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Attention: Robert C. Pierson, Director
Standardization and Non-Power Reactor Project Directorate

Subject: **Evaluation of Potential Modifications to the ABWR Design**

Enclosed are thirty-four (34) copies of Appendix 19P to Chapter 19, Evaluation of Potential Modifications to the ABWR Design.

It is intended that GE will amend the SSAR to include this information in a future amendment.

Sincerely,

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CHAPTER 19P - EVALUATION OF POTENTIAL MODIFICATIONS TO THE ABWR DESIGN

19P.1 Introduction and Summary

This section provices a description of an evaluation of potential changes to the ABWR design in crder to determine whether furt'.er modifications are warranted.

19P.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 "perform[ance 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 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 manrem averted.

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

19P.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 CRAC02 code. The regional results were then averaged to determine the exposures. Consistent with the standard used by the NRC to evealuate radiological impacts, health effect costs were evaluated based on a value of $ 1000 per offsite person-rem averted due to the design modification.

The offsite costs for other items such as relocation of local residents, elimination of land use and decontamination of contaminated land were not considered. Economic losses, replacement power costs and direct accident costs incurred by the plant owner also are not considered in this evaluation.

19P.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.

19P.1.3.1 Selection of Modifications

Potential modifications were identified from a variety of previous studies of preventative and mitigative features which address severe accidents. Based on this composite list of modifications considered on previous designs, potential modifications applicable to the ABWR design and not included in the reference PRA design were identified for further review.

19P.1.3.2 Costs Estimates

The 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 19P.5 defines the cost estimates for each of the modifications.

Even for a new plant such as the ABWR, relatively large costs (several million) 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.

19P.1.3.3 Benefit Estimates

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 the estimated change in frequency of events or associated offsite dose summarized in Tables 19P.2-1 and Table 19P.2-3. This basis is consistent with the approach taken in NRC evaluations. The cumulative offsite risk was evaluated over a 60 year plant life with no escalation in the evaluation criteria of $ 1000/person-rem.

Section 19P.4 summarizes the concept and estimated benefit for each individual potential modification. The cost per person-rem averted was evaluated for each modification to obtain the results of the individual evaluations. These conclusions are provided in Section 19P.7.

19P.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 were selected for additional review.

None of the twenty modifications considered met the $ 1,000/person-rem averted criteria as summarized in Section 19P.7. The most cost effective change was the manually initiated containment vent sized for an Anticipated Transient 'ithout Scram (ATWS) event which was evaluated at $111,000 per person-rem averted. Since the most beneficial modification is more than a factor of 100 higher than the criteria, it was therefore concluded that no additional modifications are warranted in the ABWR design to address severe accidents.

19P.2 Severe Accident Risk of ABWR

The reference design for this studv was the ABWR PRA as presented in the treated in the internal events PRA (23A6100AS, Rev. A, Amendment 8, 7/28/89) and the seismic events PRA except as indicated below. Event frequencies were the same as assumed in the base PRA.

The reference design for this evaluation was modeled to account for features which are being included in the current ABWR design to address severe accidents and discussed in Section 19.3.1.5. These features and the reference description include:

	SSAR References
1) Firewater pump crosstie	(19G.2)
2) Passive containment flooder	(19G.3)
3) Gas turbine generator	(9.5.11)
4) Overpressure Protection	(19G.4)

A summary of the core damage frequency and offsite exposure frequency with these features included is shown in Table 19P.2-1.

Review of Table 19P.2-1 indicates that the dominant contributor to the ABWR risk (64.8%) is from a sequence in which containment failure results from an ATWS following a seismic event initiator. In this event the containment rupture disc is insufficient to prevent containment failure and subsequent release.

The offsite exposures shown in Table 19P.2-1 were calculated by the CRAC2 code. Exposures per event were calculated for five representative US regions for the selected individual ABWR sequences. Table 19P.2-1 summarizes the average values obtained among the five US regions. Table 19P.2-2 provides the assumed regional values used in the analysis which were derived from Reference 19P.8.8.

Table 19P.2-3 provides additional detail on the individual contributors to the total core damage frequency. Overall, the core damage risk is dominated by low pressure transient events (48%), station blackout sequences (27%) and high pressure transient events (21%).

