risk modeling; use of conservative implementation cost estimates may be used to offset uncertainty in cost estimates; and use of an uncertainty factor derived from the ratio of the 95^{th} percentile to the mean point estimate for internal events CDF may be used to account for CDF uncertainties. Estimate an uncertainty factor based on this discussion and perform a sensitivity analysis using the uncertainty factor on the results. [Based on analysis to date the ratio of the 95^{th} percentile to the mean point estimate for typical internal events CDF values is 2 to 5 (Reference 1).]

Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis. If SAMAs appear cost-beneficial in the sensitivity results, discussion of conservatisms in the analysis, (e.g., conservatisms in cost estimates discussed in Section 7.2), and their impact on the results may be appropriate.

8.3 PEER REVIEW FINDINGS OR OBSERVATIONS

If the model used for the SAMA analysis does not address significant findings or observations from the PSA peer review discussed in Section 3.3, sensitivity analyses may be performed to support discussion of the impact of the findings or observations on the SAMA analysis results.

In these sensitivity analyses, modify the PSA model (or its results) to simulate incorporation of the finding or observation and perform the Phase II analysis with the revised severe accident risk results. Sufficient margin exists in the maximum benefit estimation that the Phase I screening should not have to be repeated in the sensitivity analysis.

Discuss the finding or observation and how its effects were simulated in the PSA model. Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis. If SAMAs appear cost-beneficial in the sensitivity results, discussion of conservatisms in the analysis, (e.g., conservatisms in cost estimates discussed in Section 7.2), and their impact on the results may be appropriate.

8.4 EVACUATION SPEED

Population dose may be significantly affected by radial evacuation speed, and uncertainties may be introduced during derivation of a single evacuation speed from emergency plan information, as discussed in Section 3.4.4. Therefore, perform sensitivity analyses to show that variations in this parameter would not impact the results of the analysis.

This sensitivity analysis should modify the evacuation speed assumed in the Level 3 PSA model and recalculate the baseline severe accident risk results. Multiple speeds may be evaluated as necessary.

Discuss uncertainty in the evacuation speed and how the modified speed was selected. Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis.

8.5 REAL DISCOUNT RATE

Calculation of severe accident impacts also involves a real discount rate, r, which is typically assumed to be 7% (0.07/year) as recommended in NUREG/BR-0184. A value of 7% is conservative because cost estimates are usually performed by utilities using values between 11 and 15%. Use of both a 7% and 3% real discount rate in regulatory analysis is specified in Office of Management Budget (OMB) guidance (Reference 5) and in NUREG/BR-0058 (Reference 6). The two discount rates represent the difference in whether a decision to undertake a project requiring investment is viewed as displacing either private investment or private consumption. A rate of 7% should be used as a baseline for regulatory analyses and represents an estimate of the average before-tax rate of return on an average investment in the private sector in recent years. A rate of 3% should also be used and represents an estimate of the "consumption rate of interest," i.e., the real, after-tax rate of return on widely available savings instruments or investment opportunities. To address this concern, perform a sensitivity analysis using a 3% real discount rate.

In this sensitivity analysis, modify the real discount rate in the Level 3 PSA model and perform the Phase II analysis with the revised severe accident risk results. Sufficient margin exists in the maximum benefit estimation that the Phase I screening should not have to be repeated in the sensitivity analysis.

Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis. If SAMAs appear cost-beneficial in the sensitivity results, discussion of conservatisms in the analysis, (e.g., conservatisms in cost estimates discussed in Section 7.2), and their impact on the results may be appropriate.

8.6 ANALYSIS PERIOD

As described in Section 4, calculation of severe accident impacts involves an analysis period term, t_f, which can be defined as either the period of extended operation (20 years), or the years remaining until the end of facility life (from the time of the SAMA analysis to the end of the period of extended operation) (25 years or more).

The value that is typically used for this term is the period of extended operation (20 years). However, NRC has asked several plants to perform a sensitivity analysis using the period from the time of the SAMA analysis to the end of the period of extended operation to determine if SAMAs are potentially cost-beneficial if performed immediately. This sensitivity analysis should be performed to provide the information wanted by the regulator.

In this sensitivity analysis, modify the analysis period in the calculation of severe accident risk and perform the Phase II analysis with the revised analysis period. The cost of additional years of maintenance, surveillance, calibrations, and training should be included in the cost estimates for SAMAs in this Phase II analysis. Sufficient margin exists in the maximum benefit estimation that the Phase I screening should not have to be repeated in the sensitivity analysis.

Provide pertinent results and discuss how they affect the conclusions of the SAMA analysis. If SAMAs appear cost-beneficial in the sensitivity results, discussion of conservatisms in the analysis, (e.g., conservatisms in cost estimates discussed in Section 7.2), and their impact on the results may be appropriate.

9 CONCLUSIONS

Discuss SAMAs that are cost-beneficial after the Phase II and sensitivity analyses. It may also be useful to discuss the combination of selected SAMAs and their impact on the overall plant risk. In some instances, addressing certain SAMAs may reduce the importance of the remaining candidates.

This analysis may not estimate all of the benefits or all of the costs of a SAMA. For instance, it may not consider increases or decreases in maintenance or operation costs following SAMA implementation. Also, it may not consider the possible adverse consequences of procedure changes, such as additional personnel dose. Since the SAMA analysis is not a complete engineering project cost-benefit analysis, the SAMAs that are cost-beneficial after the Phase II analysis and sensitivity analyses are only **potentially** cost-beneficial.

10 TABLES AND FIGURES

TABLE 1
SAMPLE Accident Class Distribution

Class	Description	Frequency (per year)	Percent of Total
1A	Transient leading to core damage with reactor at high pressure	4.00 x 10-5	90.0%
1B	SBO leading to core damage	1.52 x 10-6	3.4%
1C	ATWS leading to core damage in an intact containment	1.05 x 10-8	0.0%
1D	Transient leading to core damage with reactor at low pressure	2.72 x 10-7	0.6%
2	Loss of containment heat removal leading to core damage	1.65 x 10-6	3.7%
3A	RPV rupture leading to core damage at low pressure	5.51 x 10-7	1.2%
3B	LOCA leading to core damage with the reactor at high pressure	3.16 x 10-8	0.1%
3C	LOCA leading to core damage with the reactor at low pressure	3.14 x 10-7	0.7%
3D	LOCA with vapor suppression failure	6.63 x 10-10	0.0%
4	ATWS leading to core damage and containment overpressure failure	7.19 x 10-8	0.2%
5	LOCA bypassing containment leading to core damage	8.97 x 10-10	0.0%
Total		4.44 x 10-5	[illegible]

TABLE 2
SAMPLE Release Severity and Timing Classification Scheme

Release Severity Source Term Release Fraction		Release Timing	
Classification Category	**Cesium Iodide % Release**	**Classification Category**	**Time of Release[1]**
Extreme (E)	greater than 50	Late (L)	greater than 6 hours
Large (L)	10 to 50	Early (E)	less than 6 hours
Medium (M)	1 to 10		
Small (S)	less than 1		

(1) Relative to declaration of a General Emergency.

TABLE 3
SAMPLE Release Category Frequency and Release Fractions (Source Term)

