ATTACHMENT A*
Evaluation of Potential Modifications to the ABWR Design

A.1 INTRODUCTION AND SUMMARY

This attachment provides a description of an evaluation of potential changes to the ABWR design in order to determine whether further modifications can be justified.

A.1.1 Background

The U.S. Nuclear Regulatory Commission's policy related to severe accidents requires, in part, that an application for a design approval comply with the requirements of 10CFR50.34(f). Item (f)(1)(i) requires performance of a plant site-specific [PRA] the aim of which is to seek improvements in the reliability of core and containment heat removal systems as are significant and practical and do not impact excessively on the plant. Chapter 19 of the ABWR SSAR provides the base PRA of the ABWR plant.

To address this requirement, a review of potential modifications to the ABWR design, beyond those included in the Probabilistic Risk Assessment (PRA), was conducted to evaluate whether potential severe accident design features could be justified on the basis of cost per person-rem averted.

This attachment summarizes the results of GE's review and evaluation of the ABWR design. Improvements have been reviewed against conservative estimates of risk reduction based on the PRA and minimum order of magnitude costs, to determine what modifications are potentially attractive.

A.1.2 Evaluation Criteria

The benefit of a particular modification was defined to be its reduction in the risk to the general public.

Offsite factors evaluated were limited to health effects to the general public based on total exposure (in person-rem) to the population within 50 miles of the site. Five representative US regions were evaluated for selected individual ABWR sequences by the CRAC2 code. The regional results were then averaged to determine the exposures. Consistent with the standard used by the NRC to evaluate radiological impacts, health effect costs were evaluated based on a value of $1,000 per offsite person-rem averted due to the design modification.

*Attachment A is updated version of ABWR SSAR Appendix 19P of the same title.

The offsite costs for other items such as relocation of local residents, elimination of land use and decontamination of contaminated land were not considered. Reductions in the risk of incurring onsite costs including economic losses, replacement power costs and direct accident costs are considered in this evaluation as credits against in the cost of the modification.

Based on the PRA results (Section A.2), 82% of the offsite risk results from very low probability events which have high consequence. The maximum justifiable cost of a modification was determined to be $269. Therefore, based on this methodology, no modifications are justifiable. However, a variety of modifications were reviewed to establish the relative attractiveness of potential changes.

A.1.3 Methodology

The overall approach was to estimate the benefit of modifications in terms of dollar cost per total person-rem averted. Underestimated costs and overestimated benefits were assessed in order to favor modifications. Because of the uncertainties in the methodology and the desire to address severe accidents with sensible modifications, this basis is judged to be acceptable for purposes of this study.

A.1.3.1 Selection of Modifications

Potential modifications were identified from a variety of previous industry and NRC sponsored studies of preventative and mitigative features which address severe accidents. Based on this composite list of modifications considered on previous designs, potential modifications were selected for further review based on being

(1) applicable to the ABWR design, and

(2) not included in the reference PRA.

Additional detail on the selection of modifications is provided in Section A.3.

A.1.3.2 Costs Basis

Rough order of magnitude costs were assigned for each modification based on the costs of systems and system improvements determined by GE. These costs represent the estimated incremental costs that would be incurred in a new plant rather than costs that would apply on a backfit basis. Section A.5 defines the cost estimates for each of the modifications.

Even for a new plant such as the ABWR, relatively large costs (several million dollars) can be expected for some modifications if they involve modifications of the building structures or arrangement. This is because the cost of labor and material is often a function of the building area required. For other modifications which involve minor hardware addition, the cost is often dominated by the need for procedure and training additions which can amount to hundreds of thousands of dollars.

The costs estimates were intentionally biased on the low side, but all known or reasonably expected costs were accounted for in order that a reasonable assessment of the minimum cost would be obtained. Actual plant costs are expected to be higher than indicated in this evaluation. All costs are referenced to 1991 U.S. dollars. For modifications which reduce the core damage frequency, the costs of modifications (Section A.5) were further reduced by an amount proportional to the reduction present worth of the risk of averted onsite costs. Onsite costs include replacement power costs, direct accident costs (including onsite cleanup) and the economic loss of the facility. Evaluation of this credit included the following considerations:

(1) Accidents were assumed to occur at any time during the 60 year life of the plant. All onsite costs associated with the accident were evaluated as to their value at the time of the accident. The economic risk of such onsite costs was evaluated as a function of time based on the onsite costs and the core damage frequency determined by the PRA. The plant core damage frequency was considered to be constant over the life of the plant. The economic risks were then evaluated based on the present worth of the time dependent economic risks.

(2) Replacement power was based on a rate of $.013/kW-h differential as bar cost. The differential rate was assumed to be constant over the remaining life of the plant.

(3) The economic value of the facility at the time of the accident was based on a straight line depreciated value. The initial invested cost was taken at $1.4 Billion based on DOE cost guidelines.

(4) Accident costs for onsite cleanup and facility were evaluated based on escalated costs to the time of the accident. Reference accident costs to the facility were assumed to be $2 Billion.

(5) Th economic evaluations were based on a discount rate of 8% and escalation factor of 3%.

A.1.3.3 Benefit Basis

The cumulative risk of accidents occurring during the life of the plant was used as a basis for estimating the maximum benefit that could be derived from modifications. A particular modification's benefit was based on its effect on the frequency of events or associated offsite dose summarized in Tables A-1 and Table A-2. Dominant contributing failure probabilities were identified based on the PRA. Changes in these probabilities were estimated to evaluate the benefit of modifications. This basis is consistent with the approach taken in previous NRC evaluations. The cumulative offsite risk was evaluated over a 60 year plant life with no escalation in the evaluation criteria of $1,000/person-rem.

Section A.4 summarizes each concept and estimated benefit for each individual potential modification. For each modification the cost per person-rem averted was evaluated to obtain the results of the individual evaluations. These conclusions are provided in Section A.7.

A.1.4 Summary of Results

Potentially attractive modifications were selected based on previous evaluations of potential prevention and mitigation concepts applicable during severe accidents. Of the modifications applicable to the ABWR design and which were not already implemented, twenty one were selected for additional review.

None of the modifications considered met the $1,000/person-rem averted criteria. The low evaluated frequency of core damage and subsequent release of radioactive material does not support modification to the ABWR based on costs in relationship to the benefit of averted exposures.

Since the most beneficial modification was evaluated to be several orders of magnitude higher than the criteria, it was concluded that no additional modifications are warranted in the ABWR design to address severe accidents. Furthermore, due to its magnitude it can be calculated that this conclusion will not be sensitive to variations in the assumptions used in the PRA results.

