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4.21 Severe Accident Mitigation Alternatives

4.21.1 Description of Issue

Severe accidents

4.21.2 Finding from Table B-1, Appendix B to Subpart A

SMALL. 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. See 10 CFR 51.53(c)(3)(ii)(L).

4.21.3 Requirement [10 CFR 51.53(c)(3)(ii)(L)]

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 environmental assessment, a consideration of alternatives to mitigate severe accidents must be provided.

4.21.4 Background

The staff concluded that the generic analysis summarized in the GEIS applies to all plants and that the probability-weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts of severe accidents are of small significance for all plants. However, not all plants have performed a site-specific analysis of measures that could mitigate severe accidents. Consequently, severe accidents are a Category 2 issue for plants that have not performed a site-specific consideration of severe accident mitigation and submitted that analysis for Commission review [Reference 4-5, Section 5.5.2.5].

4.21.5 Analysis of Environmental Impact

The method used to perform the Severe Accident Mitigation Analysis (SAMA) was based on the handbook used by the NRC to analyze benefits and costs of its regulatory activities [Reference 4-6].

Environmental impact statements and environmental reports are prepared using a sliding scale in which impacts of greater concern and mitigation measures of greater potential value receive more detailed analysis than impacts of less concern and mitigation measures of less potential value. Accordingly, Entergy used less detailed feasibility investigation and cost estimation techniques for SAMA candidates having disproportionately high costs and low benefits and more detailed evaluations for the most viable candidates.

The following is a brief outline of the approach taken in the SAMA analysis.

(1) Establish the Baseline Impacts of a Severe Accident

Severe accident impacts were evaluated in four areas:

- Off-site exposure costs – monetary value of consequences (dose) to off-site population

  The Probabilistic Safety Assessment (PSA) model was used to determine total accident frequency (core damage frequency (CDF) and containment release frequency). The Melcor Accident Consequences Code System 2 (MACCS2) was used to convert release input to public dose. Dose was converted to present worth dollars (based on a valuation of $2,000 per person-rem and a present worth discount factor of 7.0%).

- Off-site economic costs – monetary value of damage to off-site property

  The PSA model was used to determine total accident frequency (CDF and containment release frequency). MACCS2 was used to convert release input to off-site property damage. Off-site property damage was converted to present worth dollars based on a discount factor of 7.0%.

- On-site exposure costs – monetary value of dose to workers

  Best estimate occupational dose values were used for immediate and long-term dose. Dose was converted to present worth dollars (based on a valuation of $2,000 per person-rem and a present worth discount factor of 7%).

- On-site economic costs – monetary value of damage to on-site property

  Best estimate cleanup and decontamination costs were used. On-site property damage estimates were converted to present worth dollars based on a discount factor of 7.0%. It was assumed that, subsequent to a severe accident, the plant would be decommissioned rather than restored. Therefore replacement and refurbishment costs were not included in on-site costs. Replacement power costs were considered.

(2) Identify SAMA Candidates

Potential SAMA candidates were identified from the following sources (see Attachment E for reference details):

- Severe Accident Mitigation Design Alternative (SAMDA) analyses submitted in support of original licensing activities for other operating nuclear power plants and advanced light water reactor plants;

- SAMA analyses for other BWR plants, including the General Electric (GE) Advanced Boiling Water Reactor (ABWR) design;

- NRC and industry documentation discussing potential plant improvements;

- PNPS Individual Plant Examination (IPE) of internal and external events reports and their updates (in both reports, several enhancements related to severe accident insights were recommended and implemented); and

- PNPS PSA model risk significant contributors.

(3) Phase I - Preliminary Screening

Potential SAMA candidates were screened out if they modified features not applicable to PNPS, if they had already been implemented at PNPS, or if they were similar in nature and could be combined with another SAMA candidate to develop a more comprehensive or plant-specific SAMA candidate.

(4) Phase II - Final Screening and Cost Benefit Evaluation

The remaining SAMA candidates were evaluated individually to determine the benefits and costs of implementation, as follows.

- The total benefit of implementing a SAMA candidate was estimated in terms of averted consequences (benefits estimate).

  - The baseline PSA model was modified to reflect the maximum benefit of the improvement. Generally, the maximum benefit of a SAMA candidate was determined with a bounding modeling assumption. For example, if the objective of the SAMA candidate was to reduce the likelihood of a certain failure mode, then eliminating the failure mode from the PSA would bound the benefit, even though the SAMA candidate would not be expected to be 100% effective in eliminating the failure. The modified model was then used to produce a revised accident frequency.