	Release Category[1,2]						
	E-E	L-E	L-L	M-E	M-L	S-E	S-L
Bin Frequency	2.64E-09	4.20E-06	7.19E-06	8.99E-08	1.09E-06	1.81E-07	3.97E-05
MAAP Run	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Time after Scram when General Emergency is declared	25 min	30 min	2 hrs	2 hrs	18 hrs	1 hr	2 hr
Fission Product Group:							
1) Noble							
Total Release Fraction at 40 Hours	9.9E-01	7.4E-01	8.5E-01	6.2E-01	1.0E+00	1.0E+00	1.0E+00
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	4.00	10.00	6.00	36.00	4.00	18.00
2) CsI							
Total Release Fraction at 40 Hours	8.3E-01	4.6E-01	2.8E-01	8.9E-02	2.7E-02	5.0E-03	2.7E-03
Start of Release (hr)	0.25	0.80	9.00	4.40	36.00	1.00	16.00
End of Release (hr)	2.00	40.00	40.00	14.00	40.00	6.00	18.00
3) TeO2							
Total Release Fraction at 40 Hours	6.8E-01	2.4E-01	9.9E-02	1.2E-01	7.5E-03	2.4E-03	9.6E-04
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	12.00	22.00	8.00	40.00	4.00	40.00
4) SrO							
Total Release Fraction at 40 Hours	1.5E-02	4.7E-03	2.0E-05	2.3E-02	7.4E-06	1.5E-04	5.2E-06
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	2.00	16.00
End of Release (hr)	6.00	6.00	9.00	6.00	40.00	6.00	26.00
5) MoO2							
Total Release Fraction at 40 Hours	2.4E-02	3.7E-03	4.1E-07	4.4E-06	6.1E-06	2.7E-04	8.4E-08
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	2.00	16.00	6.00	34.00	4.00	16.00
6) CsOH							
Total Release Fraction at 40 Hours	6.9E-01	3.1E-01	1.9E-01	1.4E-01	5.7E-03	3.4E-03	8.7E-04
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	30.00	18.00	8.00	40.00	6.00	18.00
7) BaO							
Total Release Fraction at 40 Hours	2.8E-02	6.1E-03	1.6E-05	1.0E-02	6.4E-06	3.7E-04	2.8E-06
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	6.00	9.00	6.00	40.00	4.00	16.00
8) La2O3							
Total Release Fraction at 40 Hours	6.5E-04	4.8E-04	5.6E-07	1.7E-03	1.3E-07	9.7E-06	8.9E-08
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	6.00	6.00	9.00	6.00	36.00	8.00	16.00
9) CeO2							
Total Release Fraction at 40 Hours	4.6E-03	2.0E-03	8.8E-06	1.5E-02	3.8E-07	5.9E-05	9.4E-07
Start of Release (hr)	4.00	3.00	9.00	4.40	34.00	4.00	16.00
End of Release (hr)	6.00	6.00	9.00	6.00	36.00	6.00	24.00
10) Sb							
Total Release Fraction at 40 Hours	5.9E-01	3.8E-01	1.6E-01	4.4E-01	2.0E-04	3.2E-02	3.4E-03
Start of Release (hr)	0.25	0.80	9.00	4.40	34.00	1.00	16.00
End of Release (hr)	2.00	40.00	40.00	40.00	36.00	14.00	40.00
11) Te2							
Total Release Fraction at 40 Hours	2.3E-03	2.4E-02	1.2E-02	2.4E-02	7.8E-06	3.3E-04	1.2E-03
Start of Release (hr)	4.00	3.00	9.00	4.40	36.00	5.00	16.00
End of Release (hr)	6.00	40.00	20.00	40.00	40.00	8.00	40.00
12) UO2							
Total Release Fraction at 40 Hours	2.0E-05	1.1E-05	1.8E-07	7.7E-05	1.3E-10	3.2E-07	8.0E-09
Start of Release (hr)	4.00	3.00	9.00	4.40	36.00	5.00	16.00
End of Release (hr)	6.00	6.00	20.00	6.00	40.00	8.00	40.00

(1) Puff releases are denoted in the table by those entries with equivalent start and end times.
(2) All cases run for 40 hrs

TABLE 4
SAMPLE Estimated Population Distribution Within a 50-Mile Radius

Sector	0-10 miles	10-20 miles	20-30 miles	30-40 miles	40-50 miles	50-mile total
N	1752	3211	6617	3250	1666	16496
NNE	2029	1530	5073	9080	3560	21272
NE	2357	10080	12428	4616	15346	44827
ENE	7797	9726	9548	23262	23199	73532
E	8436	25584	36954	30706	50569	152249
ESE	6243	22217	224818	322317	372411	948006
SE	9976	26461	188697	788711	785680	1799525
SSE	3114	12878	45896	179943	150702	392533
S	5132	17275	17036	24134	12217	75794
SSW	1995	6219	9689	8202	13624	39729
SW	2432	5053	9951	11975	16255	45666
WSW	1372	8140	3616	13662	6280	33070
W	1879	4061	5821	6432	8220	26413
WNW	1671	6540	14434	15309	7830	45784
NW	739	10546	130402	9655	6890	158232
NNW	4610	4129	4398	6235	10743	30115
Total	61534	173650	725378	1457489	1485192	3903243

TABLE 5
SAMPLE MACCS2 Economic Parameters

• Variable	• Description	• Value
• **DPRATE**	• **Property depreciation rate (per yr)**	• **0.2**
• **DSRATE**	• **Investment rate of return (per yr)**	• **0.12**
• **EVACST**	• **Daily cost for a person who has been evacuated ($/person-day)**	• **43**
• **POPCST**	• **Population relocation cost ($/person)**	• **7967**
• **RELCST**	• **Daily cost for a person who is relocated ($/person-day)**	• **43**
• **CDFRM0**	• **Cost of farm decontamination for various levels of decontamination ($/hectare)**	• **897** • **1992**
• **CDNFRM**	• **Cost of non-farm decontamination per resident person for various levels of decontamination ($/person)**	• **4781** • **12754**
• **DLBCST**	• **Average cost of decontamination labor ($/person-year)**	• **55793**
• **VALWF0**	• **Value of farm wealth ($/hectare)**	• **4547**
• **VALWNF**	• **Value of non-farm wealth ($/person)**	• **126108**

TABLE 6
SAMPLE Core Inventory Values

Nuclide	Core inventory (becquerels)	Nuclide	Core inventory (becquerels)
Cobalt-58	3.22E+16	Tellurium-131M	4.67E+17
Cobalt-60	2.47E+16	Tellurium-132	4.66E+18
Krypton-85	2.47E+16	Iodine-131	3.20E+18
Krypton-85M	1.16E+18	Iodine-132	4.72E+18
Krypton-87	2.11E+18	Iodine-133	6.76E+18
Krypton-88	2.86E+18	Iodine-134	7.43E+18
Rubidium-86	1.88E+15	Iodine-135	6.38E+18
Strontium-89	3.58E+18	Xenon-133	6.78E+18
Strontium-90	1.94E+17	Xenon-135	1.27E+18
Strontium-91	4.62E+18	Cesium-134	4.32E+17
Strontium-92	4.80E+18	Cesium-136	1.31E+17
Yttrium-90	2.08E+17	Cesium-137	2.41E+17
Yttrium-91	4.36E+18	Barium-139	6.27E+18
Yttrium-92	4.81E+18	Barium-140	6.21E+18
Yttrium-93	5.45E+18	Lanthanum-140	6.34E+18
Zirconium-95	5.52E+18	Lanthanum-141	5.82E+18
Zirconium-97	5.76E+18	Lanthanum-142	5.61E+18
Niobium-95	5.21E+18	Cerium-141	5.65E+18
Molybdium-99	6.09E+18	Cerium-143	5.49E+18
Technetium-99M	5.25E+18	Cerium-144	3.40E+18
Ruthenium-103	4.54E+18	Praseodymium-143	5.38E+18
Ruthenium-105	2.94E+18	Neodymium-147	2.41E+18
Ruthenium-106	1.03E+18	Neptunium-239	6.46E+19
Rhodium-105	2.04E+18	Plutonium-238	3.66E+15
Antimony-127	2.79E+17	Plutonium-239	8.25E+14
Antimony-129	9.85E+17	Plutonium-240	1.04E+15
Tellurium-127	2.69E+17	Plutonium-241	1.75E+17
Tellurium-127M	3.55E+16	Americium-241	1.16E+14
Tellurium-129	9.26E+17	Curium-242	4.43E+16
Tellurium-129M	2.44E+17	Curium-244	2.59E+15

TABLE 7
SAMPLE Release Characteristics

Parameter	Early-Rupture	Early-Leaks	Bypass	Late
Heat of Release (W)	2.1E+06	1.8E+06	1.0E+06	9.2E+05
Height of Release (m)	30	30	30	30

TABLE 8
SAMPLE Summary of Severe Accident Risk Results

Release Category	Off-Site Dose (person-rem/year)	Economic Impact ($/year)
E-E	1.39E-02	6.05E+01
L-E	1.73E+01	1.31E+05
L-L	1.58E+01	1.17E+05
M-E	2.57E-01	1.79E+03
M-L	4.43E-01	4.63E+02
S-E	7.00E-02	5.85E+01
S-L	4.13E+00	3.24E+03
None (intact)	0.0E+00	0.0E+00
Totals	3.80E+01	2.54E+05

