JAFP-06-0167
Docket No. 50-333

Attachment 3

James A. FitzPatrick Nuclear Power Plant

License Renewal Application – Amendment 1

JAFNPP SAMA Analysis – Supplement

JAFNPP SAMA Analysis – Supplement

JAFNPP Lessons Learned From VYNPS and PNPS SAMA RAIs

The VYNPS and PNPS SAMA analyses and ERs were completed before NRC comments were incorporated in NEI 05-01, "Severe Accident Mitigation Alternative (SAMA) Analysis Guidance Document". Therefore, some of the RAIs on these analyses stemmed from changes made to the guidance after the analyses were completed.

Although the JAFNPP LRA was not submitted until July 31, 2006, the JAFNPP SAMA analysis was also completed before NRC comments were incorporated in the guidance document. The VYNPS and PNPS RAIs were reviewed and those items that applied to JAFNPP and could be resolved during the ER review process were resolved before the ER was submitted (see the following list). The lessons learned with the highest potential of altering the conclusions of the SAMA analysis were incorporated in the JAFNPP ER before it was submitted for NRC review (see items 5, 9 and 10 in the following list).

1. Section E.1.4.1 – Provides the conclusion of the BWROG peer review relative to the use of the PSA. (PNPS RAI 1.d and VYNPS RAI 1.c)
2. Table E.1-11 – Provides the fission product release characteristics for each release category, including fission product release fractions, release times and duration, warning time, release elevation, and energy of release. (VYNPS RAI 2.b)
3. Section E.1.2.2 – Clarifies that MAAP analyses were performed for the current level 2 model and describes how the MAAP cases were selected to represent each release category. (PNPS RAI 2.c.i and VYNPS RAI 2.c.)
4. Section E.1.4.2.2.2 – Clarifies that the level 2 model was included in the BWROG peer review and describes changes to the model as a result of the review. (VYNPS RAI 2.d)
5. Section 4.21.5.4 – Uses correct external events multiplier to properly account for external and internal events. (PNPS RAI 3.c and VYNPS RAI 3.c)
6. Section 4.21.5.4 – Provides a description of the conservatisms in the dominant JAFNPP fire CDF sequences that would support a factor of three reduction in CDF. (PNPS RAI 3.a and VYNPS RAI 3.a)
7. Section E.1.5.2.6 – Provides a brief statement regarding the acceptability of use of 1994 data rather than a different year's data. (PNPS RAI 4.a and VYNPS RAI 4.a)
8. Section E.1.5.2.7 – Indicates what percentage of the public was assumed to evacuate. (PNPS RAI 4.b and VYNPS RAI 4.b)
9. Table E.1-14 – Increases inventory of long half-life nuclides to reflect the average core exposure at JAFNPP. (PNPS RAI 4.c and VYNPS RAI 4.c)
10. Table E.2-1 – Divides cost estimates drawn from a previous SAMA analysis for a dual-unit site by 2 for use at JAFNPP which is a single unit site. (PNPS RAI 6.b and VYNPS RAI 6.b)

Due to time constraints, some lessons learned from the VYNPS and PNPS RAIs were not incorporated in the JAFNPP ER before it was submitted for NRC review. The following sections contain supplemental information to address lessons learned from the previous SAMA reviews and align the JAFNPP SAMA submittal more with the NEI guidance endorsed by the NRC.

1. Plant Changes Since the Freeze Date of the PSA Model Used for the SAMA Analysis

In accordance with plant procedures, design change documents and emergency operating procedure changes are reviewed to determine their impact on the PSA model prior to implementation. A PSA model change request database is maintained to track potential changes and assess their degree of impact of the PSA model. As of June 2006, this database shows no outstanding changes due to modifications or procedure changes since issuance of Revision 2 of the PSA model in October 2004 that could have a significant impact on the results of the PSA or the SAMA analysis.

2. Supplement to ER Section E.1.4.2, "Major Differences between the JAFNPP Revision 2 PSA Model and the Original IPE Model"

Section E.1.4.2 of the ER discusses the major changes between the IPE model and Revision 2 of the PSA model (used for the SAMA analysis). The supplementary information below splits the information into changes between the IPE model and Revision 1 of the PSA model (reviewed by BWROG) and changes between Revision 1 and Revision 2.

Summary of Major PSA Models		
Model	CDF (/ry)	LERF (/ry)
IPE	1.92E-6	7.80E-7
Revision 1	2.44E-6	6.62E-7
Revision 2	2.74E-6	9.20E-8

<u>Changes from IPE to Revision 1 (reviewed by BWROG)</u>

Initiating event database was updated to include all scrams that occurred between 7/28/1975 and 12/31/1997.

Component failure and unavailability database was updated to reflect failures that occurred between 1/1/1986 and 4/30/1995, more equipment groups in which common-cause failures may occur and current on-line maintenance practices.

Changes were also made to data to reflect revised technical specifications and changes in the ATTS instrumentation surveillance frequency from monthly to quarterly.

Internal flooding analysis was revised. A relay room flooding scenario was identified and a procedure enhancement was implemented to cope with this flooding scenario.

Model changes were made to reflect design and procedure modifications, including the following:

- A modification to the fire protection system to allow it to supply EDG jacket cooling water directly through the ESW system cross-tie. This modification reduces the contribution to plant risk made by the dominant station blackout event.
- Installation of bonnet vents on the LPCI and core spray injection valves to preclude common-cause pressure locking of the valves.
- Installation of a keylock bypass switch that allows LPCI and core spray injection valves to be manually opened from the control room. The switch can be used to help recover from reactor pressure permissive logic failures that cause all low-pressure system injection valves to remain closed. Use of this switch would reduce the probability of core damage during LOCAs and transients with stuck open SRVs in which all low-pressure ECCS is unavailable.
- Installation of a keylock bypass switch to allow HPCI auto-transfer on high suppression pool level to be bypassed from the control room rather than by removing leads in a relay room panel. This action is important in ATWS events with MSIVs closed and in handling other transients and LOCAs.
- Changes of the RHR minimum flow bypass valve positions from normally closed to normally open. This modification reduces the probability of pump damage as a result of loss of one emergency bus.
- Installation of switches to permit transfer to the alternative power supply for LPCI injection valves to be made from the control room.
- A modification to change the RCIC enclosure fan power supply from an AC feed to an AC inverter feed from a DC power source. This modification enhances the availability of the RCIC enclosure ventilation system during station blackout events.
- Revisions to OP-19 (RCIC system), increased RCIC turbine exhaust trip set points.
- Revisions to OP-25 (CRD system) direct operators to enhance the CRD flow in certain accident sequences.
- A new procedure EP-10 (Fire Water Cross-tie to RHRSW Loop A When Directed by EOP-4) directs operators to align the fire protection system to the tube side of the RHR heat exchanger in loss of containment heat removal accident sequences.
- Revisions to AOP-49 (Station Blackout) explicitly address bus recovery should safeguard bus tie breaker lockout relays inadvertently reset.
- Revisions to EP-6 (Post Accident Venting of Primary Containment) direct operators to locally open valves 27AOV-117 and 27AOV-118 should it not be possible to open these valves from the relay room during loss of containment heat removal sequences.

Changes from Revision 1 (reviewed by BWROG) to Revision 2 (used for SAMA Analysis)

The PSA model was changed to incorporate peer review recommendations. These changes are summarized in ER Sections E.1.4.2.1.3 and E.1.4.2.2.2.

Initiating event database was updated to include all scrams that occurred between 7/28/1975 and 12/31/2003.

Component failure and unavailability database was updated to reflect failures that occurred between 1/1/1995 and 12/31/2002.

Station battery depletion time was reduced from 8 hours to 4 hours, decreasing the available time for recovery of offsite power during an SBO event from 13 to 7 hours.

Model changes were made to reflect design and procedure modifications, including the following.

- SRV alternate actuation system and ATWS recirculation pump level trip were modified.
- Service, instrument, and breathing air compressors were replaced.

The Level 2 model was changed due to updated containment performance methodology. Specific changes are described in ER Section E.1.4.2.2.1. Two of the changes described in Section E.1.4.2.2.1 had the greatest impact on lowering the LERF value for Revision 2.

1. Transients initiated by a loss of containment heat removal were conservatively binned as early releases in Revisions 0 and 1. Because this type of plant transient results in containment failure many hours after the initiation of the event (i.e. greater than six hours) these events are appropriately considered late releases instead of early releases in Revision 2.

2. The impact of water on the drywell floor and subsequent drywell liner melt-through from core debris melt was updated in Revision 2 to reflect current industry understanding. Specifically, a much lower liner melt-through probability is assigned for flooded drywell accident progressions than for dry drywell accident progressions.

Based on the BWROG review, the JAFNPP PSA can be effectively used to support Grade 3 applications involving relative risk significance; in addition, absolute risk determination applications can be performed with supporting deterministic analyses.

3. MAAP Analyses

The MAAP computer code is used to generate the radionuclide release magnitude for the MACCS2 consequence analysis. The MAAP calculations are representative deterministic thermal hydraulic calculations that portray dominant CET scenarios. Sixty-two accident progression scenarios were analyzed.

The source terms presented in Table E.1-11 (ER Section E.1.2.2) and used in the consequence analysis are determined as follows:

1. The appropriate MAAP case source terms are selected and assigned to a particular CET accident progression endstate.
2. Based on the source terms from Step 1, the source terms for each plant damage state CET accident progression endstate are determined.
3. The mean frequency of each release category is determined by summing the individual plant damage state CET accident progression endstates contained in the particular release category (i.e., no containment failure, early high release, etc.).
4. The release category individual fractional contributions for each CET accident progression are determined by dividing the result from Step 3 by the individual PDSs frequencies.
5. Each PDS accident progression CET endpoint source terms, release timing, release energy and release elevation by the value determine in Step 4.
6. Sum the individual results of Step 5 to arrive at the total final values contained in Table E.1-11 (ER Section E.1.2.2).

