GE Nuclear Energy

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Attention: R. W., Borchardt, Director
Standardization Project Directorate

Subject: **NEPA/SAMDA Submittal for the ABWR**

Reference:
1. Letter, J.F. Quirk to R.W. Borchardt, same title, August 26, 1993, MFN No. 137-93
2. Letter, J.F. Quirk to R.W Borchardt, same title, November 18, 1994, MFN No. 148-94

The attached Technical Support Document (TSD) for the ABWR supersedes the TSD transmitted August 26, 1993 (Reference 1) and November 18, 1994 (Reference 2). On December 15, 1994, GE discussed the staff's comments on Reference 2. This updated version of the TSD incorporates staff comments.

The conclusions regarding radiological risk from severe accidents in plants of ABWR design remain unchanged and GE believes that this TSD provides a sufficient basis for the NRC to issue proposed amendments to 10CFR Part 52 which concludes:

1) for the ABWR design, all reasonable steps have been taken to reduce the occurrence of a severe accident involving substantial damage to the core and to mitigate the consequences of such an accident should one occur;

2) no cost-effective SAMDAs to the ABWR design have been identified to prevent or mitigate the consequences of a severe accident involving substantial damage to the core; and,

3) no further evaluation of severe accidents for the ABWR design, including SAMDAs to the design, is required in any environmental report, environmental assessment, environmental impact statement or other environmental analysis prepared in connection with issuance of a combined license for a nuclear power plant referencing a certified ABWR design.

2222 See Attached distribution

If you have any questions on the attached TSD, please call Peter D. Knecht at (408) 925-6215.

Sincerely,

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TECHNICAL SUPPORT DOCUMENT FOR THE ABWR

General Electric Company
San Jose, California
December 1994

TECHNICAL SUPPORT DOCUMENT FOR THE ABWR

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EXECUTIVE SUMMARY

The term "severe accident" refers to those events which are "beyond the substantial coverage of design basis events" and includes those for which there is substantial damage to the reactor core whether or not there are serious off-site consequences. See Severe Accident Policy Statement, 50 Fed. Reg. 32,138 and 32,139 (August 8, 1985).

For new reactor designs, such as the ABWR, the Nuclear Regulatory Commission (NRC), in satisfaction of its severe accident safety requirements and guidance, is requiring, among other things, the evaluation of design alternatives to reduce the radiological risk from a severe accident by preventing substantial core damage (i.e., preventing a severe accident) or by limiting releases from the containment in the event that substantial core damage occurs (i.e., mitigating the impacts of a severe accident).

The National Environmental Policy Act (NEPA) requires the consideration of reasonable alternatives to proposed major Federal actions significantly affecting the quality of the human environment, including alternatives to mitigate the impacts of the proposed action. In 1989, a Federal Court of Appeals determined that NEPA required consideration of certain design alternatives; namely, severe accident mitigation design alternatives (SAMDAs). See Limerick Ecology Action v. NRC, 869 F.2d 719 (3rd Cir. 1989). The court indicated that "[SAMDAs] are, as the name suggests, possible plant design modifications that are intended not to prevent an accident, but to lessen the severity of the impact of an accident should one occur." Id. at 731. The court rejected the use of a policy statement as an acceptable basis for closing out NEPA consideration of SAMDAs in a licensing proceeding, because, among other things, it was not a rule making. Id. at 739.

Recently, the NRC Staff expanded the concept of SAMDAs to encompass design alternatives to prevent severe accidents, as well as mitigate them. See NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," (Volume I, p. 5-100). By doing so, the Staff makes the set of SAMDAs considered under NEPA the same as the set of alternatives to prevent or mitigate severe accidents considered in satisfaction of the Commission's severe accident requirements and policy.

This document provides the technical basis for determining the status of severe accident closure under NEPA for the ABWR design. The report concludes that there is an adequate technical basis for closure of severe accidents under NEPA for the ABWR design. The basis and conclusions are expected to be codified in the form of proposed amendments to 10 CFR Part 52. The amendments would provide that:

(1) For the ABWR design, all reasonable steps have been taken to reduce the occurrence of a severe accident involving substantial damage to the core and to mitigate the consequences of such an accident should one occur;

(2) No cost-effective SAMDAs to the ABWR design have been identified to prevent or mitigate the consequences of a severe accident involving substantial damage to the core;

(3) No further evaluation of severe accidents for the ABWR design, including SAMDAs to the design, is required in any environmental report, environmental assessment, environmental impact statement or other environmental analysis prepared in connection with issuance of a combined license for a nuclear power plant referencing a certified ABWR design; and,

1.0 INTRODUCTION

1.1 Background

The term "severe accident" refers to those events that are "beyond the substantial coverage of design basis events" and includes those for which there is substantial damage to the reactor core whether or not there are serious off-site consequences. See Severe Accident Policy Statement, 50 Fed. Reg. 32,138 and 32,139 (August 8, 1985). For new reactor designs, such as the ABWR, the Nuclear Regulatory Commission (NRC), in satisfaction of its severe accident safety requirements, is requiring, among other things, the evaluation of design alternatives to reduce the radiological risk from a severe accident by preventing substantial core damage (i.e., preventing a severe accident) or by limiting releases from the containment in the event that substantial core damage occurs (i.e., mitigating the impacts of a severe accident).