TABLE 9
SAMPLE PSA Importance Review

Risk Significant Terms	RRW	Disposition
LINER-MELT	9.362	This term represents the probability of sufficient corium leaving the vessel to melt the containment liner. Phase II SAMAs 004 and 009 to increase injection systems and provide a dedicated drywell spray system were examined to reduce the risk of containment liner melt.
HPCI	1.4966	This term represents random failure of the HPCI system. Phase I SAMAs to improve availability and reliability of the HPCI system include raising backpressure trip set points and proceduralizing intermittent operation. Additional improvements were evaluated in Phase II SAMAs 049, 050, 051, 052, and 053.
ECCS Low Pressure Interlock	1.3472	This term represents random failures of the 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 were examined to reduce the risk due to the failure of the ECCS low-pressure interlock.
Depressurization (SRVs and ADS Logic)	1.2724	This term represents random failures of the SRVs to open on demand to depressurize during transients and small LOCAs. Phase I SAMAs to enhance reliability of the SRVs include adopting symptom based EOPs and SAGs, modifying ADS logic, and upgrading SRV pneumatic components. Additional improvements were examined in Phase II SAMAs 059 and 060.
Loss of feedwater - Initiating event	1.1794	This term represents the initiating event for loss of feedwater. Modifications to significantly reduce or eliminate the potential for loss of feedwater have already been implemented, such as installing a digital feedwater control system, providing a backup water supply, and adding a third feedwater pump. Many of the Phase II SAMAs (e.g. 035, 051, 052, 053, and 054) explored potential benefits for mitigation of this event. No additional SAMAs were recommended for this broad subject.
Operator Action: Operator fails to open SRVs for vessel depressurization during transients and small LOCA	1.1109	This term represents the operator failing to manually open the SRVs to depressurize during transients and small LOCAs. Improvement of plant procedures and instrumentation to enhance the likelihood of success of operator action in response to accident conditions were examined in Phase I SAMAs during preliminary screening. No additional SAMAs were recommended for this subject.
EXV-STM-EX	1.009	This term represents a steam explosion which fails containment. Phase II SAMAs 014 and 006 to strengthen the drywell and add a diverse injection system were examined to reduce the risk of a steam explosion in containment.

TABLE 10
SAMPLE List of Phase I SAMA Candidates

PHASE I SAMA ID NUMBER	SAMA TITLE	SAMA DISCUSSION	SOURCE	PHASE 1 DISPOSITION	RETAINED FOR PHASE II ANALYSIS?
1	Provide an additional diesel generator	This SAMA would help mitigate LOOP events and would reduce the risk of on-line EDG maintenance. Benefit would be increased if the additional diesel generator could 1) be substituted for any current diesel that is in maintenance, and 2) if the diesel was of a diverse design such that common cause failure dependence was minimized.	Level 1 Importance List and standard list of BWR SAMA candidates	The cost of installing an additional EDG has been estimated to be greater than $20 million in the Calvert Cliffs Application for License Renewal. As this is greater than the Maximum Benefit, it has been screened from further analysis.	No
2	Add additional battery charger or portable, diesel-driven battery charger to existing DC system.	Improved availability of DC power system.	Level 1 and 2 Importance Lists and standard list of BWR SAMA candidates	Retain for Phase II analysis.	Yes
3	Provide a portable generator to support SRVs and hard pipe vent	Improved availability of DC power system.	Level 1 and 2 Importance Lists	Retain for Phase II analysis.	Yes
4	Contingency plans during switchyard work	Assessing likely failures of the off-site AC power supply due to switchyard work and providing plans for power restoration in the event that such a loss occurs could reduce the time required to recover off-site power.	Level 1 Importance List	Retain for Phase II analysis.	Yes

TABLE 11
SAMPLE Phase II SAMA List

PHASE II SAMA ID NUMBER	SAMA TITLE	SAMA DISCUSSION	UPPER BOUND ESTIMATED BENEFIT	ESTIMATED COST OF IMPLEMENTATION	CONCLUSION	BASIS FOR CONCLUSION
010	Use the fire water system as a backup source for the containment spray system	Improved containment spray capability.	$178,000	$1,500,000	Not Cost-Beneficial	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost-beneficial.
011	Make containment sump recirculation outlet valve motor-operated valves diverse from one another	Replace one of the two containment sump valves with an air-operated valve. This would reduce the potential for common cause failure of these valves.	$520,440	$424,783	Potentially Cost-Beneficial	Elimination of all core damage due to containment sump valve failures results in a benefit of $520,440 (analysis case SUMPMOV). The cost of implementing this SAMA is judged to be $424,783. Therefore, this SAMA is potentially cost-beneficial.

TABLE 12
SAMPLE Sensitivity Analysis Results

Phase II SAMA ID	SAMA Title	Upper Bound Estimate Benefit	Estimated Cost	Upper Bound Estimate Benefit	Upper Bound Estimate Benefit
		Base line		Sensitivity Case 1	Sensitivity Case 2
1	Add a service water pump.	$120,000	$5,900,000	$140,000	$160,000
2	Provide a redundant train or means of EDG room ventilation.	$470,000	$1,000,000	$550,000	$640,000
3	Add a diesel building high temperature alarm or redundant louver and thermostat.	$160,000	$2500,000	$180,000	$220,000
4	Install an independent method of suppression pool cooling.	$530,000	$5,800,000	$620,000	$720,000
5	Install a filtered containment vent to remove decay heat.	$0	$3,000,000	$0	$0
6	Install an ATWS sized filtered containment vent to remove decay heat.	$0	>$2,00,000	$0	$0
7	Create a large concrete crucible with heat removal potential to contain molten core debris	$640,000	>$100 million	$720,000	$890,000
8	Provide a reactor vessel exterior cooling system.	$640,000	$19,000,000	$720,000	$890,000
9	Enable flooding of the drywell head seal.	$20,000	>$1,000,000	$20,000	$30,000
10	Enhance fire protection system and standby gas treatment system hardware and procedures	$1,410,000	>2,500,000	$1,610,000	$1,980,000
11	Create a core melt source reduction system	$640,000	>$1,000,000	$720,000	$890,000
12	Install a passive drywell spray system	$530,000	$5,800,000	$620,000	$720,000
13	Strengthen primary/secondary containment (e.g., add ribbing to containment shell).	$530,000	$12,000,000	$620,000	$720,000
14	Increase depth of the concrete base mat or use an alternative concrete material to ensure melt-through does not occur.	$640,000	>$1,000,000	$720,000	$890,000
15	Provide a reactor vessel exterior cooling system.	$640,000	$2,500,000	$720,000	$890,000

TABLE 13
STANDARD List of BWR SAMA Candidates

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
Improvements Related to AC and DC Power			
001	Provide additional DC battery capacity.	Extended DC power availability during an SBO.	1, 3, 6, 10, 11, 12, 17
002	Replace lead-acid batteries with fuel cells.	Extended DC power availability during an SBO.	6, 10
003	Add additional battery charger or portable, diesel-driven battery charger to existing DC system.	Improved availability of DC power system.	5
004	Improve DC bus load shedding.	Extended DC power availability during an SBO.	1, 7
005	Provide DC bus cross-ties.	Improved availability of DC power system.	6
006	Provide additional DC power to the 120/240V vital AC system.	Increased availability of the 120 V vital AC bus.	3
007	Add an automatic feature to transfer the 120V vital AC bus from normal to standby power.	Increased availability of the 120 V vital AC bus.	5
008	Increase training on response to loss of two 120V AC buses which causes inadvertent actuation signals.	Improved chances of successful response to loss of two 120V AC buses.	5
009	Reduce DC dependence between high-pressure injection system and ADS.	Improved containment depressurization and high-pressure injection following DC failure.	1
010	Provide an additional diesel generator.	Increased availability of on-site emergency AC power.	1, 6, 10, 11, 12
011	Revise procedure to allow bypass of diesel generator trips.	Extended diesel generator operation.	15
012	Improve 4.16-kV bus cross-tie ability.	Increased availability of on-site AC power.	1, 6, 11, 12
013	Create AC power cross-tie capability with other unit (multi-unit site).	Increased availability of on-site AC power.	1, 7, 13
014	Install an additional, buried off-site power source.	Reduced probability of loss of off-site power.	1
015	Install a gas turbine generator.	Increased availability of on-site AC power.	1, 6