4. Benefit Presentation Revision

Table E.2-1 of the ER provided an estimated benefit which accounted for internal events with a 7% discount rate and an upper bound estimated benefit which accounted for internal events, external events and uncertainties, with a 7% discount rate. Table E.2-2 of the ER provided Sensitivity Case 2 results which included an estimated benefit which accounted for internal events with a 3% discount rate and an upper bound estimated benefit which accounted for internal events, external events and uncertainties, with a 3% discount rate.

Although the upper bound estimated benefit values are bounding, NEI 05-01 recommends that three results be reported. To more closely align with the recommendations of NEI 05-01, Table S1 presents the following three results for each of the SAMA candidates.

1. Baseline - accounts for internal and external events using a multiplier of 4 (see ER section for derivation). Uses 7% discount rate.
2. Baseline with Uncertainty - accounts for internal event and external events using a multiplier of 4. Accounts for uncertainty with a factor of 4 (ER Table E.1-3 shows that the ratio of the 95^{th} percentile to the mean is ~4). Uses 7% discount rate.

3. 3% Discount Rate Alternate Case - accounts for internal and external events using a multiplier of 4. Uses 3% discount rate.

5. Offsite Economic Cost Risk

Although NEI 05-01 does not recommend reporting the change in offsite economic cost risk for each analysis case, this information was requested for both VYNPS and PNPS and is therefore provided in Table S1.

6. Accounting of IPE and IPEEE Enhancements

Table S2 presents the Phase I SAMA candidates which are the enhancements recommended in the IPE, and IPEEE. Those with reference source [29] are from the IPE and those with reference source [18] are from the IPEEE.

Phase I SAMA candidates 253, 256, and 262 from the IPE have been implemented and included in Revision 2 of the PSA model (version used for the SAMA analysis).

Phase I SAMA candidate 280 proposed keeping ESW valves 46MOV-102A&B normally shut to prevent flow diversion. This modification was determined to be unnecessary because flow diversion to the discharge canal when ESW provides normal cooling to the EDG jacket coolers does not result in flow below required values for EDG operation.

Phase I SAMA candidates 281 through 284 were retained as Phase II SAMA candidates.

All potential modifications identified in the IPEEE have been implemented.

7. Risk Reduction for Dominant Fire Zones

ER Table E.1-12 lists a number of fire zones with CDF values above 1E-06 per year. As described in ER Section E.1.3.2, the values in Table E.1-12 are the IPEEE values following re-evaluation to include response to NRC questions regarding fire-modeling progression. Although the plant improvements identified by the IPEEE have been implemented, they are not reflected in the CDF values in Table E.1-12.

IPEEE improvements to restrain or locate flammables cabinets, to monitor and control the quantity of combustible materials in critical process areas, and to monitor and control pre-staging of outage materials would reduce CDF values for all of the dominant zones.

The following discussion for each zone explains what measures have been taken to reduce risk in that zone and explains why the fire CDF cannot be further reduced in a cost effective manner.

Cable spreading room (zone CS-1)

The IPEEE recommended relocating heat detectors in the cable spreading room to severely limit contribution from transient fires. In lieu of the hardware modification, a change was made to administrative procedures proscribing unattended combustible material in the room. This change in procedure potentially reduces the CDF contribution from transient fires in CS-1.

In the fire analysis, spurious actuation or failure due to hot shorts and open circuits within cable jackets was included with a conservatively high probability of occurrence of 1.0. However, in the latest fire PRA methodology for NFPA-805 compliance [NUREG/CR-6850], this probability is addressed by assigning a probability of occurrence based on the configuration of the cabling and nature of the short circuit. Open circuits are no longer considered, therefore reducing the impact of the cable damage assessment. JAFNPP uses thermoset cables which have a high damage temperature. A conservative estimate considering this new methodology for worst-case failure mode probabilities of hot short circuits for thermoset cables in trays with control power transformer (typical of MCC circuits) results in a probability of failure of 0.05. Therefore, the CDF contribution from fires in CS-1 can be reduced to an estimated 3.29 x 10-7 per year.

Since the cable spreading room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

Main control room (zone CR-1)

In the main control room, the dominant scenario is a generic control room fire with a forced evacuation and failure to properly shut down the plant by implementing abnormal operating procedures. The ignition frequency used for the IPEEE was 1.07 x 10-2 per year. However, with almost 10 years of additional accumulated industry experience, this frequency has been reduced to 2.5 x 10-3 per year [NUREG/CR-6850]. By factoring this into the control room fire scenarios, the overall contribution for fires in zone CR-1 reduces to an estimated 7.17 x 10-7 per year.

Since the main control room is always inhabited ensuring prompt fire detection and manual suppression, no further cost-effective changes were identified to reduce CDF in this zone.

EDG A and C switchgear room south (zone EG-5)

Since the EDG switchgear room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

Reactor building westside (zone RB-1B)

A bypass switch was installed to allow opening of the LPCI and core spray injection valves. In addition, the procedure for operation during plant fires directs operators to use the switches if necessary and includes a tabulation of potentially unavailable equipment in each fire zone. This modification reduces the reactor building fire contribution to core damage frequency from LOCAs and transients with stuck open SRVs.

This zone is equipped with a detection system that alarms in the control room. It does not have an automatic suppression system, but is separated from adjacent zones by water curtains. No further cost-effective changes were identified to reduce CDF in this zone.

Reactor building east crescent (zone RB-1E)

Cabling in trays predominates in the east crescent. As for the cable spreading room, spurious actuation or failure due to hot shorts and open circuits within cable jackets was included with a conservatively high probability of occurrence of 1.0. A conservative estimate using the methodology described for the cable spreading room would reduce the CDF contribution from fires in this zone to approximately 5.10 x 10-8 per year.

This zone is equipped with a detection system that alarms in the control room. In this zone, the HPCI pump and turbine are protected by an automatic water spray system and a manual foam-water sprinkler system which can be manually initiated from the control room. The zone is also separated from adjacent zones by water curtains. No further cost-effective changes were identified to reduce CDF in this zone.

Relay room (zone RR-1)

Cabling in trays predominates in the relay room. A conservative estimate using the methodology described for the cable spreading room would reduce the CDF contribution from fires in this zone to approximately 2.70 x 10-7 per year.

Since the relay room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

8. More Detailed SAMA Descriptions

The following paragraphs provide more information about the associated modifications and what is included in the cost estimate for several SAMAs.

SAMAs 4 (Install a containment vent large enough to remove ATWS decay heat) and 52 (Install an ATWS sized vent)

These SAMAs provide a means to remove decay heat during an ATWS event. The proposed design modification for these SAMAs involves installation of a new torus vent pipe of sufficient size to remove decay heat following an ATWS with MSIV closure and successful recirculation pump trip.

SAMAs 7 (Provide modification for flooding the drywell head) and 21 (Provide a method of drywell head flooding)

These SAMAs provide intentional flooding of the upper drywell head such that if high drywell temperatures occurred, the drywell head seal would not fail. The proposed design modification requires extensive structural modification to accommodate a drywell head flooding system. To flood the drywell head seal at elevation 346 foot, the drywell vent at the 335-foot elevation would have to be plugged and a new penetration would have to be installed in the drywell head above the 346 foot elevation. The new vent penetration would have to be tied into the existing vent line and would have to permit removal of the drywell head at each refueling outage.

These SAMAs evaluate flooding internal to the drywell. While flooding or sprays on the outside might serve the same purpose, a cost estimate for that modification was not developed because the estimated benefit for SAMAs 7 and 21 is $0.

SAMAs 8 (Enhance fire protection system and standby gas treatment system hardware and procedure) and 22 (Use alternate method of reactor building spray)

These SAMAs would improve fission product scrubbing in severe accidents. The proposed design modification would upgrade the standby gas treatment and fire protection systems to a sufficient capacity to handle postulated loads from severe accidents due to a bypass or breach of the containment. Loads produced as a result of reactor pressure vessel or containment blowdown would require large filtering capacities.

Use of existing fire water sprays or relatively simple modifications to the fire water sprays would not be effective in mitigating releases. The only fire protection automatic suppression systems within the reactor building are water curtains to separate the six fire areas within the building from each other. As such, they have limited capability in providing fission product scrubbing.

SAMA 11 (Strengthen primary and secondary containment)

This SAMA would reduce the probability of containment over-pressurization failure. This SAMA is intended for a new plant; hence, it is not practical to back-fit this modification into a plant which is already built and operating. Since JAFNPP has a Mark I containment, early release risk is dominated by events that result in early failure of the drywell shell due to direct contact with debris and events that bypass the containment. Strengthening of primary and secondary containment would have a small impact on the overall risk of these accidents. The cost estimated for ABWR was $12 million and the retrofit for an existing containment would cost more. Therefore, the cost of implementation for this SAMA exceeds the revised baseline benefit.

SAMA 23 (Provide a means of flooding the rubble bed)

This modification would contain molten core debris on the reactor pedestal and allow the debris to be cooled. The proposed design modification involves a core retention device inside the reactor pedestal area. However, the Industry Degraded Core Rulemaking (IDCOR) Program has investigated core retention devices and concluded, "Core retention devices are not effective risk reduction devices for degraded core events". The cost of implementing this SAMA at Quad Cities was estimated to be $2.5 million.

SAMA 31 (Provide an alternate pump power source)

This modification would provide a small, dedicated power source such as a dedicated diesel or gas turbine for the feedwater or condensate pumps so that they do not rely on offsite power. The proposed design modification would involve adding one 4.16 KV power source to supply AC power to one feedwater or one condensate pump. The additional diesel generator or gas turbine would have to be sufficiently sized to handle starting (inrush) and running of at least one 5,000 hp pump at a rated voltage of 4.16kV. A generator of that size would easily exceed 6,000 KW. The cost estimate assumes that the power source will be manually connected.

SAMA 47 (Improved high pressure systems)

This SAMA would improve prevention of core melt sequences by improving reliability of high pressure capability to remove decay heat. The proposed design modification considers replacing one CRD pump with a flow capacity equal to the RCIC system (400 gpm).