  - Using the revised accident frequency, the method previously described for the four baseline severe accident impact areas was used to estimate the cost associated with each impact area following implementation of the SAMA candidate.

- The benefit in terms of averted consequences for each SAMA candidate was then estimated by calculating the arithmetic difference between the total estimated cost associated with all four impact areas for the baseline plant design and the revised plant design following implementation of the SAMA candidate.

- The cost of implementing a SAMA was estimated by one of the following methods (cost estimate).

  - An estimate for a similar modification considered in a previously performed SAMA or SAMDA analysis was used. These estimates were used for comparison against an estimated benefit at PNPS since they were developed in the past and no credit was taken for inflation when applying them to PNPS. In addition, several of them were developed from SAMDA analysis (i.e., during the design phase of the plant), and therefore did not consider the additional costs associated with performing design modifications to an existing plant (i.e., reduced efficiency, minimizing dose, disposal of contaminated material, etc.).

  - Engineering judgment on the cost associated with procedural changes, engineering analysis, testing, training and hardware modification was applied to formulate a conclusion regarding the economic viability of the SAMA candidate.

The detail of the cost estimate was commensurate with the benefit. If the benefit was low, it was not necessary to perform a detailed cost estimate to determine if the SAMA was cost beneficial.

(5) Sensitivity Analyses

Two sensitivity analyses were conducted to gauge the impact of key assumptions upon the analysis. One sensitivity analysis was to investigate the sensitivity of assuming a 27-year period for remaining plant life. The other sensitivity analysis was to investigate the sensitivity of each analysis case to the discount rate of 3.0%.

The SAMA analysis for PNPS is presented in the following sections. Attachment E.1 and Attachment E.2 provide a more detailed discussion of the process presented above.

4.21.5.1 Establish the Baseline Impacts of a Severe Accident

A baseline was established to enable estimation of the risk reductions attributable to implementation of potential SAMA candidates. This severe accident risk was estimated using the PNPS PSA model and the MACCS2 consequence analysis software code. The PSA model used for the SAMA analysis (PNPS Revision 1, April 2003) is an internal events risk model.

4.21.5.1.1 The PSA Model—Level 1 and Level 2 Analysis

The PSA model (Level 1 and Level 2) used for the SAMA analysis was the most recent internal events risk model for the PNPS (PNPS Revision 1, April 2003). This current model is an updated version of the model used in the 1992 IPE and subsequently modified in 1995 to answer an RAI and reflects the PNPS configuration and design changes as of September 2001. It also uses component failure and unavailability data as of December 2001, and resolves all findings and observations during the industry peer review of the model, conducted in March 2000. The PNPS model adopts the small event tree/large fault tree approach and uses the CAFTA code for quantifying CDF.

An uncertainty analysis associated with internal events CDF was performed. The ratio of the CDF at the 95th percent confidence level to the mean CDF is a factor of 1.62. This analysis is presented in Section E.1.1 of Attachment E.1.

The PNPS Level 2 analysis uses a Containment Event Tree (CET) to analyze all core damage sequences identified in the Level 1 analysis. The CET evaluates systems, operator actions, and severe accident phenomena in order to characterize the magnitude and timing of radionuclide release. The result of the Level 2 analysis is a list of sequences involving radionuclide release, along with the frequency and magnitude/timing of release for each sequence.

4.21.5.1.2 The PSA External Events Model - Individual Plant Examination of External Events (IPEEE) Model

The PNPS IPEEE model was reviewed and used for SAMA analysis. The seismic, high wind, and external flooding analyses determined that the plant is adequately designed to protect against the effects of these natural events. The seismic portion of the IPEEE program was completed in conjunction with the Seismic Qualification Utility Group (SQUG) program. PNPS performed a seismic probabilistic Risk Assessment (PRA) following the guidance of NUREG-1407, *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*, June 1991. A number of plant improvements were identified and, as described in NUREG-1742, *Perspectives Gained from the IPEEE Program*, Final Report, April 2002, these improvements were implemented.

The PNPS fire analysis was performed using the EPRI Fire Induced Vulnerability Evaluation (FIVE) methodology for qualitative and quantitative screening of fire areas and for fire analysis of areas that did not screen. The FIVE methodology is primarily a screening approach used to identify plant vulnerabilities due to fire initiating events. The end result of PNPS IPEEE fire analysis identified the CDF for significant fire areas. A number of administrative procedures were revised to improve combustible and flammable material control.