19P.3 Potential ABWR Modifications

The list of potential modifications was derived from a survey of various studies indicated in references 19P.8.1 through 19P.8.7. From these references a composite list of modifications considered on previous designs was established. This list of potential modifications was then reviewed to identify concepts which were already included in the ABWR design or which are not applicable.

Table 19P.3-1 summarizes these 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.
3. Modification is not applicable to the ABWR design.
4. Modification is applicable to ABWR and is incorporated with the referenced modification

Table 19P.3-2 lists the Category 2 modifications which are evaluated further in this report.

19P.4 Risk Reduction of Potential Modifications

This section provides evaluations of the benefits of potential modifications to the ABWR design identified in Table 19P.3-2. For each modification the basis for the evaluation and the concept is described. Table 19P.4-1 summarizes the benefit in terms of person-rem averted risk for each of the evaluated modifications.

19P.4.1 ACCIDENT MANAGEMENT

19P.4.1.a Severe Accident EPGs

The symptom based Emergency Procedure Guidelines (EPGs), developed by the BWR Owners Group since the accident at Three Mile Island, Unit 2, are 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. It is assumed in the internal events PRA that ABWR 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 prevention actions and some mitigative actions, the incremental benefit of this item would be primarily mitigative. If a 10% improvement in mitigative actions results, especially in use of core melt arrest processes, the offsite risk would be reduced about 10%. The benefit was estimated to be about .47 person-rem over 60 years.

19P.4.1.b Computer Aided Instrumentation

This item discusses computer aided artificial intelligence including attention to risk issues in man-machine interfaces. Significant computer assisted display and plant status monitoring is already part of the 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 which already provides human engineered displays of the important variables in the Emergency Procedure Guidelines (EPGs).

Operator actions are made significantly more reliable by new features such as Emergency Procedure Guidelines, Safety Plant Parameter Displays (SPDS), and training. If the improvements described in section 19P.4.1.a are assumed to be implemented design, the incremental benefit of additional aides is expected to be low. If preventive factors involving operator action are improved by 10%, the incremental benefit over severe accident EPGs (item 19P.4.1.a) is about 1.6% in Core Damage Frequency (CDF). Because the improvement affects primarily low offsite impact sequences, the resulting benefit is about .012 person-rem.

19P.4.1.c 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 (LPCF) systems, the CDF is reduced by about 9%. This has an estimated person-rem reduction of about .36 person-rem.

19P.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 HPCS system.

19P.4.2.a Passive High Pressure System

This concept is to provide additional high pressure capability to remove decay heat through an 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 contemplated for the Simplified ABWR is employed.

The benefit of this system would be equivalent to an additional RCIC system in addition to an additional containment heat removal system. If the system were 90% reliable, seismically qualified and designed to operate independent of offsite power, the benefit would be about 2.2 person-rem averted.

19P.4.2.b Improved Depressurization

This item addresses an improved depressurization capability 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 21% of the total core damage risk, but only 2% of the offsite exposure risk. If the depressurization failure rates were reduced by a factor of 2, offsite effects would be reduced by less than 1%. The estimated benefit from this modification is about .05 person-rem.

19P.4.2.c Suppression Pool Jockey Pump

This modification would provide a small makeup pump to provide for decay heat removal from the Reactor Pressure Vessel (RPV) using suppression pool water as a source. Return path to the suppression pool is through existing piping such as shutdown cooling return lines. The benefit of this modification would be similar to that provided by the firewater injection capability, but it would have the advantage that long term containment inventory concerns would not occur.

If the system were 100% reliable, the benefit would be about .16 person-rem averted.

19P.4.2.d 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.

In the current PRA seismically initiated transient events (class 1C and 1D) represent about 30% of the total plant risk. However, the dominant failure modes are not limited by water availability and therefore the benefit of this modification is considered small. If the core damage frequency from these events were reduced by 10%, about a 3% reduction in risk or about or about .15 person-rem would be averted.

19P.4.3 CONTAINMENT CAPABILITY

19P.4.3.a 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 a containment failure.

This item would mitigate the effect of an accident by delaying the time before the severe accident source term is released. However, eventual release is not prevented. Without operation of the containment overpressure rupture disc, ultimately the containment will fail due to the long term pressurization caused by core concrete interaction or Decay Heat removal system recovery.