Minor modifications to the existing CRD system or modifications to the emergency procedures to enhance CRD flow rates would not be viable low-cost alternatives because the flow provided by the CRD system is limited by CRD pump capacity and pipe friction losses.

SAMA 57 (Control containment venting within a narrow band of pressure)

This modification would establish a narrow pressure control band to prevent rapid containment depressurization when venting is implemented thus avoiding adverse impact on the low pressure ECCS injection systems taking suction from the torus. Hence, the proposed modification for SAMA 57 requires a detailed engineering analysis examining the impact of opening the torus vent path and an examination of the NPSH requirements for LPCI and core spray systems. It would also require an engineering study of the feasibility of closing the 20-inch torus vent valves 27AOV-117 and 27AOV-118 against high containment pressures as well as potential hardware modifications. Procedure changes, simulator changes, and training would also be required. The cost estimate assumes revision of plant procedures, hardware changes and associated training lesson plan changes as well as additional analysis to address NPSH concerns.

9. SAMA 57 Benefit Modeling

SAMA 57 (Control containment venting within a narrow band of pressure), would establish a narrow pressure control band to prevent rapid containment depressurization when venting is implemented thus avoiding adverse impact on the low pressure ECCS injection systems taking suction from the torus.

The benefit for this SAMA was conservatively estimated by reducing the probability of the operator failure to vent basic event. Since the benefit of the controlled venting occurs for sequences involving successful venting which are not significantly affected by reducing the operator failure to vent, a sensitivity case was performed to assure that the benefit values reported for SAMA 57 in Table S1 are conservative.

The SAMA 57 sensitivity case estimated the benefit of this SAMA by crediting continued vessel injection from LPCI or core spray for those sequences in which torus venting is successful and alternative injection systems fail after torus venting. Specifically, an additional event (LPCI-CS) was added to cutsets that involve successful torus venting. Since the available NPSH is likely to be less that the required NPSH with the torus vent path open, a failure probability of 0.9 was assigned to event LPCI-CS.

The results of the sensitivity case are,

CDF reduction – 0.46 %,
Off-site dose reduction – 0.61%,
OECR reduction – 0.60%,
baseline – $2,516,
3% discount rate alternate case – $3,304, and
baseline with uncertainty – $10,064

Therefore, the benefit values reported for SAMA 57 in Table S1 are conservative.

10. Evaluation of SAMAs Potentially Cost-Beneficial at Other Plants

The following paragraphs discuss SAMAs that have previously been found to be potentially cost-beneficial at other plants.

a. Use portable generator to extend the coping time in loss of alternating current (AC) power events (to power battery chargers).

Upon a complete SBO, a portable generator could be used to extend the life of both 125 VDC batteries.

To assess the impact of prolonging battery life using a portable diesel generator to power the battery chargers, the probability of non-recovery of offsite power for 7 hours was changed to 24 hours for SBO scenarios (equivalent to the benefit assessment for SAMA 026, "Provide additional DC battery capacity".) This resulted in a baseline with uncertainty benefit of approximately $837,840. The estimated cost of implementing and using the portable generator is $712,347. Therefore, this SAMA is potentially cost effective for JAFNPP.

b. Enhance DC power availability (provide cables from diesel generators or another source to directly power battery chargers).

This SAMA has already been considered and implemented. Due to the number of safety-related emergency generators (4), there is benefit to being able to connect the battery chargers to one of these AC power sources and procedures currently exist to provide this capability.

c. Provide alternate DC feeds (using a portable generator) to panels supplied only by DC bus.

Upon loss of a DC bus, a portable generator could be used to provide power to an individual 125VDC MCC. This would, for example, support returning HPCI to service in the event its bus was to fail.

The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA (equivalent to the benefit assessment for SAMA 044, "Provide an additional high pressure pump with independent diesel".) This resulted in a baseline with uncertainty benefit of $33,808. The estimated cost of implementing and using the portable generator is $712K. Therefore, this SAMA is not cost effective for JAFNPP.

d. Modify procedures and training to allow operators to cross-tie emergency AC buses under emergency conditions which require operation of critical equipment.

This SAMA has already been considered and implemented. The Class 1E AC power supply is already highly diverse and reliable. During normal operating conditions, power to system buses is provided to the non-vital and emergency buses through the normal station service transformer T4, which is fed from the main generator. There are four sources available following a turbine trip: the south bus 115Kv feed through the Lighthouse Hill #3 line, the north bus 115Kv feed through Nine Mile Point #4 line, and four EDGs (two trains). Either of the incoming 115Kv lines can supply power to the 4Kv buses through the T2 or T3 transformers through the normally closed 10017 disconnect switch. The 10300 and 10400 buses can be cross-tied to one another by opening the appropriate feeder breaker and closing the applicable cross tie breaker. Procedures for performing the cross-tie operations are in place.

e. Develop guidance/procedures for local, manual control of reactor core isolation cooling following loss of DC power.

This SAMA has already been considered and implemented. JAFNPP has an existing procedure to provide local manual control of RCIC.

Table S1 – Summary of Phase II SAMA Analysis

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
001	8.a. Add a service water pump.	0.91%	1.07%	0.98%	$4,604	$6,004	$18,416	$5,900,000	Not cost effective
002	Install an independent method of suppression pool cooling.	7.77%	8.81%	8.16%	$40,388	$51,896	$161,552	$5,800,000	Not cost effective
003	Install a filtered containment vent to provide fission product scrubbing. Option 1: Gravel Bed Filter Option 2: Multiple Venturi Scrubber	0.00%	3.73%	7.74%	$16,360	$22,864	$65,440	$1,500,000	Not cost effective
004	Install a containment vent large enough to remove ATWS decay heat.	2.55%	8.14%	8.39%	$28,020	$37,860	$112,080	>$1,000,000	Not cost effective
005	Create a large concrete crucible with heat removal potential under the base mat to contain molten core debris.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	>$100 million	Not cost effective
006	Create a water-cooled rubble bed on the pedestal.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	$19 million	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
007	Provide modification for flooding the drywell head.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
008	Enhance fire protection system and standby gas treatment system hardware and procedures.	0.00%	0.00%	0.00%	$0	$0	$0	>$2,500,000	Not cost effective
009	Create a core melt source reduction system.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	>$5,000,000	Not cost effective
010	Install a passive containment spray system.	7.67%	8.71%	8.07%	$39,592	$51,000	$158,368	$5,800,000	Not cost effective
011	Strengthen primary and secondary containment.	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
012	Increase the depth of the concrete base mat or use an alternative concrete material to ensure melt-through does not occur.	0.00%	0.28%	0.17%	$428	$604	$1,712	>$5,000,000	Not cost effective
013	Provide a reactor vessel exterior cooling system.	0.00%	2.62%	2.53%	$6,888	$9,628	$27,552	$2,500,000	Not cost effective
014	Construct a building connected to primary containment that is maintained at a vacuum.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
015	2.g. Add dedicated suppression pool cooling.	7.77%	8.81%	8.16%	$40,388	$51,896	$161,552	$5,800,000	Not cost effective
016	3.a. Create a larger volume in containment.	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$8,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
017	3.b. Increase containment pressure capability (sufficient pressure to withstand severe accidents).	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
018	3.c. Install improved vacuum breakers (redundant valves in each line).	0.02%	7.44%	8.26%	$22,388	$31,284	$89,552	>$500,000	Not cost effective
019	3.d. Increase the temperature margin for seals.	0.00%	0.00%	0.00%	$0	$0	$0	$12,000,000	Not cost effective
020	5.b/c. Install a filtered vent.	0.00%	3.73%	7.74%	$16,360	$22,864	$65,440	$1,500,000	Not cost effective
021	7. a. Provide a method of drywell head flooding.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
022	13. a. Use alternate method of reactor building spray.	0.00%	0.00%	0.00%	$0	$0	$0	>$2,500,000	Not cost effective
023	14.a. Provide a means of flooding the rubble bed.	0.00%	1.22%	1.07%	$3,444	$4,816	$13,776	$2,500,000	Not cost effective
024	14.b. Install a reactor cavity flooding system.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	$8,750,000	Not cost effective
025	Add ribbing to the containment shell.	0.00%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
026	Provide additional DC battery capacity.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
027	Use fuel cells instead of lead-acid batteries.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	>$1,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
028	Incorporate an alternate battery charging capability.	3.49%	0.39%	0.29%	$8,452	$9,868	$33,808	$90,000	Not cost effective
029	Install a modification improving DC bus reliability.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$500,000	Not cost effective
030	2.i. Provide 16 hour SBO injection.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
031	9.b. Provide an alternate pump power source.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	>$1,000,000	Not cost effective
032	10.a. Add a dedicated DC power supply.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$3,000,000	Not cost effective
033	10.b. Install additional batteries or divisions.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$3,000,000	Not cost effective
034	10.c. Install fuel cells.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	>$1,000,000	Not cost effective
035	10.d. Install DC bus cross-ties.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$300,000	Not cost effective
036	10.e. Extended SBO provisions.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
037	Locate residual heat removal (RHR) inside containment.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	>$500,000	Not cost effective
038	Increase frequency of valve leak testing.	0.93%	2.09%	2.09%	$7,188	$9,612	$28,752	$100,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
039	8.e. Improve MSIV design.	0.20%	7.44%	8.27%	$22,388	$31,284	$89,552	>$1,000,000	Not cost effective
040	Install a digital feed water upgrade.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	$1,500,000	Not cost effective
041	Create ability for emergency connections of existing or alternate water sources to feedwater/ condensate.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	$170,000	Not cost effective
042	Install an independent diesel for the CST makeup pumps.	1.78%	0.24%	0.13%	$2,388	$2,688	$9,552	$135,000	Not cost effective
043	Install motor-driven feed water pump.	0.18%	0.00%	0.00%	$0	$0	$0	$1,650,000	Not cost effective
044	Provide an additional high pressure injection pump with independent diesel.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
045	Install independent AC high pressure injection system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
046	2. a. Install a passive high pressure system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
047	2. d. Improved high pressure systems.	2.43%	0.41%	0.30%	$6,064	$7,180	$24,256	>$1,000,000	Not cost effective
048	2. e. Install an additional active high pressure system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
049	8.c. Add a diverse injection system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
050	Modify EOPs for ability to align diesel power to more air compressors.	0.12%	0.00%	0.00%	$0	$0	$0	$1,200,000	Not cost effective
051	Increase safety relief valve (SRV) reseat reliability.	3.67%	3.92%	3.67%	$18,288	$23,396	$73,152	$2,200,000	Not cost effective
052	11. a. Install an ATWS sized vent.	2.55%	8.14%	8.39%	$28,020	$37,860	$112,080	>$1,000,000	Not cost effective
053	Diversify explosive valve operation.	0.03%	0.00%	0.00%	$0	$0	$0	>$200,000	Not cost effective
054	4. d. Implement passive overpressure relief.	2.05%	2.43%	2.23%	$10,436	$13,504	$41,744	>$500,000	Not cost effective
055	Change CRD flow control valve failure position.	0.09%	0.00%	0.00%	$0	$0	$0	>$140,000	Not cost effective
056	Provide digital large break LOCA protection.	0.06%	0.00%	0.00%	$0	$0	$0	>$100,000	Not cost effective
057	Control containment venting within a narrow band of pressure.	13.84%	15.94%	15.21%	$73,788	$95,100	$295,152	$400,000	Not cost effective
058	Provide a tap from the fire protection system to RHR heat exchanger "B" via RHRSW header B.	0.39%	0.51%	0.39%	$2,088	$2,704	$8,352	$150,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
059	Provide a cross-tie between RHRSW trains downstream of the RHRSW pump discharge valves.	10.52%	12.13%	11.53%	$56,292	$72,600	$225,168	$400,000	Not cost effective
060	Improve turbine bypass valve capability.	9.97%	7.23%	6.75%	$41,720	$52,456	$166,880	$745,000	Not cost effective
061	Develop a procedure to use a portable power supply for battery chargers.	3.49%	0.39%	0.29%	$8,452	$9,868	$33,808	$10,000	Retain
062	Develop a procedure to open the doors of the EDG buildings upon receipt of a high temperature alarm.	21.15%	24.28%	24.45%	$115,900	$149,396	$463,600	$10,000	Retain
063	Provide additional reactor vessel monitoring and actuation system.	1.51%	1.53%	1.36%	$7,056	$9,000	$28,224	$1,200,000	Not cost effective