The Commission's severe accident safety requirements for new designs are set forth in 10 CFR Part 52, §52.47(a)(1)(ii), (iv) and (v). Paragraph 52.47(a)(1)(ii) references the Commission's Three Mile Island safety requirements in §50.34(f). Paragraph 52.47(a)(1)(iv) concerns the treatment of unresolved safety issues and generic safety issues. Paragraph 52.47(a)(1)(v) requires the performance of a design-specific probabilistic risk assessment (PRA). The Commission's Severe Accident Policy Statement elaborates what the Commission is requiring for new designs. The Commission's Safety Goal Policy Statement (51 Fed. Reg. 30,028 (August 21, 1986)) sets goals and objectives for determining an acceptable level of radiological risk.

As part of its application for certification of the ABWR design, GE has prepared a Standard Safety Analysis Report (ABWR SSAR). Chapter 19 of the ABWR SSAR, "Response to Severe Accident Policy Statement," demonstrates how the ABWR design meets the Commission's severe accident safety requirements and policies. In particular, Chapter 19 includes:

(1) Identification of the dominant severe accident sequences and associated source terms for the ABWR design;

(2) Descriptions of modifications that have been made to the ABWR design, based on the results of the Probabilistic Risk Assessment (PRA), to prevent or mitigate severe accidents and reduce the risk of a severe accident;

(3) Bases for concluding that "all reasonable steps [have been taken] to reduce the chances of occurrence of a severe accident involving substantial damage to the reactor core and to mitigate the consequences of such an accident should one occur," (Severe Accident Policy Statement (50 Fed. Reg. 32,139)); and

(4) Bases for concluding that the ABWR meets Commission's Safety Goals and objectives as set forth in the Safety Goal Policy Statement

Conse ly, the conclusions are drawn in Chapter 19 that further modifications to the ABWR design educe severe accident risk are not warranted. The National Environmental Policy Act (NEPA) requires the consideration of reasonable alternatives to proposed major Federal actions significantly affecting the quality of the human environment, including alternatives to mitigate the impacts of the proposed action. In 1989, a Federal Court of Appeals determined that NEPA required consideration of certain design alternatives; namely, severe accident mitigation design alternatives (SAMDAs). Limerick Ecology Action v. NRC, 869 F.2d 719 (3rd Cir. 1989). The court indicated that "[SAMDAs] are, as the name suggests, possible plant design modifications that are intended not to prevent an accident, but to lessen the severity of the impact of an accident should one occur." Id. at 731. The court rejected the use of a policy statement as an acceptable basis for closing out NEPA consideration of SAMDAs in a licensing proceeding, because, among other things, it was not a rule making, see id. at 739.

Subsequent to the Limerick decision, the NRC issued Supplemental Final Environmental Impact Statements for the Limerick and Comanche Peak facilities that considered whether there were any cost-effective SAMDAs that should be added to these facilities ("NEPA/SAMDA FES Supplements"). On the basis of the evaluations in the supplements (called "NEPA/SAMDA evaluations"), the NRC determined that further modifications would not be cost-effective and were not necessary in order to satisfy the mandates of NEPA.

In recognition of the Limerick decision, the Commission is requiring NEPA consideration in Part 52 licensing of whether there are cost-effective SAMDAs that should be added to a new reactor design to reduce severe accident risk. While this consideration could be done later on a facility-specific basis for each combined license application under Subpart C to Part 52, the Commission has decided that maintenance of design standardization will be enhanced if this is done on a generic basis for each standard design in conjunction with design certification. See SECY-91-229, "Severe Accident Mitigation Design Alternatives for Certified Standard Designs." That is, the Commission has decided to resolve the NEPA/SAMDA question through rule-making at the time of certification in a so called unitary proceeding, rather than in the context of later licensing proceedings

Recently, the NRC Staff expanded the definition of SAMDAs to encompass design alternatives to prevent severe accidents, as well as mitigate them. See NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," (Volume I, p. 5-100). By doing so, the Staff makes the set of SAMDAs considered under NEPA the same as the set of alternatives to prevent or mitigate severe accidents considered in satisfaction of the Commission's severe accident requirements and policies.

1.2 Purpose

The purpose of this technical support document is to provide a basis for determining the status of severe accident closure under NEPA for the ABWR design. The document supports a determination, which could be codified in a manner similar to the format of the Waste

Confidence Rule (10 CFR §51.23), as proposed in amendments to 10 CFR Part 52. These amendments would provide that:

(1) For the ABWR design, all reasonable steps have been taken to reduce the occurrence of a severe accident involving substantial damage to the core and to mitigate the consequences of such an accident should one occur;

(2) No cost-effective SAMDAs to the ABWR design have been identified to prevent or mitigate the consequences of a severe accident involving substantial damage to the core;

(3) No further evaluation of severe accidents for the ABWR design, including SAMDAs to the design, is required in any environmental report, environmental assessment, environmental impact statement or other environmental analysis prepared in connection with issuance of a combined license for a nuclear power plant referencing a certified ABWR design; and,

The evaluation presented in this document is modeled after that found in the Limerick and Comanche Peak NEPA/SAMDA FES Supplements for those facilities. Additional information concerning the radiological risk from severe accidents for those plants is not found in the supplements, but in the FESs for the Limerick and Comanche Peak facilities. That information with respect to the ABWR design is presented in this document. The discussion herein of the radiological risk from severe accidents is based on Chapter 19 of the ABWR SSAR. Attachment A to this document presents the basis for concluding that further modifications to the ABWR design are not warranted in order to reduce the risk of a severe accident through the addition of design features to prevent or mitigate a severe accident. This information originally appeared as Appendix P to Chapter 19 of the SSAR. It was subsequently agreed with the NRC staff that this information should be set forth in an attachment to this document; accordingly, it has been located, in updated form, as Attachment A hereto.