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
016	Install tornado protection on gas turbine generator.	Increased availability of on-site AC power.	18
017	Install a steam-driven turbine generator that uses reactor steam and exhausts to the suppression pool.	Increased availability of on-site AC power.	6
018	Improve uninterruptible power supplies.	Increased availability of power supplies supporting front-line equipment.	6
019	Create a cross-tie for diesel fuel oil (multi-unit site).	Increased diesel generator availability.	1
020	Develop procedures for replenishing diesel fuel oil.	Increased diesel generator availability.	1
021	Use fire water system as a backup source for diesel cooling.	Increased diesel generator availability.	1
022	Add a new backup source of diesel cooling.	Increased diesel generator availability.	1
023	Develop procedures to repair or replace failed 4 KV breakers.	Increased probability of recovery from failure of breakers that transfer 4.16 kV non-emergency buses from unit station service transformers.	1
024	In training, emphasize steps in recovery of off-site power after an SBO.	Reduced human error probability during off-site power recovery.	1
025	Develop a severe weather conditions procedure.	Improved off-site power recovery following external weather-related events.	1, 3, 17
026	Bury off-site power lines.	Improved off-site power reliability during severe weather.	1
Improvements Related to Core Cooling Systems			
027	Install an independent active or passive high pressure injection system.	Improved prevention of core melt sequences.	5, 6
028	Provide an additional high pressure injection pump with independent diesel.	Reduced frequency of core melt from small LOCA and SBO sequences.	5
029	Raise HPCI/RCIC backpressure trip set points.	Increased HPCI and RCIC availability when high suppression pool temperature exists.	15
030	Revise procedure to allow bypass of RCIC turbine exhaust pressure trip.	Extended RCIC operation.	15
031	Revise procedure to allow intermittent operation of HPCI and RCIC.	Extended HPCI and RCIC operation.	1

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
032	Revise procedure to control torus temperature, torus level, and primary containment pressure to increase available net positive suction head (NPSH) for injection pumps.	Increased probability that injection pumps will be available to inject coolant into the vessel.	1
033	Revise procedure to manually initiate HPCI and RCIC given auto initiation failure.	Increased availability of HPCI and RCIC given auto initiation signal failure.	1
034	Modify automatic depressurization system components to improve reliability.	Reduced frequency of high pressure core damage sequences.	3, 21
035	Add signals to open safety relief valves automatically in an MSIV closure transient.	Reduced likelihood of SRV failure to open in an MSIV closure transient reduces the probability of a medium LOCA.	3
036	Revise procedure to allow manual initiation of emergency depressurization.	Improved prevention of core damage during transients, small and medium LOCAs, and ATWS.	21
037	Revise procedure to allow operators to inhibit automatic vessel depressurization in non-ATWS scenarios.	Extended HPCI and RCIC operation.	5
038	Add a diverse low pressure injection system.	Improved injection capability.	5, 6
039	Increase flow rate of suppression pool cooling.	Improved suppression pool cooling.	6
040	Provide capability for alternate injection via diesel-driven fire pump.	Improved injection capability.	5
041	Provide capability for alternate injection via reactor water cleanup (RWCU).	Improved injection capability.	1
042	Revise procedure to align EDG and allow use of essential CRD for vessel injection.	Improved injection capability.	15
043	Revise procedure to allow use of condensate pumps for injection.	Improved injection capability.	15
044	Revise procedure to allow use of suppression pool jockey pump for injection.	Improved injection capability.	6
045	Revise procedure to re-open MSIVs.	Regains the main condenser as a heat sink.	15
046	Improve ECCS suction strainers.	Enhanced reliability of ECCS suction.	22
047	Revise procedure to align LPCI or core spray to CST on loss of suppression pool cooling.	Improved injection in loss of suppression pool cooling scenarios.	15
048	Remove LPCI loop select logic.	Enables use of LPCI A loop for injection in the event of a B injection path failure.	18

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
049	Replace two of the four electric safety injection pumps with diesel-powered pumps.	Reduced common cause failure of the safety injection system. This SAMA was originally intended for the Westinghouse-CE System 80+, which has four trains of safety injection. However, the intent of this SAMA is to provide diversity within the high- and low-pressure safety injection systems.	5, 10
Improvements Related to Cooling Water			
050	Change procedures to allow cross connection of motor cooling for RHRSW pumps.	Continued operation of both RHRSW pumps on failure of one train of SW.	3
051	Add redundant DC control power for SW pumps.	Increased availability of SW.	3
052	Replace ECCS pump motors with air-cooled motors.	Elimination of ECCS dependency on component cooling system.	1
053	Provide self-cooled ECCS seals.	Elimination of ECCS dependency on component cooling system.	1
054	Enhance procedural guidance for use of cross-tied component cooling or service water pumps.	Reduced frequency of loss of component cooling water and service water.	1
055	Implement modifications to allow manual alignment of the fire water system to RHR heat exchangers.	Improved ability to cool RHR heat exchangers.	1
056	Add a service water pump.	Increased availability of cooling water.	6
057	Enhance the screen wash system.	Reduced potential for loss of SW due to clogging of screens.	23
Improvements Related to Feedwater and Condensate			
058	Install a digital feedwater upgrade.	Reduced chance of loss of main feedwater following a plant trip.	1
059	Create ability for emergency connection of existing or new water sources to feedwater and condensate systems.	Increased availability of feedwater.	5
060	Install an independent diesel for the condensate storage tank makeup pumps.	Extended inventory in CST during an SBO.	5
061	Add a motor-driven feedwater pump.	Increased availability of feedwater.	1, 3
Improvements Related to Heating, Ventilation, and Air Conditioning			
062	Provide reliable power to control building fans.	Increased availability of control room ventilation.	2
063	Provide a redundant train or means of ventilation.	Increased availability of components dependent on room cooling.	1

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
064	Enhance procedures for actions on loss of HVAC.	Increased availability of components dependent on room cooling.	3
065	Add a diesel building high temperature alarm or redundant louver and thermostat.	Improved diagnosis of a loss of diesel building HVAC.	1
066	Create ability to switch HPCI and RCIC room fan power supply to DC in an SBO event.	Increased availability of HPCI and RCIC in an SBO event.	1
067	Enhance procedure to trip unneeded RHR or CS pumps on loss of room ventilation.	Extended availability of required RHR or CS pumps due to reduction in room heat load.	3
068	Stage backup fans in switchgear rooms.	Increased availability of ventilation in the event of a loss of switchgear ventilation.	5
069	Add a switchgear room high temperature alarm.	Improved diagnosis of a loss of switchgear HVAC.	5
Improvements Related to Instrument Air and Nitrogen Supply			
070	Provide cross-unit connection of uninterruptible compressed air supply.	Increased ability to vent containment using the hardened vent.	3
071	Modify procedure to provide ability to align diesel power to more air compressors.	Increased availability of instrument air after a LOOP.	18
072	Replace service and instrument air compressors with more reliable compressors which have self-contained air cooling by shaft driven fans.	Elimination of instrument air system dependence on TBCCW and service water cooling.	5
073	Install nitrogen bottles as backup gas supply for safety relief valves.	Extended SRV operation time.	18
074	Improve SRV and MSIV pneumatic components.	Improved availability of SRVs and MSIVs.	6
Improvements Related to Containment Phenomena			
075	Install an independent method of suppression pool cooling.	Increased availability of containment heat removal.	6, 8, 9
076	Revise procedure to initiate suppression pool cooling during transients, LOCAs and ATWS.	Improved containment pressure control and containment heat removal capability.	6, 8, 9
077	Cross-tie open cycle cooling system to enhance drywell spray system.	Increased availability of containment heat removal.	8, 9
078	Enable flooding of the drywell head seal.	Reduced probability of leakage through the drywell head seal.	6, 8, 9
079	Create a reactor cavity flooding system.	Enhanced debris cool ability, reduced core concrete interaction, and increased fission product scrubbing.	1, 7, 11, 12