A.2 SEVERE ACCIDENT RISK OF ABWR

The reference design for this study was the ABWR PRA as presented in the internal events PRA (Section 19.3 of the ABWR SSAR). This evaluation accounts for features which were included in the current ABWR design-specifically to address severe accidents. These features and the reference description include:

	Design Feature	SSAR References
(1)	Firewater pump crosstie	5.4.7.1.1.10
(2)	Passive containment flooder	9.5.12
(3)	Gas turbine generator	9.5.11
(4)	Overpressure Protection	6.2.5.2.6

A summary of the core damage frequency and offsite exposure frequency with these features included is shown in Table A-1. Event frequencies used in this evaluation were the same as assumed in the base PRA. The offsite exposures shown in Table A-1 were calculated by the CRAC2 code for release cases with similar consequences. The cases can be characterized as follows:

Case 1 — Core Melt arrested in vessel or in Containment with actuation of containment rupture disk.

Case 2 — Low Pressure Core Melt with suppression pool bypass and actuation of containment rupture disk.

Case 3 High Pressure Core Melt with drywell Head failure and fire water spray initiation.

Case 4 Suppression Pool Decontamination reduction (Not used).

Case 5 Large Break LOCA without recovery and with actuation of containment rupture disk.

Case 6 High Pressure Core Melt with Drywell Head failure and no firewater spray initiation.

Case 7 Low Pressure Core Melt with Drywell Head failure and no mitigation

Case 8 High Pressure Core Melt with Early Containment failure.

Case 9 ATWS event with Drywell Head failure.

NCL Normal Containment Leakage to Reactor Building.

The offsite exposures for each case shown in Table A-1 were calculated by the CRAC2 code for five representative US regions for the selected individual ABWR sequences as discussed in Section 19E.3 of the ABWR SSAR.

Table A-2 provides additional detail on the individual contributors to the total core damage frequency. As indicated on Table A-2, the core damage frequency is dominated by low pressure transient events (LCLP) (61.4%), followed by high pressure transient events (LCHP) (28.1%) and station blackout sequences (SBRC) (10.3%).

Review of Table A-1 also indicates that the dominant contributors to the ABWR offsite exposure risk are the relatively low probability (less than 4E-10/yr), high consequence events (Cases 6 through 9) which contribute about 82% of the offsite exposure risk.

A.3 POTENTIAL ABWR MODIFICATIONS

Potential modifications to the ABWR design were derived from a survey of various studies indicated in References A-1 through A-7 and the ABWR design process discussed in Section 19.7 of the ABWR SSAR. From these, a composite list of modifications was established. This list of potential modifications was reviewed to identify concepts which were already included in the ABWR design or which are not applicable.

Table A-3 summarizes the complete list of modifications and their classification according to the following categories:

(1) Modification is applicable to ABWR and already incorporated in the ABWR design. No further evaluation is needed.

(2) Modification is applicable to ABWR and not incorporated in ABWR design. (Table A-4 lists the Category 2 modifications which are evaluated further in this attachment.)

(3) Modification is not applicable to the ABWR design due to the basis provided.

(4) Modification is applicable to ABWR and is incorporated with the referenced modification.

A.4 RISK REDUCTION OF POTENTIAL MODIFICATIONS

This section provides evaluations of the benefits of potential modifications to the ABWR design identified in Table A-4. For each modification the basis for the evalu:.uon and the concept is described. Table A-5 summarizes the benefit in terms of person-rem averted risk for each of the evaluated modifications.

A.4.1 Accident Management

Accident management is a current topic under generic development within the Industry through the development of Accident Management Guidelines (AMGs) and revisions to Emergency Procedure Guidelines (EPGs). The following modifications are based on implementation of such generic activity.

A.4.1.1 Severe Accident EPGs/AMGs

The symptom based EPGs, were developed by the BWR Owners Group following the accident at Three Mile Island, Unit 2. Currently the EPGs are under revision and accident management guidelines (AMGs) are being developed for severe accidents. These should provide a significant improvement which reduces the likelihood of a severe accident. Elements of these guidelines (such as containment pressure and temperature control guidelines) also deal with mitigating the effects of accidents.

In the ABWR PRA, Emergency Operating Procedures (EOPs) are based on these guidelines. Additional extensions of the EPGs and EOPs could be made to address arrest of a core melt, emergency planning, radiological release assessment and other areas related to severe accidents.

Since the existing EPGs cover preventive actions and some mitigative actions, the incremental benefit of this item would be primarily mitigative. It was judged that the reliability of manual actions associated with mitigation could be improved by 10%, especially in use of core melt arrest processes. Failure rates for manually initiated mitigative systems were decreased by 10%, to estimate the benefit. The resulting offsite risk reduction is about 0.015 person-rem over 60 years.

A.4.1.2 Computer Aided Instrumentation

Computer aided artificial intelligence can be added which provides attention to risk issues in man-machine interfaces. Significant computer assisted display and plant status monitoring is already part of the ABWR control room design. Additional artificial intelligence could be designed which would display procedural options for the operator to evaluate during severe accidents. The system would be an extension of ERIS to provide human engineered displays of the important variables in the EPGs and AMGs.

Operator actions are made significantly more reliable by new features such as Emergency Procedure Guidelines, Safety Plant Parameter Displays (SPDS), and training on simulators. If the improvements described in Subsection A.4.1.1 are assumed to be implemented, the incremental benefit of additional improvements is expected to be low. The reliability of manually initiated preventive systems was increased by 10% to estimate the benefit. The estimated incremental benefit over severe accident EPGs (Subsection A.4.1.1) is about 3% in core damage frequency (CDF). Because the improvement affects all release cases, the incremental benefit is about 0.01 person-rem.

A.4.1.3 Improved Maintenance Procedures/Manuals

For the GE scope of supply this item would provide additional information on the components important to the risk of the plant. As a result of improved maintenance manuals and information it would be expected that increased reliability of the important equipment would occur. This item would be a preventative improvement which would address several system or components to different degrees.

Based on a 10% improvement in the reliability of the High Pressure Core Flooder (HPCF), Reactor Core Isolation Cooling (RCIC), Residual Heat Removal (RHR) and Low Pressure Core Flooder (LPFL) systems, the CDF is reduced by about 9% which has a corresponding estimated person-rem reduction of about 0.016.

A.4.2 Decay Heat Removal

Significant improvements in the reliability of ABWR high pressure systems have been made. Among these are RCIC restart (NUREG 0737, II.K.3.13) and isolation reliability improvements (NUREG 0737, II.K.3.15). Additionally, the redundant HPCF is an improvement over early product lines which used the single HPCF system.

A.4.2.1 Passive High Pressure System

This concept would provide additional high pressure capability to remove decay heat through a diverse isolation condenser type system. Such a system would have the advantage of removing not only decay heat, but containment heat if a similar system to that under consideration for the Simplified BWR (SBWR) is employed.

