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ATTACHMENT 2

Benefit Cost Analysis of Enhancing Combustible Gas Control Availability at Ice Condenser and Mark III Containment Plants

Draft Letter Report

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1. BACKGROUND

SECY-00-0198 [1] presented a risk-informed alternative to the current regulation in 10 CFR 50.44 that deals with the threat of combustible gases to the integrity of the containment in light-water reactor nuclear power plants. In particular, risk insights developed in SECY-00-0198 indicated that station blackout (SBO) accident sequences represented a threat to containment integrity in BWR plants with a Mark III containment and PWR plants with an ice condenser containment. These pressure-suppression containments were mandated under 50.44 to install combustible gas igniters that would burn the hydrogen evolved via the metal-water reaction during severe core melt accidents. The igniters are designed to burn the evolved hydrogen at relatively low concentrations and thus reduce the potential for large deflagrations or detonations that could challenge containment integrity. However, the igniters need AC power to operate and would not be available in an SBO accident. Thus, enhancements that would allow combustible gas control during SBO accidents could reduce the risk from combustible gases. The issue to be analyzed is whether such enhancements would be cost beneficial, i.e., whether the averted risk, evaluated in terms of the expected value of averted costs, would be greater than the direct cost of implementation of the enhancement.

Under Task 4 of the Statement of Work (SOW) for JCN W-6224 Brookhaven National Laboratory (BNL) is providing an estimate of the benefit values associated with making enhancements to the combustible gas control systems in PWR plants with ice condenser containments and BWR plants with Mark III containments. This estimate of benefit values is the subject of the present report. The enhancement would make combustible gas control available during SBO accidents, and this could be accomplished in a number of ways. BNL is not considering the implementation costs of any enhancements (these are calculated elsewhere), and therefore this report is silent on the particular means by which the combustible gas control will be accomplished.

As called for in the Statement of Work, this report discusses what averted costs should be included in the analysis and how they should be treated. Avoided (offsite) person-rem and avoided (offsite) property damage are mentioned as potential benefits in the Task Action Plan for Generic Safety Issue 189. The Statement of Work indicates that the analysis should include all types of averted costs in accordance with NUREG/BR-0058, Rev. 3 [2] and the estimation and evaluation of values should comply with Section 4.3 of NUREG/BR-0058, Rev. 3.

2. APPROACH

As stated in the previous Section, this report provides an estimate of the benefit accrued from enhancing the currently installed combustible gas control systems in PWR nuclear power plants with ice condenser containments and BWR plants with Mark III containments. The current systems are not available during SBO accident sequences, and the enhancement whose benefit is being estimated would allow combustible gas control during SBO sequences. The analysis presented here is concerned only with the value of the benefit obtained from such an enhanced system, not the details involving what changes, additional systems, etc. are implemented to achieve the enhancements. Note that this means that any negative benefit associated with the installation of the enhancement, such as worker exposure during installation, is not considered here, and is dependent on the particular means chosen to implement the enhancement. It is expected that items such as worker exposure would be included in the estimates for the cost of the enhancement, which is being estimated elsewhere. The benefit calculated here is expressed in terms of the risk averted as a result of the enhancement, stated in terms of current dollars.

In terms of current dollars the averted risk for the enhancement in question, where risk equals likelihood times consequences, is calculated for this study using the following steps:

1. The frequencies of the affected accident sequences are determined in terms of frequency per reactor year. For the combustible gas control enhancement the applicable sequences are the SBO sequences.
2. The change in conditional containment failure probability for each relevant containment failure mode as a result of the enhancement is determined.
3. The consequences associated with each containment failure mode are determined. If the consequences are in terms of person-rem (such as for health effects) for a population density estimated for a previous year, the person-rem are adjusted by a factor which reflects the estimated change in population density from the year of the calculation to the current year. The person-rem are then monetized by a dollar/person-rem factor. If the consequences are in dollars estimated for a previous year (such as for property damage) the dollars are converted to current dollars with an appropriate inflation factor.
4. The product of the conditional containment failure modes times their consequences without the enhancement are summed, as is the product of the conditional containment failure modes times their consequences with the enhancement in place.
5. The sum obtained with the enhancement in step 4 is subtracted from the sum without the enhancement. The difference is multiplied by the frequency determined in Step 1. The result is the averted risk, in terms of dollars per reactor year.
6. A present value calculation is performed using the result of Step 5, and the remaining years of assumed plant life, to obtain the benefit for the life of the plant in terms of current dollars.

The benefit analysis carried out here are in accordance with the guidance on estimation of values provided in NUREG/BR-0058 and in NUREG/BR-0184 [3]. In particular, in conformance with

Section 4.3.2 of NUREG/BR-0058, the estimation of value attributes related to the enhancement considered here include:
- reductions in public and occupational radiation exposure,
- averted offsite property damage, and
- averted onsite impacts

Additional potential value attributes listed in NUREG/BR-0184 are: enhancements to health, safety, or the natural environment; savings to licensees; savings to NRC; savings to State, local, or tribal governments; improved plant availability; promotion of the efficient functioning of the economy; and reductions in safeguards risk. These were not considered in the present analysis because they were deemed to be either not applicable or would have a negligible impact on the results.

In the present analysis, again as called for in NUREG/BR-0058:
- changes in public health and safety from radiation exposure and offsite property impacts are examined over a 50 mile distance from the plant site,
- the recommended dollar conversion factor of $2000 per person-rem is used and used only to capture the health effects attributable to radiological exposure,
- offsite property damage consequences are addressed separately and treated as an added factor in the value assessment,
- estimated values are expressed in monetary terms whenever possible and expressed in constant dollars from the most recent year for which price adjustment data are available,
- all values and impacts are expressed on a present worth basis for lifetime benefits, and
- a discount rate of 7% is used for the present-worth calculation, with a sensitivity analysis at a 3% discount rate.

NUREG/BR-0058 also calls for value estimates to be based on mean or 'expected value' calculations when possible, and to consider uncertainties. However, NUREG/BR-0058 also recognizes that the level of detail available from data sources may not allow expected value estimates to be used, and allows sensitivity analyses, including hypothetical best and worst case values, to be used in lieu of uncertainty analyses. The enhancement under consideration here carries with it no potential reduction in core-damage frequency, only in containment failure probability. The emphasis of the evaluation is on containment performance, i.e., the reduction in the conditional containment failure probability when combustible gas control is available during SBO events. Estimating changes in containment failure probability are especially uncertain and involve sparse data. In addition, the analysis here relies on calculations from previous analyses carried out for other purposes. Therefore, the benefit estimate calculated here is not always based on expected value, and uses sensitivity estimates rather than uncertainty analysis.

It should also be noted that NUREG/BR-0058 calls for a safety goal evaluation, using certain safety goal screening criteria relative to the enhancement, under some situations. However, as stated at the end of Section 3.3.2 of NUREG/BR-0058, "...the safety goal screening criteria described here do not address issues that deal only with containment performance. Consequently, issues that have no impact on core damage frequency (delta CDF of zero) cannot be addressed with the safety goal screening criteria." No safety goal evaluation has been carried out in the present analysis.