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
080	Install a passive drywell spray system.	Improved drywell spray capability.	6, 14
081	Use the fire water system as a backup source for the drywell spray system.	Improved drywell spray capability.	4, 6
082	Enhance procedures to refill CST from demineralized water or service water system.	Reduced risk of core damage during station blackouts or LOCAs that render the suppression pool unavailable as an injection source.	15
083	Enhance procedure to maintain ECCS suction on CST as long as possible.	Reduced chance of pump failure due to high suppression pool temperature.	15
084	Modify containment flooding procedure to restrict flooding to below the top of active fuel.	Reduced forced containment venting.	16
085	Install an unfiltered, hardened containment vent.	Increased decay heat removal capability for non-ATWS events, without scrubbing released fission products.	6, 8, 9
086	Install a filtered containment vent to remove decay heat. Option 1: Gravel Bed Filter Option 2: Multiple Venturi Scrubber	Increased decay heat removal capability for non-ATWS events, with scrubbing of released fission products.	6, 8, 9, 14
087	Enhance fire protection system and standby gas treatment system hardware and procedures.	Improved fission product scrubbing in severe accidents.	9
088	Modify plant to permit suppression pool scrubbing.	Increased scrubbing of fission products by directing vent path through water in the suppression pool.	6
089	Enhance containment venting procedures with respect to timing, path selection, and technique.	Improved likelihood of successful venting.	16
090	Control containment venting within a narrow band of pressure.	Reduced probability of rapid containment depressurization thus avoiding adverse impact on low pressure injection systems that take suction from the torus.	18
091	Improve vacuum breaker reliability by installing redundant valves in each line.	Decreased consequences of a vacuum breaker failure to reseat.	6
092	Enhance air return fans (ice condenser plants).	Reduced probability of containment failure in SBO sequences.	1
093	Provide post-accident containment inerting capability.	Reduced likelihood of hydrogen and carbon monoxide gas combustion.	6, 7, 12
094	Create a large concrete crucible with heat removal potential to contain molten core debris.	Increased cooling and containment of molten core debris. Molten core debris escaping from the vessel is contained within the crucible and a water cooling mechanism cools the molten core in the crucible, preventing melt-through of the base mat.	6, 8, 9

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
095	Create a core melt source reduction system.	Increased 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.	13
096	Strengthen primary/secondary containment (e.g., add ribbing to containment shell).	Reduced probability of containment over-pressurization.	5, 6, 10, 14
097	Increase depth of the concrete base mat or use an alternate concrete material to ensure melt-through does not occur.	Reduced probability of base mat melt-through.	10
098	Provide a reactor vessel exterior cooling system.	Increased potential to cool a molten core before it causes vessel failure, by submerging the lower head in water.	10
099	Construct a building to be connected to primary/secondary containment and maintained at a vacuum.	Reduced probability of containment over-pressurization.	6, 10
100	Institute simulator training for severe accident scenarios.	Improved arrest of core melt progress and prevention of containment failure.	6
101	Improve leak detection procedures.	Increased piping surveillance to identify leaks prior to complete failure. Improved leak detection would reduce LOCA frequency.	6
102	Install an independent power supply to the hydrogen control system using either new batteries, a non-safety grade portable generator, existing station batteries, or existing AC/DC independent power supplies, such as the security system diesel.	Reduced hydrogen detonation potential.	5, 10
103	Install a passive hydrogen control system.	Reduced hydrogen detonation potential.	5, 10
104	Erect a barrier that would provide enhanced protection of the containment walls (shell) from ejected core debris following a core melt scenario at high pressure.	Reduced probability of containment failure.	5
Improvements Related to Containment Bypass			
105	Install additional pressure or leak monitoring instruments for detection of ISLOCAs.	Reduced ISLOCA frequency.	4, 7, 11, 12, 15
106	Add redundant and diverse limit switches to each containment isolation valve.	Reduced frequency of containment isolation failure and ISLOCAs.	1

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
107	Increase leak testing of valves in ISLOCA paths.	Reduced ISLOCA frequency.	1
108	Improve MSIV design.	Decreased likelihood of containment bypass scenarios.	6
109	Install self-actuating containment isolation valves.	Reduced frequency of isolation failure.	5
110	Locate residual heat removal (RHR) inside containment	Reduced frequency of ISLOCA outside containment.	14
111	Ensure ISLOCA releases are scrubbed. One method is to plug drains in potential break areas so that break point will be covered with water.	Scrubbed ISLOCA releases.	1
112	Revise EOPs to improve ISLOCA identification.	Increased likelihood that LOCAs outside containment are identified as such. A plant had a scenario in which an RHR ISLOCA could direct initial leakage back to the pressurizer relief tank, giving indication that the LOCA was inside containment.	1
113	Improve operator training on ISLOCA coping.	Decreased ISLOCA consequences.	1
Improvements Related to ATWS			
114	Create cross-connect ability for standby liquid control (SLC) trains.	Improved availability of boron injection during ATWS.	18
115	Revise procedures to control vessel injection to prevent boron loss or dilution following SLC injection.	Improved availability of boron injection during ATWS.	15
116	Provide an alternate means of opening a pathway to the RPV for SLC injection.	Improved probability of reactor shutdown.	18
117	Increase boron concentration in the SLC system.	Reduced time required to achieve shutdown concentration provides increased margin in the accident timeline for successful initiation of SLC.	18
118	Add an independent boron injection system.	Improved availability of boron injection during ATWS.	18
119	Provide ability to use control rod drive (CRD) or RWCU for alternate boron injection.	Improved availability of boron injection during ATWS.	1
120	Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS.	Improved equipment availability after an ATWS.	19
121	Increase safety relief valve (SRV) reseat reliability.	Reduced risk of dilution of boron due to SRV failure to reseat after standby liquid control (SLC) injection.	1

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
122	Provide an additional control system for rod insertion (e.g., AMSAC).	Improved redundancy and reduced ATWS frequency.	18
123	Install an ATWS sized filtered containment vent to remove decay heat.	Increased ability to remove reactor heat from ATWS events.	6
124	Revise procedure to bypass MSIV isolation in turbine trip ATWS scenarios.	Affords operators more time to perform actions. Discharge of a substantial fraction of steam to the main condenser (i.e., as opposed to into the primary containment) affords the operator more time to perform actions (e.g., SLC injection, lower water level, depressurize RPV) than if the main condenser was unavailable, resulting in lower human error probabilities.	1, 20
125	Revise procedure to allow override of low pressure core injection during an ATWS event.	Allows immediate control of low pressure core injection. On failure of high pressure core injection and condensate, some plants direct reactor depressurization followed by five minutes of automatic low pressure core injection.	16
		Improvements Related to Internal Flooding	
126	Seal penetrations between turbine building basement and switchgear rooms.	Increased flood propagation prevention.	1
127	Improve inspection of rubber expansion joints on main condenser.	Reduced frequency of internal flooding due to failure of circulating water system expansion joints.	1
128	Modify swing direction of doors separating turbine building basement from areas containing safeguards equipment.	Prevents flood propagation.	5
		Improvements to Reduce Seismic Risk	
129	Increase seismic ruggedness of plant components.	Increased availability of necessary plant equipment during and after seismic events.	3, 10
130	Provide additional restraints for CO_2 tanks.	Increased availability of fire protection given a seismic event.	17
131	Modify safety related condensate storage tank.	Improved availability of CST following a seismic event.	6
132	Replace anchor bolts on diesel generator oil cooler.	Improved availability of diesel generators following a seismic event.	1
		Improvements to Reduce Fire Risk	
133	Replace mercury switches in fire protection system.	Decreased probability of spurious fire suppression system actuation.	7
134	Upgrade fire compartment barriers.	Decreased consequences of a fire.	7
135	Install additional transfer and isolation switches.	Reduced number of spurious actuations during a fire.	18

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
136	Enhance procedures to use alternate shutdown methods if the control room becomes uninhabitable.	Increased probability of shutdown if the control room becomes uninhabitable.	6, 7
137	Enhance fire brigade awareness.	Decreased consequences of a fire.	7
138	Enhance control of combustibles and ignition sources.	Decreased fire frequency and consequences.	7
Other Improvements			
139	Install digital large break LOCA protection system.	Reduced probability of a large break LOCA (a leak before break).	5
140	Enhance procedures to mitigate large break LOCA.	Reduced consequences of a large break LOCA	7
141	Install computer aided instrumentation system to assist the operator in assessing post-accident plant status.	Improved prevention of core melt sequences by making operator actions more reliable.	6
142	Improve maintenance procedures.	Improved prevention of core melt sequences by increasing reliability of important equipment.	6
143	Increase training and operating experience feedback to improve operator response.	Improved likelihood of success of operator actions taken in response to abnormal conditions.	6
144	Develop procedures for transportation and nearby facility accidents.	Reduced consequences of transportation and nearby facility accidents.	7

Table 13 References

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18. 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.