Table S2 – Phase I SAMA Candidates from IPE and IPEEE

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
253	Operator Action: Recovery of offsite power within 7 hours during loss of normal power event	[29]	This SAMA would reduce the core damage frequency contribution from the loss of offsite power event	#3 - Already installed	Restoring power from offsite sources after SBO is proceduralized in AOP-49, Station Blackout.
256	Operator Action: Align Fire water to RHRSW loop A for alternate injection	[29]	This SAMA would provide the Firewater to RHRSW loop A for late core injection during a loss of containment heat removal sequence	#3 - Already installed	This operator action is taken in response to align firewater source to cross-tie to the RHRSW A header which, in turn can also be cross-tied to the "A" LPCI injection path. Use of this alternative injection path further reduces the core damage frequency during a loss of containment heat removal sequence. This operator action has already been proceduralized at JAF EP-8, "Alternate Injection Systems ".
262	Operator action: Shedding DC load and limiting DC power use during SBO scenarios	[29]	This SAMA would conserve battery power to allow continued operation of the RCIC or HPCI system during SBO scenarios	#3 - Already installed	This operator action is taken in response to shed DC load from the batteries under SBO conditions to extend the life of batteries to allow continued operation of the RCIC or HPCI system and maintain adequate instrumentation. This operator action has already been implemented at JAF Procedure AOP-49, Station Blackout.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
280	Keep ESW valves 46MOV-102A&B normally shut	[29]	This SAMA would improve the availability of the ESW system to provide normal cooling to the EDG jacket coolers.	#1 - NA	This modification is unnecessary because flow diversion to the discharge canal when ESW provides normal cooling to the EDG jacket coolers does not result in flow below required values for EDG operation. Measured flows for each EDG with both valves open were: A – 566 gpm, C – 556 gpm B – 569 gpm, D – 581 gpm
281	Improve turbine bypass valve capability	[29]	This SAMA would improve the availability of the turbine bypass valve and EHC to reduce the transient core damage frequency.	Retain	This modification requires installing additional turbine bypass valve or providing more reliable power to the EHC system to improve its availability to reduce the core damage contribution from transient.
282	Develop a procedure to use a portable power supply for battery chargers	[29]	This SAMA would Improve the availability of the DC Power System	Retain	The procedure change is to use a portable supply power for battery chargers to keep batteries charged and battery control boards energized during SBO event.
283	Develop a procedure to open the door EDG buildings upon the high temperature alarm	[29]	This SAMA would Improve the availability of the EDG Power System.	Retain	The procedure is to direct the operator to open the respective EDG buildings' door when the high temperature alarm annunciates.
284	Provide additional reactor vessel monitoring and actuation system	[29]	This SAMA would improve the availability of the reactor vessel instrumentation system to Feedwater during the loss of the instrument reference leg.	Retain	This modification is to enhance the availability of the reactor vessel instrumentation system input to Feedwater to minimize the potential for Feedwater transients and thereby reduce the core damage contribution during the loss of the instrument reference leg event.
285	Strengthen the EDG building block walls	[18]	This SAMA would reduce the core damage contribution from the seismic induced station blackout event.	#3 - Already installed	This modification was implemented to Strengthen the EDG building block walls EGB-272-6, 7, 9 and 10 to reduce the core damage contribution from the seismic induced station blackout event.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
286	Close hydrogen supply isolation valve during seismic event	[18]	This SAMA would reduce the fire or explosion as result of seismic induced failure of hydrogen line in turbine building.	#3 - Already installed	A note was added to AOP-14, Earthquake, stating that the hydrogen piping in the turbine building is susceptible to failure during a seismic event and that piping can be isolated by closing the hydrogen supply isolation valve 89A-H2HAS-1.
287	Restrain or locate flammables cabinets to reduce the likelihood of overturning caused by seismic or other events.	[18]	This SAMA would eliminate probability of cabinets overturning, spilling flammable liquid contents.	#3 - Already installed	JAF flammables cabinets contain small quantities of flammables, usually in the original containers that seal tightly, so overturning a cabinet would not result in releasing a significant amount of flammable material. In addition, station procedures require that cabinets are secured against overturning in safety-related areas.
288	Ensure that the quantity of combustible materials in critical process areas is monitored	[18]	This SAMA would minimize combustibles and chance of prolonged fire in safety-related areas	#3 - Already installed	JAF has a procedure governing the fire-safe use and storage of combustible materials within the process buildings.
289	Monitor and control pre-staging of outage materials	[18]	This SAMA would reduce fire risk	#3 - Already installed	JAF Procedure AP14.02 “Combustible and Flammable Material Control” establishes the requirements for the control of site specific combustible material storage, ignition sources and impairments of fire systems to prevent or minimize the effects of a fire at Pilgrim. This procedure also provides a control mechanism for tracking system impairments and instituting compensatory measures to minimize the effects that those impairments may have on safety controls combustible materials within the plant.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
290	Install a bypass switch to allow opening the low reactor pressure LPCI or core spray injection valves	[18]	This SAMA would reduce the reactor building fire contribution to core damage frequency from the transients with stuck open SRVs or LOCAs cases. Core Spray and LPCI injection valves require a low permissive signal from the same two sensors to open the valves for RPV injection.	#3 - Already installed	A bypass switch was installed in the LPCI and core spray injection valves 10MOV-25A/B and 14MOV-12A/B. In addition, JAF Procedure AOP-28 "Operation during Plant Fires" directs the operators to use the switches if necessary and includes a tabulation of potentially unavailable equipment in each fire zone.
291	Relocate heat detector from the bottom of ceiling beams to the ceiling	[18]	This SAMA would reduce the cable spreading room fire contribution to core damage frequency.	#3 - Already installed	In lieu of the hardware modification, JAF procedure AP14.02 "Combustible and Flammable Material Control" was modified to eliminate the combustible material into the cable spreading room during power operation. This change in procedure reduces the CDF contribution from transient fires in cable spreading room.
292	Prevent loss of EDG air supply during tornado, hurricanes and high winds	[18]	This SAMA would reduce the probability due to loss of EDG air supply during tornado, hurricanes and high winds.	#3 - Already installed	A note was added to AOP-13, "Hurricanes, Tornadoes and High Winds" warning the operators that a hurricane, tornado, or high wind could threaten the integrity of the air intake duct work supplying the EDG room ventilation system because of a decrease in internal pressure. The note also states that adequate ventilation to the switchgear room and sufficient combustion air for EDG operation can be ensured by opening switchgear room doors or creating an opening within damaged duct work.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
293	Reducing the icing incidents in the intake structure and screenwell	[18]	This SAMA would reduce the icing incidents in the intake structure and screenwell	#3 - Already installed	A screenwell low level alarm to the control room was provided; alerting operators to a low screenwell water level should the intake, trash rack, or traveling screen be blocked by ice or debris. An EPIC computer alarm was added to alert the operators of rising screenwell and circulating water system intake water temperatures that may result should the inflow of cold lake water be restricted. AOP-64 (Loss of Intake Water Level) was changed to define the proper corrective actions to pursue should an ice blockage occur.

Attachment 3

James A. FitzPatrick Nuclear Power Plant

License Renewal Application – Amendment 1

JAFNPP SAMA Analysis – Supplement

JAFNPP SAMA Analysis – Supplement

JAFNPP Lessons Learned From VYNPS and PNPS SAMA RAIs

The VYNPS and PNPS SAMA analyses and ERs were completed before NRC comments were incorporated in NEI 05-01, "Severe Accident Mitigation Alternative (SAMA) Analysis Guidance Document". Therefore, some of the RAIs on these analyses stemmed from changes made to the guidance after the analyses were completed.