As noted above, the results presented in this report were calculated based on information gathered from various existing analyses. The severe accident progression scenarios, including conditional containment failure probabilities, are based primarily on several sources. These are (1) the NUREG-1150 [4] work, including the descriptions and values reported in the NUREG-1150 supporting documents for the Sequoyah [5] and the Grand Gulf [5] analysis, (2) NUREG/CR-6427, "Assessment of the DCH Issue for Plants with Ice Condenser Containments" [7], and (3) NUREG/CR-xxxx, "Basis Document For Large Early Release Frequency (LERF) Significance Determination Process (SDP) [8]. It should be noted that all these references, with the exception of Reference 7and Reference 8 are included in NUREG/BR-0184, the Regulatory Technical Analysis Handbook, as appropriate references for value impact analysis. References 7 and 8 are too new to be included in NUREG/BR-0184. SBO frequencies used here are those reported in the Individual Plant Examinations (IPE) and in the IPE for External Events (IPEEE) for the plants under discussion. For the ice condenser plant discussed, Catawba, the updated IPE values were used. The value of offsite property damage and offsite person-rem are taken mostly from an earlier BNL study, NUREG/CR-6349 [10]. The exception are the values of offsite person-rem conditional on different modes of containment failure (early, late, no) for Catawba, which is taken from the Catawba IPE update. Discussion provided on the values of onsite health costs and onsite property damage costs are based on the information provided in Burke and Aldrich [11], and in NUREG/BR-0184 [3]. Updates of population densities are based on population projections found in the Final Safety Analysis Reports of the plants examined, not on actual current population statistics.

The remainder of this report is organized as follows: Section 3 below provides a discussion of averted costs, i.e., benefits of providing means (such as installing a backup power supply for the hydrogen igniters) to allow combustible gas control to function during SBO accidents. The various categories of applicable costs, including offsite health costs, offsite property damage costs, and the onsite costs, including employee health costs and onsite cleanup and decontamination costs for accidents that fail containment, are discussed and summarized. Sources of data for the various categories of costs are identified and referenced, where relevant.

Section 4 presents the results obtained for a PWR ice condenser plant, Catawba, and includes a sensitivity analysis using Sequoyah fragility values. Various cases are considered, including assumptions about late containment failure, the inclusion of different categories of avoided costs, and discount rates.

Section 5 presents similar results for a BWR Mark III plant, Grand Gulf. In addition, some of the Grand Gulf results are extrapolated to the other BWR Mark III plants in this Section to obtain a more generic estimate of the benefit that could be obtained for BWR Mark III plants from a combustible gas control system that is operational during station blackout.

In Section 6 the results obtained are discussed, and some reasons for the differences between the PWR ice condenser results and the BWR Mark III results are provided.

3. DISCUSSION OF AVERTED COSTS

The averted costs arise from the averted consequences of reactor accidents. In general, there are several categories of offsite consequences that follow the occurrence of an accident that begins with core melt and progresses to containment failure and the release of radioactive material from the reactor core to the environment: (1) acute effects of large radiation doses generally in excess of 200 rem to offsite populations in the initial phases of the release that can lead to early health effects (early fatalities or early injuries), (2) chronic effects of lower radiation doses that can lead to cancer induction over long periods of time and cause latent cancer fatalities or injuries, and (3) the offsite costs of emergency response and long-term protective actions that are taken to protect the public from radiation.

The risk metrics used to estimate offsite acute and chronic health effects are early (or prompt) fatalities and early injuries and latent cancer fatalities and injuries, respectively. Acute health effects arise soon after exposure via the inhalation, cloudshine, and groundshine pathways. As noted above, acute doses in excess of about 200 rem whole body can lead to early fatality. Chronic effects of long-term exposure are due to three pathways: groundshine from living on contaminated land, inhalation from breathing resuspended radioactive material, and ingestion of contaminated food or water. Dose models embedded in consequence codes predict the dose to a population living in a certain spatial segment based on the characteristics of the release (magnitude, timing, and energy), sampling over the weather at the site, and on any counter-measures that are taken. Dose-response models then are used to predict the early fatalities and latent cancers based on the extent of exposure.

The counter-measures that are taken to protect the offsite public from the released material involve costs that depend on the nature of the protective measures and their duration. The sum of these costs are usually called the "offsite property damage costs." In the early stages of an accident, costs are associated with emergency evacuation and relocation. These will depend on the number of people affected and the duration of the emergency period. Evacuated individuals will generally remain relocated and will not be allowed to return until the projected groundshine dose is below the protective action guideline value for at least the duration of the emergency phase. In the longer term, people will remain relocated and thus continue to incur costs associated with temporary relocation, depending on the doses from the resuspension inhalation and groundshine pathways. Over a time period of several years following the release, a decision has to be made whether contaminated property, such as farmland and non-farm areas, should be decontaminated or permanently interdicted. The consequence code MACCS, for example, models three successively higher levels of decontamination, each associated with respectively higher costs. If the decontamination efforts plus natural decay cannot reduce the projected long-term dose to an individual below a specified value, or the cost of decontamination exceeds the value of the farmland or non-farm property, then the property or farmland is interdicted and its discounted value is added to the other offsite costs. If people must be permanently resettled because their property is condemned, further costs are added based on estimates of personal income loss and moving costs for a transitional period. Finally, costs are associated with the disposal of contaminated farm products and restrictions on crop, dairy, and meat production from contaminated farmland. Dose criteria associated with protective action guidelines on ingestion of contaminated food are used to determine whether farm products should be discarded.

In value-impact analysis, the averted costs that are ascribed to the averted offsite health impacts are calculated based on the monetary equivalent of averted collective dose (person-rem) at the current NRC-recommended value of $2000 per averted person-rem. They are not calculated based on assigning a monetary value to the early fatality and latent cancer fatality risk metrics. The figure of $2000 per person-rem is assumed to subsume the early and latent fatalities, as well as severe hereditary effects. To obtain the total averted offsite cost (or benefit) of a proposed action, the offsite property damage costs that arise from the long-term protective actions, as discussed above, are added. It should be noted that the costs of long-term protective actions depend on the criteria selected for the allowable dose levels of long-term exposure of the affected population, i.e., there is a trade-off between a higher dose limit/lower cost and a lower dose limit/higher cost. This feature of benefit-cost analysis is discussed at some length in Reference 10.

In addition, there are also potential onsite consequences that are associated with severe accidents. Onsite consequences are not generally modeled in consequence codes, such as MACCS, and NUREG/BR-0058 cautions that particular care should be taken in estimating dollar savings derived from averting onsite costs, since values are often difficult to estimate accurately. There have been a limited number of studies which have attempted to estimate onsite costs. In particular, Strip [12] looked at the impact on worker health, including fatalities and injuries of severe accidents involving core melt and vessel breach. Burke and Aldrich [11] estimated the cleanup and decontamination costs for both degraded core accidents, such as TMI-2, and severe accidents involving vessel breach and possibly containment failure. In the latter case, it is estimated that the cost of cleanup could be significantly higher due to the additional cost of working in high-radiation environments significantly higher than those experienced at TMI-2. A “best estimate” cleanup cost of $1.7E09 (in 1982 dollars) was estimated by Burke and Aldrich for this latter type of accident, compared to half that cost for a TMI-2 type of accident. However, the discussion in Burke and Aldrich implies that the major component of the additional cost is due to the clean-up work carried out in the higher radiation environments due to vessel failure. Since combustible gas control systems cannot reduce the likelihood of vessel breach, only the likelihood of containment failure, the above difference in cleanup costs does not seem to apply for the case considered in this report. There is no explicit discussion in Burke and Aldrich on the difference between the consequences from accidents that lead to core damage but do not cause containment failure, and those that do involve containment failure.