The benefit of this system would be equivalent to an additional diverse RCIC system in addition to an additional containment heat removal system. The added system was assumed to be 90% reliable, designed to operate independent of offsite power and to be capable of in-vessel core melt arrest. Based on a reduction in the RCIC failure rate, the benefit is estimated at about 0.069 person-rem averted.

A.4.2.2 Improved Depressurization

This item would provide an improved depressurization system which would allow more reliable access to low pressure systems. Additional depressurization capability may be achieved through manually controlled, seismically protected, air powered operators which permit depressurization to be manually accomplished in the event of loss of DC control power or control air events.

The ABWR high pressure core damage events represent about 28% of the total core damage frequency, but about 46% of the offsite exposure risk. The success of manual initiation was assumed to be improved by 50% and therefore the depressurization failure rate was reduced by a factor of 2. Based on this estimate of benefit offsite person-rem is reduced by about 23% and the estimated benefit is about 0.042 person-rem.

A.4.2.3 Suppression Pool Jockey Pump

This modification would provide a small makeup pump to provide low pressure decay heat removal from the Reactor Pressure Vessel (RPV) using suppression pool water as a source. The return path to the suppression pool would be through existing piping such as shutdown cooling return lines.

The benefit of this modification would be similar to that provided by the firewater injection and spray capability, but it would have the advantage that long term containment inventory concerns would not occur.

If the system could make low pressure coolant makeup systems 10% more reliable, significant reductions in CDF would not be achieved because other low pressure systems are already highly reliable. The estimated benefit is that CDF is reduced 2% and the averted risk would be 0.002 person-rem.

A.4.2.4 Safety-Related Condensate Storage Tank

The current ABWR design consists of a standard non-seismically qualified Condensate Storage Tank (CST). This modification would upgrade the structure of the CST such that it would be available to provide makeup to the reactor following a seismic event.

This modification only benefits the risks of core damage following seismic events. However, because the suppression pool provides an alternate suction source and the HCLPF for the suppression pool is relatively high (Appendix 19I of the ABWR SSAR), the dominant failure modes are not limited by water availability. Therefore the benefit of this modification is considered small. A benefit of 0.01 person-rem averted was arbitrarily chosen for an upgraded CST.

A.4.3 Containment Capability

The ABWR containment is designed for about 45 psig internal pressure and includes a containment rupture disk which would relieve excessive pressure if it develops during a severe accident. By providing the release point from the wetwell airspace, mitigation of releases are achieved through scrubbing of the fission products in the suppression pool.

A.4.3.1 Larger Volume Containment

This modification would provide a larger volume containment as a means to mitigate the effects of severe accidents. By increasing the size the containment could be able to absorb additional noncondensible gas generation and delay activation of the containment rupture disk or early containment failure.

This item would mitigate the consequence of an accident by delaying the time before the severe accident source term is released and allowing more time for radioactive decay and recovery of systems. However, if recovery does not occur, eventual release is not prevented and if operation of the containment overpressure rupture disk does not occur, ultimately the containment will fail due to the long term pressurization caused by core concrete interaction and steam generation.

If sequences involving drywell head failure were eliminated (Cases 3, 6, 7, 8 and 9), the offsite risks would be reduced by about 82% and about 0.15 person-rem would be averted.

A.4.3.2 Increased Containment Pressure Capacity

The design pressure of the ABWR containment is 45 psig. The containment rupture disk pressure and ultimate capability are significantly higher. By increasing the ultimate pressure capability of the containment (including seals), the effects of a severe accident could be reduced or eliminated by delaying the time of release. If the strength exceeded the maximum pressure obtainable in a severe accident, only normal containment leakage would result.

This modification would mitigate the event, not change the core damage frequency and the increased pressure capability may not be sufficient to contain the long term pressurization caused by core concrete interaction and steam generation. However, if it were able to prevent all severe source term release except for normal containment leakage, the person-rem risk would be about 0.02 person-rem/60 years. Therefore, the benefit would be about 0.16 person-rem.

A.4.3.3 Improved Vacuum Breakers

The ABWR design contains single vacuum breaker valves in each of eight drywell to wetwell vacuum breaker lines. The PRA included failure of vacuum breakers in Case 2 assuming operation of wetwell spray. This modification would reduce the probability of a stuck open vacuum breaker by making the valves redundant in each line and eliminate the need for operator action.

If Case 2 sequences were eliminated, the benefit of this modification would be about 0.00004 person-rem averted.

A.4.3.4 Improved Bottom Head Penetration Design

The ABWR design includes a 2-inch stainless steel drainline from the bottom of the RPV which is used to prevent thermal stratification in the RPV during operation and to provide cleanup of the bottom head by the CUW system. A carbon steel transition piece connects the drain line to the RPV. During a severe accident this transition piece may be susceptible to melting and may provide the earliest path for release of molten core material from the RPV to the containment.

The penetrations for the fine motion control rod drives in the ABWR also may provide a pathway for release from the RPV following a severe accident. Failure of the internal blowout supports on the lower core plate, provided to eliminate the support structure in current generation BWRs, and welds of the drives at the bottom of the vessel may allow the CRDs to be partially ejected into the drywell during the severe accident which would provide a small pathway for release to the containment.

The modification is to change the transition piece material to Inconel or Stainless Steel which has a higher melting point. By so doing, additional time would be available for recovery of core cooling systems. This modification also would establish external welds or restraints on the CRDs external to the vessel so that the drives would not be ejected following failure of the internal welds. The concept would be to make such external welds and supports small enough that the benefit is not lost from eliminating the support beams in current generation BWRs. The benefit of these modifications would be to reduce the probability of in-vessel arrest failure (NO IV). Based on consideration of the heatup rate of the bottom head, it has been estimated that making these changes could provide up to two hours additional time for recovery of systems. It is estimated, based on engineering judgment, that this time could result in the in-vessel arrest failure probabilities being reduced by a factor of two. The resulting benefit is about 0.057 person-rem averted.

A potential negative aspect of the modifications is that RPV failure could occur at another unknown location such as the bottom head itself. Although the time of vessel failure would be extended, the failure mode from these other locations could be potentially more energetic and lead to unevaluated consequences.

A.4.4 Containment Heat Removal

The ABWR design contains 3 divisions of suppression pool cooling and provisions for a containment rupture disk for decay heat removal. In addition, modifications have been made to use the CUW heat exchangers to the maximum extent possible. Consequently, loss of containment heat removal events contribute only 0.1% of the total core damage frequency and offsite exposures. Additional modifications are not likely to show substantial safety benefits.

A.4.4.1 Larger Volume Suppression Pool

This item would increase the size of the suppression pool so that the heatup rate in the pool is reduced. The increased size would allow more time for recovery of a heat removal system.

Since this modification primarily affects LHRC events (Table A-2), the maximum benefit would be elimination of the LHRC contribution to the Case 9 sequences. These events are mitigated by the containment rupture disk and only contribute about 0.0002 person-rem to the base case risk. The assessed maximum benefit is therefore about 0.0002 person-rem.