4.21.5.1.3 The MACCS2 Model - Level 3 Analysis

A "Level 3" model was developed using the MACCS2 consequence analysis software code to estimate the hypothetical impacts of severe accidents on the surrounding environment and

members of the public. The principal phenomena analyzed were atmospheric transport of radionuclides; mitigation actions (i.e., evacuation, condemnation of contaminated crops and milk) based on dose projection; dose accumulation by a number of pathways, including food and water ingestion; and economic costs. Input for the Level 3 analysis included the core radionuclide inventory, source terms from the PNPS PSA model, site meteorological data, projected population distribution (within 50-mile radius) for the year 2032, emergency response evacuation modeling, and economic data. The MACCS2 input data are described in Section E.1.5 of Attachment E.1.

4.21.5.1.4 Evaluation of Baseline Severe Accident Impacts Using the Regulatory Analysis Technical Evaluation Handbook Method

This section describes the method used for calculating the cost associated with each of the four impact areas for the baseline case (i.e., without SAMA implementation). This analysis was used to establish the maximum benefit that a SAMA could achieve if it eliminated all risk due to PNPS at-power internal events [Reference 4-6].

Off-Site Exposure Costs

The Level 3 baseline analysis resulted in an annual off-site exposure risk of 13.6 Person rem. This value was converted to its monetary equivalent (dollars) via application of the $2,000 per person rem conversion factor from the Regulatory Analysis Technical Evaluation Handbook [Reference 4-6]. This monetary equivalent was then discounted to present value using the formula from the same source:

$$APE = (F_S D_{P_S} - F_A D_{P_A}) R \frac{1 - e^{-rt_f}}{r}$$

where

APE =monetary value of accident risk avoided from population doses, after discounting;

R = monetary equivalent of unit dose, ($/person-rem);

F = accident frequency (events/year);

D_P = population dose factor (person-rem/event);

S = status quo (current conditions);

A = after implementation of proposed action;

r = discount rate (%); and

t_f = license renewal period (years).

Using a 20-year license renewal period, a 7.0% discount rate, assuming FA is zero, and the baseline CDF of 6.41E-06/year resulted in the monetary equivalent value of $292,751. This value is presented in Table 4-3.

Off-Site Economic Costs

The Level 3 baseline analysis resulted in an annual off-site economic risk monetary equivalent of $45,900. This value was discounted in the same manner as the public health risks in accordance with the following equation:

$$AOC = (F_S P_{D_S} - F_A P_{D_A}) \frac{1 - e^{-rt_f}}{r}$$

where

AOC =monetary value of risk avoided from off-site property damage, after discounting;

P_D = off-site property loss factor ($/event);

F = accident frequency (events/year);

S = status quo (current conditions);

A = after implementation of proposed action;

r = discount rate (%); and

t_f = license renewal period (years).

Using previously defined values, the resulting monetary equivalent is $494,017. This value is presented in Table 4-3.

On-Site Exposure Costs

The values for occupational exposure associated with severe accidents were not derived from the PSA model, but from information in the *Regulatory Analysis Technical Evaluation Handbook* [Reference 4-6]. The values for occupational exposure consist of "immediate dose" and "long-term dose." The best estimate value provided for immediate occupational dose is 3,300 person rem, and long-term occupational dose is 20,000 person-rem (over a 10 year clean-up period). The following equations were used to estimate monetary equivalents.

Immediate Dose

$$W_{IO} = (F_S D_{IO_S} - F_A D_{IO_A}) R \frac{1 - e^{-rt_f}}{r} \qquad (1)$$

where

W_{IO} = monetary value of accident risk avoided from immediate doses, after discounting;

IO = immediate occupational dose;

R = monetary equivalent of unit dose, ($/person-rem);

F = accident frequency (events/year);

D_{IO} = immediate occupational dose (person-rem/event;

S = status quo (current conditions);

A = after implementation of proposed action;

r = discount rate (%); and

t_f = license renewal period (years).

The values used in the analysis were

R = $2,000/person rem;

r = 0.07;

D_{IO} = 3,300 person rem /accident; and

t_f = 20 years.