1.3 Description of Technical Support Document

Section 2.0 provides an overview of the radiological risks from severe accidents. Sections 3.0 through 5.0 provide the NEPA/SAMDA analysis. Section 3.0 discusses the methodological approach to the evaluation of SAMDAs under NEPA. Section 4.0 presents the results of the cost-effectiveness evaluation of the potential SAMDA modifications. Section 5.0 presents the conclusions and Section 6.0 the references.

2.0 EVALUATIONS OF RADIOLOGICAL RISK FROM NUCLEAR POWER PLANTS

2.1 Evaluation of SAMDAs Under NEPA and Limerick Ecology Action

Limerick Ecology Action stands for two propositions. First, NEPA requires explicit consideration of SAMDAs unless the Commission makes a finding that the severe accidents being mitigated are remote and speculative. Second, the Commission may not make this finding and dispose of

NEPA consideration of SAMDAs by means of a policy statement. The purpose of evaluating SAMDAs under NEPA is to assure that all reasonable means have been considered to mitigate the impacts of severe accidents that are not remote and speculative. As discussed above, the Commission has indicated that it will resolve the NEPA/SAMDA issue for a new reactor design in the same proceeding, called a unitary proceeding, in which it certifies that design.

The Commission's Severe Accident and Safety Goal policy statements require the Commission to make certain findings about each new reactor design. For evolutionary designs, of which the ABWR is one, this must be done by the Staff in conjunction with FDA approval and by the Commission in conjunction with certification. First, the Commission must find that an evolutionary plant meets the safety goals and objectives; i.e., that the radiological risk from operating an evolutionary plant will be acceptable, meaning that any further reduction in risk will not be substantial.

Second, the Commission must find that all reasonable means have been taken to reduce severe accident risk in the evolutionary plant design. As part of the basis for making this finding, the cost-effectiveness of risk reduction alternatives of a preventive or mitigative nature must be evaluated.

Chapter 19 of the ABWR SSAR demonstrates that these findings can be made for the ABWR design. Given the nature and findings of these severe accident and safety goal evaluations, GE believes that a sufficient basis exists for finding by rule that further consideration of severe accidents, including evaluation of SAMDAs pursuant to NEPA, is neither necessary nor reasonable.

2.2 Cost/Benefit Standard for NEPA Evaluation of SAMDAs

The Limerick decision interpreted NEPA to require evaluation of SAMDAs for their risk reduction potential. In implementing the court's decision, the NRC considered the cost-effectiveness of each candidate SAMDA in mitigating the impact of a severe accident, using the $1,000 per person-rem averted standard. This standard is a surrogate for all off-site consequences.

The basic approach in this study is to rank the SAMDAs in terms of their cost-effectiveness in mitigating the impact of a severe accident. The criterion applied is the $1,000 per person-rem averted standard, which is what the Commission has historically used in distinguishing among and ranking design alternatives, including SAMDAs.

The Commission has used this standard in the context of both safety and NEPA analyses. For example, in the context of safety analysis, the standard has been used to perform evaluations associated with implementation of the Safety Goal Policy Statement; the Severe Accident Policy Statement; and §50.34(f) requirements. In the context of environmental analysis, it has been used in the Limerick and Comanche Peak NEPA/SAMDA FES Supplements; and in the draft Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437).

As indicated above, the Commission is preparing a Generic Environmental Impact Statement for License Renewal of Nuclear Plants. The draft statement, NUREG-1437, makes clear that the use of this standard in the evaluation of severe accident risk reduction alternatives, which include SAMDAs, is acceptable (see NUREG-1437, Vol. I, p. 5-108).

On the basis of these considerations, the cost/benefit ratio of $1,000 per person-rem averted is viewed as an acceptable standard for the purposes of evaluating SAMDAs under NEPA.

2.3 Socio-Economic Risks for Severe Accidents

As discussed above in Section 2.2, the Commission uses the $1,000/person-rem-averted standard as a surrogate for all off-site consequences. See SECY-89-102, "Implementation of Safety Goal Policy." However, Environmental Impact Statements (EIS) for nuclear power plants provide separate, general discussions of the socio-economic risks from severe accidents. In keeping with this precedent, GE is providing a general discussion of socio-economic risks for the ABWR design, based in large measure on the discussion of such risks in NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants."