Although the JAFNPP LRA was not submitted until July 31, 2006, the JAFNPP SAMA analysis was also completed before NRC comments were incorporated in the guidance document. The VYNPS and PNPS RAIs were reviewed and those items that applied to JAFNPP and could be resolved during the ER review process were resolved before the ER was submitted (see the following list). The lessons learned with the highest potential of altering the conclusions of the SAMA analysis were incorporated in the JAFNPP ER before it was submitted for NRC review (see items 5, 9 and 10 in the following list).

1. Section E.1.4.1 – Provides the conclusion of the BWROG peer review relative to the use of the PSA. (PNPS RAI 1.d and VYNPS RAI 1.c)
2. Table E.1-11 – Provides the fission product release characteristics for each release category, including fission product release fractions, release times and duration, warning time, release elevation, and energy of release. (VYNPS RAI 2.b)
3. Section E.1.2.2 – Clarifies that MAAP analyses were performed for the current level 2 model and describes how the MAAP cases were selected to represent each release category. (PNPS RAI 2.c.i and VYNPS RAI 2.c.)
4. Section E.1.4.2.2.2 – Clarifies that the level 2 model was included in the BWROG peer review and describes changes to the model as a result of the review. (VYNPS RAI 2.d)
5. Section 4.21.5.4 – Uses correct external events multiplier to properly account for external and internal events. (PNPS RAI 3.c and VYNPS RAI 3.c)
6. Section 4.21.5.4 – Provides a description of the conservatisms in the dominant JAFNPP fire CDF sequences that would support a factor of three reduction in CDF. (PNPS RAI 3.a and VYNPS RAI 3.a)
7. Section E.1.5.2.6 – Provides a brief statement regarding the acceptability of use of 1994 data rather than a different year's data. (PNPS RAI 4.a and VYNPS RAI 4.a)
8. Section E.1.5.2.7 – Indicates what percentage of the public was assumed to evacuate. (PNPS RAI 4.b and VYNPS RAI 4.b)
9. Table E.1-14 – Increases inventory of long half-life nuclides to reflect the average core exposure at JAFNPP. (PNPS RAI 4.c and VYNPS RAI 4.c)
10. Table E.2-1 – Divides cost estimates drawn from a previous SAMA analysis for a dual-unit site by 2 for use at JAFNPP which is a single unit site. (PNPS RAI 6.b and VYNPS RAI 6.b)

Due to time constraints, some lessons learned from the VYNPS and PNPS RAIs were not incorporated in the JAFNPP ER before it was submitted for NRC review. The following sections contain supplemental information to address lessons learned from the previous SAMA reviews and align the JAFNPP SAMA submittal more with the NEI guidance endorsed by the NRC.

1. **Plant Changes Since the Freeze Date of the PSA Model Used for the SAMA Analysis**

In accordance with plant procedures, design change documents and emergency operating procedure changes are reviewed to determine their impact on the PSA model prior to implementation. A PSA model change request database is maintained to track potential changes and assess their degree of impact of the PSA model. As of June 2006, this database shows no outstanding changes due to modifications or procedure changes since issuance of Revision 2 of the PSA model in October 2004 that could have a significant impact on the results of the PSA or the SAMA analysis.

2. **Supplement to ER Section E.1.4.2, "Major Differences between the JAFNPP Revision 2 PSA Model and the Original IPE Model"**

Section E.1.4.2 of the ER discusses the major changes between the IPE model and Revision 2 of the PSA model (used for the SAMA analysis). The supplementary information below splits the information into changes between the IPE model and Revision 1 of the PSA model (reviewed by BWROG) and changes between Revision 1 and Revision 2.

Summary of Major PSA Models		
Model	CDF (/ry)	LERF (/ry)
IPE	1.92E-6	7.80E-7
Revision 1	2.44E-6	6.62E-7
Revision 2	2.74E-6	9.20E-8

<u>Changes from IPE to Revision 1 (reviewed by BWROG)</u>

Initiating event database was updated to include all scrams that occurred between 7/28/1975 and 12/31/1997.

Component failure and unavailability database was updated to reflect failures that occurred between 1/1/1986 and 4/30/1995, more equipment groups in which common-cause failures may occur and current on-line maintenance practices.

Changes were also made to data to reflect revised technical specifications and changes in the ATTS instrumentation surveillance frequency from monthly to quarterly.

Internal flooding analysis was revised. A relay room flooding scenario was identified and a procedure enhancement was implemented to cope with this flooding scenario.

Model changes were made to reflect design and procedure modifications, including the following:

- A modification to the fire protection system to allow it to supply EDG jacket cooling water directly through the ESW system cross-tie. This modification reduces the contribution to plant risk made by the dominant station blackout event.
- Installation of bonnet vents on the LPCI and core spray injection valves to preclude common-cause pressure locking of the valves.
- Installation of a keylock bypass switch that allows LPCI and core spray injection valves to be manually opened from the control room. The switch can be used to help recover from reactor pressure permissive logic failures that cause all low-pressure system injection valves to remain closed. Use of this switch would reduce the probability of core damage during LOCAs and transients with stuck open SRVs in which all low-pressure ECCS is unavailable.
- Installation of a keylock bypass switch to allow HPCI auto-transfer on high suppression pool level to be bypassed from the control room rather than by removing leads in a relay room panel. This action is important in ATWS events with MSIVs closed and in handling other transients and LOCAs.
- Changes of the RHR minimum flow bypass valve positions from normally closed to normally open. This modification reduces the probability of pump damage as a result of loss of one emergency bus.
- Installation of switches to permit transfer to the alternative power supply for LPCI injection valves to be made from the control room.
- A modification to change the RCIC enclosure fan power supply from an AC feed to an AC inverter feed from a DC power source. This modification enhances the availability of the RCIC enclosure ventilation system during station blackout events.
- Revisions to OP-19 (RCIC system), increased RCIC turbine exhaust trip set points.
- Revisions to OP-25 (CRD system) direct operators to enhance the CRD flow in certain accident sequences.
- A new procedure EP-10 (Fire Water Cross-tie to RHRSW Loop A When Directed by EOP-4) directs operators to align the fire protection system to the tube side of the RHR heat exchanger in loss of containment heat removal accident sequences.
- Revisions to AOP-49 (Station Blackout) explicitly address bus recovery should safeguard bus tie breaker lockout relays inadvertently reset.
- Revisions to EP-6 (Post Accident Venting of Primary Containment) direct operators to locally open valves 27AOV-117 and 27AOV-118 should it not be possible to open these valves from the relay room during loss of containment heat removal sequences.

Changes from Revision 1 (reviewed by BWROG) to Revision 2 (used for SAMA Analysis)

The PSA model was changed to incorporate peer review recommendations. These changes are summarized in ER Sections E.1.4.2.1.3 and E.1.4.2.2.2.

Initiating event database was updated to include all scrams that occurred between 7/28/1975 and 12/31/2003.

Component failure and unavailability database was updated to reflect failures that occurred between 1/1/1995 and 12/31/2002.

Station battery depletion time was reduced from 8 hours to 4 hours, decreasing the available time for recovery of offsite power during an SBO event from 13 to 7 hours.

Model changes were made to reflect design and procedure modifications, including the following.

- SRV alternate actuation system and ATWS recirculation pump level trip were modified.
- Service, instrument, and breathing air compressors were replaced.

The Level 2 model was changed due to updated containment performance methodology. Specific changes are described in ER Section E.1.4.2.2.1. Two of the changes described in Section E.1.4.2.2.1 had the greatest impact on lowering the LERF value for Revision 2.

1. Transients initiated by a loss of containment heat removal were conservatively binned as early releases in Revisions 0 and 1. Because this type of plant transient results in containment failure many hours after the initiation of the event (i.e. greater than six hours) these events are appropriately considered late releases instead of early releases in Revision 2.

2. The impact of water on the drywell floor and subsequent drywell liner melt-through from core debris melt was updated in Revision 2 to reflect current industry understanding. Specifically, a much lower liner melt-through probability is assigned for flooded drywell accident progressions than for dry drywell accident progressions.

Based on the BWROG review, the JAFNPP PSA can be effectively used to support Grade 3 applications involving relative risk significance; in addition, absolute risk determination applications can be performed with supporting deterministic analyses.

3. MAAP Analyses

The MAAP computer code is used to generate the radionuclide release magnitude for the MACCS2 consequence analysis. The MAAP calculations are representative deterministic thermal hydraulic calculations that portray dominant CET scenarios. Sixty-two accident progression scenarios were analyzed.

The source terms presented in Table E.1-11 (ER Section E.1.2.2) and used in the consequence analysis are determined as follows:

1. The appropriate MAAP case source terms are selected and assigned to a particular CET accident progression endstate.
2. Based on the source terms from Step 1, the source terms for each plant damage state CET accident progression endstate are determined.
3. The mean frequency of each release category is determined by summing the individual plant damage state CET accident progression endstates contained in the particular release category (i.e., no containment failure, early high release, etc.).
4. The release category individual fractional contributions for each CET accident progression are determined by dividing the result from Step 3 by the individual PDSs frequencies.
5. Each PDS accident progression CET endpoint source terms, release timing, release energy and release elevation by the value determine in Step 4.
6. Sum the individual results of Step 5 to arrive at the total final values contained in Table E.1-11 (ER Section E.1.2.2).

4. Benefit Presentation Revision

Table E.2-1 of the ER provided an estimated benefit which accounted for internal events with a 7% discount rate and an upper bound estimated benefit which accounted for internal events, external events and uncertainties, with a 7% discount rate. Table E.2-2 of the ER provided Sensitivity Case 2 results which included an estimated benefit which accounted for internal events with a 3% discount rate and an upper bound estimated benefit which accounted for internal events, external events and uncertainties, with a 3% discount rate.

Although the upper bound estimated benefit values are bounding, NEI 05-01 recommends that three results be reported. To more closely align with the recommendations of NEI 05-01, Table S1 presents the following three results for each of the SAMA candidates.