If doubling the volume would delay the time before long term release and reduce the offsite risks by a factor of 2 for ATWS sequences, about .85 person-rem would be averted.

19P.4.3.b Increased Containment Pressure Capacity

The ABWR design pressure of the containment is 45 psig and the containment rupture disc 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 but not change the core damage frequency. The increased pressure capability may not be sufficient to contain the long term pressurization caused by core concrete interaction. However if it were able to prevent all severe source term release except for normal containment leakage, the risk reduction would be about 4.7 person-rem.

19P.4.3.c Improved Vacuum Breakers

The ABWR design contains single vacuum breaker valves in each of eight vacuum breaker lines. Section 19E.2.4.6 evaluated the consequence of a stuck open vacuum breaker and concluded that the risk was within the uncertainty of the PRA. This modification would reduce the probability of a stuck open vacuum breaker by making the valves redundant in each line.

The risk of suppression pool bypass discussed in Section 19E.2.3.3 is about 10% of the total plant risk or about .47 person-rem. The benefit of this modification would be to reduce this exposure by about 30% or .15 person-rem.

19P.4.4 CONTAINMENT HEAT REMOVAL

The ABWR design contains 3 divisions of suppression pool cooling and provisions for a containment rupture disc for decay heat removal. Consequently, loss of containment heat removal events contribute only 1.3% of the total core damage frequency and .08% of the offsite exposures. Additional modifications are not likely to show substantial benefits.

19P.4.4.a 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 type II events (see Table 19P.2-3), the maximum benefit would be a 1.3 % reduction in CDF and associated offsite costs. However, because these events are mitigated by the containment rupture disc, they only contribute about .004 person-rem to the base case risk. The assessed maximum benefit is therefore about .004 person-rem.

19P.4.4.b RWCU Decay Heat Removal

The Reactor Water Cleanup System (RWCU) contains nonregenerative heat exchangers which can be used for reactor decay heat removal if normal shutdown cooling fails. Use of this system is procedural and involves positioning of valves which bypass the RWCU Regenerative Heat exchanger, increasing in the service water flow rate and increasing the RWCU system flow. The availability of the RWCU capacity for successful use has been assumed. It is also assumed that with sufficient procedural actions the system could remove decay heat 4 hours after reactor scram. During that period the suppression pool has adequate capacity to absorb all decay heat.

The benefit of this system change would be in the reduction of Class II type events which contribute less than 1.3% to the total core damage frequency. If a 90% reduction in the type II events were achieved (including seismic events), the benefit would be similar to that discussed for item 19P.4.4.a or about .004 person-rem.

19P.4.5 CONTAINMENT ATMOSPHERE MASS REMOVAL

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

19P.4.6 COMBUSTIBLE GAS CONTROL

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

19P.4.7 CONTAINMENT SPRAY SYSTEMS

19P.4.7.a 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 would result. The estimated benefit of this is about .002 person-rem assuming a 50% reliability of initiation.

190.4.8 PREVENTION CONCEPTS

19P.4.8.a 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 LPCF 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.

Common cause dependencies from support systems could conceivably reduce the plant risk through an improvement in system reliability. The concept for this item is to provide dedicated support systems for each of the four diverse injection 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 additional support systems. 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 (item 19P.4.1.c). This results in an estimated benefit of about .36 person-rem.

19P.4.9 AC POWER SUPPLIES

19P.4.9.a 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 in a similar way as the concept described in Section 19P.3.9.a.

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 the system has a 80 % availability for all events including seismically induced events, the benefit is about 3.0 person-rem.

19P.4.9.b Alternate Pump Power Source

The ABWR provides separate diesel drive power supplies to the HPCF and LPCF 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 about .04 person-rem. If the system were further hardened to be available during seismic events, the benefit would be about .16 person-rem.

19P.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.

19P.4.10.a 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 49% of the total CDF. If the effective unavailability of the RCIC is reduced by a factor of 10 due to the availability of a diverse system, a total benefit of about 3.2 person-rem would result.

19P.4.11 ATWS CAPABILITY

19P.4.11.a 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 disc (which is currently sized to pass reactor power consistent with RCIC injection), but it would be of the larger size required to pass the additional steam associated with LPCF 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. ATWS events following a seismic event (Class 1C) contribute about 65% of the remaining risk of the ABWR. The evaluation shows that an ATWS sized vent manually initiated with a 90% reliability would reduce the offsite dose by about 2.7 person-rem.