A.4.5 Containment Atmosphere Mass Removal

The ABWR design contains a containment rupture disk which provides containment overpressure protection from the wetwell airspace and utilizes the suppression pool scrubbing feature of the suppression pool to reduce the amount of radioactive material released. One additional modification was considered.

A.4.5.1 Low Flow Filtered Vent

Some BWR facilities, especially in Europe, recently have added a filter system external to the containment to further reduce the magnitude of radioactive release. The systems typically use a multi-venturi scrubbing system to circulate the exhaust gas and remove particulate material. In the ABWR because of the suppression pool scrubbing capability, a significant safety improvement is not expected due to this modification.

The release of radioactive isotopes from the ABWR following severe accidents occurs through the containment rupture disk for Cases 1, 2 and 5. These sequences total about 8% of the exposure risk. The remaining sequences involve drywell head failure or early containment failure which would not be affected by this modification. The maximum benefit of the external vent system is therefore about 0.014 person-rem assuming perfect initiation of the filtered containment vent system.

A.4.6 Combustible Gas Control

No additional modifications to the ABWR were identified in this group.

A.4.7 Containment Spray Systems

A.4.7.1 Drywell Head Flooding

This concept would provide intentional flooding of the upper drywell head such that if high drywell temperatures occurred, the drywell head seal would not fail. Additionally, if the seal were to fail due to overpressurization of the drywell, some scrubbing of the released fission products would occur. This system would be designed to operate passively or use an AC-independent water source.

If an extension of the fire pump to drywell spray crosstie were considered for manual initiation of upper head flooding, additional reduction in the high temperature containment failure sequences (Case 8) would result. Additionally, a reduction in the high consequence drywell head failure sequences (Cases 6 and 7) could be achieved. If Case 8 sequences were eliminated and Case 6 and 7 source terms were reduced to a level similar to Case 3, the conservative benefit would be 0.12 person-rem. The estimated benefit of this is about 0.06 person-rem assuming a 50% reliability of initiation.

A.4.8 Prevention Concepts

The ABWR design contains an additional division of high pressure makeup capability to improve its capability to prevent severe accidents other features such as the fire pump injection capability and the combustion gas turbine have been included in the design to enhance the plant capability to prevent core damage. The following additional concepts were considered:

A.4.8.1 Additional Service Water Pumps

This item addresses a reduction in the common cause dependencies through such items as improved manufacturer diversity, separation of equipment and support systems such as service water, air supplies, or heating and ventilation (HVAC). The HPCF, RCIC, and LPFL pumps are diverse in the ABWR design since they are either supplied by different manufacturers or have different flow characteristics. Equipment is separated in the ABWR design in accordance with Regulatory Guide 1.75. Thus, no further improvement is expected with regard to separation.

A reduction in common cause dependencies from support systems such as service water systems, could conceivably reduce the plant risk through an improvement in system reliability. The concept for this item would be to provide an additional cooling water system capable of supporting each of the four divisional systems identified above.

The current design provides support to these systems from one of three divisions. Thus, the effect of this change would be to include a diverse and additional support system. In addition, diversity in instrumentation which controls these systems could be included so that redundant indication and trip channels would rely on diverse instrumentation.

A 10% increase in the reliability of the four systems was assumed which is the same improvement that may be derived from improved maintenance (Subsection A.4.1.3). This results in an estimated benefit of about 0.016 person-rem.

A.4.9 AC Power Supplies

The current ABWR electrical design is improved through application of a gas-turbine generator to augment the offsite electrical grid. The following concepts were considered for additional onsite power supplies.

A.4.9.1 Steam Driven Turbine Generator

A steam driven turbine generator could be installed which uses reactor steam and exhausts to the suppression pool. The system would be conceptually similar to the RCIC system with the generator connected to the offsite power grid.

The benefit of this item would be similar to the addition of another gas turbine generator, but would be somewhat less due to the relative unreliability of the steam turbine compared with a diesel generator and its unavailability after the RPV is depressurized. If it were sized large enough, it could have the advantage of providing power to additional equipment.

If the system has a 80% availability for all events, the benefit is similar to an 80% reduction in the diesel generator common mode failure rate. Evaluation of the PRA indicates that the resulting benefit is about 0.052 person-rem.

A.4.9.2 Alternate Pump Power Source

The ABWR provides separate diesel driven power supplies to the HPCF and LPFL pumps. Offsite power supplies the feedwater pumps. 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 benefit would be less dependence on low pressure systems during loss of offsite power events and station blackout events. If the feedwater system were made to be 90% available during loss of offsite power events and station blackouts, the benefit would be similar to adding an additional RCIC system (Subsection A.4.2.1). The resulting benefit would be about 0.069 person-rem.

A.4.10 DC Power Supplies

The ABWR contains 4 DC divisions with sufficient capacity to sustain 8 hours of station blackout (with some load shedding). This represents an improvement over current operating plant designs.

A.4.10.1 Dedicated DC Power Supply

This item addresses the use of a diverse DC power system such as an additional battery or fuel cell for the purpose of providing motive power to certain components. Conceptually a fuel cell or separate battery could be used to power a DC motor/pump combination and provide high pressure RPV injection and containment cooling. With proper starting controls such a system could be sized to provide several days capability.

Providing a separate DC powered high pressure injection capability has a benefit of further reducing the station blackout and loss of offsite power event risks which represent about 75% of the total CDF, but only a small fraction of the offsite risk. If the effective unavailability of the RCIC is reduced by a factor of 10 due to the availability of a diverse system, one benefit would be similar to adding a power supply for feedwater (Subsection A.4.9.2) and the benefit would be about 0.069 person-rem.

A.4.11 ATWS Capability

The current ABWR design provides improvements in containment heat removal and detection of ATWS events to limit the impact of this class of events. The PRA indicates that ATWS events contribute about 0.1% of the core damage frequency (Table A-2) and about 17% of the offsite risk (Case 9).

A.4.11.1 ATWS Sized Vent

This modification would be available to remove reactor heat from ATWS events in addition to severe accidents and Class II events. It would be similar to the containment rupture disk (which is currently sized to pass reactor power consistent with that generated during RCIC injection), but it would be of the larger size required to pass the additional steam associated with LPFL injection. The system would need to be manually initiated.

The benefit of this venting concept is to prevent core damage and to reduce the source term available for release following ATWS events. The evaluation shows that an ATWS sized vent manually initiated with a 100% reliability would have a maximum benefit of reducing the offsite dose by about 0.03 person-rem by reassigning the consequences from Case 9 to Case 1.