The term "socio-economic risk from a severe accident" means the probability of a severe accident multiplied by the socio-economic impacts of a severe accident. "Socio economic impacts," in turn, relate to off-site costs. The off-site costs considered in NUREG-1437 (see Vol. I, p. 5-90) are:

- Evacuation costs
- Value of crops or milk, contaminated and condemned
- Costs of decontaminating property where practical
- Indirect costs due to the loss of the use of property or incomes derived therefrom (including interdiction to prevent human injury), and
- Impacts in wider regional markets and on sources of supply outside the contaminated area.

NUREG-1437 estimated the socio-economic risks from severe accidents. The estimates were based on 27 FESs for nuclear power plants that contain analyses considering the probabilities and consequences of severe accidents. For these plants, the off-site costs were estimated to be as high as $6 billion to $8 billion dollars for severe accidents with a probability of once in one million operating years of occurring. Higher costs were estimated for severe accidents with much lower probabilities. The projected cost of adverse health effects from deaths and illnesses were estimated to average about 10-20% of off-site mitigation costs and were not included in the $6-$8 billion dollar estimate.

Another source of costs, which NUREG-1437 indicated could reach into the billions of dollars, was costs associated with the termination of economic activities in a contaminated area, which would create adverse economic impacts in wider regional markets and sources of supplies outside the contaminated area. The predicted conditional land contamination was estimated to be small (10 acres/year at most). (See NUREG-1437, Vol. I, pp. 5-90 through 5-93.)

NUREG-1437 provides the bases for concluding that the socio-economic risks from severe accidents are predicted to be small and the residual impacts of severe accidents so minor that detailed consideration of mitigation alternatives is not warranted. See 56 Fed. Reg. 47,016, 47,019, 47,034 and 47,035 (September 17, 1991).

The socio-economic risks contained in NUREG-1437 are bounding for plants of ABWR design. First, the core damage frequency for plants of ABWR design is 1.6E-7 per year. Thus, no accidents, and hence no off-site costs, are expected at probabilities at or greater than once in one million years. Second, plants of ABWR design meet the safety goals set forth by the NRC. See Section 3.2, below.

3.0 RADIOLOGICAL RISK FROM SEVERE ACCIDENTS IN PLANTS OF ABWR DESIGN

3.1 Severe Accidents in Plants of ABWR Design

Chapter 19 of the ABWR SSAR, "Response to Severe Accident Policy Statement," establishes that the Commission's severe accident safety requirements have been met for the ABWR design, including treatment of internal and external events, uncertainties, performance of sensitivity studies, and support of conclusions by appropriate deterministic analyses and the evaluations required by 10 CFR Part 50.34(f). It also establishes that the Commission's safety goals have been met.

Specifically, the following topics were addressed in Chapter 19 of the ABWR SSAR:

(1) Consideration of the contributions of internal events (Section 19.3), Shutdown events (Section 19.4) and external events (Section 19.4) to severe accident risks, including a seismic risk analysis based on the application of the seismic margins methodology (Appendix 19I);

(2) Identification of the ABWR dominant accident sequences;

(3) Identification of severe accident risk reduction features which were included in the ABWR design to achieve accident prevention and mitigation (addressed in Subsection 19.7.3(2));

Consideration of additional modifications, evaluated in accordance with §50.34(f)(1), is addressed in Attachment A. Chapter 19 concludes that the severe accident requirements of 10 CFR Part 52 (§52.47 (a)(1)(ii), (iv) & (v)) and the Severe Accident Policy Statement have been

met. It also provides a summary of the bases for these conclusions. In particular, Chapter 19 presents a summary of the bases for concluding that the requirements of § 50.34(f) (referenced in §52.47(a)(1)(ii)) have been met, including §50.34(f)(1)(i), which requires "perform[ance of] a plant/site-specific [PRA], the aim of which is to seek such improvements in the reliability of core and containment heat removal systems as are significant and practical and do not impact excessively on the plant." Attachment A presents the bases for concluding that further modifications to the ABWR design are not warranted in order to reduce the risk of a severe accident through the addition of design features to prevent or mitigate a severe accident.

Section 19.6 of the ABWR SSAR addresses how the goals of the Severe Accident Policy Statement have been met for plants of ABWR design. These goals include:

- Prevention of core damage
- Prevention of early containment failure for dominant accident sequences
- Evaluation of the effects of hydrogen generation
- Heat removal to reduce the probability of containment failure
- Prevention of hydrogen deflagration and detonation
- Offsite dose, and
- Containment conditional failure probability.

Specific conclusions concerning severe accidents for plants of ABWR design based on the ABWR SSAR Chapter 19 evaluations are as follows:

(1) Core Damage Frequency. The ABWR core damage frequency was determined to be 1.6E-7 per reactor year in Subsection 19.6.2. The goal was 1E-6 per reactor year.

(2) Conditional Containment Failure Probability. The conditional containment failure probability was shown to be 0.002 in Subsection 19.6.8. This is significantly below the goal of 0.1.

(3) Individual Risk (Prompt Fatality Risk). The prompt fatality risk to a biologically average individual within one mile of an ABWR site boundary was determined to be 1.4E-13 per individual per year in Section 19E.3. This is significantly less than the goal of one tenth of one percent of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. Population are generally exposed. The numerical value of this goal is 3.9E-7 per individual per year (or 0.04 per 100,000 people per year).