NUREG/BR-0184, the Regulatory Analysis Technical Evaluation Handbook, does provide some data on occupational exposure that can be used for estimates possibly applicable for the case under consideration here. Section 5.7.3 of this handbook discussed the immediate dose and the long term dose workers may receive during cleanup of a severe accident. For the long term dose three accident scenarios are considered. The difference between Scenario 2 and 3 appears to be applicable for the case under consideration. Scenario 2 simulates the TMI-2 accident: 50% of the fuel cladding ruptures, some fuel melts, and the containment is extensively contaminated, but there is minimal physical damage. In Scenario 3 all fuel cladding ruptures, there is significant fuel melting and core damage, the containment is contaminated and physically damaged, and the auxiliary building undergoes some contamination. The best estimate long term total exposure for Scenario 2 is 7,640 person-rem, while that for Scenario 3 is 19,760 person-rem. Assuming that the immediate dose is roughly the same for both scenarios, the difference in exposure between the two scenarios is about 12, 000 person-rem. It is not clear from the discussion in NUREG/BR-0184 how much of the additional exposure was due to the containment failure alone, and how much was due to the greater core damage postulated for Scenario 3, and therefore the numbers must be viewed with caution for a situation where the enhancement only addresses containment failure. However, since Scenario 3 explicitly mentions containment failure and the resulting auxiliary building contamination, it would seem that containment failure plays a significant role in the elevated exposure levels of Scenario 3.

It would also seem reasonable to assume that containment failure would have an impact on onsite property damage, since plant equipment and structures outside of containment would be contaminated in such an accident, while remaining relatively uncontaminated if the containment remains intact. Even if the plant is assumed to be unusable after a severe accident with or without containment failure, the net value of the equipment for resale or reuse at another site would be significantly impacted by contamination. Therefore, there would appear to be some benefit from averted onsite property damage when containment failure can be prevented. However, these costs may be small compared to the offsite costs in many cases. But if there is more than one unit at a site, these considerations may be important. For example, Unit 1 at TMI was put back into service subsequent to the accident at Unit 2 after a number of years. Had the TMI-2 containment failed and contaminated the other unit, the start-up of the other unit would most likely have been significantly further delayed or not happened at all. Of course, the Chernobyl accident, where there was no containment, did not prevent the other units on site from restarting eventually, but given the conditions under which these units were restarted, such a restart would have been unlikely in the United States under similar conditions.

The benefit that avoidance of containment failure can have for averting onsite costs associated with a second unit on the same site is difficult to estimate, since it can vary so widely depending on the scenario postulated. For example, replacement power costs, which are the dominant onsite costs, would only occur if it is assumed that contamination resulting from containment failure results in incremental downtime for the accident-free reactor. It is interesting to note that in the case of Three Mile Island, the accident-free unit remained unavailable for about six years even though it was physically unaffected by the accident at its sister unit. Assuming there was increased unavailability, the magnitude of the replacement power cost would be highly sensitive to when in the reactor's remaining life the accident occurred and the actual number of years of additional unavailability. Given the highly speculative nature and large uncertainties inherent in this type of cost analysis, replacement power considerations will not be included in the total averted cost estimates developed herein.

Among the plants analyzed in this report, the PWR ice condenser plants are all dual nuclear unit sites (Watts Bar is a single unit but is not one of the plants considered here), while the BWR Mark III plants are all single nuclear unit sites.

Finally, it should be noted that the difference in onsite costs between core melt accidents that involve containment failure, and those that do not, does not appear to have been addressed very well in the literature. A study focusing on this difference could be helpful.

To summarize, the various categories of averted costs that are used in the analysis presented below include:

(1) Offsite Health Costs: These are based on the 50-mile radius offsite population dose (person-rem) associated with the release, conditional on the failure mode, and monetized at $2000/person-rem.

(2) Offsite Property Damage Costs: These are based on the 50-mile offsite costs reported in Reference 10. The 1990 costs shown in Reference 10 have been updated to 2002 dollars using the inflation calculator provided on the Bureau of Labor Statistics (BLS) website [13].

(3) Onsite Employee Health Costs: A value of 20,000 person-rem is used here for occupational exposure for severe accidents with containment failure. A value of 8,000 person-rem is used for occupational exposure for severe accidents without containment failure. These values are based on the results found in NUREG/BR-0184 and discussed above. The person-rem are monetized at $2000/person-rem.

The present worth calculation, i.e., the discounted value of the benefit of the enhancement over the remaining lifetime of the plant (assumed to be 40 years for the Catawba, Sequoyah, and Grand Gulf plants, taking a life extension of 20 years into account) is calculated using the expression $\int \exp(-rt)dt$, where r is the discount rate. Calculations have been performed for the base case of r = 7% and the alternative sensitivity case or r = 3% as recommended in Section 4.3 of NUREG/BR-0058.

4. RESULTS FOR A PWR ICE CONDENSER PLANT

The benefits accrued from an enhanced combustible gas control system, i.e., one which remains functional during SBO sequences are calculated below for the Catawba plant. In addition, a sensitivity calculation using the Catawba SBO frequencies but the Sequoyah containment fragility is also carried out. The reason for including Sequoyah parameters in a sensitivity calculation is twofold: Sequoyah has a much lower containment fragility than Catawba, and there is a significant amount of information regarding accident progression and hydrogen combustion available for Sequoyah as a result of the NUREG-1150 studies. Since no external event SBO frequencies are available for Sequoyah a stand-alone Sequoyah analysis was not carried out. Instead the Catawba SBO frequencies were used for both plants. The benefit calculation is carried out below, following the steps found at the beginning of Section 2:

Step 1 - Frequencies of SBO sequences

For Catawba, from Reference 9 (as quoted in Reference 14), the total SBO frequency is 2.5E-5 per reactor year (ry) with 1.5E-5/ry from internal events and 1.0E-5/ry from external events.

Step 2 - Change in conditional containment failure probability

The conditional early containment failure probabilities due to hydrogen combustion events during SBO in ice condenser containments is based on the results of NUREG/CR-6427 [7], which is a recent, detailed study of severe accident phenomena in ice condenser containment plants, focused on the direct containment heating issue, carried out by Sandia National Laboratories(SNL). The study considered all the significant early containment failure mode issues examined in NUREG-1150.

In assessing the containment response to severe accidents, the study used the CONTAIN code that been extensively validated for predictions of containment response to steam sources and non-DCH related hydrogen combustion deflagration. The results of the CONTAIN calculations indicate that the ice condenser containment integrity is not challenged except for SBO (no igniters available) accident sequences that are associated with high hydrogen concentrations. The conditional early containment failure probabilities based on the results of NUREG/CR-6427 are shown in Table 1 below for Catawba and Sequoyah.

Table 1: Conditional Early Containment Failure Probability at Catawba and Sequoyah

Plant	Cond. Early Cont. Failure Prob. from Hydrogen Combustion
Catawba	0.29
Sequoyah	0.97

As requested in the statement of work for this task, no credit for random ignition of pre-existing hydrogen is taken in this analysis. Hence, the early failure probabilities used in this study will be as shown above. It will be further assumed that the enhanced combustible gas control system will be fully effective in reducing the early failure probability to zero. There is a possibility that even if early failure is averted, the accident could proceed to late failure from over-pressurization late in the accident sequence due to steam and non-condensible gases. The presence of functional combustible gas control is not likely to make much difference to the conditional probability of late failure. However, recovery of AC power late in the accident, assuming early failure is prevented, could lead to other systems becoming functional that would allow containment to remain intact. Hence, two possibilities are analyzed: (1) there is no late failure and containment remains intact if early failure is prevented, and (2) late failure occurs even if early failure is prevented.