19P.4.12 SEISMIC CAPABILITY

19P.4.12.a Increased Seismic Margins

Seismic events contribute about 60% of the total release frequency. Of those events, about 68% are contributed by long term station blackout or low pressure core melt events. Improved margin provided by seismic hardening of specific modifications has been discussed in sections 19P.4.2.a, 19P.4.2.b, and 19P.4.9.a. However, structural modifications could be made to increase the seismic capacity of the reactor building which would improve the availability of systems following the seismic event.

If structural modifications were made to increase the mean capacity of the reactor building by 10%, the benefit would be worth about .32 person-rem.

19P.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.

19P.4.13.a 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 valving 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 in which the containment fails. If 10% of the releases were arbitrarily mitigated by this method, the benefit would be about .47 person-rem.

19P.5 Cost Impacts of Potential Modifications

As discussed in Section 19P.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. This section summarizes the basis for the cost estimates of each of the modification evaluated in Section 19P.4. Table 19P.5-1 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.

19P.5.1 ACCIDENT MANAGEMENT

19P.5.1.a Severe Accident EPGs

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.

19P.5.1.b 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.

19P.5.1.c Improved Maintenance Procedures/Manuals

The cost of at least $ 300,000 would be required to identify components which should recieve enhanced maintenance attention and to prepare the additional detailed procedures or recommended information beyond that currently planned.

19P.5.2 DECAY HEAT REMOVAL

19P.5.2.a 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.

19P.5.2.b Improved Depressurization

The cost of the additional logic changes, pneumatic supplies, piping and qualification is estimated to be at least $ 600,000 for an improved system for depressurization. This estimate assumes no building space increase.

19P.5.2.c 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.

19P.5.2.d 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.

19P.5.3 CONTAINMENT CAPABILITY

19P.5.3.a 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 per square foot, 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.

19P.5.3.b Increased Containment Pressure Capacity

The cost of a stronger containment design would be similar in magnitude to increasing its size (see 3a). 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.

19P.5.3.c 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.

19P.5.4 CONTAINMENT HEAT REMOVAL

19P.5.4.a Larger Volume Suppression Pool

This concept would result in similar costs as item 19P.4.3.a for providing a larger containment. An estimate of $ 8,000,000 is assigned to this item.

19P.5.4.b RWCU Decay Heat Removal

The cost of this modification is relatively minor in that it involves no significant hardware modification. If it is assumed that a bypass line and valving must be added, the procedures, training and hardware would cost about $ 85,000.

19P.4.5 CONTAINMENT ATMOSPHERE MASS REMOVAL

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

19P.4.6 COMBUSTIBLE GAS CONTROL

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

19P.5.7 CONTAINMENT SPRAY SYSTEMS

19P.5.7.a Drywell Head Flooding

An additional line to flood the drywell head using existing firewater piping would be relatively inexpensive. 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 $ 60,000.

19P.5.8 PREVENTION CONCEPTS

19P.5.8.a 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.

19P.5.9 AC POWER SUPPLIES

19P.5.9.a 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.

19P.5.9.b Alternate Pump Power Source

A separate power supply and the supporting auxiliaries is estimated to cost at least $ 1,000,000 for a single generator sized to operate a feedwater pump. This cost would include wiring and installation of the alternate generator, but does not assume additional structural costs.

19P.5.10 DC POWER SUPPLIES

19P.5.10.a Dedicated RHR 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 system would be less expensive. A similar system using batteries could conceptually be installed for about $ 2,500,000 including space requirement modifications, pumps and logic.

19P.5.11 ATWS CAPABILITY

19P.5.11.a 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 $ 250,000.

19P.5.12 SEISMIC CAPABILITY

19P.5.12.a Increased Seismic Margins

Improvements in the structural design and material of construction for the ABWR is expected to cost at least $ 1,200,000 for added analysis to determine the weakest points and follow-on strengthening. This estimate is considered very conservative.

19P.5.13 SYSTEM SIMPLIFICATION

19P.5.13.a Reactor Building Sprays

The cost of this modification is judged to be similar to the concept of drywell head flooding (item 19P.5.5.a) if it only involves piping and valves which are tied into the firewater system. An estimate of $ 60,000 has been assigned to this item.