For the basis discount rate, assuming F_A is zero, the bounding monetary value of the immediate dose associated with PNPS's accident risk is

$$W_{IO} = (F_S D_{IO_S}) R \frac{1 - e^{-rt_f}}{r}$$

$$W_{IO} = 3,300 \times F_S \times \$2,000 \times \frac{1 - e^{-0.07 \times 20}}{0.07}$$

$$W_{IO} = (\$7.10 \times 10^7) F_s$$

For the baseline CDF, 6.41 x 10^{-6}/year,

$$W_{IO} = \$455$$

Long-Term Dose

$$W_{LTO} = (F_S D_{LTO_S} - F_A D_{LTO_A}) R \times \frac{1 - e^{-rt_f}}{r} \times \frac{1 - e^{-rm}}{rm} \qquad (2)$$

where

W_{LTO} =monetary value of accident risk avoided long-term doses, after discounting ($);

LTO = long-term occupational dose;

m = years over which long-term doses accrue;

R = monetary equivalent of unit dose, ($/person-rem);

F = accident frequency (events/year);

D_{LTO} = long-term occupational dose (person-rem/event);

S = status quo (current conditions);

A = after implementation of proposed action;

r = discount rate (%); and

t_f = license renewal period (years).

The values used in the analysis were

R = $2,000/person rem;

r = 0.07;

D_{LTO} = 20,000 person-rem /accident;

m = 10 years; and

t_f = 20 years.

For the basis discount rate, assuming F_A is zero, the bounding monetary value of the long-term dose associated with PNPS's accident risk is

$$W_{LTO} = (F_S D_{LTO_S}) R \times \frac{1 - e^{-rt_f}}{r} \times \frac{1 - e^{-rm}}{rm}$$

$$W_{LTO} = (F_S \times 20,000)\$2,000 \times \frac{1 - e^{-0.07 \times 20}}{0.07} \times \frac{1 - e^{-0.07 \times 10}}{0.07 \times 10}$$

$$W_{LTO} = (\$3.10 \times 10^8) F_S$$

For the CDF for the baseline, 6.41 x 10^{-6}/year,

W_{LTO} = $1,985.

Total Occupational Exposures

Combining equations (1) and (2) above, using delta (Δ) to signify the difference in accident frequency resulting from the proposed actions, and using the above numerical values, the long-term accident related on-site (occupational) exposure avoided is

$$AOE = \Delta W_{IO} + \Delta W_{LTO} \ (\$)$$

where

AOE = on-site exposure avoided.

The bounding value for occupational exposure (AOE_B) is

$$AOE_B = W_{IO} + W_{LTO} = \$455 + \$1,985 = \$2,440$$

The resulting monetary equivalent of $2,440 is presented in Table 4-3.

<u>*On-Site Economic Costs*</u>

Clean-up/Decontamination

The total cost of clean-up/decontamination of a power reactor facility subsequent to a severe accident is estimated in the *Regulatory Analysis Technical Evaluation Handbook* [Reference 4-6] to be $1.5 x 10^9. This same value was adopted for

these analyses. Considering a 10-year cleanup period, the present value of this cost is

$$PV_{CD} = \left(\frac{C_{CD}}{m}\right)\left(\frac{1 - e^{-rm}}{r}\right)$$

where

PV_{CD} =present value of the cost of cleanup/decontamination;

CD = clean-up/decontamination;

C_{CD} = total cost of the cleanup/decontamination effort ($);

m = cleanup period (years);

r = discount rate (%).

Based upon the values previously assumed,

$$PV_{CD} = \left(\frac{\$1.5E+9}{10}\right)\left(\frac{1 - e^{-0.07 \times 10}}{0.07}\right)$$

$$PV_{CD} = \$1.08E+9.$$

This cost is integrated over the term of the proposed license extension as follows:

$$U_{CD} = PV_{CD}\frac{1 - e^{-rt_f}}{r}$$

where,

U_{CD} = total cost of clean up/decontamination over the life of the plant.

Based upon the values previously assumed,

$$U_{CD} = \$1.16E+10\,.$$

Replacement Power Costs

Replacement power costs were estimated in accordance with the *Regulatory Analysis Technical Evaluation Handbook* [Reference 4-6]. Since replacement power will be needed for the time period following a severe accident, for the remainder of the expected generating plant life, long-term power replacement

calculations have been used. The present value of replacement power was estimated as follows:

$$PV_{RP} = \left(\frac{\$1.2x10^8}{r}\right)(1 - e^{-rt_f})^2$$

where

PV_{RP} =present value of the cost of replacement power for a single event;

t_f = license renewal period (years); and

r = discount rate (%).

The $\$1.2x10^8$ value has no intrinsic meaning but is a substitute for a string of non-constant replacement power costs that occur over the lifetime of a "generic" reactor after an event. This equation was developed in the *Regulatory Analysis Technical Evaluation Handbook* [Reference 4-6] for discount rates between 5% and 10% only.