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TABLE 14
STANDARD List of PWR SAMA Candidates

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
Improvements Related to AC and DC Power			
001	Provide additional DC battery capacity.	Extended DC power availability during an SBO.	1, 3, 6, 10, 11, 12, 17
002	Replace lead-acid batteries with fuel cells.	Extended DC power availability during an SBO.	6, 10
003	Add additional battery charger or portable, diesel-driven battery charger to existing DC system.	Improved availability of DC power system.	5
004	Improve DC bus load shedding.	Extended DC power availability during an SBO.	1, 7
005	Provide DC bus cross-ties.	Improved availability of DC power system.	6
006	Provide additional DC power to the 120/240V vital AC system.	Increased availability of the 120 V vital AC bus.	3
007	Add an automatic feature to transfer the 120V vital AC bus from normal to standby power.	Increased availability of the 120 V vital AC bus.	5
008	Increase training on response to loss of two 120V AC buses which causes inadvertent actuation signals.	Improved chances of successful response to loss of two 120V AC buses.	5
009	Provide an additional diesel generator.	Increased availability of on-site emergency AC power.	1, 6, 10, 11, 12
010	Revise procedure to allow bypass of diesel generator trips.	Extended diesel generator operation.	15
011	Improve 4.16-kV bus cross-tie ability.	Increased availability of on-site AC power.	1, 6, 11, 12
012	Create AC power cross-tie capability with other unit (multi-unit site)	Increased availability of on-site AC power.	1, 7, 13
013	Install an additional, buried off-site power source.	Reduced probability of loss of off-site power.	1
014	Install a gas turbine generator.	Increased availability of on-site AC power.	1, 6
015	Install tornado protection on gas turbine generator.	Increased availability of on-site AC power.	18
016	Improve uninterruptible power supplies.	Increased availability of power supplies supporting front-line equipment.	6

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
017	Create a cross-tie for diesel fuel oil (multi-unit site).	Increased diesel generator availability.	1
018	Develop procedures for replenishing diesel fuel oil.	Increased diesel generator availability.	1
019	Use fire water system as a backup source for diesel cooling.	Increased diesel generator availability.	1
020	Add a new backup source of diesel cooling.	Increased diesel generator availability.	1
021	Develop procedures to repair or replace failed 4 KV breakers.	Increased probability of recovery from failure of breakers that transfer 4.16 kV non-emergency buses from unit station service transformers.	1
022	In training, emphasize steps in recovery of off-site power after an SBO.	Reduced human error probability during off-site power recovery.	1
023	Develop a severe weather conditions procedure.	Improved off-site power recovery following external weather-related events.	1, 3, 17
024	Bury off-site power lines.	Improved off-site power reliability during severe weather.	1
Improvements Related to Core Cooling Systems			
025	Install an independent active or passive high pressure injection system.	Improved prevention of core melt sequences.	5, 6
026	Provide an additional high pressure injection pump with independent diesel.	Reduced frequency of core melt from small LOCA and SBO sequences.	5
027	Revise procedure to allow operators to inhibit automatic vessel depressurization in non-ATWS scenarios.	Extended HPCI and RCIC operation.	5
028	Add a diverse low pressure injection system.	Improved injection capability.	5, 6
029	Provide capability for alternate injection via diesel-driven fire pump.	Improved injection capability.	5
030	Improve ECCS suction strainers.	Enhanced reliability of ECCS suction.	22
031	Add the ability to manually align emergency core cooling system recirculation.	Enhanced reliability of ECCS suction.	5
032	Add the ability to automatically align emergency core cooling system to recirculation mode upon refueling water storage tank depletion.	Enhanced reliability of ECCS suction.	5
033	Provide hardware and procedure to refill the reactor water storage tank once it reaches a specified low level.	Extended reactor water storage tank capacity in the event of a steam generator tube rupture.	5, 10

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
034	Provide an in-containment reactor water storage tank.	Continuous source of water to the safety injection pumps during a LOCA event, since water released from a breach of the primary system collects in the in-containment reactor water storage tank, and thereby eliminates the need to realign the safety injection pumps for long-term post-LOCA recirculation.	10
035	Throttle low pressure injection pumps earlier in medium or large-break LOCAs to maintain reactor water storage tank inventory.	Extended reactor water storage tank capacity.	5
036	Emphasize timely recirculation alignment in operator training.	Reduced human error probability associated with recirculation failure.	5
037	Upgrade the chemical and volume control system to mitigate small LOCAs.	For a plant like the Westinghouse AP600, where the chemical and volume control system cannot mitigate a small LOCA, an upgrade would decrease the frequency of core damage.	5
038	Change the in-containment reactor water storage tank suction from four check valves to two check and two air-operated valves.	Reduced common mode failure of injection paths.	5
039	Replace two of the four electric safety injection pumps with diesel-powered pumps.	Reduced common cause failure of the safety injection system. This SAMA was originally intended for the Westinghouse-CE System 80+, which has four trains of safety injection. However, the intent of this SAMA is to provide diversity within the high- and low-pressure safety injection systems.	5, 10
040	Provide capability for remote, manual operation of secondary side pilot-operated relief valves in a station blackout.	Improved chance of successful operation during station blackout events in which high area temperatures may be encountered (no ventilation to main steam areas).	5
041	Create a reactor coolant depressurization system.	Allows low pressure emergency core cooling system injection in the event of small LOCA and high-pressure safety injection failure.	5, 10
042	Make procedure changes for reactor coolant system depressurization.	Allows low pressure emergency core cooling system injection in the event of small LOCA and high-pressure safety injection failure.	5
		Improvements Related to Cooling Water	
043	Add redundant DC control power for SW pumps.	Increased availability of SW.	3
044	Replace ECCS pump motors with air-cooled motors.	Elimination of ECCS dependency on component cooling system.	1
045	Enhance procedural guidance for use of cross-tied component cooling or service water pumps.	Reduced frequency of loss of component cooling water and service water.	1
046	Add a service water pump.	Increased availability of cooling water.	6
047	Enhance the screen wash system.	Reduced potential for loss of SW due to clogging of screens.	23
048	Cap downstream piping of normally closed component cooling water drain and vent valves.	Reduced frequency of loss of component cooling water initiating events, some of which can be attributed to catastrophic failure of one of the many single isolation valves.	5

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
049	Enhance loss of component cooling water (or loss of service water) procedures to facilitate stopping the reactor coolant pumps.	Reduced potential for reactor coolant pump seal damage due to pump bearing failure.	5
050	Enhance loss of component cooling water procedure to underscore the desirability of cooling down the reactor coolant system prior to seal LOCA.	Reduced probability of reactor coolant pump seal failure.	5
051	Additional training on loss of component cooling water.	Improved success of operator actions after a loss of component cooling water.	5
052	Provide hardware connections to allow another essential raw cooling water system to cool charging pump seals.	Reduced effect of loss of component cooling water by providing a means to maintain the charging pump seal injection following a loss of normal cooling water.	5
053	On loss of essential raw cooling water, proceduralize shedding component cooling water loads to extend the component cooling water heat-up time.	Increased time before loss of component cooling water (and reactor coolant pump seal failure) during loss of essential raw cooling water sequences.	5
054	Increase charging pump lube oil capacity.	Increased time before charging pump failure due to lube oil overheating in loss of cooling water sequences.	5
055	Install an independent reactor coolant pump seal injection system, with dedicated diesel.	Reduced frequency of core damage from loss of component cooling water, service water, or station blackout.	5, 10
056	Install an independent reactor coolant pump seal injection system, without dedicated diesel.	Reduced frequency of core damage from loss of component cooling water or service water, but not a station blackout.	5, 10
057	Use existing hydro test pump for reactor coolant pump seal injection.	Reduced frequency of core damage from loss of component cooling water or service water, but not a station blackout.	5
058	Install improved reactor coolant pump seals.	Reduced likelihood of reactor coolant pump seal LOCA.	5
059	Install an additional component cooling water pump.	Reduced likelihood of loss of component cooling water leading to a reactor coolant pump seal LOCA.	5
060	Prevent makeup pump flow diversion through the relief valves.	Reduced frequency of loss of reactor coolant pump seal cooling if spurious high pressure injection relief valve opening creates a flow diversion large enough to prevent reactor coolant pump seal injection.	5
061	Change procedures to isolate reactor coolant pump seal return flow on loss of component cooling water, and provide (or enhance) guidance on loss of injection during seal LOCA.	Reduced frequency of core damage due to loss of seal cooling.	5
062	Implement procedures to stagger high pressure safety injection pump use after a loss of service water.	Extended high pressure injection prior to overheating following a loss of service water.	5
063	Use fire prevention system pumps as a backup seal injection and high pressure makeup source.	Reduced frequency of reactor coolant pump seal LOCA.	5