19P.6 Evaluation of Potential Modifications

A ranking of the modifications by $/person-rem averted is shown in Table 19P.6-1 based on the results and estimates provided in Sections 19P.4 and 19P.5.

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.

19P.7 Summary and Conclusions

The low level of risk in the ABWR is demonstrated by the total lifetime offsite exposure risk of 4.7 person-rem. At this level only modifications which cost less than $ 4,700 are justified.

To identify potentially attractive modifications, previous evaluations of potential prevention and mitigation concepts applicable during severe accidents 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 were selected for additional review. The most cost effective change was the manually initiated ATWS sized containment vent which was evaluated at more than $ 100,000 per person-rem averted.

One of the major differences between this study and previous studies is the offsite exposures resulting from the severe accident. In the Limerick study (Reference 19P.8.2), modifications were evaluated against a much higher reference risk of 370 person-rem per year with a core damage frequency (CDF) of 4.2E-5/yr. The difference between these two studies can be attributed to the following factors:

1. Implementation of the containment overpressure relief effectively eliminates Class II events from contributing to plant risk.

2. Implementation of the diesel firepump crosstie to containment sprays and the drywell flooder mitigate the releases from several sequences that could have resulted in limited scrubbing by the suppression pool.

3. The assessed Core Damage Frequency at Limerick is significantly higher than that evaluated for the ABWR.

19P.8 References

1. Evaluation of Proposed Modifications to the GESSAR II Design, NEDE 30640, Class III, June 1984.

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

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

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

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

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

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

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

Table 19P.2-1
OFFSITE ACCIDENT IMPACTS PER EVENT

EVENT*	FREQUENCY (per yr)	MANREM EXPOSURE (per event)	(per 60 yrs)	CONTRIBUTION (%)
LCHP PFEH	3.4E-11	2,640,000	0.0054	.1
NSRC PFDH	0	2,357,600	0.0	0.0
SBRC PFDH	4.5E-10	2,237,600	0.061	1.3
LCLP PFDH	1.3E-12	2,155,520	0.00017	0.003
LBLC PFDM	4.2E-09	1,976,000	0.50	10.7
NSCH PFPH	2.7E-09	1,952,000	0.31	6.7
NSCL FSDM	6.3E-08	804,000	3.0	64.8
LCLP FSDL	3.8E-08	309,360	0.71	15.1
LCLP PFSN	9.1E-09	17,280	0.0094	.2
SBRC FSVN	4.7E-08	12,000	0.034	.7
Normal Leakage	2.3E-07	1,270	0.018	.4
TOTAL	4.0E-07		4.7	100

* For case descriptions see Table 19E.2-3

Table 19P.2-2

OFFSITE COST ASSUMPTIONS

(Used in CRAC2)

Region	Population Density (People/ sq mi)	Meteorology
Northeast	230	Caribou, Me.
Midwest	120	Madison, Wi.
South	100	Lake Charles, La.
West	50	Medford, Or.
South West	30	Brownsville, Tx.

Distance considered (See Note Below)	25 Miles
Evacuation	Included
Isotopic Assumptions	See Table 19E.3-6

Note: CRAC2 calculated values to 25 miles were increased by a factor of 4 to provide a conservative estimate of the cumulative dose at 50 miles to be consistent with previous evaluations of Severe Accident Design Alternatives.

Table 19P.2-3

Core Damage Frequency Contributors

OFFSITE RELEASE GROUP

INTERNAL EVENTS ANALYSIS — SEQUENCE*

	1A	1B1	1B2	1B3	1D	II	IIID	IV	TOTAL	% CONTRIB
LCLP FSDL		0.0E+00		0.0E+00	1.6E-11				1.6E-11	.0
SBRC FSVN		5.8E-13	0.0E+00	3.2E-14	0.0E+00	1.5E-09			1.5E-09	0.9
LCHP PFEH	3.4E-11								3.4E-11	.0
NSCH PFPH	3.4E-10								3.4E-10	0.2
LCLP PFDH		1.9E-13		6.9E-15	1.6E-13				3.6E-13	.0
LBLC PFDM							2.6E-14		2.6E-14	.0
NSCL FSDM		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00			0.0E+00	0.0
SBRC PFDH			1.9E-13			0.0E+00		2.7E-11	2.7E-11	.0
NCL (N)	3.5E-08	1.8E-08	1.6E-08	6.5E-10	8.0E-08	1.2E-11	1.3E-08		1.6E-07	98.8
LBLC FSDL							2.6E-12		2.6E-12	.0
INTERNAL	3.6E-08	1.8E-08	1.6E-08	6.5E-10	8.0E-08	1.5E-09	1.3E-08	2.7E-11	1.6E-07	100.0
	21.7	10.8	9.4	0.4	48.8	0.9	7.9	.0	100	