Based upon the values previously assumed,

$$PV_{RP} = \left(\frac{\$1.2x10^8}{r}\right)(1 - e^{-rt_f})^2 = \left(\frac{\$1.2x10^8}{0.07}\right)(1 - e^{-(0.07)(20)})^2 = \$9.73x10^8$$

To account for the entire lifetime of the facility, U_{RP} was then calculated from PV_{RP}, as follows:

$$U_{RP} = \left(\frac{PV_{RP}}{r}\right)(1 - e^{-rt_f})^2$$

where

U_{RP} = present value of the cost of replacement power over the remaining life;

t_f = license renewal period (years); and

r = discount rate (%).

Based upon the values previously assumed,

$$U_{RP} = \left(\frac{PV_{RP}}{r}\right)(1 - e^{-rt_f})^2 = \left(\frac{\$9.73\text{x}10^8}{0.07}\right)\left(1 - e^{-(0.07)(20)}\right)^2 = \$7.89\text{x}10^9 .$$

Total On-Site Property Damage Costs

Combining the cleanup/decontamination and replacement power costs, using delta (ΔF) to signify the difference in accident frequency resulting from the proposed actions, and using the above numerical values, the best-estimate value of averted occupational exposure can be expressed as

$$AOSC = \Delta F(U_{CD} + U_{RP}) = \Delta F(\$1.16\text{x}10^{10} + \$7.89\text{x}10^9) = \Delta F(\$1.95\text{x}10^{10})$$

where

ΔF = difference in annual accident frequency resulting from the proposed action.

For the baseline CDF, $6.41\text{x}10^{-6}$/year,

AOSC = $125,086.

The resulting monetary equivalent of $125,086 is presented in Table 4-3.

Table 4-3
Estimated Present Dollar Value Equivalent of Internal Events CDF at PNPS

Parameter	Present Dollar Value ($)
Off-site exposure costs	$292,751
Off-site economic costs	$494,017
On-site exposure costs	$2,440
On-site economic costs	$125,086
Total	**$914,294**

4.21.5.2 Identify SAMA Candidates

Based on a review of industry documents, an initial list of SAMA candidates was identified. Since PNPS is a typical GE boiling water reactor design, considerable attention was paid to the SAMA candidates from SAMA analyses for other plants with a GE boiling water reactor design. Attachment E lists the specific documents from which SAMA candidates were initially gathered.

In addition to SAMA candidates identified from the review of industry documents, additional SAMA candidates were obtained from plant-specific sources, such as the PNPS IPE and IPEEE. In both the IPE and IPEEE, several enhancements related to severe accident insights were recommended and implemented. These enhancements were included in the comprehensive list of SAMA candidates and were verified to have been implemented during preliminary screening.

The current PNPS PSA model was used to identify plant-specific modifications for inclusion in the comprehensive list of SAMA candidates. The risk significant terms from the PSA model were reviewed for similar failure modes and effects that could be addressed through a potential enhancement to the plant. The correlation between candidate SAMAs and the risk significant terms are listed in Table E.1-2 of Attachment E.1. The comprehensive list contained a total of 281 SAMA candidates. The first step in the analysis of these candidates was to eliminate the non-viable SAMA candidates through preliminary screening.

4.21.5.3 Preliminary Screening (Phase I)

The purpose of the preliminary SAMA screening was to eliminate from further consideration enhancements that were not viable for implementation at PNPS. Potential SAMA candidates were screened out if they modified features not applicable to PNPS or if they had already been implemented at PNPS. In addition, where it was determined those SAMA candidates were potentially viable, but were similar in nature, they were combined to develop a more comprehensive or plant-specific SAMA candidate.

During this process, 222 of the 281 initial SAMA candidates were eliminated, leaving 59 SAMA candidates for further analysis. The list of original 281 SAMA candidates and applicable screening criterion is available in on-site documentation.

4.21.5.4 Final Screening and Cost Benefit Evaluation (Phase II)

A cost/benefit analysis was performed on the remaining SAMA candidates. The method for determining if a SAMA candidate was cost beneficial consisted of determining whether the benefit provided by implementation of the SAMA candidate exceeded the expected cost of implementation (COE). The benefit was defined as the sum of the reduction in dollar equivalents for each severe accident impact area (off-site exposure, off-site economic costs, occupational exposure, and on-site economic costs). If the expected implementation cost exceeded the estimated benefit, the SAMA was not considered to be cost beneficial.