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
064	Implement procedure and hardware modifications to allow manual alignment of the fire water system to the component cooling water system, or install a component cooling water header cross-tie.	Improved ability to cool residual heat removal heat exchangers.	5
Improvements Related to Feedwater and Condensate			
065	Install a digital feed water upgrade.	Reduced chance of loss of main feed water following a plant trip.	1
066	Create ability for emergency connection of existing or new water sources to feedwater and condensate systems.	Increased availability of feedwater.	5
067	Install an independent diesel for the condensate storage tank makeup pumps.	Extended inventory in CST during an SBO.	5
068	Add a motor-driven feedwater pump.	Increased availability of feedwater.	1, 3
069	Install manual isolation valves around auxiliary feedwater turbine-driven steam admission valves.	Reduced dual turbine-driven pump maintenance unavailability.	5
070	Install accumulators for turbine-driven auxiliary feedwater pump flow control valves.	Eliminates the need for local manual action to align nitrogen bottles for control air following a loss of off-site power.	5
071	Install a new condensate storage tank (auxiliary feedwater storage tank).	Increased availability of the auxiliary feedwater system.	5, 10
072	Modify the turbine-driven auxiliary feedwater pump to be self-cooled.	Improved success probability during a station blackout.	5
073	Proceduralize local manual operation of auxiliary feedwater system when control power is lost.	Extended auxiliary feedwater availability during a station blackout. Also provides a success path should auxiliary feedwater control power be lost in non-station blackout sequences.	5
074	Provide hookup for portable generators to power the turbine-driven auxiliary feedwater pump after station batteries are depleted.	Extended auxiliary feedwater availability.	5, 10
075	Use fire water system as a backup for steam generator inventory.	Increased availability of steam generator water supply.	5
076	Change failure position of condenser makeup valve if the condenser makeup valve fails open on loss of air or power.	Allows greater inventory for the auxiliary feedwater pumps by preventing condensate storage tank flow diversion to the condenser.	5
077	Provide a passive, secondary-side heat-rejection loop consisting of a condenser and heat sink.	Reduced potential for core damage due to loss-of-feedwater events.	5

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
078	Modify the startup feedwater pump so that it can be used as a backup to the emergency feedwater system, including during a station blackout scenario.	Increased reliability of decay heat removal.	10
079	Replace existing pilot-operated relief valves with larger ones, such that only one is required for successful feed and bleed.	Increased probability of successful feed and bleed.	5
Improvements Related to Heating, Ventilation, and Air Conditioning			
080	Provide a redundant train or means of ventilation.	Increased availability of components dependent on room cooling.	1
081	Add a diesel building high temperature alarm or redundant louver and thermostat.	Improved diagnosis of a loss of diesel building HVAC.	1
082	Stage backup fans in switchgear rooms.	Increased availability of ventilation in the event of a loss of switchgear ventilation.	5
083	Add a switchgear room high temperature alarm.	Improved diagnosis of a loss of switchgear HVAC.	5
084	Create ability to switch emergency feedwater room fan power supply to station batteries in a station blackout.	Continued fan operation in a station blackout.	5
Improvements Related to Instrument Air and Nitrogen Supply			
085	Provide cross-unit connection of uninterruptible compressed air supply.	Increased ability to vent containment using the hardened vent.	3
086	Modify procedure to provide ability to align diesel power to more air compressors.	Increased availability of instrument air after a LOOP.	18
087	Replace service and instrument air compressors with more reliable compressors which have self-contained air cooling by shaft driven fans.	Elimination of instrument air system dependence on service water cooling.	5
088	Install nitrogen bottles as backup gas supply for safety relief valves.	Extended SRV operation time.	18
089	Improve SRV and MSIV pneumatic components.	Improved availability of SRVs and MSIVs.	6
Improvements Related to Containment Phenomena			
090	Create a reactor cavity flooding system.	Enhanced debris cool ability, reduced core concrete interaction, and increased fission product scrubbing.	1, 7, 11, 12
091	Install a passive containment spray system.	Improved containment spray capability.	6, 14

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
092	Use the fire water system as a backup source for the containment spray system.	Improved containment spray capability.	4, 6
093	Install an unfiltered, hardened containment vent.	Increased decay heat removal capability for non-ATWS events, without scrubbing released fission products.	6, 8, 9
094	Install a filtered containment vent to remove decay heat Option 1: Gravel Bed Filter Option 2: Multiple Venturi Scrubber	Increased decay heat removal capability for non-ATWS events, with scrubbing of released fission products.	6, 8, 9, 14
095	Enhance fire protection system and standby gas treatment system hardware and procedures.	Improved fission product scrubbing in severe accidents.	9
096	Provide post-accident containment inerting capability.	Reduced likelihood of hydrogen and carbon monoxide gas combustion.	6, 7, 12
097	Create a large concrete crucible with heat removal potential to contain molten core debris.	Increased cooling and containment of molten core debris. Molten core debris escaping from the vessel is contained within the crucible and a water cooling mechanism cools the molten core in the crucible, preventing melt-through of the base mat.	6, 8, 9
098	Create a core melt source reduction system.	Increased 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.	13
099	Strengthen primary/secondary containment (e.g., add ribbing to containment shell).	Reduced probability of containment over-pressurization.	5, 6, 10, 14
100	Increase depth of the concrete base mat or use an alternate concrete material to ensure melt-through does not occur.	Reduced probability of base mat melt-through.	10
101	Provide a reactor vessel exterior cooling system.	Increased potential to cool a molten core before it causes vessel failure, by submerging the lower head in water.	10
102	Construct a building to be connected to primary/secondary containment and maintained at a vacuum.	Reduced probability of containment over-pressurization.	6, 10
103	Institute simulator training for severe accident scenarios.	Improved arrest of core melt progress and prevention of containment failure.	6
104	Improve leak detection procedures.	Increased piping surveillance to identify leaks prior to complete failure. Improved leak detection would reduce LOCA frequency.	6
105	Delay containment spray actuation after a large LOCA.	Extended reactor water storage tank availability.	5

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
106	Install automatic containment spray pump header throttle valves.	Extended time over which water remains in the reactor water storage tank, when full containment spray flow is not needed.	5
107	Install a redundant containment spray system.	Increased containment heat removal ability.	5, 10
108	Install an independent power supply to the hydrogen control system using either new batteries, a non-safety grade portable generator, existing station batteries, or existing AC/DC independent power supplies, such as the security system diesel.	Reduced hydrogen detonation potential.	5, 10
109	Install a passive hydrogen control system.	Reduced hydrogen detonation potential.	5, 10
110	Erect a barrier that would provide enhanced protection of the containment walls (shell) from ejected core debris following a core melt scenario at high pressure.	Reduced probability of containment failure.	5
Improvements Related to Containment Bypass			
111	Install additional pressure or leak monitoring instruments for detection of ISLOCAs.	Reduced ISLOCA frequency.	4, 7, 11, 12, 15
112	Add redundant and diverse limit switches to each containment isolation valve.	Reduced frequency of containment isolation failure and ISLOCAs.	1
113	Increase leak testing of valves in ISLOCA paths.	Reduced ISLOCA frequency.	1
114	Install self-actuating containment isolation valves.	Reduced frequency of isolation failure.	5
115	Locate residual heat removal (RHR) inside containment	Reduced frequency of ISLOCA outside containment.	14
116	Ensure ISLOCA releases are scrubbed. One method is to plug drains in potential break areas so that break point will be covered with water.	Scrubbed ISLOCA releases.	1
117	Revise EOPs to improve ISLOCA identification.	Increased likelihood that LOCAs outside containment are identified as such. A plant had a scenario in which an RHR ISLOCA could direct initial leakage back to the pressurizer relief tank, giving indication that the LOCA was inside containment.	1
118	Improve operator training on ISLOCA coping.	Decreased ISLOCA consequences.	1
119	Institute a maintenance practice to perform a 100% inspection of steam generator tubes during each refueling outage.	Reduced frequency of steam generator tube ruptures.	5, 10
120	Replace steam generators with a new design.	Reduced frequency of steam generator tube ruptures.	5