SEISMIC EVENTS ANALYSIS

	1A	1E	1B2	1C	1D	II	IIID	IV	TOTAL	% CONTRIB
LCHP FSDL	1.5E-11								1.5E-11	.0
SBRC PFVN			4.2E-08			3.7E-09		0.0E+00	4.6E-08	19.7
LCLP FSDL		3.8E-08			1.6E-11				3.8E-08	16.5
NSCH PFPH		2.3E-09							2.3E-09	1.0
LCLP PFSN	9.8E-11	1.8E-09	2.9E-09	3.6E-09	7.7E-10				9.1E-09	3.9
NSCL PFDH				4.2E-09					4.2E-09	1.8
NSCL FSDM			7.5E-11	6.2E-08		2.5E-11		9.3E-10	6.3E-08	27.3
LCHP PFPH	8.1E-11								8.1E-11	.0
LCLP PFDH					9.2E-13				9.2E-13	.0
NSRC PFDH								0.0E+00	0.0E+00	.0
SBRC PFDH			4.2E-10			0.0E+00			4.2E-10	.2
NCL (N)	2.2E-09	2.8E-08	2.6E-08	1.9E-08	1.9E-08				6.8E-08	100.0
SEISMIC	2.44E-09	4.51E-08	7.14E-08	8.89E-08	1.94E-08	3.72E-09		9.27E-10	2.32E-07	
	1.1	19.5	30.8	38.3	8.4	1.6		0.4	100.0	

	1A/1E	1B1	1B2/1B3	1C/1D	II	IIID	IV	TOTAL
TOTAL CDF	8.3E-08	1.8E-08	8.8E-08	1.9E-07	5.3E-09	1.3E-08	9.5E-10	3.96E-07
% CONTRIBUTION	21.0	4.5	22.1	47.6	1.3	3.3	0.2	100.0

* For description see Section 19.3.2.2

Table 19P.3-1
Modifications Considered

Modification	Category	Basis	Reference
1. [illegible]T MANAGEMENT			
a. Severe Accident EPGs	2		1
b. Computer Aided Instrumentation	2		1
c. Improved Maintenance Procedures/Manuals	2		1
d. Preventive Maintenance Features	4	See 1c	1
e. Improved Accident Mgt Instrumentation	4	See 1b	1
f. Remote Shutdown Station Interfaces	1		1
g. Security System Interfaces	1		1
h. Simulator Training for Severe Accidents	4	See 1b	1
2. REACTOR DECAY HEAT REMOVAL			
a. Passive High Pressure System	2		1
b. Improved Depressurization	2		1,2,3,5
c. Suppression Pool Jockey Pump	2		1
d. Improved High Pressure Systems	1		1
e. Additional Active High Pressure System	1		1,5
f. Improved Low Pressure System (Firepump)	1		1,2,3
g. Dedicated Suppression Pool Cooling	1		1,2
h. Safety Related Condensate Storage Tank	2		1
i. 16 hour Station Blackout Injection	4	see 9c	1
j. Improved Recirculation Mode	3	PWR	3
3. CONTAINMENT CAPABILITY			
a. Larger Volume Containment	2		1,4
b. Increased Containment Pressure Capacity	2		1
c. Improved Vacuum Breakers	2		1
d. Increased Temperature Margin for Seals	1		1,4
e. Improved Leak Detection	1		3
f. Suppression Pool Scrubbing	1		5
4. CONTAINMENT HEAT REMOVAL			
a. Larger Volume Suppression Pool	2		1
b. RWCU Decay Heat Removal	2		2
c. High Flow Suppression Pool Cooling	1		1,4
d. Passive Overpressure relief	1		1,2,5
5. CONTAINMENT ATMOSPHERE MASS REMOVAL			
a. High Flow Unfiltered Vent	3	Mark III	1,4
b. High Flow Filtered Vent	3	Mark III	1,4
c. Low Flow Vent (filtered)	3	Mark III	1,2,3,4
6. COMBUSTIBLE GAS CONTROL			
a. Post Accident Inerting System	3	Inerted	1,4
b Hydrogen Control by Venting	3	Inerted	1,4
c. Preinerting	1	Inerted	1,4
d. Ignition Systems	3	Inerted	1,3,4,6
e. Fire Suppression System Inerting	3	Inerted	1,4