(4) Societal Risk (Latent Fatality Risk). The latent fatality risk to the population within 50 miles of an ABWR site boundary was determined to be 9.0E-13 per individual per year in Section 19E.3. This is significantly less than the goal of one tenth of one percent of the sum of the cancer fatality risks resulting from all other causes. The numerical value of this goal is 1.7E-6 per individual per year (or 0.17 deaths per 100,000 people per year).

(5) Probability of Large Off-Site Dose. The probability of exceeding a whole body dose of 25 rem at a distance of one-half mile from a ABWR was determined to be less than 1E-9 per reactor year in Section 19E.3.

Residual radiological risk from severe accidents in plants of ABWR design is summarized in Table A-1 (reproduced here as Table 1). The cumulative exposure risk to the population within 50 miles of a plant of ABWR design is approximately 0.269 person-rem for an assumed plant life of 60 years. This calculation includes the dominant sequences, as well as several sequences that are considered remote and speculative.

3.2 Dominant Severe Accident Sequences for Plants of ABWR Design

In performing the PRA for the ABWR design, GE identified and evaluated many severe accident sequences. For each sequence, the analysis identified an initiating event and traced the accident's progression to its end. For sequences involving core damage, conditional containment failure probabilities and offsite consequences were estimated. After the accident scenarios were binned according to radiological release (source term) parameters, only two dominant cases remained.

The dominant cases are: Case 1 (best estimate core damage sequences that had rupture disk activation); and the NCL case (core damage with normal containment leakage). The residual risks of these two cases can be found in Table 1. The complete radiological consequence analysis of the dominant sequences can be found in Section 19E.3 of the ABWR SSAR.

The probability of occurrence of dominant sequences is greater than 1E-9 per year. Several sequences with occurrence probabilities less than 1E-9 per year were carried through the severe accident analysis in order to determine the sensitivity of plants of ABWR design to certain phenomena and parameters. These sequences were also considered in the SAMDA evaluation for sensitivity purposes.

Sequences with probabilities of occurrence less than 1E-9 were considered remote and speculative. While the Commission has not yet specified a quantitative point at which it will consider severe accident probabilities as remote and speculative, it has indicated that a decision to consider severe accidents remote and speculative would be based upon the accident probabilities and the accident scenarios being analyzed. See Vermont Yankee Nuclear Power Corporation, (Vermont Yankee Nuclear Power Station), CLI-90-07, 32 NRC 129, 132 (1990).

GE believes that the severe accident analysis in Chapter 19 of the ABWR SSAR provides a sufficient basis for the Commission to find that ABWR sequences that are not dominant can be deemed remote and speculative.

3.3 Overall Conclusions from Chapter 19 of the ABWR SSAR

The specific conclusions about severe accident risk discussed above support the overall conclusion that the environmental impacts of severe accidents for plants of ABWR design represent a low risk to the population and to the environment. For the ABWR design, all reasonable steps have been taken to reduce the occurrence of a severe accident involving substantial damage to the core and to mitigate the consequences of such an accident should one occur. No further cost-effective modifications to the ABWR design have been identified to reduce the risk from a severe accident involving substantial damage to the core. No further evaluation of severe accidents for the ABWR design is required to demonstrate compliance with the Commission's severe accident requirements or policy or the safety goal.

4.0 COST/BENEFIT EVALUATION OF SAMDAS FOR PLANTS OF ABWR DESIGN

4.1 SAMDA Definition Applied to Plants of ABWR Design

Attachment A considers whether the ABWR design should be modified in order to prevent or mitigate the consequences of a severe accident in satisfaction of the NRC's severe accident requirements in 10 CFR Parts 50 & 52 and the Severe Accident Policy Statement. The cost/benefit evaluation of SAMDAs to plants of ABWR design uses the expanded definition of SAMDAs set forth in NUREG-1437: design alternatives that could prevent and/or mitigate the consequences of a severe accident.

4.2 Cost/Benefit Standard for Evaluation of ABWR SAMDAs

As discussed in Section 2.2 above, the cost/benefit ratio of $1,000 per person-rem averted is viewed by the NRC and the nuclear industry as an acceptable standard for the purposes of evaluating SAMDAs under NEPA. This standard was used as a surrogate for all off-site costs in the cost/benefit evaluation of SAMDAs to plants of ABWR design. Averted on-site costs were incorporated for SAMDAs that were at least partially preventive in nature[1]. On-site costs resulting from a severe accident include replacement power, on-site cleanup costs, and economic loss of the facility. A more detailed discussion of averted on-site costs can be found in Attachment A. The equation used to determine the cost/benefit ratio is:

$$\text{Cost/benefit ratio} = \frac{\text{Cost of SAMDA implementation MINUS averted on-site costs}}{\text{Reduction in residual risk (person-rem/plant life)}}$$

A plant lifetime of 60 years was assumed to maximize the reduction in residual risk.

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[1]Assessment of averted on-site costs are provided for information only. It is GE's position that the NRC is not required to account for these costs.