The result of implementation of each SAMA candidate would be a change in the severe accident risk (i.e., a change in frequency or consequence of severe accidents). The method of calculating the magnitude of these changes is straightforward. First, the severe accident risk after implementation of each SAMA candidate was estimated using the same method as for the baseline. The results of the Level 2 model were combined with the Level 3 model to calculate these post-SAMA risks. The results of the benefit analyses for the SAMA candidates are presented in Table E.2-1 of Attachment E.2.

Each SAMA evaluation was performed in a bounding fashion. Bounding evaluations were performed to address the generic nature of the initial SAMA concepts. Such bounding calculations overestimate the benefit and thus are conservative calculations. For example, one SAMA dealt with installing digital large break LOCA protection; the bounding calculation estimated the benefit of this improvement by total elimination of risk due to large break LOCA (see the Phase II analysis of SAMA 52 in Table E.2-1). Such a calculation obviously overestimated the benefit, but if the inflated benefit indicated that the SAMA is not cost beneficial, then the purpose of the analysis was satisfied.

As described above for the baseline, values for avoided public and occupational health risk were converted to a monetary equivalent (dollars) via application of the *Regulatory Analysis Technical Evaluation Handbook* [Reference 4-6] conversion factor of $2,000 per person rem and discounted to present value. Values for avoided off-site economic costs were also discounted to present value. The formula for calculating net value for each SAMA was

Net value =($APE + $AOC + $AOE + $AOSC) - COE

where

$APE =value of averted public exposure ($);

$AOC =value of averted off-site costs ($);

$AOE =value of averted occupational exposure ($);

$AOSC = value of averted on-site costs ($); and

COE = cost of enhancement ($).

If the net value of a SAMA was negative, the cost of the enhancement was greater than the benefit and the SAMA was not cost beneficial.

The SAMA analysis considered that external events (including fires and seismic events) could lead to potentially significant risk contributions. To account for the risk contribution from external events and uncertainties, the cost of SAMA implementation was compared with a benefit value calculated by applying a multiplier of six to the internal events estimated benefit. This value is defined as an **upper bound estimated benefit**. This treatment accounts for the impact of external events and uncertainty associated with the internal events.

The IPEEE analyses using the FIVE methodology and seismic PSA provide quantitative, but conservative results. Therefore, the results were combined as described below to represent the total external events risk.

The conservative EPRI FIVE methodology was used for the PNPS IPEEE fire analysis. The fire analysis was done as a screening analysis only and not as a determination of the fire CDF at PNPS. Since fire zone conditional core damage probability is estimated by failing all equipment

in the fire zone, a SAMA that reduces internal events CDF may not reduce fire CDF for a zone. Thus the resulting benefit value is inflated and therefore, overly conservative.

The sum of the fire zone CDF values (Table E.1-12) is approximately 1.91 x 10^{-5} per reactor-year. This value is lower than the originally published fire CDF value of 2.20 x 10^{-5} due to updated equipment failure probability and unavailability values. As described above, this fire CDF is only a screening value. A more realistic fire CDF may be about a factor of three less than this value [Reference 4-8]. With a factor of three reduction, the fire CDF is about 6.37 x 10^{-6} per reactor-year.

The seismic PSA analysis is also a conservative analysis. Therefore, its results should not be compared directly with the best-estimate internal events results. Conservative assumptions in the seismic PSA analysis include the following.

- Each of the sequences in the seismic PSA assumes unrecoverable loss of off-site power. If off-site power were maintained, or recovered, following a seismic event, there would be many more systems available to maintain core cooling and containment integrity than are presently credited in the analysis.

- Each of the sequences in the seismic PSA assumes unrecoverable loss of the nitrogen system and the fire water crosstie to the RHR system.

- Each of the sequences in the seismic PSA assumes unrecoverable loss of the CSTs water source for the high pressure injection systems.

- A single, conservative, surrogate element whose failure leads directly to core damage is used in the seismic risk quantification to model the most seismically rugged components.

- Dual initiators are included in the seismic small LOCA, medium LOCA, large LOCA, and ISLOCA event trees. For example, the seismic small LOCA initiating event frequency is a combination of the probability that the seismic event induced a small LOCA and the probability that a small LOCA will occur due to a random event during the 24-hour mission time.

- The ATWS event tree was conservatively simplified so that all conditions which lead to a failure to scram result in core damage, without the benefit of standby liquid control (SLC) or other mitigating systems.

- Because there is little industry experience with crew actions following seismic events, human actions were conservatively characterized.