A.4.12 Seismic Capability

The current ABWR is designed for a Safe Shutdown Earthquake of 0.3g acceleration. The seismic margins analysis (Appendix 19I of the ABWR SSAR) addresses the margins associated with the seismic design and concludes that there is a 95% confidence that existing equipment has less than a 5% probability of failure at twice the SSE level. This capability is considered adequate for the ABWR design and no additional changes are considered.

A.4.13 System Simplification

This item is intended to address system simplification by the elimination of unnecessary interlocks, automatic initiation of manual actions or redundancy as a means to reduce overall plant risk. Elimination of seismic and pipe whip restraints is included in the concept.

While there are several examples of redundant systems, valves and features on the ABWR design which could conceivably be simplified, there are several areas in which the ABWR design already has been improved and simplified, especially in the area of controls and logic. System interactions during accidents were included in this category. One area was identified in which simple modification of an existing system could provide some benefit.

A.4.13.1 Reactor Building Sprays

This concept would use the firewater sprays in the reactor building to mitigate releases of fission products into the reactor building following an accident. The concept would require additional valves and nozzles, separate from the fire protection fusible links, to spray in areas vulnerable to release, such as near the containment overpressure relief line routing.

The benefit of this modification could be to reduce the impact of events which do not involve the operation of the containment rupture disk. Such events release fission products from the containment into the reactor building. Releases from normal containment leakage and cases 3, 6, 7, 8 and case 9 sequences could potentially be reduced. If 10% of these releases from these cases were arbitrarily mitigated by this method, the benefit would be about 1.7E-04 person-rem.

A.4.14 Core Retention Devices

Core retention features are incorporated into the ABWR Design. As discussed in Subsection 19E.2.2(paragraph FS) of the ABWR SSAR, if a severe accident has resulted in a loss of RPV integrity, accident management guidance specifies that drywell sprays be initiated which will cause the suppression pool to overflow into the lower drywell after a few hours and quench the debris bed. After the molten core has been quenched, no further ablation of concrete is expected and the decay heat can be removed by normal containment cooling methods such as suppression pool cooling. If sprays can not be initiated, the Lower Drywell Flooder System described in Subsection 9.5.12 of the ABWR SSAR cools a debris bed by flooding over the molten core in the lower drywell with water from the suppression pool. This system is similar to the Post Accident Flooding concept included in Reference A-4. One additional concept from Reference A-4 is included.

A.4.14.1 Flooded Rubble Bed

This concept consists of a bed of refractory pebbles which fill the lower drywell cavity and are flooded with water. The bed impedes the flow of molten corium and increases the available heat transfer area which enhances debris coolability. The use of thoria ($ThO2$) pellets in a multiple layer geometry has been shown to stop melt penetration; thus, preventing core-concrete interaction. Drawbacks to using thorium dioxide include cost, toxicity, and the radiological impact of radon gas release into the lower drywell via the radioactive decay of thorium. Other refractories such as alumina slow corium penetration but may fail to stop core-concrete contact. Other refractories may be susceptible to chemical attack by the corium and may melt at lower temperatures. Pebbles composed of refractories other than thoria also may be susceptible to floating because they have lower density than the corium. A major drawback common to all flooded rubble bed core retention systems is the need for further experimental testing in order to validate the concept in BWR applications.

The benefit of this modif··ation lies in the potential elimination of core-concrete interaction and a corresponding decrea n non-condensable gas generation. Attachment 19EC to Appendix 19E of the ABWR SSAR indicates a 90% certainty that debris on a concrete floor covered with water will be coolable in the current ABWR design.

Only sequences in which no liquid injection to the drywell occurs will result in core-concrete interaction. A conservative estimate of the benefit of this concept over the existing design would be elimination of sequences with core-concrete interaction except those with containment cooling failure. A review of Subsection 19E.2 of the ABWR SSAR indicates that this would effect about 1% of Cases 1, 6 and 7. This corresponds to about 0.001 person-rem averted.

A.5 COST IMPACTS OF POTENTIAL MODIFICATIONS

As discussed in Subsection A.1.3.1, rough order of magnitude costs were assigned to each modification based on the costs of systems determined by GE. These costs represent the incremental costs that would be incurred in a new plant rather than costs that would apply on a backfit basis. Credit for the onsite costs averted by the modification are discussed in Subsection A.1.3.2. For each modification which reduces the core damage frequency an estimate of the impact was made and then applied to the potential averted offsite cost. This section summarizes the cost basis for each of the modification evaluated in Section A.4. This basis is generally the cost estimate less the credit for onsite averted costs. Table A-6 summarizes the results.

The costs were biased on the low side, but all known or reasonably expected costs were accounted for in order that a reasonable assessment of the minimum cost would be obtained. Actual plant costs are expected to be higher than indicated in this evaluation. All costs are referenced to 1991 U.S. dollars based on changes in the Consumer Price Index.

A.5.1 Accident Management

A.5.1.1 Severe Accident EPGs/AMGs

The cost of extending the EPGs would be largely a one-time cost which should be prorated over several plants if accomplished by the BWROG. Current industry activity is addressing this as part of Accident Management Guidelines (AMG). If plant specific, symptom based, severe accident emergency procedures were to be prepared based on AMGs, the cost would be at least $600,000 for plant specific modifications to EOPs.

A.5.1.2 Computer-Aided Instrumentation

Additional software and development costs associated with modifying existing Safety Plant Display Systems are estimated to cost at least $600,000 for a new plant. This estimate is based on assumed additions of isolation devices to transmit data to the computer and in-plant wiring. Because this modification reduces the frequency of core damage events, a present worth of $400 onsite costs are averted and the cost basis is $599,600.

A.5.1.3 Improved Maintenance Procedures/Manuals

The cost of at least $300,000 would be required to identify components which should receive enhanced maintenance attention and to prepare the additional detailed procedures or recommended information beyond that currently planned. Credit for reduction in onsite costs reduces the cost basis to $299,000.

A.5.2 Decay Heat Removal

A.5.2.1 Passive High Pressure System

The cost of an additional high pressure system for core cooling would be extensive since it would not only require additional system hardware which would cost at least $1,200,000, but it would also require additional building costs for space available for the system. Assuming the system could be located in the reactor building without increasing its height, building costs are estimated to be another $550,000. The credit for averted onsite costs is about $6,000 which brings the cost basis to $1,744,000.

A.5.2.2 Improved Depressurization

The cost of the additional logic changes, pneumatic supplies, piping and qualification was estimated for the GESSAR II design (Reference A-1). A similar cost would be expected for the ABWR design. The cost is estimated to be at least $600,000 for an improved system for depressurization. This estimate assumes no building space increase for the added equipment. The credit for averted onsite costs was evaluated to be $1,400 which makes the cost basis $598,600.

A.5.2.3 Suppression Pool Jockey Pump

The cost of an additional small pump and associated piping is estimated at more than $60,000 including installation of the equipment. It is assumed that increases in power supply capacity and building space are not required. Controls and associated wiring could cost an additional $60,000 for a total cost of at least $120,000. A credit of $200 for averted onsite costs makes the cost basis $119,800.