4.3 Candidate SAMDAs for the ABWR Design

The complete list of SAMDAs considered for plants of ABWR design is contained in Table 2. This list is also contained in Table A-3 of Attachment A. The SAMDAs are classified according to the following categories:

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

(2) Modification is applicable to the ABWR but not incorporated into the design. These modifications were considered further in Attachment A and the results of the cost/benefit analysis will be presented in this document.

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

(4) Modification is considered as part of another modification listed in the table.

Table 3 lists the advantages and disadvantages of each design alternative that is applicable to the ABWR but not incorporated into the design ("2" classification in Table 2). A detailed discussion of each alternative is contained in Section A.4 of Attachment A.

4.4 Cost Estimates of Potential Modifications to the ABWR Design

Table 4 provides a brief explanation of the estimated costs of each design alternative applicable to the ABWR design. Details of the cost estimation methodology are provided in Section A.1.3.2 of Attachment A. As discussed in Attachment A, rough order of magnitude costs, biased in favor of making a modification, were assigned to each modification. The costs represent the incremental costs that would be incurred in a new plant rather than costs that would apply on a backfit basis.

The estimated costs of design alternatives that are, at least partially, preventive in nature were adjusted for averted on-site costs. This adjustment is included in the cost estimates in Table 4. Design alternatives that are purely mitigative in nature are not assigned any averted on-site costs because these modifications do not significantly affect site clean up cost nor significantly lessen the plant investment loss. Section A.5 of Attachment A discusses the bases for assigning averted on-site costs in detail.

Considerable uncertainties prevent precise cost estimates because design details have not been developed and construction and licensing delays cannot be accurately evaluated. For purpose of this evaluation, all known or reasonably expected costs were accounted for in order that a reasonable assessment of the minimum cost could be obtained. Using a minimum cost favors implementation of a modification. Actual implementation costs are expected to be significantly higher than those used in this evaluation.

4.5 Benefits of Potential Modifications to the ABWR Design

Table 5 summarizes the basis for assigning a benefit to each SAMDA. In general, benefits were estimated from the PRA results of Chapter 19 of the ABWR SSAR by considering which sequences are affected by each modification. Detailed discussion of the method for estimating benefit is provided in Section A.4 of Attachment A. The averted residual risk for each SAMDA is also given in Table 5.

4.6 Cost/Benefit Comparison of SAMDAs

Table 6 summarizes the results of combining the cost estimates from Table 4 with the benefit estimates from Table 5. As is evident from Table 6, none of the SAMDAs requires further evaluation since the cost/benefit standard was not met. The closest design alternative exceeds the criteria by more than a factor of 1000.

On the basis of the small residual risk of a plant of ABWR design, 0.269 person-rem for the entire plant life, a design modification would have to cost $269 or less in order to meet the standard of $1,000 per person-rem averted.

5.0 SUMMARY AND CONCLUSIONS

A reasonable and comprehensive set of candidate SAMDAs relevant to the ABWR design was evaluated in terms of minimum costs, averted on-site costs and potential benefits. A screening criterion of $1,000 per person-rem averted was used to determine which alternatives, if any, were cost-effective. None was found to meet the criterion. In fact, the implementation cost of a SAMDA would have to be less than $269 in order to pass. Given the low residual risk profile of the ABWR design, SAMDAs cannot be reasonably incorporated in a cost-effective manner.

On the basis of the foregoing analysis, further incorporation of SAMDAs into the ABWR design is not warranted. No further screening of SAMDAs is needed and no SAMDAs need be incorporated into ABWR design in satisfaction of NEPA.

6.0 REFERENCES

1. ABWR Standard Safety Analysis Report, 23A6100, Docket No. 52-001, GE Nuclear Energy.

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

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

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

5. Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, August 1991.

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

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

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

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

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

11. Title 10, Code of Federal Regulations, Part 50 and 52.

12. 50FR32138, Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants, August, 1985.

13. 50FR30028, Safety Goals for the Operations of Nuclear Power Plants; Policy Statement, August 1986.

Table 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	0.004
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 2
Severe Accident Mitigation Design Alternatives (SAMDAs)*
Considered for the ABWR Design

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

* SAMDAs include both preventive and mitigative design alternatives

Table 2 (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 2 (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 3
SAMDAs Evaluated Under NEPA for the ABWR

Potential Improvement	Advantages	Disadvantages
1a. Severe Accident EPGs/AMGs	Improved arrest of core melt progress and prevention of containment failure.	None
1b. Computer Aided Instrumentation	Improved prevention of core melt sequences	Additional training
1c. Improved Maintenance Procedures/Manuals	Improved prevention of core melt sequences	Increased documentation cost
2a. Passive High Pressure System	Improved prevention of core melt sequences	High cost of additional system
2b. Improved Depressurization	Improved utilization of Low Pressure systems for prevention of core melt sequences	Cost of additional equipment
2c. Suppression Pool Jockey Pump	Improved prevention of core melt sequences	Cost of additional equipment
2d. Safety Related Condensate Storage Tank	Availability following Seismic events	Design and structural costs
3a. Larger Volume Containment (Double Free Volume)	a. Increases time before containment failure b. Increases time for recovery	a. High cost b. Containment failure not prevented c. Minor radiological benefit since risks dominated by long lived isotopes
3b. Increased Containment Pressure Capability (Sufficient pressure to withstand severe accidents)	a. Eliminates large releases	a. Extreme costs b. High temperature failures not prevented
3c. Improved Vacuum Breakers (Redundant valves in each line)	a. Reduces probability of suppression pool bypass	a. Increased maintenance and equipment costs
3d. Improved Bottom Head Penetration Design	a. Increased time for in-vessel arrest	a. Cost for equipment and analysis
4a. Larger Volume Suppression Pool (Double effective liquid volume)	a. Increases heat absorption capability within containment	a. High cost