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
121	Increase the pressure capacity of the secondary side so that a steam generator tube rupture would not cause the relief valves to lift.	Eliminates release pathway to the environment following a steam generator tube rupture.	5, 10
122	Install a redundant spray system to depressurize the primary system during a steam generator tube rupture	Enhanced depressurization capabilities during steam generator tube rupture.	5, 10
123	Proceduralize use of pressurizer vent valves during steam generator tube rupture sequences.	Backup method to using pressurizer sprays to reduce primary system pressure following a steam generator tube rupture.	5
124	Provide improved instrumentation to detect steam generator tube ruptures, such as Nitrogen-16 monitors).	Improved mitigation of steam generator tube ruptures.	5, 10
125	Route the discharge from the main steam safety valves through a structure where a water spray would condense the steam and remove most of the fission products.	Reduced consequences of a steam generator tube rupture.	10
126	Install a highly reliable (closed loop) steam generator shell-side heat removal system that relies on natural circulation and stored water sources	Reduced consequences of a steam generator tube rupture.	5
127	Revise emergency operating procedures to direct isolation of a faulted steam generator.	Reduced consequences of a steam generator tube rupture.	5
128	Direct steam generator flooding after a steam generator tube rupture, prior to core damage.	Improved scrubbing of steam generator tube rupture releases.	5
129	Vent main steam safety valves in containment.	Reduced consequences of a steam generator tube rupture.	5, 10
Improvements Related to ATWS			
130	Add an independent boron injection system.	Improved availability of boron injection during ATWS.	18
131	Add a system of relief valves to prevent equipment damage from pressure spikes during an ATWS.	Improved equipment availability after an ATWS.	19
132	Provide an additional control system for rod insertion (e.g., AMSAC).	Improved redundancy and reduced ATWS frequency.	18
133	Install an ATWS sized filtered containment vent to remove decay heat.	Increased ability to remove reactor heat from ATWS events.	6
134	Revise procedure to bypass MSIV isolation in turbine trip ATWS scenarios.	Affords operators more time to perform actions. Discharge of a substantial fraction of steam to the main condenser (i.e., as opposed to into the primary containment) affords the operator more time to perform actions (e.g., SLC injection, lower water level, depressurize RPV) than if the main condenser was unavailable, resulting in lower human error probabilities.	1, 20

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
135	Revise procedure to allow override of low pressure core injection during an ATWS event.	Allows immediate control of low pressure core injection. On failure of high pressure core injection and condensate, some plants direct reactor depressurization followed by five minutes of automatic low pressure core injection.	16
136	Install motor generator set trip breakers in control room.	Reduced frequency of core damage due to an ATWS.	5
137	Provide capability to remove power from the bus powering the control rods.	Decreased time required to insert control rods if the reactor trip breakers fail (during a loss of feedwater ATWS which has rapid pressure excursion).	5
Improvements Related to Internal Flooding			
138	Improve inspection of rubber expansion joints on main condenser.	Reduced frequency of internal flooding due to failure of circulating water system expansion joints.	1
139	Modify swing direction of doors separating turbine building basement from areas containing safeguards equipment.	Prevents flood propagation.	5
Improvements to Reduce Seismic Risk			
140	Increase seismic ruggedness of plant components.	Increased availability of necessary plant equipment during and after seismic events.	3, 10
141	Provide additional restraints for CO_2 tanks.	Increased availability of fire protection given a seismic event.	17
Improvements to Reduce Fire Risk			
142	Replace mercury switches in fire protection system.	Decreased probability of spurious fire suppression system actuation.	7
143	Upgrade fire compartment barriers.	Decreased consequences of a fire.	7
144	Install additional transfer and isolation switches.	Reduced number of spurious actuations during a fire.	18
145	Enhance fire brigade awareness.	Decreased consequences of a fire.	7
146	Enhance control of combustibles and ignition sources.	Decreased fire frequency and consequences.	7
Other Improvements			
147	Install digital large break LOCA protection system.	Reduced probability of a large break LOCA (a leak before break).	5
148	Enhance procedures to mitigate large break LOCA.	Reduced consequences of a large break LOCA.	7
149	Install computer aided instrumentation system to assist the operator in assessing post-accident plant status.	Improved prevention of core melt sequences by making operator actions more reliable.	6

SAMA ID	Potential Enhancement (SAMA Title)	Result of Potential Enhancement	Source Reference
150	Improve maintenance procedures.	Improved prevention of core melt sequences by increasing reliability of important equipment.	6
151	Increase training and operating experience feedback to improve operator response.	Improved likelihood of success of operator actions taken in response to abnormal conditions.	6
152	Develop procedures for transportation and nearby facility accidents.	Reduced consequences of transportation and nearby facility accidents.	7
153	Install secondary side guard pipes up to the main steam isolation valves.	Prevents secondary side depressurization should a steam line break occur upstream of the main steam isolation valves. Also guards against or prevents consequential multiple steam generator tube ruptures following a main steam line break event.	5, 10

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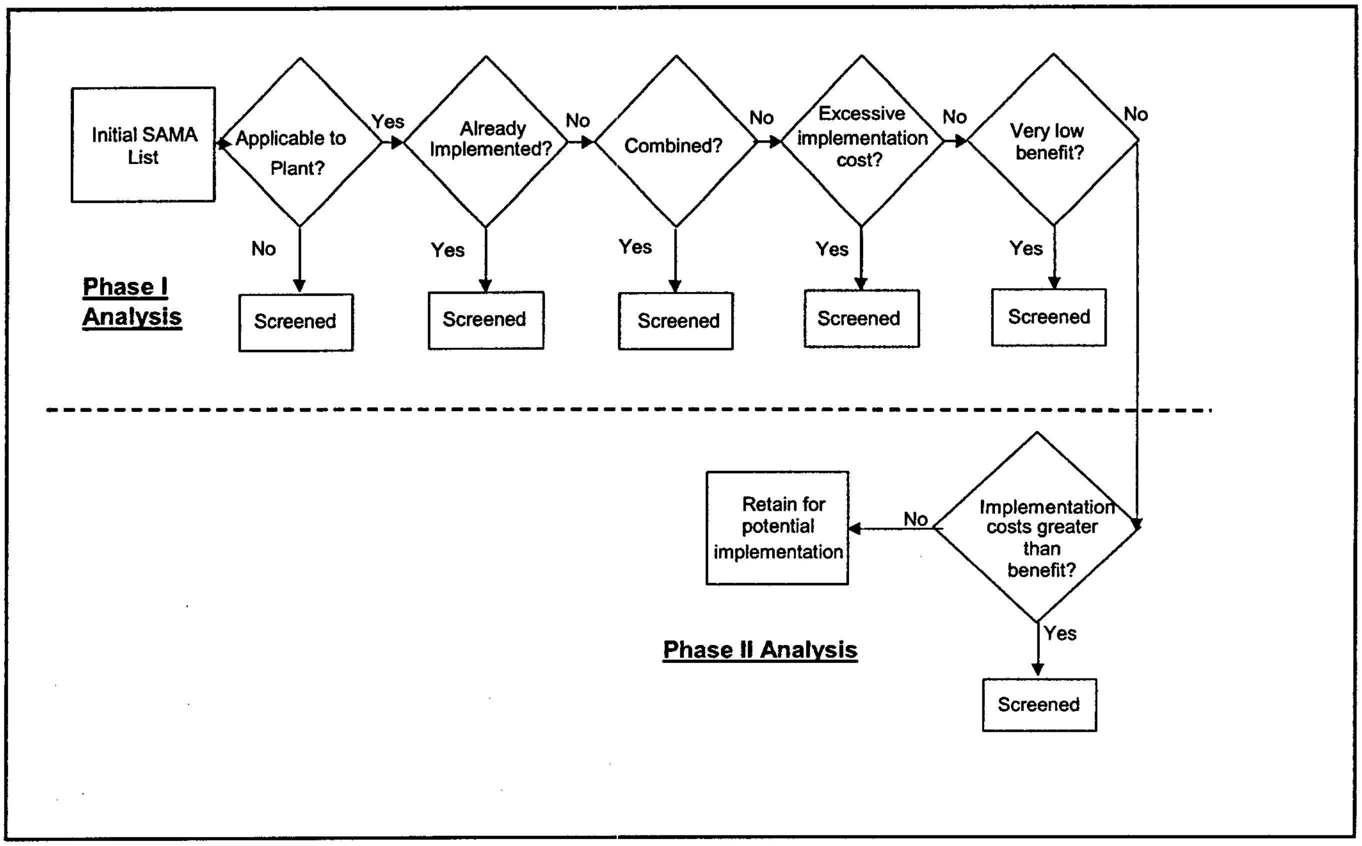
Figure 1
SAMA Screening Process



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