A.5.2.4 Safety Related Condensate Storage Tank

Estimating the cost of upgrading the CST structure to withstand seismic events requires a detailed structural analysis and resultant material. It is judged that the final cost increase would be in excess of $1,000,000. No credit for onsite cost averted was assumed for this modification.

A.5.3 Containment Capability

A.5.3.1 Larger Volume Containment

Doubling the containment volume requires an increase in the concrete and rebar. If structural costs of the containment can be made for $1,200/ft^2, doubling the containment volume without increasing its height, the cost would be at least $8,000,000. This estimate does not include reanalysis and other documentation costs. Since this modification is mitigative, no credit fo. onsite averted costs was assumed.

A.5.3.2 Increased Containment Pressure Capacity

The cost of a stronger containment design would be similar in magnitude to increasing its size (Subsection A.5.3.1). If the costs are primarily due to denser rebar required during installation and additional analysis, an estimate of at least $12,000,000 could be required. Since this modification is mitigative, no credit for onsite averted costs was assumed.

A.5.3.3 Improved Vacuum Breakers

The cost of redundant vacuum breakers including installation and hardware is estimated at more than $10,000 per line. Instrumentation associated with this modification is not included. For the eight lines the cost of this modification is more than $100,000. Since this modification is mitigative, no credit for onsite averted costs was assumed.

A.5.3.4 Improved Bottom Penetration Design

The cost increase of using a stainless or inconel transition piece as opposed to carbon steel would be expected to be small in comparison to the engineering and documentation change costs associated with the change. Costs, associated with external welds and support for the CRDs is estimated to be at least $1000 per drive. In addition, about $500,000 of analysis would be required to develop the changes. This would dominate the cost of this modification when applied to all 205 drives. Such changes are estimated to be at least $750,000.

Since this modification is mitigative, no credit for averted onsite costs applies.

A.5.4 Containment Heat Removal

A.5.4.1 Larger Volume Suppression Pool

This concept would result in similar costs as item Subsection A.5.3.1 for providing a larger containment. An estimate of $8,000,000 is assigned to this item.

A.5.5 Containment Atmosphere Mass Removal

A.5.5.1 Low Flow Filtered Vent

The cost of added equipment associated with the FILTRA system (excluding a test program) was estimated to be about $5,000,000 in Reference A-4. Although a detailed estimate was not prepared for the ABWR, an estimate of $3,000,000 has been assumed for the purpose of this evaluation.

Since this modification is mitigative, no credit for averted onsite costs applies.

A.5.6 Combustible Gas Control

No additional modifications to the ABWR were identified in this group.

A.5.7 Containment Spray Systems

A.5.7.1 Drywell Head Flooding

An additional line to flood the drywell head using existing firewater piping would be a relatively inexpensive addition to the current system. Instrumentation and controls to permit manual control from the control room would be needed. It is estimated that the total modification cost would be at least $100,000 for the engineering, piping, valves and cabling.

Because this modification is mitigative, no credit for averted onsite costs has been applied.

A.5.8 Prevention Concepts

A.5.8.1 Additional Service Water Pump

The use of diverse instrumentation would not presumably have a significant equipment cost, but there would be an increased cost of maintenance and spare parts due to less interchangeability and less standardization of procedures.

These costs, however, are probably low in comparison with the extra support systems for air supply and service water. Equipment, power supplies and structural changes to include these new systems are estimated to cost at least $6,000,000. A small credit for averted onsite costs makes the cost basis for this item $5,999,000, based on the benefits discussed in Subsections A.4.1.3 and A.5.1.3.

A.5.9 AC Power Supplies

A.5.9.1 Steam-Driven Turbine Generator

The cost of the system should be similar to that for the RCIC system, but additional cost would be needed for structural changes to the reactor building plus the generator and its controls. This item is expected to cost at least $6,000,000.

With credit for averted onsite costs, the cost basis for this item becomes $5,994,300.

A.5.9.2 Alternate Pump Power Source

A typical feedwater pump for an ABWR sized plant could require a 4000 kWe sized generator, at $300 per kWe, a separate diesel generator and the supporting auxiliaries could cost at least $1,200,000. This cost would include wiring and installation of the alternate generator, but does not assume additional structural costs.

With credit for averted onsite costs, the cost basis for this item becomes $1,194,000.

A.5.10 DC Power Supplies

A.5.10.1 Dedicated DC Power Supply

Fuel cells are largely a developmental technology, at least in the large size range required for this application. In addition the process involves some risk of fire. To address these concerns a cost of at least $6,000,000 would be expected. A separate battery would be less expensive than fuel cells, but would involve additional space requirements which could make this modification more expensive than adding a diesel generator as discussed in Subsection A.5.9.2.

A battery bank capable of supplying 400 kWe would be about 50 times larger in capacity than the emergency batteries. This number of batteries would require at least 5,000 ft^2 of space, assuming extensive stacking and without concern for seismic response. At $500/$ft^2$ construction cost, the additional space required would amount to $2,500,000 for this modification. Additional costs would be required for DC pumps, cabling and instrumentation and controllers. A total cost would be at least $3,000,000.

A.5.11 ATWS Capability

A.5.11.1 ATWS Sized Vent

Larger piping and additional training would be required to extend the existing rupture disk feature to be available during an ATWS event. Additional instrumentation and cabling would be required to make the vent operable from the control room. It is estimated that the incremental cost would be at least $300,000.

A.5.12 Seismic Capability

No modifications were considered for this group.

A.5.13 System Simplification

A.5.13.1 Reactor Building Sprays

The cost of this modification is judged to be similar to the concept of drywell head flooding (Subsection A.5.5.1) if it only involves piping and valves which are tied into the firewater system. An estimate of $100,000 has been assigned to this item.

Onsite cleanup costs also could be affected by this modification. If the cleanup costs were eliminated an averted cost would conservatively be about $5,000.

A.5.14 Core Retention Devices

A.5.14.1 Flooded Rubble Bed

Reference A-4 estimated that the refractory material needed for this modification would cost approximately $1,000/lb. If the lower drywell were filled with about 1.5 ft of this material, which would remain well below the service platform, at least 1250 ft^3 of material would be required. If it weighs 15 lb/ft^3, the material cost alone would amount to $18,750,000.

A.6 EVALUATION OF POTENTIAL MODIFICATIONS

A ranking of the modifications by $/person-rem averted is shown in Table A-7 based on the results and estimates provided in Sections A.4 and A.5.

The lowest cost/person-rem averted modification is more than 1600 times the target criteria of $1,000 per person-rem averted. Clearly none of the modifications is justifiable on the basis of costs for person-rem averted. This can be attributed to the low probability of core damage in the ABWR with the modifications to reduce risk already installed.