There is another early containment failure mode, direct impingement by molten core debris of the containment wall adjoining the seal table room, that is assigned a small conditional probability of 0.018 in the NUREG/CR-6427 study. This failure mode, besides having a small conditional probability of occurrence, is independent of hydrogen combustion phenomena and therefore is ignored in this study.

The pertinent conditional containment failure probability cases for Catawba and Sequoyah are summarized in Table 2.

Table 2 Conditional Containment Failure Probabilities for Catawba and Sequoyah

	Gas Control	**Late Failure**	**CPEF**	**CPLF**	**CPNF**
Catawba	no	no	0.29	0	0.71
	yes	no	0	0	1.0
	no	yes	0.29	0.71	0
	yes	yes	0	1.0	0
Sequoyah	no	no	0.97	0	0.03
	yes	no	0	0	1.0
	no	yes	0.97	0.03	0
	yes	yes	0	1.0	0

Where: CPEF is conditional probability of early failure
CPLF is conditional probability of late failure
CPNF is conditional probability of no failure

Step 3 - Consequences associated with each containment failure mode

Offsite consequences for releases representative of both early and late containment failure are presented in Table 3 below for the Catawba and Sequoyah. Offsite person-rem estimates are based on the data provided in References 9 and 10, respectively, while the offsite property costs from Reference 10 for Sequoyah are used for both Catawba and Sequoyah. These results are conditional consequences (i.e., conditional on occurrence of the release) out to 50 miles from the plant and include offsite population dose (person-rem) and offsite damage costs. The release categories for Sequoyah, i.e., source terms, are based on the results presented in the NUREG-1150 study. The offsite property damage costs for Catawba are assumed to be the same as those for Sequoyah for the relevant containment failure mode. It is assumed that there are zero offsite consequences associated with no containment failure.

Two values for offsite person-rem are shown for Sequoyah. The 1990 values are based on Reference 10. The 2000 values have been updated based on the change in population density from 1990 to 2000 as estimated in the Sequoyah Final Safety Analysis Report. The change is an increase of about 9%. The Catawba person-rem are based on the 2001 update of the IPE and presumably reflect current population density.

Two values are also shown for the offsite property damage costs. The first is taken from Reference 10 and is in 1990 dollars. The second updates the 1990 dollar values to current year dollars based on the price inflation calculator (approximately 36% over the 1990-2002 period) of the U.S. Bureau of Labor Statistics (www.bls.gov).

Table 3: Offsite Consequences (50-mile radius) of Containment Failure Releases at Selected Plants

Plant	Fail Mode	Offsite Person-rem 1990	Offsite Person-rem 2000	Offsite Health Effects $	Offsite Property 1990$	Offsite Property 2002$
Catawba	Early	NA	1.4E+06	2.8E+09	4.83E+09	6.57E+09
Catawba	Late	NA	9.0E+05	1.80E+09	5.03E+08	6.84E+08
Sequoyah	Early	2.82E+06	3.07E+06	6.14E+09	4.83E+09	6.57E+09
Sequoyah	Late	5.20E+05	5.67E+05	1.13E+09	5.03E+08	6.84E+08

The sequence used for Sequoyah for early failure consequences is SEQ-11-2 from Reference 5 which is also used in Reference 10. This is a typical early failure sequence with about 88% of noble gases, 29% of iodine, 26% of cesium, and 21% of tellurium released. The late failure sequence used for Sequoyah is SEQ-06-1 from Reference 5 and Reference 10. This is a typical late failure sequence with all noble gases, about 8% of iodine, 1% of cesium and less than 1% of tellurium released. The discussion in Reference 5 indicates that in both these sequences the ice bed was functional and had some mitigating effect on the releases. It should be noted that the (1990) consequences reported in Reference 10 differ somewhat from those reported in the NUREG-1150 reports, even though Reference 10 is based on the NUREG-1150 analyses. This is primarily because in the NUREG-1150 study the consequence analysis was carried out using Version 1.5.11 of the MACCS code, while the consequences in Reference 10 were recalculated with Version 1.5.11.1 of MACCS. This later version explicitly incorporates the higher BEIR V risk coefficient for the latent cancer-dose relationship while the earlier version of MACCS used the BEIR III risk coefficient. In addition, a few input errors in the NUREG-1150 MACCS calculations were corrected for the recalculations of Reference 10.

The Catawba sequences are from the updated Catawba IPE, which could not be examined directly for this study. Therefore the character of the source terms cannot be provided here. It is interesting to note that for early failures the Catawba offsite person-rem are half those for Sequoyah, while for late failures the Catawba values are almost two times those for Sequoyah.

Onsite health consequences are calculated assuming 20,000 person-rem occupational exposure, or \$4E+07 after using the \$2000/person-rem factor, for both early and late containment failures, and 8,000 person-rem, or \$1.6E+07, for no containment failure. Onsite property damage is not included as per the discussion in Section 3.

Step 4 - Summation of conditional containment failure modes and their consequences

The results of the summation of conditional containment failure modes and their consequences for the various cases outlined above are shown in Table 4.

Table 4: Summation of Offsite Costs and Onsite Health Effect Costs

Plant	Gas Control	Late Failure	Total Offsite Cost ($) conditional on SBO	On-site Health Effects Cost ($) conditional on SBO
Catawba	no	no	2.73E+09	2.30E+07
	yes	no	0	1.60E+07
	no	yes	4.49E+09	4.00E+07
	yes	yes	2.48E+09	4.00E+07
Sequoyah	no	no	1.24E+10	3.93E+07
	yes	no	0	1.6E+07
	no	yes	1.25E+10	4.00E+07
	yes	yes	1.81E+09	4.00E+07

Step 5 - Subtraction of costs and multiplication by frequency

The calculation in Step 4 was made with and without the gas control system present. The control system is assumed to be fully effective in preventing early failure (but not late failure). The difference between the cases where gas control is 'yes' and the cases where gas control is 'no,' when multiplied by the SBO frequency, represents the averted offsite cost on a per reactor-year basis.

The results are summarized for Catawba and Sequoyah for accidents with and without late failure in Table 5 below. Results are broken out by internal event related costs, external event related costs and total costs. Costs are divided into offsite and onsite costs, as well as total costs. Offsite costs are the dominant contributor in all cases. Costs are in 2002 dollars.

Step 6 - Calculation of lifetime benefit

Multiplication by the present worth factor, based on the discount rate selected and plant lifetime remaining, yields the total averted offsite cost, or benefit, over the plant's lifetime. Results for a lifetime of 40 years for a discount rate of 7% and 3% are shown in Tables 6 and 7 respectively. This step completes the analysis.

The results are dominated by the offsite costs. For Catawba, assuming no late failure, the total averted offsite costs amount to $914K for a 7% discount rate and $1.59M for a 3% discount rate. Assuming that late failure does occur, the averted offsite costs are less, $673K for a 7% discount rate and $1.17M for a 3% discount rate. For an ice condenser containment with the fragility of Sequoyah, the averted offsite costs are significantly higher due to the much greater conditional probability of early failure resulting from a hydrogen combustion event. With a 7% discount rate, and no late failure, averted offsite costs are $4.17M and $7.24M with a 3% discount rate. With late failure a 7% discount rate results in a $3.58M benefit, while the 3% rate yields a $6.21M benefit.