Table 3 (Continued)

Potential Improvement	Advantages	Disadvantages
4a. (Continued)	b. Increases time for recovery of systems c. Increases time before containment failure	b. Minor radiological benefit since risks dominated by long lived isotopes
5a. Low Flow Filtered Vent	a. Provides some scrubbing of fission products if head fails b. Reduces containment leakage if movable penetrations are degraded c. low cost	a. Probability of drywell head failure is low relative to the other containment failure modes
7a. Drywell Head Flooding (Firewater crosstie to drywell head area)	Improved prevention of core melt sequences	Additional cost of equipment
8a. Additional Service Water Pump	Improved prevention of core melt sequences	Additional cost of equipment
9a. Steam Driven Turbine Generator	Improved prevention of core melt sequences	Additional cost of equipment
9b. Alternate Pump Power Source	Improved prevention of core melt sequences	Additional cost of equipment
10a. Dedicated DC Power Supply	Additional time before containment overpressure	Marginal benefit
11a. ATWS Sized Vent	a. Provides scrubbing of fission products, except noble gases, which pass through reactor building	a. Uncertain location b. Potential for inadvertent actuation c. Floods reactor building which greatly hinders site recovery after accident d. Potential failure of electrical equipment in reactor building
13a. Reactor Building Sprays (Firewater crosstie for reactor building sprays)	Reduced release of fission products from Reactor Building	Uncertain location and unknown potential consequences from inadvertent actuation

Table 3 (Continued)

Potential Improvement	Advantages	Disadvantages
14a. Flooded Rubble Bed	Prevention of core-concrete interaction affects	Small benefit over passive flooding system.

Table 4
Cost Estimates of SAMDAs Evaluated for the ABWR Under NEPA

Potential Improvement	Cost Basis	Estimated Minimum Cost
1a. Severe Accident EPGs/AMGs	Plant specific procedure preparation beyond generic work by Owners' Group.	$ 600,000
1b. Computer Aided Instrumentation	Software modifications and interface hardw re. Credit for averted onsite cost included.	$ 599,600
1c. Improved Maintenance Procedures/Manuals	Procedure preparation. Credit for averted onsite cost included.	$ 299,000
2a. Passive High Pressure System	System hardware and installation ($1,200,000), Building modification ($550,000). Credit for averted onsite cost included.	$ 1,744,000
2b. Improved Depressurization	Logic, pneumatic supplies, piping and qualification. Credit for averted onsite cost included.	$ 598,600
2c. Suppression Pool Jockey Pump	System hardware and electrical connections. Credit for averted onsite cost included.	$ 120,000
2d. Safety Related Condensate Storage Tank	Structural analysis and material. Credit for averted onsite cost included.	$ 1,000,000
3a. Larger Volume Containment (Double Free Volume)	Double current volume at $1200/ft^3. Analysis not included.	$ 8,000,000
3b. Increased Containment Pressure Capability (Sufficient pressure to withstand severe accidents)	Similar to Larger Volume Containment, but denser rebar and labor required. Assumed 50% higher cost	$ 12,000,000
3c. Improved Vacuum Breakers (Redundant valves in each line)	Eight lines at $10,000 per line	$ 100,000

Table 4 (Continued)

Potential Improvement	Cost Basis	Estimated Minimum Cost
3d. Improved Bottom Head Penetration Design	205 drives at $1,000/drive and $500,000 of analysis	$ 750,000
4a. Larger Volume Suppression Pool (Double effective liquid volume)	Assumed to be the same as Larger Volume Containment	$ 8,000,000
5a. Low Flow Filtered Vent	Hardware and Testing program	$ 3,000,000
7a. Drywell Head Flooding (Firewater crosstie to drywell head area)	Minor valve and piping modification with instrumentation	$ 100,000
8a. Additional Service Water Pump	System hardware, power supplies and support systems. Credit for averted onsite cost included.	$ 5,999,000
9a. Steam Driven Turbine Generator	System hardware, cabling and structural changes. Credit for averted onsite cost included.	$ 5,994,300
9b. Alternate Pump Power Source	400 kW generator at $300/kW. Credit for averted onsite cost included.	$ 1,194,000
10a. Dedicated DC Power Supply	5000 ft^2 building structure addition at $500/$ft^2$ and cabling	$ 3,000,000
11a. ATWS Sized Vent	Instrumentation and cabling in addition to training	$ 300,000
13a. Reactor Building Sprays (Firewater crosstie for reactor building sprays)	Minor valve and piping modification with instrumentation.	$ 100,000
14a. Flooded Rubble Bed	1250 ft^2 of material at $1000/lb	$ 18,750,000