A.7 SUMMARY OF CONCLUSIONS

Potentially attractive modifications were identified from previous evaluations of potential prevention and mitigation concepts applicable during severe accidents and discussion with the NRC staff. Potential modifications were reviewed to select those which are applicable to the ABWR design and which have not already been implemented in the design. Of these modifications, twenty one were selected for additional review.

The low level of risk in the ABWR is demonstrated by the total 60 year offsite exposure risk of 0.269 person-rem. At this level only modifications which cost less than $269 can be justified.

Based on this low level no modifications are justified for the ABWR. Based on the PRA results, none of the modifications provided a substantial improvement in plant safety.

A.8 REFERENCES

A-1 Evaluation of Proposed Modifications to the GESSAR II Design, NEDE 30640 (Proprietary), June 1984.

A-2 Supplement to the Final Environmental Statement - Limerick Generating Station, Units 1 and 2, NUREG-0974 Supplement, August 16, 1989

A-3 Issuance of Supplement to the Final Environmental Statement- Comanche Peak Steam Electric Station, Units 1 and 2, NUREG 0775 Supplement, December 15, 1989

A-4 Survey of the State of the Art in Mitigation Systems, NUREG/CR-3908, R&D Associates, December 1985

A-5 Assessment of Severe Accident Prevention and Mitigation Features, NUREG/CR-4920, Brookhaven National Laboratory, July 1988.

A-6 Design and Feasibility of Accident Mitigation Systems for Light Water Reactors, NUREG/CR-4025, R&D Associates, August 1985

A-7 Severe Accident Risks: An Assessment for Five US Nuclear Power Plants, NUREG 1150, January 1991.

A-8 Technical Guidance for Siting Criteria Development, NUREG/CR-2239, Sandia National Laboratories, December 1982.

Table A-1
Radiological Consequences of ABWR Accident Sequences

Case	Probability (Event/year)*	Whole Body Exposure, 50 mile (person-rem)	Cumulative Exposure Risk (per-rem/60 yr)
NCL	1.3E-07	9.60E3	0.075
1	2.1E-08	1.38E4	0.017
2	7.8E-11	8.33E3	0.00004
3	0	3.71E5	0.000
4	0	2.06E5	0.000
5	7.5E-12	9.34E4	0.00004
6	3.1E-12	2.42E6	0.0004
7	3.9E-10	2.73E6	0.064
8	4.1E-10	3.20E6	0.079
9	1.7E-10	3.31E6	0.034
		Total:	0.269

* Sequences with probabilities of occurrence less than 1E-9 per year are considered remote and speculative.

Table A-2
Core Damage Frequency Contributors*

Event Sequence

Init. Event	1A	1B1	1B2	1B3	1D	II	IIID	IV	Total	% Cont.
Scram	1.1E-08				4.3E-10	9.5E-13			1.1E-08	7.3
Turbine Trip	6.8E-09				2.7E-10	3.7E-11			7.1E-09	4.5
Isolation	1.8E-08				7.1E-10	1.1E-11			1.9E-08	11.9
LOOP2	4.1E-09				1.5E-11	4.2E-13			4.1E-09	2.6
LOOP8	2.4E-09				9.6E-12	1.4E-12			2.4E-09	1.5
LOOP8+	5.8E-10				1.1E-09	6.0E-11			1.7E-09	1.1
SBO2	6.6E-12				6.7E-08				6.7E-08	42.9
SBO8		2.6E-08							2.6E-08	16.7
SBO8+			1.5E-08	8.9E-10					1.6E-08	10.3
IORV	1.1E-09				2.0E-10	9.5E-13			1.3E-09	0.8
SB LOCA							2.5E-10		2.5E-10	0.2
ATWS								1.5E-10	1.5E-10	0.1
TOTAL	4.4E-08	2.6E-08	1.5E-08	8.9E-10	7.0E-08	1.1E-10	2.5E-10	1.5E-10	1.57E-07	100

Offsite Release Group

	LCHP	SBRC	LCLP	LHRC	LBLC	ATWS	Total Case
Case 1	3.4E-09	7.9E-10	1.6E-08		5.1E-11		2.0E-08
Case 2			7.8E-11				7.8E-11
Case 3	1.3E-12						1.3E-12
Case 4							0
Case 5					6.3E-12		6.3E-12
Case 6	1.2E-10						1.2E-10
Case 7	1.1E-10		2.6E-10				3.70E-10
Case 8	2.1E-10						2.1E-10
Case 9				1.1E-12		1.5E-10	1.5E-10
NCL (N)	4.0E-08	1.5E-08	8.0E-08		2.0E-10		1.4E-07
Total	4.4E-08	1.6E-08	9.6E-08	1.1E-12	2.5E-10	1.5E-10	1.57E-07
Contrib. %	28.1	10.3	61.4	0.122	0.2	0.1	100

* SAMDAs include both preventive and mitigative design alternatives

Table A-3
Modifications Considered

Modification	Category
1. ACCIDENT MANAGEMENT	
a. Severe Accident EPGs/AMGs	2
b. Computer Aided Instrumentation	2
c. Improved Maintenance Procedures/Manuals	2
d. Preventive Maintenance Features	4
e. Improved Accident Management Instrumentation	4
f. Remote Shutdown Station	1
g. Security System	1
h. Simulator Training for Severe Accident	4
2. REACTOR DECAY HEAT REMOVAL	
a. Passive High Pressure System	2
b. Improved Depressurization	2
c. Suppression Pool Jockey Pump	2
d. Improved High Pressure Systems	1
e. Additional Active High Pressure System	1
f. Improved Low Pressure System (Firepump)	1
g. Dedicated Suppression Pool Cooling	1
h. Safety Related Condensate Storage Tank	2
i. 16 hour Station Blackout Injection	4
j. Improved Recirculation Model	4
3. CONTAINMENT CAPABILITY	
a. Larger Volume Containment	2
b. Increased Containment Pressure Capacity	2
c. Improved Vacuum Breakers	2
d. Increased Temperature Margin for Seals	1
e. Improved Leak Detection	1
f. Suppression Pool Scrubbing	1
g. Improved Bottom Penetration Design	2

Table A-3 (Continued)