Inclusion of averted onsite costs produces a negligible change in all cases. However, since the ice condenser containments considered here are dual units, the discussion of Section 3 regarding onsite costs related to the effect of containment failure of the damaged unit on the undamaged unit may apply. This means that for the case where containment failure is averted, the onsite averted costs could be significantly higher than estimated here, under certain conditions, as discussed in Section 3. However, if late containment failure occurs, the benefit from averted onsite costs is likely to be very small. This is due to the assumption that the main driver is the additional cost of site cleanup and decontamination of the undamaged unit from failure of containment of the damaged unit. This cost is assumed to be the same whether containment fails early or late, thus combustible gas control will offer very little benefit if late failure occurs.

It should also be pointed out that the inclusion of averted costs from external events assumes that the combustible gas control system is designed to withstand the external event. For example, the control system would have to be seismically qualified to the appropriate g level to withstand an earthquake of a certain magnitude. Obviously this would increase the cost of the combustible control system above that designed to deal only with internal events.

Table 5: Cost Summary per reactor year

	SBO frequency	Total Averted Offsite Costs $ per reactor year	Averted Onsite Health Effects Costs $ per reactor year	Total Averted Costs $ per reactor year
Catawba No Late Failure				
Internal Events	1.5E-5	4.09E+04	1.04E+02	4.10E+04
External Events	1.0E-5	2.73E+04	6.96E+01	2.73E+04
Total	2.5E-5	6.82E+04	1.74E+02	6.83E+04
Sequoyah No Late Failure				
Internal Events	1.5E-5	1.86E+05	3.49E+02	1.87E+05
External Events	1.0E-5	1.24E+05	2.33E+02	1.87E+05
Total	2.5E-5	3.11E+05	5.82E+02	1.87E+05
Catawba with Late Failure				
Internal Events	1.5E-5	3.01E+04	0.	3.01E+04
External Events	1.0E-5	2.01E+04	0.	2.01E+04
Total	2.5E-5	5.02E+04	0.	5.02E+04
Sequoyah with Late Failure				
Internal Events	1.5E-5	1.60E+05	0.	1.60E+05
External Events	1.0E-5	1.07E+05	0.	1.07E+05
Total	2.5E-5	2.67E+05	0.	2.67E+05

Table 6: Lifetime benefit base case (7% discount rate)

Discount Rate of 7 %	Lifetime Averted Offsite Costs 2002$	Lifetime Averted Onsite Health Effects Costs 2002$	Lifetime Total Costs Averted 2002$
Catawba No Late Failure			
Internal Events	5.49E+05	1.40E+03	5.50E+05
External Events	3.66E+05	9.34E+02	3.67E+05
Total	9.14E+05	2.33E+03	9.17E+05
Sequoyah No Late Failure			
Internal Events	2.50E+06	4.69E+03	2.51E+06
External Events	1.67E+06	3.12E+03	1.67E+06
Total	4.17E+06	7.81E+03	4.18E+06
Catawba with Late Failure			
Internal Events	4.04E+05	0.	4.04E+05
External Events	2.69E+05	0.	2.69E+05
Total	6.73E+05	0.	6.73E+05
Sequoyah with Late Failure			
Internal Events	2.15E+06	0.	2.15E+06
External Events	1.43E+06	0.	1.43E+06
Total	3.58E+06	0.	3.58E+06

Table 7: Lifetime benefit sensitivity case (3% discount rate)

Discount Rate of 3 %	Lifetime Averted Offsite Costs 2002$	Lifetime Averted Onsite Health Effects Costs 2002$	Lifetime Total Costs Averted 2002$
Catawba No Late Failure			
Internal Events	9.52E+05	2.43E+03	9.55E+05
External Events	6.35E+05	1.62E+03	6.37E+05
Total	1.59E+06	4.05E+03	1.59E+06
Sequoyah No Late Failure			
Internal Events	4.34E+06	8.13E+03	4.35E+06
External Events	2.89E+06	5.42E+03	2.90E+06
Total	7.24E+06	5.42E+03	2.90E+06
Catawba with Late Failure			
Internal Events	7.01E+05	0.	7.01E+05
External Events	4.67E+05	0.	4.67E+05
Total	1.17E+06	0.	4.67E+05
Sequoyah with Late Failure			
Internal Events	3.73E+06	0.	3.73E+06
External Events	2.48E+06	0.	2.48E+06
Total	6.21E+06	0.	6.21E+06

5. RESULTS FOR A BWR MARK III PLANT

In this Section the benefits accrued from a combustible gas control system which remains functional during SBO sequences are calculated for the Grand Gulf plant, a BWR 6 with a Mark III containment. In the case of Grand Gulf, and all the other BWR Mark III plants, there is some uncertainty in the estimation of input values for the SBO frequency. The SBO frequency is only available for internal initiating events from the IPE and the NUREG-1150 study. In the IPE for External Events (IPEEE), Grand Gulf applied the EPRI seismic margins assessment method based on a review level earthquake of 0.3 g to assess the safe shutdown equipment list. A fire core damage frequency (CDF) was calculated, but the information provided did not permit an estimate of the SBO portion of the fire CDF. Extreme wind hazards were screened out, so no data on SBO from this hazard was provided. Therefore, an assumption about the value of the external event SBO frequency needs to be made to obtain a complete benefit estimate.

At the end of this Section a rationale is presented to extrapolate the benefit from the Grand Gulf results to the group of domestic Mark III plants. The benefit calculation for Grand Gulf is carried out below, again following the steps found at the beginning of Section 2:

Step 1 - Frequencies of SBO sequences

For Grand Gulf the IPE shows an SBO frequency of 7.5E-6 per reactor year (ry) for internal events. Since no external event SBO frequency is available a similar value will be assumed for external events, bringing the total SBO frequency to 1.5E-5 per reactor year.

Step 2 - Change in conditional containment failure probability

Considerable information on accident progression and hydrogen deflagration and detonation for Grand Gulf was developed during the NUREG-1150 study and is documented in NUREG-1150 and the supporting documents [4,6]. This information is summarized in Reference 8 and the following discussion is based on Reference 8.

Mark III containments depend on glow plug hydrogen igniters to control pressure loads resulting from hydrogen combustion events. If the igniters are not operating, due to lack of AC power (the dominant sequence being a station blackout) or operator failure to manually actuate them, there is a possibility of an energetic hydrogen combustion (deflagration or detonation) event at the time of vessel failure (or at other times if the operators fail to follow procedures and the igniters are actuated when a significant amount of hydrogen has accumulated). These energetic combustion events were reported in NUREG/CR-1150 and the supporting documentation for Grand Gulf (NUREG/CR-4551, Volume 6 [6]) to result in early containment failure with a relatively high conditional probability (~0.5). However, in a Mark III containment an unscrubbed release (one which does not pass through the suppression pool) requires failure of the drywell in addition to containment failure. Drywell failure can occur: (1) directly as a result of loads associated with vessel breach or from hydrogen combustion, or (2) indirectly as a result of structural failure of the pedestal.