The seismic CDF in the IPEEE was conservatively estimated to be 5.82x10^{-5} per reactor-year. The seismic CDF has recently been re-evaluated to reflect the updated Gothic computer code room heat up calculations that predict no room cooling requirements for HPCI, RCIC, core spray,

and RHR areas; to update random component failure probabilities; and to model replacement of certain relays with a seismically rugged model. The new seismic CDF is 3.22×10^{-5} per reactor-year. As described above, this is a conservative value. Engineering judgment indicates that a more realistic value would be at least a factor of two less than this value. With a factor of two reduction, the seismic CDF is 1.61×10^{-5} per year.

Combination of the reduced fire and seismic CDF values results in an external events risk estimate of 2.25×10^{-5} per year, which is 3.51 times higher than the internal events CDF. This would justify use of a multiplier of four on the averted cost estimates (for internal events) to represent the additional SAMA benefits in external events.

CDF uncertainty calculations resulted in a factor of 1.62 (Table E.1-3). Since 3.51 x 1.62 = 5.69, a multiplier of six would be reasonable to account for both external events and uncertainties.

Use of an upper bound estimated benefit is considered appropriate because of the inherent conservatism in the external events modeling approach and conservative assumptions in benefit modeling of individual SAMA candidates. In addition, not all potential enhancements would be impacted by an external event. In some cases an external event would only impose partial failure of systems or trains. Therefore, using six times the internal events estimated benefit to account for external events and uncertainty is conservative.

The expected Cost of Implementation (COE) of each SAMA was established from existing estimates of similar modifications combined with engineering judgment. Most of the cost estimates were developed from similar modifications considered in previous performed SAMA and SAMDA analyses. In particular, these cost-estimates were derived from the following major sources.

- GE ABWR SAMDA Analysis
- Peach Bottom SAMA Analysis
- Quad Cities SAMA Analysis
- Dresden SAMA Analysis
- ANO-2 SAMA Analysis

A number of additional conservatisms associated with implementation were included in the cost benefit analysis. The cost estimates for implementing the SAMAs did not include the cost of replacement power during extended outages required to implement the modifications, nor did they include contingency costs associated with unforeseen implementation obstacles. Estimates based on modifications that were implemented or estimated in the past were presented in terms of dollar values at the time of implementation and were not adjusted to present-day dollars. In addition, several of the implementation cost estimates were originally developed for SAMDA analyses (i.e., during the design phase of the plant), and therefore do not capture the additional

costs associated with performing design modifications to existing plants (i.e., reduced efficiency, minimizing dose, disposal of contaminated material, etc.).

Detailed cost estimates were often not required to make informed decisions regarding the economic viability of a potential plant enhancement when compared to attainable benefit. Implementation costs for several of the SAMA candidates were clearly in excess of the attainable benefit estimated from a particular analysis case. For less clear cases, engineering judgment was applied to determine if a more detailed cost estimate was necessary to formulate a conclusion regarding the economic viability of a particular SAMA. Nonetheless, the cost of SAMA candidates was conceptually estimated to the point where conclusions regarding the economic viability of the proposed modification could be adequately gauged. The cost-benefit comparison and disposition of each of the 59 Phase II SAMA candidates is presented in Table E.2-1 of Attachment E.2.

4.21.5.5 Sensitivity Analysis

Two sensitivity analyses were conducted to gauge the impact of key assumptions upon the analysis. The main factors affecting present worth are the extended plant life and the discount rate. A description of each follows.

Sensitivity Case 1: Years Remaining Until End of Plant Life

The purpose of this sensitivity case was to investigate the sensitivity of assuming a 27-year period for remaining plant life (i.e. seven years on the original plant license plus the 20-year license renewal period). The 20-year licensing renewal period was used in the base case. The resultant monetary equivalent for internal event was calculated by using 27 years remaining until end of facility life to investigate the impact on each analysis case.

Sensitivity Case 2: Conservative Discount Rate

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the discount rate. The discount rate of 7.0% used in the base case analyses is conservative relative to corporate practices; nonetheless, a lower discount rate of 3.0% was assumed in this case to investigate the impact on each analysis case.

The benefits estimated for each of these sensitivities are presented in Table E.2-2 of Attachment E.2.

4.21.6 Conclusion

This analysis addressed 281 SAMA candidates for mitigating severe accident impacts. Phase I screening eliminated 222 SAMA candidates from further consideration, based on either inapplicability to PNPS's design or features that had already been incorporated into PNPS's current design, procedures and/or programs. During the Phase II cost benefit evaluation of the

remaining 59 SAMA candidates, an additional 54 SAMA candidates were eliminated because their cost was expected to exceed their benefit and were therefore determined not to be cost beneficial.