Table 19P.3-1
Modifications Considered

Modification		Category	Basis	Reference
7.	**CONTAINMENT SPRAY SYSTEMS**			
a.	Drywell Head Flooding	2		2
b.	Containment Spray Augmentation	1		1,2,3,6
8.	**PREVENTION CONCEPTS**			
a.	Additional Service Water Pump	2		3
b.	Improved Operating Response	1		1
c.	Reduced Common Cause Dependencies	4	See 8g	1
d.	Operating Experience Feedback	1		1
e.	Reduction in Water Hammer (USI A-1)	1		1
f.	Degraded ECCS Operation (USI A-43)	1		1
g.	Improved Valve Design	1		1
9.	**AC POWER SUPPLIES**			
a.	Steam Driven Turbine Generator	2		1
b.	Alternate Pump Power Source	2		1
c.	16 Hour Station Blackout Provisions	1		1
d.	Additional Diesel Generator	1		1,3
e.	Increased Electrical Divisions	1		1
f.	Improved Uninterruptable Power Supplies	1		1
g.	AC Bus Cross-ties	1		1
h.	Gas Turbine	1		1
i.	Dedicated RHR (bunkered) Power Supply	1		1
10.	**DC POWER SUPPLIES**			
a.	Dedicated DC Power Supply	2		1
b.	Additional Batteries/Divisions	4	See 10e	1
c.	Fuel Cells	4	See 10e	1
d.	DC Cross-ties	1		1
e.	Larger Battery Capacity	1		1,3
11.	**ATWS CAPABILITY**			
a.	ATWS Sized Vent	2		2,4,6
b.	Improved ATWS Capability	1		1,5,6
12.	**SEISMIC CAPABILITY**			
a.	Increased Seismic Margins	2		1
b.	Integral Basemat	3		1
13.	**SYSTEM SIMPLIFICATION**			
a.	Reactor Building Sprays	2		2
b.	System Simplification	1		1
c.	Reduction in Reactor Bldg Flooding	1		5
14.	**CORE RETENTION DEVICES**			
a.	Core Retention Devices	1		1,2,4,6
b.	Reactor Cavity Flooder	1		3

Table 19P.3-2
Modifications Evaluated

1 ACCIDENT MANAGEMENT	a.	Severe Accident EPGs
	b.	Computer Aided Instrumentation
	c.	Improved Maintenance Procedures/Manuals
2 DECAY HEAT REMOVAL	a.	Passive High Pressure System
	b.	Improved Depressurization
	c.	Suppression Pool Jockey Pump
	d.	Safety Related Condensate Storage Tank
3 CONTAINMENT CAPABILITY	a.	Larger Volume Containment
	b.	Increased Containment Pressure Capacity
	c.	Improved Vacuum Breakers
4 CONTAINMENT HEAT REMOVAL	a.	Larger Volume Suppression Pool
	b.	RWCU Decay Heat Removal
7 CONTAINMENT SPRAY	a.	Drywell Head Flooding
8 PREVENTION CONCEPTS	a.	Additional Service Water Pump
9 AC POWER SUPPLIES	a.	Steam Driven Turbine Generator
	b.	Alternate Pump Power Source
10 DC POWER SUPPLIES	a.	Dedicated DC Power Supply
11 ATWS CAPABILITY	a.	ATWS Sized Vent
12 SEISMIC CAPABILITY	a.	Increased Seismic Margins
13 SYSTEM SIMPLIFICATION	a.	Reactor Building Sprays