Before vessel breach the only significant event that was found in NUREG/CR-4551, Volume 6, to cause drywell failure was hydrogen combustion in the wetwell. However, at the time of vessel breach loads from direct containment heating, ex-vessel steam explosions, hydrogen combustion, and RPV blow down contribute to the probability of drywell failure. Accordingly, loads from high pressure vessel breach and hydrogen combustion were determined to be the leading causes of containment and drywell failure.

The Grand Gulf (NUREG/CR-4551, Volume 6) results are summarized in the Table 8 below. This Table indicates that accident sequences that contribute to large releases (which require failure of the drywell in addition to containment failure) are sensitive to the type of accident (i.e., SBO vs non-SBO) and the pressure (i.e., transient vs large break LOCA) in the reactor pressure vessel at the time of vessel breach.

Table 8: Conditional Containment and Drywell Failure Probabilities for Mark III Containments

RCS Pressure at Vessel Breach	Station Blackout, SBO (Igniters and Sprays unavailable)		Non-SBO (Igniters and Sprays available)	
	Containment Fail	Containment and Drywell Fail	Containment Fail	Containment and Drywell Fail
High	~ 0.5	~ 0.2	~ 0.5	~ 0.2
Low	~ 0.5	~ 0.2	~ 0.01 - 0.02	~ 0.01

As shown in the Table, if the RCS is at high pressure the likelihood of containment failure is relatively independent of whether or not the igniters are operating. In addition, the likelihood of simultaneous failure of the drywell is also independent of igniter operation if the RCS is at high pressure.

As the above Table indicates, if the RCS is depressurized at vessel breach the likelihood of containment failure is dependent on whether or not the igniters are operating. If the igniters are not available the conditional probability of containment failure is approximately 0.5 even with the RCS at low pressure. The likelihood of simultaneous failure of the drywell is also about 0.2 at the time of vessel breach. Thus all SBO sequences (without combustible gas control) have a conditional probability of 0.2 of a large release, regardless of the pressure in the RCS.

The potential for containment failure at the time of vessel breach when the RCS is at low pressure and the igniters are operating is not directly assessed in NUREG/CR-4551, Volume 6. However, the conditions prior to vessel breach should be applicable to this situation because the RCS is depressurized and none of the issues associated with high pressure melt ejection would occur. The results prior to vessel breach indicate a conditional probability of containment failure in the range of 0.01 to 0.02 if the igniters are operating.

In summary, for transient sequences with the RCS at high pressure and for all SBO sequences the conditional probability is close to 0.2 that the Mark III containment fails at the same time that the suppression pool is bypassed. However, if the RCS is depressurized and the igniters are operating then the conditional probability is less than 0.1 that the Mark III containment will fail. The IPE database (www.nrc.gov/NRC/NUREGs/SR1603/index.html) information on the plant damage states (PDSs) for the four domestic Mark III plants was searched to determine the fraction of PDSs that have low RCS pressure. The average across the four plants for PDSs with this attribute is approximately 40 percent, with high RCS pressure making up the remaining 60 percent.

Based on Table 8, and the above discussion, the following event tree can be constructed and quantified, conditional on an SBO event without a hydrogen control system operating. The late failure split fractions are based on NUREG-4551 Vol. 6 results.

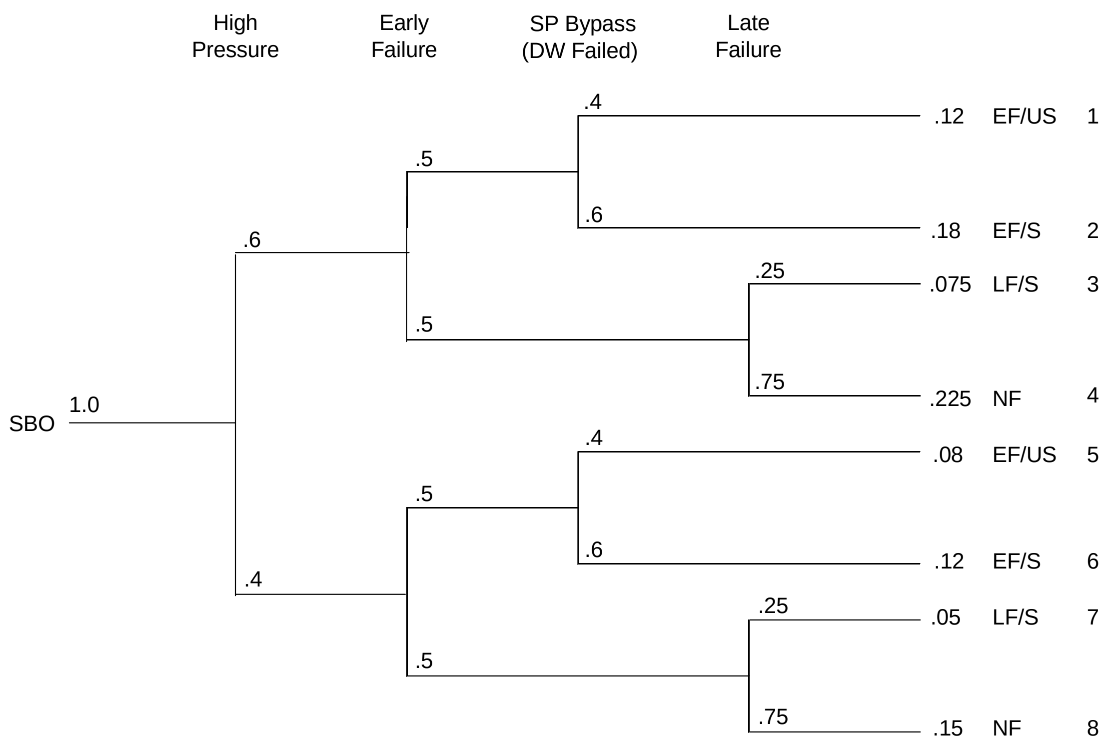

Figure 1: Event tree conditional on SBO without combustible gas control

The top events are high RCS pressure, early containment failure, drywell failure, and late containment failure. A late containment failure will always be scrubbed. The conditional probability for each of the 8 end states is shown in the Figure. EF, LF, and NF indicate early containment failure, late containment failure, and no containment failure, respectively. US indicates an unscrubbed release, S indicates a scrubbed release.

A similar event tree, based on Table 8 and the accompanying discussion, can be constructed for SBO events assuming combustible gas control is still functional. This event tree is shown in Figure 2. (Note that the 1.0/0.0 split fraction on the low pressure branch SP Bypass event is chosen for conservatism, and has very little effect on the results).