1. Baseline - accounts for internal and external events using a multiplier of 4 (see ER section for derivation). Uses 7% discount rate.
2. Baseline with Uncertainty - accounts for internal event and external events using a multiplier of 4. Accounts for uncertainty with a factor of 4 (ER Table E.1-3 shows that the ratio of the 95^{th} percentile to the mean is ~4). Uses 7% discount rate.

3. 3% Discount Rate Alternate Case - accounts for internal and external events using a multiplier of 4. Uses 3% discount rate.

5. Offsite Economic Cost Risk

Although NEI 05-01 does not recommend reporting the change in offsite economic cost risk for each analysis case, this information was requested for both VYNPS and PNPS and is therefore provided in Table S1.

6. Accounting of IPE and IPEEE Enhancements

Table S2 presents the Phase I SAMA candidates which are the enhancements recommended in the IPE, and IPEEE. Those with reference source [29] are from the IPE and those with reference source [18] are from the IPEEE.

Phase I SAMA candidates 253, 256, and 262 from the IPE have been implemented and included in Revision 2 of the PSA model (version used for the SAMA analysis).

Phase I SAMA candidate 280 proposed keeping ESW valves 46MOV-102A&B normally shut to prevent flow diversion. This modification was determined to be unnecessary because flow diversion to the discharge canal when ESW provides normal cooling to the EDG jacket coolers does not result in flow below required values for EDG operation.

Phase I SAMA candidates 281 through 284 were retained as Phase II SAMA candidates.

All potential modifications identified in the IPEEE have been implemented.

7. Risk Reduction for Dominant Fire Zones

ER Table E.1-12 lists a number of fire zones with CDF values above 1E-06 per year. As described in ER Section E.1.3.2, the values in Table E.1-12 are the IPEEE values following re-evaluation to include response to NRC questions regarding fire-modeling progression. Although the plant improvements identified by the IPEEE have been implemented, they are not reflected in the CDF values in Table E.1-12.

IPEEE improvements to restrain or locate flammables cabinets, to monitor and control the quantity of combustible materials in critical process areas, and to monitor and control pre-staging of outage materials would reduce CDF values for all of the dominant zones.

The following discussion for each zone explains what measures have been taken to reduce risk in that zone and explains why the fire CDF cannot be further reduced in a cost effective manner.

Cable spreading room (zone CS-1)

The IPEEE recommended relocating heat detectors in the cable spreading room to severely limit contribution from transient fires. In lieu of the hardware modification, a change was made to administrative procedures proscribing unattended combustible material in the room. This change in procedure potentially reduces the CDF contribution from transient fires in CS-1.

In the fire analysis, spurious actuation or failure due to hot shorts and open circuits within cable jackets was included with a conservatively high probability of occurrence of 1.0. However, in the latest fire PRA methodology for NFPA-805 compliance [NUREG/CR-6850], this probability is addressed by assigning a probability of occurrence based on the configuration of the cabling and nature of the short circuit. Open circuits are no longer considered, therefore reducing the impact of the cable damage assessment. JAFNPP uses thermoset cables which have a high damage temperature. A conservative estimate considering this new methodology for worst-case failure mode probabilities of hot short circuits for thermoset cables in trays with control power transformer (typical of MCC circuits) results in a probability of failure of 0.05. Therefore, the CDF contribution from fires in CS-1 can be reduced to an estimated 3.29 x 10-7 per year.

Since the cable spreading room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

Main control room (zone CR-1)

In the main control room, the dominant scenario is a generic control room fire with a forced evacuation and failure to properly shut down the plant by implementing abnormal operating procedures. The ignition frequency used for the IPEEE was 1.07 x 10-2 per year. However, with almost 10 years of additional accumulated industry experience, this frequency has been reduced to 2.5 x 10-3 per year [NUREG/CR-6850]. By factoring this into the control room fire scenarios, the overall contribution for fires in zone CR-1 reduces to an estimated 7.17 x 10-7 per year.

Since the main control room is always inhabited ensuring prompt fire detection and manual suppression, no further cost-effective changes were identified to reduce CDF in this zone.

EDG A and C switchgear room south (zone EG-5)

Since the EDG switchgear room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

Reactor building westside (zone RB-1B)

A bypass switch was installed to allow opening of the LPCI and core spray injection valves. In addition, the procedure for operation during plant fires directs operators to use the switches if necessary and includes a tabulation of potentially unavailable equipment in each fire zone. This modification reduces the reactor building fire contribution to core damage frequency from LOCAs and transients with stuck open SRVs.

This zone is equipped with a detection system that alarms in the control room. It does not have an automatic suppression system, but is separated from adjacent zones by water curtains. No further cost-effective changes were identified to reduce CDF in this zone.

Reactor building east crescent (zone RB-1E)

Cabling in trays predominates in the east crescent. As for the cable spreading room, spurious actuation or failure due to hot shorts and open circuits within cable jackets was included with a conservatively high probability of occurrence of 1.0. A conservative estimate using the methodology described for the cable spreading room would reduce the CDF contribution from fires in this zone to approximately 5.10 x 10-8 per year.

This zone is equipped with a detection system that alarms in the control room. In this zone, the HPCI pump and turbine are protected by an automatic water spray system and a manual foam-water sprinkler system which can be manually initiated from the control room. The zone is also separated from adjacent zones by water curtains. No further cost-effective changes were identified to reduce CDF in this zone.

Relay room (zone RR-1)

Cabling in trays predominates in the relay room. A conservative estimate using the methodology described for the cable spreading room would reduce the CDF contribution from fires in this zone to approximately 2.70 x 10-7 per year.

Since the relay room is equipped with a detection system that alarms in the control room and a carbon dioxide suppression system, no further cost-effective changes were identified to reduce CDF in this zone.

8. More Detailed SAMA Descriptions

The following paragraphs provide more information about the associated modifications and what is included in the cost estimate for several SAMAs.

SAMAs 4 (Install a containment vent large enough to remove ATWS decay heat) and 52 (Install an ATWS sized vent)

These SAMAs provide a means to remove decay heat during an ATWS event. The proposed design modification for these SAMAs involves installation of a new torus vent pipe of sufficient size to remove decay heat following an ATWS with MSIV closure and successful recirculation pump trip.

SAMAs 7 (Provide modification for flooding the drywell head) and 21 (Provide a method of drywell head flooding)

These SAMAs provide intentional flooding of the upper drywell head such that if high drywell temperatures occurred, the drywell head seal would not fail. The proposed design modification requires extensive structural modification to accommodate a drywell head flooding system. To flood the drywell head seal at elevation 346 foot, the drywell vent at the 335-foot elevation would have to be plugged and a new penetration would have to be installed in the drywell head above the 346 foot elevation. The new vent penetration would have to be tied into the existing vent line and would have to permit removal of the drywell head at each refueling outage.

These SAMAs evaluate flooding internal to the drywell. While flooding or sprays on the outside might serve the same purpose, a cost estimate for that modification was not developed because the estimated benefit for SAMAs 7 and 21 is $0.

SAMAs 8 (Enhance fire protection system and standby gas treatment system hardware and procedure) and 22 (Use alternate method of reactor building spray)

These SAMAs would improve fission product scrubbing in severe accidents. The proposed design modification would upgrade the standby gas treatment and fire protection systems to a sufficient capacity to handle postulated loads from severe accidents due to a bypass or breach of the containment. Loads produced as a result of reactor pressure vessel or containment blowdown would require large filtering capacities.

Use of existing fire water sprays or relatively simple modifications to the fire water sprays would not be effective in mitigating releases. The only fire protection automatic suppression systems within the reactor building are water curtains to separate the six fire areas within the building from each other. As such, they have limited capability in providing fission product scrubbing.

SAMA 11 (Strengthen primary and secondary containment)

This SAMA would reduce the probability of containment over-pressurization failure. This SAMA is intended for a new plant; hence, it is not practical to back-fit this modification into a plant which is already built and operating. Since JAFNPP has a Mark I containment, early release risk is dominated by events that result in early failure of the drywell shell due to direct contact with debris and events that bypass the containment. Strengthening of primary and secondary containment would have a small impact on the overall risk of these accidents. The cost estimated for ABWR was $12 million and the retrofit for an existing containment would cost more. Therefore, the cost of implementation for this SAMA exceeds the revised baseline benefit.

SAMA 23 (Provide a means of flooding the rubble bed)

This modification would contain molten core debris on the reactor pedestal and allow the debris to be cooled. The proposed design modification involves a core retention device inside the reactor pedestal area. However, the Industry Degraded Core Rulemaking (IDCOR) Program has investigated core retention devices and concluded, "Core retention devices are not effective risk reduction devices for degraded core events". The cost of implementing this SAMA at Quad Cities was estimated to be $2.5 million.

SAMA 31 (Provide an alternate pump power source)

This modification would provide a small, dedicated power source such as a dedicated diesel or gas turbine for the feedwater or condensate pumps so that they do not rely on offsite power. The proposed design modification would involve adding one 4.16 KV power source to supply AC power to one feedwater or one condensate pump. The additional diesel generator or gas turbine would have to be sufficiently sized to handle starting (inrush) and running of at least one 5,000 hp pump at a rated voltage of 4.16kV. A generator of that size would easily exceed 6,000 KW. The cost estimate assumes that the power source will be manually connected.

SAMA 47 (Improved high pressure systems)

This SAMA would improve prevention of core melt sequences by improving reliability of high pressure capability to remove decay heat. The proposed design modification considers replacing one CRD pump with a flow capacity equal to the RCIC system (400 gpm).

Minor modifications to the existing CRD system or modifications to the emergency procedures to enhance CRD flow rates would not be viable low-cost alternatives because the flow provided by the CRD system is limited by CRD pump capacity and pipe friction losses.