Five Phase II SAMA candidates (30, 34, 56, 57, and 58) presented in Table 4-4 were found to be potentially cost beneficial for mitigating the consequences of a severe accident for PNPS.

- A plant modification and procedural change was recommended to install keylocked control switches to enable AC bus cross-ties to enhance the reliability of AC power system (SAMA candidate 30).

- A plant procedural enhancement was recommended to use DC bus cross-ties to enhance the reliability of DC power system (SAMA candidate 34).

- A plant modification was recommended to install additional fuses in panel C7 to enable the DTV valve function during loss of containment heat removal accident sequences (SAMA candidate 56).

- A plant procedural enhancement was recommended to allow use of the hydro turbine in the event that EDG A or fuel oil transfer pump P-141A is unavailable (SAMA candidate 57).

- A plant procedural enhancement was recommended to allow alternately feeding B1 loads via B3 when A3 is available and alternately feeding B2 loads via B4 when A4 is available (SAMA candidate 58).

These SAMA candidates do not relate to adequately managing the effects of aging during the period of extended operation. In addition, since the SAMA analysis is conservative and is not a complete engineering project cost-benefit analysis, it does not estimate all of the benefits or all of the costs of a SAMA. For instance, it does not consider increases or decreases in maintenance or operation costs following SAMA implementation. Also, it does not consider the possible adverse consequences of procedure changes, such as additional personnel dose. Therefore, the above, potentially cost-beneficial SAMAs have been submitted for engineering project cost-benefit analysis.

The sensitivity studies indicated that the results of the analysis would not change for the conditions analyzed.

Table 4-4
Final SAMAs

Phase II SAMA ID	SAMA Title	Result of Potential Enhancement	CDF Reduction	Off-site Dose Reduction	Estimated Benefit	Upper Bound Estimated Benefit	Estimated Cost
030	9.g. Enhance procedures to make use of AC bus cross-ties.	SAMA would provide increased reliability of AC power system and reduce core damage and release frequencies.	11.10%	8.47%	$78,902	$473,410	$146,120
	Basis for Conclusion: The CDF contribution due to loss of MCC B17, B18, and B15 was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $146,120 by engineering judgment.						
034	10.d. Enhance procedures to make use of DC bus cross-ties.	This SAMA would improve DC power availability.	4.65%	1.91%	$19,761	$118,568	$13,000
	Basis for Conclusion: The CDF contribution due to loss of DC buses D16 and D17 was eliminated to assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $13,000 by engineering judgment.						
056	Provide redundant DC power supplies to DTV valves.	This SAMA would improve reliability of the DTV valves and enhance containment heat removal capability.	8.81%	3.51%	$36,773	$220,639	$112,400
	Basis for Conclusion: The CDF contribution from sequences involving DC power supply failures to the direct torus vent valves was eliminated to conservatively assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $112,400 by engineering judgment.						

Table 4-4
Final SAMAs

Phase II SAMA ID	SAMA Title	Result of Potential Enhancement	CDF Reduction	Off-site Dose Reduction	Estimated Benefit	Upper Bound Estimated Benefit	Estimated Cost
057	Proceduralize use of the diesel fire pump hydro turbine in the event of EDG A failure or unavailability.	This SAMA would increase capability to provide makeup to the fire pump day tank to allow continued operation of the diesel fire pump, without dependence on electrical power.	2.25%	3.14%	$29,213	$175,279	$26,000
	Basis for Conclusion: The CDF contribution from sequences involving loss of offsite power and failure of either EDG A, or the EDG A fuel oil transfer oil pump, was eliminated to assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $26,000 by engineering judgment.						
058	Proceduralize the operator action to feed B1 loads via B3 When A5 is unavailable post-trip. Similarly, feed B2 loads via B4 when A6 is unavailable post trip.	This SAMA would provide the direction to restore B15 and B17 loads upon loss of A5 initiating events as long as A3 is available. Additionally, it would provide the direction to restore B14 and B18 loads upon loss of A6 initiating events as long as A4 is available.	4.92%	3.14%	$31,799	$190,797	$50,000
	Basis for Conclusion: The CDF contribution from sequences involving loss of 4160VAC safeguard bus A5 was conservatively eliminated to assess the benefit of this SAMA. The cost of implementing this SAMA was estimated to be $50,000 by engineering judgment.						