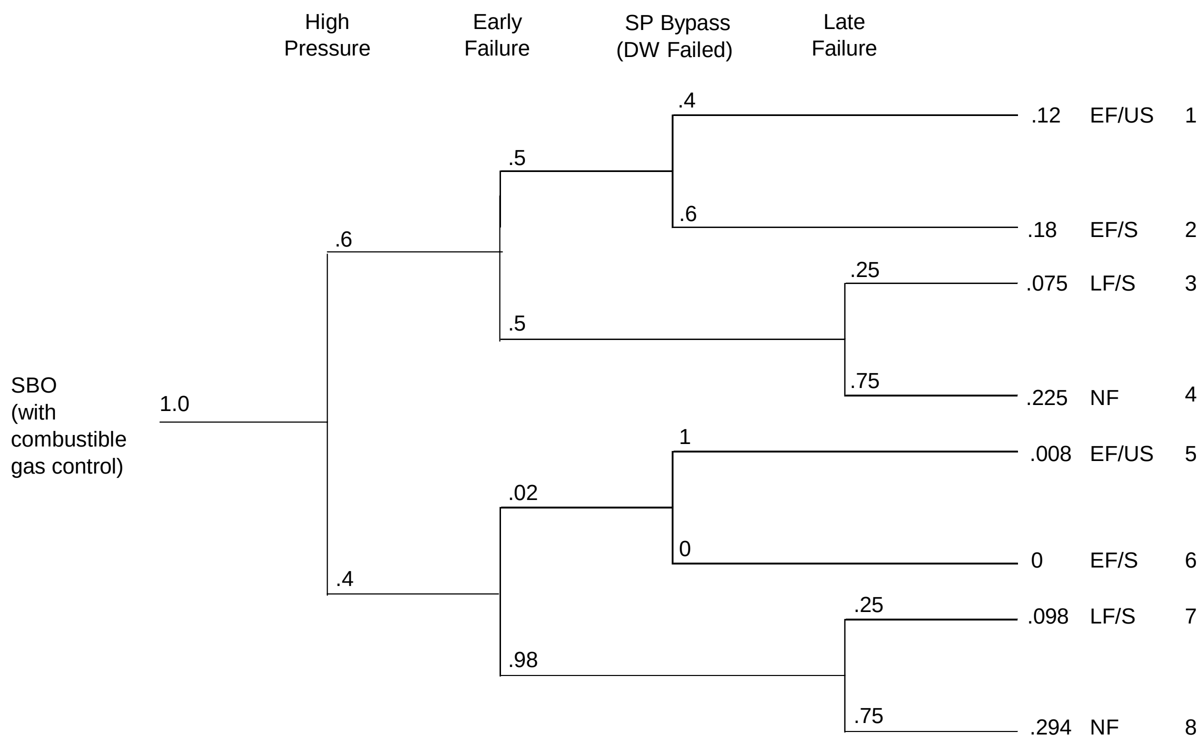

Figure 2: Event tree conditional on SBO with combustible gas control functional

A comparison of the trees shows that the high pressure, i.e., upper, half of both trees is identical. This means that any benefit gained from a combustible gas control system which functions during station blackout will depend only on the different conditional probabilities associated with low pressure scenarios (end states 5 through 8).

Step 3 - Consequences associated with each containment failure mode

Offsite consequences for releases at Grand Gulf representative of each of the end states indicated in Figures 1 and 2 are shown in Table 9. No consequences are assumed for no containment failure. Offsite person-rem and offsite property cost estimates are based on the data provided in References

10. These results are conditional consequences (i.e., conditional on occurrence of the release) out to 50 miles from the plant and include offsite population dose (person-rem) and offsite damage costs.

Two values for offsite person-rem are shown here as well. The 1990 values are based on Reference 10. The 2000 values have been updated based on the change in population density from 1990 to 2000 as estimated in the Grand Gulf Final Safety Analysis Report. The change is an increase of about 7%.

Two values are also shown for the offsite property damage costs. The first is taken from Reference 10 and is in 1990 dollars. The second updates the 1990 dollar values to current year dollars based on the price inflation calculator (approximately 36% over the 1990-2002 period) of the U.S. Bureau of Labor Statistics (www.bls.gov).

Table 9: Offsite Consequences (50-mile radius) of Containment Failure Releases at Grand Gulf

Sequence	Fail Mode	Offsite Person-rem 1990	Offsite Person-rem 2000	Offsite Health Effects $	Offsite Property 1990$	Offsite Property 2002$
GG-11-1	Early unscrubbed	5.66E+05	6.06E+05	1.21E+09	8.14E+08	1.11E+09
GG-04-1	Early scrubbed	1.03E+05	1.10E+05	2.20E+08	4.32E+07	5.88E+07
GG-18-1	Late scrubbed	7.02E+04	7.51E+04	1.50E+08	1.06E+07	1.44E+07

GG-11-1 from Reference 6 is a typical early failure unscrubbed sequence with about 99% of noble gases, 38% of iodine, 14% of cesium, and 9% of tellurium released.   GG-04-1 is a typical early failure scrubbed sequence with about 76% of noble gases, 5% of iodine, >1% of cesium, and negligible amounts of tellurium released.   GG-18-1 is a typical late failure scrubbed sequence with about 83% of noble gases, 1% of iodine, and negligible amounts of cesium and tellurium released.

Again, it should be noted that the (1990) consequences reported in Reference 10 differ somewhat from those reported in the NUREG-1150 reports, even though Reference 10 is based on the NUREG-1150 analyses. This is primarily because in the NUREG-1150 study the consequence analysis was carried out using Version 1.5.11 of the MACCS code, while the consequences in Reference 6 were recalculated with Version 1.5.11.1 of MACCS. This later version explicitly incorporates the higher BEIR V risk coefficient for the latent cancer-dose relationship while the earlier version of MACCS used the BEIR III risk coefficient. In addition, a few input errors in the NUREG-1150 MACCS calculations were corrected for the recalculations of Reference 10.

Onsite health consequences again are calculated assuming 20,000 person-rem occupational exposure, or $4E+07 after using the $2000/person-rem factor, for all early and late containment failures, and 8,000 person-rem, or $1.6E+07, for no containment failure. Onsite property damage is not included as per the discussion in Section 3.

Step 4 - Summation of conditional containment failure modes and their consequences

The results of the summation of conditional containment failure modes and their consequences are shown in Table 10.

Table 10: Summation of Offsite Costs and Onsite Health Effect Costs

Gas Control	Total Offsite Cost conditional on SBO	On-site Health Effects Cost conditional on SBO
no	2.27E+08	1.24E+07
yes	3.47E+07	8.94E+06

Step 5 - Subtraction of costs and multiplication by frequency

The calculation in Step 4 was made with and without the gas control system present. The difference between the cases where gas control is 'yes' and the cases where gas control is 'no,' when multiplied by the SBO frequency, represents the averted offsite cost on a per reactor-year basis. The results are summarized for Grand Gulf in Table 11 below. Results are broken out by internal event related costs, external event related costs and total costs. Costs are divided into offsite and onsite costs, as well as total costs. Offsite costs are the dominant contributor in all cases. Costs are in 2002 dollars.

Table 11: Cost Summary per reactor year for Grand Gulf

	SBO frequency	Total Averted Offsite Costs $ per reactor year	Averted Onsite Health Effects Costs $ per reactor year	Total Costs $ per reactor year
Internal Events	7.5E-6	1.45E+03	2.59E+01	1.47E+03
External Events	7.5E-6	1.45E+03	2.59E+01	1.47E+03
Total	1.5E-5	2.89E+03	5.18E+01	2.94E+03

It should again be noted that the external event SBO frequency quoted above is only a guess (setting external event frequency equal to internal event frequency) and not based on any analysis.

Step 6 - Calculation of lifetime benefit

Multiplication by the present worth factor, based on the discount rate selected and plant lifetime remaining, yields the total averted offsite cost, or benefit, over the plant's lifetime. Results for a lifetime of 40 years for a discount rate of 7% and 3% are shown in Tables 12 and 13 respectively. This step completes the analysis.