SAMA 57 (Control containment venting within a narrow band of pressure)

This modification would establish a narrow pressure control band to prevent rapid containment depressurization when venting is implemented thus avoiding adverse impact on the low pressure ECCS injection systems taking suction from the torus. Hence, the proposed modification for SAMA 57 requires a detailed engineering analysis examining the impact of opening the torus vent path and an examination of the NPSH requirements for LPCI and core spray systems. It would also require an engineering study of the feasibility of closing the 20-inch torus vent valves 27AOV-117 and 27AOV-118 against high containment pressures as well as potential hardware modifications. Procedure changes, simulator changes, and training would also be required. The cost estimate assumes revision of plant procedures, hardware changes and associated training lesson plan changes as well as additional analysis to address NPSH concerns.

9. SAMA 57 Benefit Modeling

SAMA 57 (Control containment venting within a narrow band of pressure), would establish a narrow pressure control band to prevent rapid containment depressurization when venting is implemented thus avoiding adverse impact on the low pressure ECCS injection systems taking suction from the torus.

The benefit for this SAMA was conservatively estimated by reducing the probability of the operator failure to vent basic event. Since the benefit of the controlled venting occurs for sequences involving successful venting which are not significantly affected by reducing the operator failure to vent, a sensitivity case was performed to assure that the benefit values reported for SAMA 57 in Table S1 are conservative.

The SAMA 57 sensitivity case estimated the benefit of this SAMA by crediting continued vessel injection from LPCI or core spray for those sequences in which torus venting is successful and alternative injection systems fail after torus venting. Specifically, an additional event (LPCI-CS) was added to cutsets that involve successful torus venting. Since the available NPSH is likely to be less that the required NPSH with the torus vent path open, a failure probability of 0.9 was assigned to event LPCI-CS.

The results of the sensitivity case are,
- CDF reduction – 0.46 %,
- Off-site dose reduction – 0.61%,
- OECR reduction – 0.60%,
- baseline – $2,516,
- 3% discount rate alternate case – $3,304, and
- baseline with uncertainty – $10,064

Therefore, the benefit values reported for SAMA 57 in Table S1 are conservative.

10. Evaluation of SAMAs Potentially Cost-Beneficial at Other Plants

The following paragraphs discuss SAMAs that have previously been found to be potentially cost-beneficial at other plants.

a. Use portable generator to extend the coping time in loss of alternating current (AC) power events (to power battery chargers).

Upon a complete SBO, a portable generator could be used to extend the life of both 125 VDC batteries.

To assess the impact of prolonging battery life using a portable diesel generator to power the battery chargers, the probability of non-recovery of offsite power for 7 hours was changed to 24 hours for SBO scenarios (equivalent to the benefit assessment for SAMA 026, "Provide additional DC battery capacity".) This resulted in a baseline with uncertainty benefit of approximately $837,840. The estimated cost of implementing and using the portable generator is $712,347. Therefore, this SAMA is potentially cost effective for JAFNPP.

b. Enhance DC power availability (provide cables from diesel generators or another source to directly power battery chargers).

This SAMA has already been considered and implemented. Due to the number of safety-related emergency generators (4), there is benefit to being able to connect the battery chargers to one of these AC power sources and procedures currently exist to provide this capability.

c. Provide alternate DC feeds (using a portable generator) to panels supplied only by DC bus.

Upon loss of a DC bus, a portable generator could be used to provide power to an individual 125VDC MCC. This would, for example, support returning HPCI to service in the event its bus was to fail.

The CDF contribution due to failure of the HPCI system was eliminated to conservatively assess the benefit of this SAMA (equivalent to the benefit assessment for SAMA 044, "Provide an additional high pressure pump with independent diesel".) This resulted in a baseline with uncertainty benefit of $33,808. The estimated cost of implementing and using the portable generator is $712K. Therefore, this SAMA is not cost effective for JAFNPP.

d. Modify procedures and training to allow operators to cross-tie emergency AC buses under emergency conditions which require operation of critical equipment.

This SAMA has already been considered and implemented. The Class 1E AC power supply is already highly diverse and reliable. During normal operating conditions, power to system buses is provided to the non-vital and emergency buses through the normal station service transformer T4, which is fed from the main generator. There are four sources available following a turbine trip: the south bus 115Kv feed through the Lighthouse Hill #3 line, the north bus 115Kv feed through Nine Mile Point #4 line, and four EDGs (two trains). Either of the incoming 115Kv lines can supply power to the 4Kv buses through the T2 or T3 transformers through the normally closed 10017 disconnect switch. The 10300 and 10400 buses can be cross-tied to one another by opening the appropriate feeder breaker and closing the applicable cross tie breaker. Procedures for performing the cross-tie operations are in place.

e. Develop guidance/procedures for local, manual control of reactor core isolation cooling following loss of DC power.

This SAMA has already been considered and implemented. JAFNPP has an existing procedure to provide local manual control of RCIC.

Table S1 – Summary of Phase II SAMA Analysis

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
001	8.a. Add a service water pump.	0.91%	1.07%	0.98%	$4,604	$6,004	$18,416	$5,900,000	Not cost effective
002	Install an independent method of suppression pool cooling.	7.77%	8.81%	8.16%	$40,388	$51,896	$161,552	$5,800,000	Not cost effective
003	Install a filtered containment vent to provide fission product scrubbing. Option 1: Gravel Bed Filter Option 2: Multiple Venturi Scrubber	0.00%	3.73%	7.74%	$16,360	$22,864	$65,440	$1,500,000	Not cost effective
004	Install a containment vent large enough to remove ATWS decay heat.	2.55%	8.14%	8.39%	$28,020	$37,860	$112,080	>$1,000,000	Not cost effective
005	Create a large concrete crucible with heat removal potential under the base mat to contain molten core debris.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	>$100 million	Not cost effective
006	Create a water-cooled rubble bed on the pedestal.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	$19 million	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
007	Provide modification for flooding the drywell head.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
008	Enhance fire protection system and standby gas treatment system hardware and procedures.	0.00%	0.00%	0.00%	$0	$0	$0	>$2,500,000	Not cost effective
009	Create a core melt source reduction system.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	>$5,000,000	Not cost effective
010	Install a passive containment spray system.	7.67%	8.71%	8.07%	$39,592	$51,000	$158,368	$5,800,000	Not cost effective
011	Strengthen primary and secondary containment.	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
012	Increase the depth of the concrete base mat or use an alternative concrete material to ensure melt-through does not occur.	0.00%	0.28%	0.17%	$428	$604	$1,712	>$5,000,000	Not cost effective
013	Provide a reactor vessel exterior cooling system.	0.00%	2.62%	2.53%	$6,888	$9,628	$27,552	$2,500,000	Not cost effective
014	Construct a building connected to primary containment that is maintained at a vacuum.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
015	2.g. Add dedicated suppression pool cooling.	7.77%	8.81%	8.16%	$40,388	$51,896	$161,552	$5,800,000	Not cost effective
016	3.a. Create a larger volume in containment.	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$8,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
017	3.b. Increase containment pressure capability (sufficient pressure to withstand severe accidents).	7.36%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
018	3.c. Install improved vacuum breakers (redundant valves in each line).	0.02%	7.44%	8.26%	$22,388	$31,284	$89,552	>$500,000	Not cost effective
019	3.d. Increase the temperature margin for seals.	0.00%	0.00%	0.00%	$0	$0	$0	$12,000,000	Not cost effective
020	5.b/c. Install a filtered vent.	0.00%	3.73%	7.74%	$16,360	$22,864	$65,440	$1,500,000	Not cost effective
021	7. a. Provide a method of drywell head flooding.	0.00%	0.00%	0.00%	$0	$0	$0	>$1,000,000	Not cost effective
022	13. a. Use alternate method of reactor building spray.	0.00%	0.00%	0.00%	$0	$0	$0	>$2,500,000	Not cost effective
023	14.a. Provide a means of flooding the rubble bed.	0.00%	1.22%	1.07%	$3,444	$4,816	$13,776	$2,500,000	Not cost effective
024	14.b. Install a reactor cavity flooding system.	0.00%	5.03%	4.74%	$13,776	$19,252	$55,104	$8,750,000	Not cost effective
025	Add ribbing to the containment shell.	0.00%	10.15%	10.87%	$30,136	$42,112	$120,544	$12,000,000	Not cost effective
026	Provide additional DC battery capacity.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
027	Use fuel cells instead of lead-acid batteries.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	>$1,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
028	Incorporate an alternate battery charging capability.	3.49%	0.39%	0.29%	$8,452	$9,868	$33,808	$90,000	Not cost effective
029	Install a modification improving DC bus reliability.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$500,000	Not cost effective
030	2.i. Provide 16 hour SBO injection.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
031	9.b. Provide an alternate pump power source.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	>$1,000,000	Not cost effective
032	10.a. Add a dedicated DC power supply.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$3,000,000	Not cost effective
033	10.b. Install additional batteries or divisions.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$3,000,000	Not cost effective
034	10.c. Install fuel cells.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	>$1,000,000	Not cost effective
035	10.d. Install DC bus cross-ties.	1.46%	1.20%	1.05%	$4,540	$5,696	$18,160	$300,000	Not cost effective
036	10.e. Extended SBO provisions.	39.0%	43.74%	44.44%	$209,460	$269,744	$837,840	$500,000	Retain
037	Locate residual heat removal (RHR) inside containment.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	>$500,000	Not cost effective
038	Increase frequency of valve leak testing.	0.93%	2.09%	2.09%	$7,188	$9,612	$28,752	$100,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
039	8.e. Improve MSIV design.	0.20%	7.44%	8.27%	$22,388	$31,284	$89,552	>$1,000,000	Not cost effective
040	Install a digital feed water upgrade.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	$1,500,000	Not cost effective
041	Create ability for emergency connections of existing or alternate water sources to feedwater/ condensate.	0.78%	0.67%	0.54%	$3,312	$4,200	$13,248	$170,000	Not cost effective
042	Install an independent diesel for the CST makeup pumps.	1.78%	0.24%	0.13%	$2,388	$2,688	$9,552	$135,000	Not cost effective
043	Install motor-driven feed water pump.	0.18%	0.00%	0.00%	$0	$0	$0	$1,650,000	Not cost effective
044	Provide an additional high pressure injection pump with independent diesel.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
045	Install independent AC high pressure injection system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
046	2. a. Install a passive high pressure system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
047	2. d. Improved high pressure systems.	2.43%	0.41%	0.30%	$6,064	$7,180	$24,256	>$1,000,000	Not cost effective
048	2. e. Install an additional active high pressure system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
049	8.c. Add a diverse injection system.	3.44%	0.54%	0.43%	$8,452	$9,868	$33,808	>$1,000,000	Not cost effective
050	Modify EOPs for ability to align diesel power to more air compressors.	0.12%	0.00%	0.00%	$0	$0	$0	$1,200,000	Not cost effective
051	Increase safety relief valve (SRV) reseat reliability.	3.67%	3.92%	3.67%	$18,288	$23,396	$73,152	$2,200,000	Not cost effective
052	11. a. Install an ATWS sized vent.	2.55%	8.14%	8.39%	$28,020	$37,860	$112,080	>$1,000,000	Not cost effective
053	Diversify explosive valve operation.	0.03%	0.00%	0.00%	$0	$0	$0	>$200,000	Not cost effective
054	4. d. Implement passive overpressure relief.	2.05%	2.43%	2.23%	$10,436	$13,504	$41,744	>$500,000	Not cost effective
055	Change CRD flow control valve failure position.	0.09%	0.00%	0.00%	$0	$0	$0	>$140,000	Not cost effective
056	Provide digital large break LOCA protection.	0.06%	0.00%	0.00%	$0	$0	$0	>$100,000	Not cost effective
057	Control containment venting within a narrow band of pressure.	13.84%	15.94%	15.21%	$73,788	$95,100	$295,152	$400,000	Not cost effective
058	Provide a tap from the fire protection system to RHR heat exchanger "B" via RHRSW header B.	0.39%	0.51%	0.39%	$2,088	$2,704	$8,352	$150,000	Not cost effective