Table 5
Benefit Estimates of SAMDAs*
Evaluated for the ABWR Under NEPA

Potential Improvement	Benefit Basis	Averted Risk Person-REM
1a. Severe Accident EPGs/AMGs	10% improvement in mitigative actions	0.015
1b. Computer Aided Instrumentation	10% improvement in preventative actions	0.01
1c. Improved Maintenance Procedures/Manuals	10% improvement in reliability of RCIC, HPCF, RHR and LPFL	0.016
2a. Passive High Pressure System	90% reliable diverse additional high pressure system	0.069
2b. Improved Depressurization	50% reduction in manual depressurization reliability	0.042
2c. Suppression Pool Jockey Pump	10% improvement in low pressure makeup reliability.	0.002
2d. Safety Related Condensate Storage Tank	Arbitrary selection due to high suppression pool availability.	0.01
3a. Larger Volume Containment (Double Free Volume)	Elimination of drywell head failure sequences	0.15
3b. Increased Containment Pressure Capability (Sufficient pressure to withstand severe accidents)	Elimination of all cases except normal containment leakage (NCL)	0.16
3c. Improved Vacuum Breakers (Redundant valves in each line)	Elimination of Case 2 sequences	0.00004
3d. Improved Bottom Head Penetration Design	50% improvement in in-vessel arrest due to additional available time	0.057
4a. Larger Volume Suppression Pool (Double effective liquid volume)	Elimination of Case 9 sequences involving loss of suppression pool cooling systems	0.0002

* SAMDAs include both preventive and mitigative design alternatives

Table 5 (Continued)

Potential Improvement	Benefit Basis	Averted Risk Person-REM
5a. Low Flow Filtered Vent	Elimination of sequences involving initiation of containment rupture disc	0.014
7a. Drywell Head Flooding (Firewater crosstie to drywell head area)	Reduction in high temperature containment failure sequences and drywell head failure sequences	0.06
8a. Additional Service Water Pump	10% improvement in reliability of RCIC, HPCF, RHR and LPFL due to improved support systems	0.016
9a. Steam Driven Turbine Generator	Improved effective availability of EDG	0.052
9b. Alternate Pump Power Source for high pressure systems	Similar to additional high pressure system. See 2a.	0.069
10a. Dedicated DC Power Supply	Similar to additional high pressure system. See 2a.	0.069
11a. ATWS Sized Vent	Reduction in Case 9 sequences	0.03
13a. Reactor Building Sprays (Firewater crosstie for reactor building sprays)	10% reduction in consequence of sequences involving containment leakage	0.017
14a. Flooded Rubble Bed	Elimination of sequences involving core-concrete interaction.	0.001

Table 6
Comparison of Estimated Costs and Benefits on SAMDAs*
Evaluated for the ABWR Under NEPA

Potential Improvement	Estimated Minimum Cost ($)	Averted Risk Person-rem	Cost-Benefit Ratio ($K per Person-rem)
1a. Severe Accident EPGs/AMGs	$ 600,000	0.015	$ 40,000
1b. Computer Aided Instrumentation	$ 599,600	0.01	$ 59,600
1c. Improved Maintenance Procedures/Manuals	$ 299,000	0.016	$ 18,700
2a. Passive High Pressure System	$ 1,744,000	0.069	$ 25,270
2b. Improved Depressurization	$ 598,600	0.042	$ 14,250
2c. Suppression Pool Jockey Pump	$ 119,800	0.002	$ 59,900
2d. Safety Related Condensate Storage Tank	$ 1,000,000	0.01	$ 100,000
3a. Larger Volume Containment (Double Free Volume)	$ 8,000,000	0.15	$ 53,300
3b. Increased Containment Pressure Capability (Sufficient pressure to withstand severe accidents)	$ 12,000,000	0.16	$ 75,000
3c. Improved Vacuum Breakers (Redundant valves in each line)	$ 100,000	0.00004	$ 2,500,000
3d. Improved Bottom Head Penetration Design	$ 750,000	0.057	$ 13,160
4a. Larger Volume Suppression Pool (Double effective liquid volume)	$ 8,000,000	0.0002	$ 40,000,000
5a. Low Flow Filtered Vent	$ 3,000,000	0.014	$ 214,300
7a. Drywell Head Flooding (Firewater crosstie to drywell head area)	$ 100,000	0.06	$ 1,700

* SAMDAs include both preventive and mitigative design alternatives

Table 6 (Continued)

Potential Improvement	Estimated Minimum Cost ($)	Averted Risk Person-rem	Cost-Benefit Ratio ($K per Person-rem)
8a. Additional Service Water Pump	$ 5,999,000	0.016	$ 375,000
9a. Steam Driven Turbine Generator	$ 5,994,300	0.052	$ 115,300
9b. Alternate Pump Power Source	$ 1,194,000	0.069	$ 17,300
10a. Dedicated DC Power Supply	$ 3,000,000	0.069	$ 43,500
11a. ATWS Sized Vent	$ 300,000	0.03	$ 10,000
13a. Reactor Building Sprays (Firewater crosstie for reactor building sprays)	$ 100,000	0.017	$ 5,900
14a. Flooded Rubble Bed	$ 18,750,000	0.001	$ 18,750,000