Modification	Category
4. CONTAINMENT HEAT REMOVAL	
a. Larger Volume Suppression Pool	2
b. CUW Decay Heat Removal	1
c. High Flow Suppression Pool Cooling	1
d. Passive Overpressure Relief	1
5. CONTAINMENT ATMOSPHERE MASS REMOVAL	
a. High Flow Unfiltered Vent	3
b. High Flow Filtered Vent	3
c. Low Flow Vent (Filtered)	2
d. Low Flow Vent (Unfiltered)	1
6. COMBUSTIBLE GAS CONTROL	
a. Post Accident Inerting System	3
b. Hydrogen Control by Venting	3
c. Pre-inerting	1
d. Ignition Systems	3
e. Fire Suppression System Inerting	3
7. CONTAINMENT SPRAY SYSTEMS	
a. Drywell Head Flooding	2
b. Containment Spray Augmentation	1
8. PREVENTION CONCEPTS	
a. Additional Service Water Pump	2
b. Improved Operating Response	1
c. Diverse Injection System	4
d. Operating Experience Feedback	1
e. Improved MSIV/SRV Design	1
9. AC POWER SUPPLIES	
a. Steam Driven Turbine Generator	2
b. Alternate Pump Power Source	2
c. Deleted	
d. Additional Diesel Generator	1

Table A-3 (Continued)

Modification		Category
9.	(Continued)	
	e. Increased Electrical Divisions	1
	f. Improved Uninterruptable Power Supplies	1
	g. AC Bus Cross-ties	1
	h. Gas Turbine	1
	i. Dedicated RHR (bunkered) Power Supply	4
10.	DC POWER SUPPLIES	
	a. Dedicated DC Power Supply	2
	b. Additional Batteries/Divisions	4
	c. Fuel Cells	4
	d. DC Cross-ties	1
	e. Extended Station Blackout Provisions	1
11.	ATWS CAPABILITY	
	a. ATWS Sized Vent	2
	b. Improved ATWS Capability	1
12.	SEISMIC CAPABILITY	
	a. Increased Seismic Margins	1
	b. Integral Basemat	3
13.	SYSTEM SIMPLIFICATION	
	a. Reactor Building Sprays	2
	b. System Simplification	1
	c. Reduction in Reactor Bldg Flooding	1
14.	CORE RETENTION DEVICES	
	a. Flooded Rubble Bed	2
	b. Reactor Cavity Flooder	1
	c. Basaltic Cements	1

Table A-4
Modifications Evaluated

1. Accident Management	1a. Severe Accident EPGs/AMGs 1b. Computer Aided Instrumentation 1c. Improved Maintenance Procedures/Manuals
2. Decay Heat Removal	2a. Passive High Pressure System 2b. Improved Depressurization 2c. Suppression Pool Jockey Pump 2d. Safety Related Condensate Storage Tank
3. Containment Capability	3a. Larger Volume Containment 3b. Increased Containment Pressure Capability 3c. Improved Vacuum Breakers 3d. Improved Bottom Head Penetration Design
4. Containment Heat Removal	4a. Larger Volume Suppression Pool
5. Containment Atmosphere Gas Removal	5a. Low Flow Filtered Vent
7. Containment Spray	7a. Drywell Head Flooding
8. Prevention Concepts	8a. Additional Service Water Pump
9. AC Power Supplies	9a. Steam Driven Turbine Generator 9b. Alternate Pump Power Source
10. DC Power Supplies	10a. Dedicated DC Power Supply
11. ATWS Capability	11a. ATWS Sized Vent
13. System Simplification	13a. Reactor Building Sprays
14. Core Retention Devices	14a. Flooded Rubble Bed

Table A-5
Summary of Benefits

Potential Improvement	Averted Risk Person-rem
1a. Severe Accident EPGs/AMGs	1.5E-2
1b. Computer Aided Instrumentation	1.0E-2
1c. Improved Maintenance Procedures/Manuals	1.6E-2
2a. Passive High Pressure System	6.9E-2
2b. Improved Depressurization	4.2E-2
2c. Suppression Pool Jockey Pump	0.2E-2
2d. Safety Related Condensate Storage Tank	1.0E-2
3a. Larger Volume Containment	15E-2
3b. Increased Containment Pressure Capability	16E-2
3c. Improved Vacuum Breakers	0.004E-2
3d. Improved Bottom Head Penetration Design	5.7E-2
4a. Larger Volume Suppression Pool	0.02E-2
5a. Low Flow Filtered Vent	1.4E-2
7a. Drywell Head Flooding	6.0E-2
8a. Additional Service Water Pump	1.6E-2
9a. Steam Driven Turbine Generator	5.2E-2
9b. Alternate Pump Power Source for high pressure systems	6.9E-2
10a. Dedicated DC Power Supply	6.9E-2
11a. ATWS Sized Vent	3.0E-2
13a. Reactor Building Sprays	1.7E-2
14a. Flooded Rubble Bed	0.1E-2

Table A-6
Summary of Costs

Potential Improvement	Estimated Minimum Cost
1a. Severe Accident EPGs/AMGs	$ 600,000
1b. Computer Aided Instrumentation	$ 599,600
1c. Improved Maintenance Procedures/Manuals	$ 299,000
2a. Passive High Pressure System	$ 1,744,000
2b. Improved Depressurization	$ 598,600
2c. Suppression Pool Jockey Pump	$ 119,800
2d. Safety Related Condensate Storage Tank	$ 1,000,000
3a. Larger Volume Containment	$ 8,000,000
3b Increased Containment Pressure Capability	$ 12,000,000
3c. Improved Vacuum Breakers	$ 100,000
3d. Improved Bottom Head Penetration Design	$ 750,000
4a. Larger Volume Suppression Pool	$ 8,000,000
5a. Low Flow Filtered Vent	$ 3,000,000
7a. Drywell Head Flooding	$ 100,000
8a Additional Service Water Pump	$ 5,999,000
9a. Steam Driven Turbine Generator	$ 5,994,300
9b. Alternate Pump Power Source	$ 1,194,000
10a. Dedicated DC Power Supply	$ 3,000,000
11a. ATWS Sized Vent	$ 300,000
13a. Reactor Building Sprays	$ 100,000
14a. Flooded Rubble Bed	$ 18,750,000

Table A-7
Summary of Results

Modification	Cost (K`/Person-rem Averted
7a. Drywell Head Flooding	$1,667
13a. Reactor Building Sprays	$5,882
11a. ATWS Sized Vent	$10,000
3d. Improved Bottom Penetration Design	$13,158
2b. Improved Depressurization	$14,252
9b. Alternate Pump Power Source	$17,304
1c. Improved Maintenance Procedures/Manuals	$18,688
2a. Passive High Pressure System	$25,275
1a. Severe Accident EPGs	$40,000
10a. Dedicated DC Power Supply	$43,478
3a. Larger Volume Containment	$53,333
2c. Suppression Pool Jockey Pump	$59,990
1b. Computer Aided Instrumentation	$59,960
3b. Increased Containment Pressure Capacity	$75,000
2d. Safety Related Condensate Storage Tank	$100,000
9a. Steam Driven Turbine Generator	$115,275
5a. Low Flow Filtered Vent	$214,286
8a. Additional Service Water Pump	$374,938
3c. Improved Vacuum Breakers	$2,500,000
14a. Flooded Rubble Bed	$18,750,000
4a. Larger Volume Suppression Pool	$40,000,000