Phase II SAMA ID	SAMA Title	CDF Reduction	Off-Site Dose Reduction	OECR Reduction	Baseline	3% discount Rate Alternate Case	Baseline With Uncertainty	Estimated Cost	Conclusion
059	Provide a cross-tie between RHRSW trains downstream of the RHRSW pump discharge valves.	10.52%	12.13%	11.53%	$56,292	$72,600	$225,168	$400,000	Not cost effective
060	Improve turbine bypass valve capability.	9.97%	7.23%	6.75%	$41,720	$52,456	$166,880	$745,000	Not cost effective
061	Develop a procedure to use a portable power supply for battery chargers.	3.49%	0.39%	0.29%	$8,452	$9,868	$33,808	$10,000	Retain
062	Develop a procedure to open the doors of the EDG buildings upon receipt of a high temperature alarm.	21.15%	24.28%	24.45%	$115,900	$149,396	$463,600	$10,000	Retain
063	Provide additional reactor vessel monitoring and actuation system.	1.51%	1.53%	1.36%	$7,056	$9,000	$28,224	$1,200,000	Not cost effective

Table S2 – Phase I SAMA Candidates from IPE and IPEEE

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
253	Operator Action: Recovery of offsite power within 7 hours during loss of normal power event	[29]	This SAMA would reduce the core damage frequency contribution from the loss of offsite power event	#3 - Already installed	Restoring power from offsite sources after SBO is proceduralized in AOP-49, Station Blackout.
256	Operator Action: Align Fire water to RHRSW loop A for alternate injection	[29]	This SAMA would provide the Firewater to RHRSW loop A for late core injection during a loss of containment heat removal sequence	#3 - Already installed	This operator action is taken in response to align firewater source to cross-tie to the RHRSW A header which, in turn can also be cross-tied to the "A" LPCI injection path. Use of this alternative injection path further reduces the core damage frequency during a loss of containment heat removal sequence. This operator action has already been proceduralized at JAF EP-8, "Alternate Injection Systems ".
262	Operator action: Shedding DC load and limiting DC power use during SBO scenarios	[29]	This SAMA would conserve battery power to allow continued operation of the RCIC or HPCI system during SBO scenarios	#3 - Already installed	This operator action is taken in response to shed DC load from the batteries under SBO conditions to extend the life of batteries to allow continued operation of the RCIC or HPCI system and maintain adequate instrumentation. This operator action has already been implemented at JAF Procedure AOP-49, Station Blackout.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
280	Keep ESW valves 46MOV-102A&B normally shut	[29]	This SAMA would improve the availability of the ESW system to provide normal cooling to the EDG jacket coolers.	#1 - NA	This modification is unnecessary because flow diversion to the discharge canal when ESW provides normal cooling to the EDG jacket coolers does not result in flow below required values for EDG operation. Measured flows for each EDG with both valves open were: A – 566 gpm, C – 556 gpm B – 569 gpm, D – 581 gpm
281	Improve turbine bypass valve capability	[29]	This SAMA would improve the availability of the turbine bypass valve and EHC to reduce the transient core damage frequency.	Retain	This modification requires installing additional turbine bypass valve or providing more reliable power to the EHC system to improve its availability to reduce the core damage contribution from transient.
282	Develop a procedure to use a portable power supply for battery chargers	[29]	This SAMA would Improve the availability of the DC Power System	Retain	The procedure change is to use a portable supply power for battery chargers to keep batteries charged and battery control boards energized during SBO event.
283	Develop a procedure to open the door EDG buildings upon the high temperature alarm	[29]	This SAMA would Improve the availability of the EDG Power System.	Retain	The procedure is to direct the operator to open the respective EDG buildings' door when the high temperature alarm annunciates.
284	Provide additional reactor vessel monitoring and actuation system	[29]	This SAMA would improve the availability of the reactor vessel instrumentation system to Feedwater during the loss of the instrument reference leg.	Retain	This modification is to enhance the availability of the reactor vessel instrumentation system input to Feedwater to minimize the potential for Feedwater transients and thereby reduce the core damage contribution during the loss of the instrument reference leg event.
285	Strengthen the EDG building block walls	[18]	This SAMA would reduce the core damage contribution from the seismic induced station blackout event.	#3 - Already installed	This modification was implemented to Strengthen the EDG building block walls EGB-272-6, 7, 9 and 10 to reduce the core damage contribution from the seismic induced station blackout event.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
286	Close hydrogen supply isolation valve during seismic event	[18]	This SAMA would reduce the fire or explosion as result of seismic induced failure of hydrogen line in turbine building.	#3 - Already installed	A note was added to AOP-14, Earthquake, stating that the hydrogen piping in the turbine building is susceptible to failure during a seismic event and that piping can be isolated by closing the hydrogen supply isolation valve 89A-H2HAS-1.
287	Restrain or locate flammables cabinets to reduce the likelihood of overturning caused by seismic or other events.	[18]	This SAMA would eliminate probability of cabinets overturning, spilling flammable liquid contents.	#3 - Already installed	JAF flammables cabinets contain small quantities of flammables, usually in the original containers that seal tightly, so overturning a cabinet would not result in releasing a significant amount of flammable material. In addition, station procedures require that cabinets are secured against overturning in safety-related areas.
288	Ensure that the quantity of combustible materials in critical process areas is monitored	[18]	This SAMA would minimize combustibles and chance of prolonged fire in safety-related areas	#3 - Already installed	JAF has a procedure goveming the fire-safe use and storage of combustible materials within the process buildings.
289	Monitor and control pre-staging of outage materials	[18]	This SAMA would reduce fire risk	#3 - Already installed	JAF Procedure AP14.02 "Combustible and Flammable Material Control" establishes the requirements for the control of site specific combustible material storage, ignition sources and impairments of fire systems to prevent or minimize the effects of a fire at Pilgrim. This procedure also provides a control mechanism for tracking system impairments and instituting compensatory measures to minimize the effects that those impairments may have on safety controls combustible materials within the plant.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
290	Install a bypass switch to allow opening the low reactor pressure LPCI or core spray injection valves	[18]	This SAMA would reduce the reactor building fire contribution to core damage frequency from the transients with stuck open SRVs or LOCAs cases. Core Spray and LPCI injection valves require a low permissive signal from the same two sensors to open the valves for RPV injection.	#3 - Already installed	A bypass switch was installed in the LPCI and core spray injection valves 10MOV-25A/B and 14MOV-12A/B. In addition, JAF Procedure AOP-28 "Operation during Plant Fires" directs the operators to use the switches if necessary and includes a tabulation of potentially unavailable equipment in each fire zone.
291	Relocate heat detector from the bottom of ceiling beams to the ceiling	[18]	This SAMA would reduce the cable spreading room fire contribution to core damage frequency.	#3 - Already installed	In lieu of the hardware modification, JAF procedure AP14.02 "Combustible and Flammable Material Control" was modified to eliminate the combustible material into the cable spreading room during power operation. This change in procedure reduces the CDF contribution from transient fires in cable spreading room.
292	Prevent loss of EDG air supply during tornado, hurricanes and high winds	[18]	This SAMA would reduce the probability due to loss of EDG air supply during tornado, hurricanes and high winds.	#3 - Already installed	A note was added to AOP-13, "Hurricanes, Tornadoes and High Winds" warning the operators that a hurricane, tornado, or high wind could threaten the integrity of the air intake duct work supplying the EDG room ventilation system because of a decrease in internal pressure. The note also states that adequate ventilation to the switchgear room and sufficient combustion air for EDG operation can be ensured by opening switchgear room doors or creating an opening within damaged duct work.

Phase I SAMA ID	SAMA Title	Source Reference of SAMA	Result of Potential Enhancement	Screening Criteria	Disposition
293	Reducing the icing incidents in the intake structure and screenwell	[18]	This SAMA would reduce the icing incidents in the intake structure and screenwell	#3 - Already installed	A screenwell low level alarm to the control room was provided; alerting operators to a low screenwell water level should the intake, trash rack, or traveling screen be blocked by ice or debris. An EPIC computer alarm was added to alert the operators of rising screenwell and circulating water system intake water temperatures that may result should the inflow of cold lake water be restricted. AOP-64 (Loss of Intake Water Level) was changed to define the proper corrective actions to pursue should an ice blockage occur.