Table 12: Lifetime benefit base case (7% discount rate) for Grand Gulf

Discount Rate of 7 %	Lifetime Averted Offsite Costs 2002$	Lifetime Averted Onsite Health Effects Costs 2002$	Lifetime Total Costs Averted 2002$
Internal Events	1.94E+04	3.48E+02	1.97E+04
External Events	1.94E+04	3.48E+02	1.97E+04
Total	3.88E+04	6.96E+02	3.95E+04

Table 13: Lifetime benefit sensitivity case (3% discount rate) for Grand Gulf

Discount Rate of 3%	Lifetime Averted Offsite Costs 2002$	Lifetime Averted Onsite Health Effects Costs 2002$	Lifetime Total Costs Averted 2002$
Internal Events	3.37E+04	6.04E+02	3.43E+04
External Events	3.37E+04	6.04E+02	3.43E+04
Total	6.73E+04	1.21E+03	6.85E+04

The results are again dominated by the offsite costs but much smaller than for the ice condensers. For Grand Gulf the total averted offsite costs amount to $39K for a 7% discount rate and $67K for a 3% discount rate.

Inclusion of averted onsite costs produces a negligible change in all cases. Since the Mark III containments considered here are single nuclear units, the discussion of Section 3 regarding onsite costs related to the effect of containment failure would imply that onsite property damage costs averted by adding a combustible gas control system which functions under SBO conditions would also be small.

It should also be pointed again out that the inclusion of averted costs from external events (whose frequency is only a guess in the Grand Gulf case) assumes that the combustible gas control system is designed to withstand the external event. For example, the control system would have to be seismically qualified to the appropriate g level to withstand an earthquake of a certain magnitude. Obviously this would increase the cost of the combustible control system above that designed to deal only with internal events.

To provide an estimate of how the Grand Gulf benefit results may be extrapolated to other domestic BWR Mark III plants, one can compare the SBO frequencies and population densities within 50 miles at other Mark III plants with those of Grand Gulf. Table 14 shows the comparison. The second column gives the ratio of SBO frequencies of the other Mark III's to the Grand Gulf SBO frequency. The third column shows the ratio of the population density of the other sites to the population density at Grand Gulf. The population density used here comes from the projections made in each plant's Final Safety Analysis Report and is not based on current census data. The fourth column is the product of the two ratios.

Table 14: Comparison of domestic BWR Mark III plants

Plant Name	**SBO frequency ratio**	**2000 population ratio (estimated)**	**Product of ratios**
Grand Gulf	1.00	1.00	1.00
Clinton	1.31	3.14	4.13
Perry	0.30	7.53	2.27
River Bend	1.81	3.14	5.68

Based on this Table, a factor of 6 on the Grand Gulf results would seem to provide an approximate upper bound on the benefits for domestic Mark III plants. With such a factor applied to the benefits mentioned above, maximum averted costs (again assuming SBO frequency for external events is comparable to the internal event SBO frequency) would be on the order of \$235K with a 7% discount rate, and on the order of \$400K with a 3% discount rate.

The above factor on total averted costs implicitly assumes there is also a factor of 6 difference in offsite property costs. A comparison of Table 9 with Table 3 shows that the offsite property costs calculated in Reference 10 for Grand Gulf are about 6 times lower than those at Sequoyah. Further scrutiny of Tables 3 and 9 shows that, at least for some sequences, the offsite health effects costs and offsite property costs are of similar magnitude, and therefore, differences in property values can be important in estimating total averted costs. The Grand Gulf location would indeed appear to have relatively low offsite property values when compared to the other plants for which property values were calculated in Reference 10. Therefore the factor of 6 seems applicable for property values as well, and can be applied to the total averted cost, as done above.

6. DISCUSSION OF RESULTS

Comparison of the results in Section 4 for the PWR ice condenser plant, Catawba, with the results in Section 5 for the BWR Mark III plant, Grand Gulf, shows that the estimated benefit differs significantly for the two cases. Using lifetime averted offsite costs for internal events (for which more accurate estimates are available for Grand Gulf), for the base case (7% discount rate) Catawba (ice condenser) cost estimates range from \$4.04E+05 to \$5.49E+05, while Grand Gulf (Mark III) lifetime averted costs are estimated at \$1.94E+04. In other words, the Catawba results are higher than the Grand Gulf results by a factor ranging from 20 to roughly 30.

The reasons for this large difference can be attributed to a number of parameters, as illustrated in Table 15 below.

Table 15: Parameter comparison

Parameter	**Catawba value**	**Grand Gulf value**	**Catawba/Grand Gulf**
SBO frequency	1.5E-5	7.5E-6	2.0
Approximate averted CCFP*	0.29	0.10	2.9
Population density 2000 estimate	1,656,063	321,319	5.2
TOTAL FACTOR			~30
*CCFP: conditional containment failure probability - for Grand Gulf the value shown is a weighted (by consequences) average of the CCFP averted in end states 5 and 6 of Figure 2.			

For the Sequoyah sensitivity calculation the difference with the Grand Gulf results is even greater, i.e, the ice condenser results are about 100 times the BWR Mark III results. This is due mainly to the fact that the averted CCFP for the Sequoyah calculation is more than 3 times as large as the averted CCFP for Catawba.

7. REFERENCES

1. US NRC, "Risk-Informing 10 CFR 50.44," SECY-00-0198, December 2000.

2. US NRC, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/BR-0058, Rev. 3, Final Report, July 2000.

3. US NRC, "Regulatory Analysis Technical Evaluation Handbook," NUREG/BR-0184, Final Report, January 1997.

4. US NRC, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, Final Summary Report, December 1990.

5. J.J. Gregory, et al., "Evaluation of Severe Accident Risks: Sequoyah, Unit 1," NUREG/CR-4551, Vol. 5, Rev. 1, Part 1, Main Report, December 1990.

6. T.D. Brown, et al., "Evaluation of Severe Accident Risks: Grand Gulf, Unit 1," NUREG/CR-4551, Vol. 6, Rev. 1, Part 1, Main Report, December 1990.

7. M.M. Pilch, et al., "Assessment of the DCH Issue for Plants with Ice Condenser Containments," Sandia National Laboratories, NUREG/CR-6427, February 2000.

8. W.T. Pratt and V. Mubayi, "Basis Document For Large Early Release Frequency (LERF) Significance Determination Process (SDP)," NUREG/CR-xxxx, (to be published)

9. G.R. Peterson (Duke) letter dated April 18, 2001 to Document Control Desk (NRC), Probabilistic Risk Assessment Revision 2b, Catawba Nuclear Station, Docket Nos. 50-413 and 50-414, cited in Reference 3. (Not available for this study but pertinent values quoted in Reference 14 below, which was available).

10. V. Mubayi, et al., "Cost-Benefit Considerations in Regulatory Analysis," Brookhaven National Laboratory, NUREG/CR-6349, October 1995.

11. Richard P. Burke, David C. Aldrich, and Norman C. Rasmussen, "Economic Risks of Nuclear Power Reactor Accidents," Sandia National Laboratories, NUREG/CR-3673, April 1984.

12. D.R. Strip, "Estimates of the Financial Consequences of Nuclear Power Reactor Accidents," Sandia National Laboratories, NUREG/CR-2723, September 1982.

13. Bureau of Labor Statistics website www.bls.gov.

14. Michael Zavisca and Mohsen Khatib-Rahbar, Energy Research, Inc., “Combustible Gas Control Risk Calculations (DRAFT) for Risk-Informed Alternative to Combustible Gas Control Rule for PWR Ice Condenser, BWR Mark I, and BWR Mark III (10 CFR 50.44),” Memorandum to Michael Snodderly (NRC) and James Meyer (ISL), October 22, 2001.