Table 19P.4-1
Summary of Benefits

Modification	Potential Manrem Averted
1 ACCIDENT MANAGEMENT	
1a. Severe Accident EPGs	0.47
1b. Computer Aided Instrumentation	0.012
1c. Improved Maintenance Procedures/Manuals	0.36
2 DECAY HEAT REMOVAL	
2a. Passive High Pressure System	2.2
2b. Improved Depressurization	0.05
2c. Suppression Pool Jockey Pump	0.16
2d. Safety Related Condensate Storage Tank	0.15
3 CONTAINMENT CAPABILITY	
3a. Larger Volume Containment	0.85
3b. Increased Containment Pressure Capacity	4.7
3c. Improved Vacuum Breakers	0.15
4 CONTAINMENT HEAT REMOVAL	
4a. Larger Volume Suppression Pool	0.004
4b. RWCU Decay Heat Removal	0.004
7 CONTAINMENT SPRAY SYSTEMS	
7a. Drywell Head Flooding	0.002
8 PREVENTION CONCEPTS	
8a. Additional Service Water Pump	0.36
9 AC POWER SUPPLIES	
9a. Steam Driven Turbine Generator	3.0
9b. Alternate Pump Power Source	0.16
10 DC POWER SUPPLIES	
10a. Dedicated DC Power Supply	3.2
11 ATWS CAPABILITY	
11a. ATWS Sized Vent	2.7
12 SEISMIC CAPABILITY	
12a. Increased Seismic Margins	0.32
13 SYSTEM SIMPLIFICATION	
13a. Reactor Building Sprays	0.47

Table 19P.5-1
Summary of Costs

Modification	Estimated Cost
1 ACCIDENT MANAGEMENT	
1a. Severe Accident EPGs	$ 600K
1b. Computer Aided Instrumentation	$ 600K
1c. Improved Maintenance Procedures/Manuals	$ 300K
2 DECAY HEAT REMOVAL	
2a. Passive High Pressure System	$ 1750K
2b. Improved Depressurization	$ 600K
2c. Suppression Pool Jockey Pump	$ 120K
2d. Safety Related Condensate Storage Tank	$ 1000K
3 CONTAINMENT CAPABILITY	
3a. Larger Volume Containment	$ 8000K
3b. Increased Containment Pressure Capacity	$ 12000K
3c. Improved Vacuum Breakers	$ 100K
4 CONTAINMENT HEAT REMOVAL	
4a. Larger Volume Suppression Pool	$ 8000K
4b. RWCU Decay Heat Removal	$ 85K
7 CONTAINMENT SPRAY SYSTEMS	
7a. Drywell Head Flooding	$ 60K
8 PREVENTION CONCEPTS	
8a. Additional Service Water Pump	$ 6000K
9 AC POWER SUPPLIES	
9a. Steam Driven Turbine Generator	$ 6000K
9b. Alternate Pump Power Source	$ 1200K
10 DC POWER SUPPLIES	
10a. Dedicated RHR DC Power Supply	$ 2500K
11 ATWS CAPABILITY	
11a. ATWS Sized Vent	$ 300K
12 SEISMIC CAPABILITY	
12a. Increased Seismic Margins	$ 1200K
13 SYSTEM SIMPLIFICATION	
13a. Reactor Building Sprays	$ 60K

Table 19P.6-1
Summary of Results

Modification		Cost/Manrem Averted
11a.	ATWS Sized Vent	$ 111K
13a.	Reactor Building Sprays	$ 128K
3c.	Improved Vacuum Breakers	$ 625K
2c.	Suppression Pool Jockey Pump	$ 750K
10a.	Dedicated DC Power Supply	$ 781K
2a.	Passive High Pressure System	$ 795K
1c.	Improved Maintenance Procedures/Manuals	$ 833K
1a.	Severe Accident EPGs	$ 1276K
3b.	Increased Containment Pressure Capacity	$ 2553K
9a.	Steam Driven Turbine Generator	$ 3000K
12a.	Increased Seismic Margins	$ 3750K
2d.	Safety Related Condensate Storage Tank	$ 5882K
9b.	Alternate Pump Power Source	$ 7500K
3a.	Larger Volume Containment	$ 9411K
2b.	Improved Depressurization	$ 12000K
8a.	Additional Service Water Pump	$ 16666K
4b.	RWCU Decay Heat Removal	$ 21250K
7a.	Drywell Head Flooding	$ 30000K
1b.	Computer Aided Instrumentation	$ 50000K
4a.	Larger Volume Suppression Pool	$ 2000000K